Increasing Crop Production through Improved Plant Protection

Volume I

Edited by
Abraham Tadesse

Jointly organized by PPSE and EIAR

Sponsored by the USAID-Ethiopia and BTC through MoARD

USAID
FROM THE AMERICAN PEOPLE

MoARD

Increasing Crop Production Through Improved Plant Protection

Volume I

Edited by
Abraham Tadesse

Jointly organized by PPSE and EIAR

Sponsored by the USAID-Ethiopia and BTC through MoARD

MoARD

Increasing Crop Production Through Improved Plant Protection

Volume I

ISBN 978-99944-53-28-3

Edited by
Abraham Tadesse

Presented at the 14th Annual Conference of the Plant Protection Society of Ethiopia (PPSE)
19-22 December 2006, Addis Ababa, Ethiopia

Page layout: Simachew Manaye and Abebe Kirub
Cover design: Abraham Tadesse

Citation:
Abraham Tadesse (ed.). 2008. Increasing Crop Production through Improved Plant Protection – Volume I. Plant Protection Society of Ethiopia (PPSE), 19-22 December 2006. Addis Ababa, Ethiopia. PPSE and EIAR, Addis Ababa, Ethiopia. 598 pp.

The Plant Protection Society of Ethiopia

The Plant Protection Society of Ethiopia (PPSE) is a non-profit professional association established in 1992 by the merger of two previously formed committees: the Ethiopian Phytopathological Committee (EPC), established in 1976, and the Committee of Ethiopian Entomologists (CEE), established in 1981. The objective of PPSE is to contribute towards the development of Ethiopian agriculture by reducing crop losses caused by pests through promoting effective research, documenting and dissemination of scientific information, encouraging professional growth and fostering inter disciplinary interaction among plant protection scientists to solve problems related to plant protection.

PPSE has organized 15 annual conferences since its establishment. The 14th annual conference was special of its kind because of two reasons: firstly, two decades of plant protection research in the country was reviewed, and secondly, it was conducted during the celebration of the society's 15th Anniversary.

Members of the Executive Committee of PPSE during the conference

Dr. Abraham Tadesse	President	EIAR, Holetta
Dr. Mohammed Dawd	V/President	EIAR, Ambo
Mr. Belayneh Admasu	Secretary	EIAR, Ambo
Dr. Mekuria Tadesse	Treasurer	EIAR, Addis Ababa
Dr. Seid Ahmed	PMJoE Editor-in-Chief	EIAR, Addis Ababa

Current members of the Executive Committee of PPSE

Dr. Abraham Tadesse	President	EIAR, Holetta
Dr. Mohammed Yesuf	V/President	EIAR, Melkassa
Dr. Adane Abraham	Secretary	EIAR, Ambo
Mr. Kassahun Yitaferu	Finance Officer	MoARD, Addis Ababa
Mr. Abiy Tilahun	Treasurer	EIAR, Melkassa
Dr. Kemal Ali	PMJoE Editor-in-Chief	EIAR, Holetta

Plant Protection Society of Ethiopia
P. O. Box 8441
Addis Ababa, Ethiopia

Contents

Acknowledgements

We gratefully acknowledge the Ethiopian Institute of agricultural Research (EIAR) for its financial and logistic support and for jointly organizing the Conference. The Conference was also sponsored by the Ministry of Agriculture and Rural Development (MoARD) with funds from the USAID-Ethiopia and the Belgian Technical Cooperation (BTC), both funded the publication of this volume.

In addition, we are grateful to Chemtex PLC, Upper Awash Agro-Industry Enterprise (UAAIE), Bale Agricultural Development Enterprise, Metahara Sugar Factory, Golden Rose Agro-farms Ltd., Amhara Regional Agricultural Research Institute (ARARI), Axum Green Line Trading PLC, Ethiopian Science and Technology Agency (ESTA), SG 2000, Haramaya University, and the Ethiopian Seed Enterprise (ESE) for their financial support for the Conference. A special word of thanks should go to His Excellency Dr. Abera Deressa, State Minister, Ministry of Agriculture and Rural Development, not only for his interest and encouragement during preparation for the Conference but also for his kind assistance in securing funds from the USAID-Ethiopia and the BTC. We would like to express our gratitude to Dr. Solomon Assefa, DG of EIAR, for his encouragement and wholehearted moral, material, and financial support to PPSE.

We wish to thank the Conference Organizing Committee members Dr. Amsal Ayana (Crops Research Director, ORARI), Dr. Eshetu Bekele (EIAR, Holetta), Dr. Ferdu Azerefegne (Hawassa University), Dr. Fasil Reda (EIAR, Melkassa), Dr. Seid Ahmed (Crops Reseach Director, EIAR), Mr. Wondirad Mandefro (Ambo, PPRC), Mrs Tsehay Azage (Crop Protection Department, MoARD), and Dr. Taye Tessema (Ethiopian Weed Science Society) for their valuable contributions at the initial stage of organizing the Conference.

We also thank all contributors and reviewers for their cooperation in prepaing these papers for publication. The reviewers include Dr. Tadesse G/ Medhin, Dr. Habtu Assefa, Dr. Meseret Wondimu, Dr. Melaku Wale, Dr. Fasil Reda, Dr. Ayele Badebo, Dr. Nigussie Tadesse, Dr. Kemal Ali, Dr. Mashilla Dejene, Dr. Gashawbeza Ayalew, Dr. Ferdu Azerefegn, Dr. Getaneh Weldeab, Mr. Kassahun Yitaferu, Dr. Emana Getu, Dr. Eshetu Derso, Dr. Eshetu Bekele, Dr. Taye Tessema, Dr. Amare Ayalew and Dr. Woldeyesus Sinebo.

Our sincere thanks go to the group of panelists namely Dr. Seme Debella (moderator), Dr. Brhane G/ Kidan, Dr. Dereje Ashagari, Dr. Tessema Megenassa, Dr. Chemeda Fininsa, and Mr. Rezene Fessahaie. Dr. Ferdu Azerefegn and Dr. Seid Ahmed served the session as rapporteurs.

PPSE
Executive Committee

Foreword

Despite the fact that agriculture is the backbone of the Ethiopian economy, agricultural production and productivity remained very low, even by African standard. Several factors contribute to the poor performance of the Ethiopian agriculture; low level of access to improved crop production and protection technologies is among the most important constraints.

In the past two decades, enormous research activities have been carried out at the EIAR and other research and higher learning institutions in order to find solutions to the problems. A number of plant protection technologies such as chemical, varietal, biological and physical methods have been developed, and a wealth of research information has been accumulated prompting this effort to review and publish in a form readily available to users.

I greatly appreciate the efforts made by the Plant Protection Society of Ethiopia to have taken the initiative to organize the Conference and make the publication of this volume possible.

In our effort to attain food security, there is no doubt that the application of plant protection technologies is the key factor without which, when put into practice, success becomes remote. It is in this context that the information presented in this publication will prove to be helpful in minimizing the extent of losses due to pests, and in identifying the gaps for future research thrusts. I believe that the publication serves as a valuable source of information for planners, researchers, producers, teachers and others interested in plant protection in Ethiopia.

I would like to express my heartfelt appreciation to those organizations, groups and individuals for making their contributions to the success of the conference and the publication.

Solomon Assefa (PhD)
Director General, EIAR

Preface

Concerted research on plant protection was launched with the establishment of the Institute of Agricultural Research (IAR) in 1966. Research carried out at various IAR centers and other institutions had been reviewed in the First Ethiopian Crop Protection Symposium organized by the Crop Protection Department of IAR in 1985. Results were published. Research results obtained ever since have been scattered over different publications and in unpublished forms denying easy access to users. It was therefore felt necessary to arrange a forum whereby plant protection research conducted since 1985 can be reviewed and documented. The Plant Protection Society of Ethiopia (PPSE) took the initiative to gear its 14th Annual Conference towards achieving this goal. The Conference was jointly organized by PPSE and the Ethiopian Institute of Agricultural Research (EIAR). This publication is the outcome of the Conference under the theme *Two Decades of Plant Protection Research in Ethiopia and Prospects for the New Millennium* held at EIAR, Addis Ababa, Ethiopia, 19 - 22 December 2006. A total of 37 review papers (11 on Entomology, 10 on plant pathology, 10 on weed science, six on general plant protection and 1 on policy and regulatory aspects of plant protection) were presented and discussed in the four-day conference. A panel discussion was conducted by a group of panelists on selected issues at the end of the Conference.

The publication is divided into two volumes. This volume consists of results of Entomology, Pathology and Weed research on cereals and pulses. Several other papers should have been included in this volume. Regrettably, however, the authors did not heed to our repeated callings to submit the final version on time. This volume is expected to serve as a valuable source of information for planners, researchers, extension workers, teachers and ultimately the farming community.

As the principal objective is to review the results generated by the various disciplines and to collate a comprehensive bibliography of local publications on plant protection research, contributors were encouraged to include as much data as possible in tabular forms and to be exhaustive in their bibliographic lists.

In view of the multidisciplinary and interdependent nature of plant protection, we sought the cooperation of scientists from numerous organizations in carrying out the peer review of the papers. Although the names of the scientists appear in the acknowledgements, we would like to record our gratitude here for their participation in this demanding task.

We hope that this volume would be better for all the efforts expended on it by authors, reviewers and editors. Any imperfections that remain, however, are the responsibility of the authors.

Abraham Tadesse (PhD)
President, PPSE

Welcome Address

Abraham Tadesse (PhD)
President PPSE

On behalf of the organizers, the organizing committee and myself, I take a great honour to welcome all of you to the 14th and special annual conference of the *Plant Protection Society of Ethiopia (PPSE),* which is organized in collaboration with the Ethiopian Institute of Agricultural Research (EIAR). This annual conference is different from its kind for many reasons: First, it reviews plant protection researches conducted for the last two decades in this country. Second, it is being conducted during the 15th anniversary of the Society, and third, it is being held following the approval of the society's new name, “PPSE.”

Let me give you a bird’s eye view of the history of research on agriculture in general and that of plant protection in particular in this country. I hope that this may serve as a springboard for all of the review papers that are going to be presented in this conference.

Agricultural research in this country is said to have been started in the late 1940s with the establishment of the agricultural high school at Ambo. This was followed by the establishment of an additional high school at Jimma, and finally, an agricultural college at Alemaya (now Haramaya University) in the early 1950s. This process culminated in 1955 with the establishment of the country’s first full-fledged agricultural research station at Debre Zeit, the Debre Zeit Agricultural Experiment Station. It was established with the financial support of the then *Point Four* program of the US government and the Oklahoma State University as the executive agency within the framework of the then the Imperial Ethiopian College of Agriculture and Mechanical Arts.

The history of plant protection research in the country begins with the birth of the then IAR (now EIAR), formally established in February 1966 by an agreement signed by representatives of the United Nations Development Programme, the Food and Agriculture Organization of the United Nations and the Imperial Ethiopian Government, to conduct researches relevant to agricultural development in Ethiopia. Crop protection research has formed one of the core programmes since the inception of the IAR.

Sources indicate that researches were conducted by the Research Department of the then Ministry of Agriculture when IAR was established. Prior to the establishment of IAR, the attention given to plant protection research was comparatively little, and most of the works were focused on surveys and identification of crop pests. Accordingly, *Some diseases occurring in Kaffa province during 1954–1956* by R. B. Stewart, and *Plant Diseases of Economic Importance in Ethiopia* by Dagnachew Yirgou in 1967 were published. The last one is said to be a very useful starting point for plant pathological work in the country. One of the earlier works published on agricultural entomology is *Insect Pests of Cultivated and Wild Plants, Harar Province, Ethiopia 1960-1964* by Bob Hill in 1966.

Concerted entomological work began with the arrival of the FAO entomologist on 22 October 1966 to undertake a three-year assignment as an entomologist in the IAR. The plant pathology section was established in November 1967 (concentrated on cereal diseases), following the arrival of the FAO pathologist. The expert (entomologist) helped in the planning and conducting of a plant protection conference, which was held in the Africa Hall in March 1968 with participants being representatives of government and private organizations concerned with crop production, agricultural research, and extension, trading agricultural chemicals and aerial spraying. This meeting was reported to be the first of its kind in Ethiopia and led to a greater understanding of Ethiopian crop protection problems from the various points of views.

Regarding researches on weed science, the earliest reports I came across are those of 1969 by CADU (Chilalo Agricultural Development Unit). In the IAR, weed research started with the recruitment of a graduate in 1969/70.

The rodent section was established in 1976 with a small laboratory located in the Ministry of Agriculture laboratories at Shola, Addis Abeba. The section was then moved to another location near IAR. However, reports indicate that rodent survey began in the country in January 1972. Prior to 1972, only the Chercher highlands had been covered in 1968.

In an effort to strengthen the discipline, the Crop Protection Department was established in 1976 consisting of four major sections: entomology, pathology, rodent, and weed science, which lasted until the middle of 1980. The Debre Zeit Agricultural Research Center also established the crop protection program in the same year (1976) with the three disciplines (entomology, pathology and weed science). Moreover, the establishment of the Scientific Phytopathological Laboratory (SPL) at Ambo in 1977 had strengthened the research work on crop protection.

Following these events, the need for a forum to promote and facilitate better professional contacts for the exchange of experiences among the few crop protectionists was sought. This led to the establishment of the Ethiopian Phytopathological Committee (EPC) in April 1976 and the Committee of the

Ethiopian Entomologists (CEE) in January 1981 with 23 members in the latter. The Ethiopian Weed Science Committee was established in 1982 and grew to EWSS (Ethiopian Weed Science Society) in November 1992.

Although each of these professional committees have contributed significantly to their set goals, it was felt that their efforts could have been more strengthened and their contributions could have been more significant and influential if they had united under one umbrella than standing apart. After debates and discussions in several forums for several years on the issue, the first two sister committees, EPC and CEE, accepted the idea and the merger became a reality in March 1992 under the banner of the Crop Protection Society of Ethiopia (CPSE). The merger, as expected, has strengthened us more than would otherwise have been the case. We greatly appreciated the pioneers of this noble idea. In March 2006, exactly 15 years after the merger, the name CPSE was changed to PPSE with the intention to include non-crop plants in its mandate.

Since its establishment, PPSE has organized 13 annual conferences dealing with various current issues within the broad topic of strengthening plant protection research and development in the country as key to agricultural development. It has also published numerous leaflets on important plant pests and their management. Publishing the Amharic version began last year and there is a plan to start producing them in other major languages of the country in the future. PPSE´s journal *Pest Management Journal of Ethiopia (PMJoE)* was launched in 1997, six years after its establishment and reached its 10th volume in this year. We used to publish proceedings, which ceased after the commencement of PMJoE. However, we have the plan to restart publishing proceedings as soon as possible, if finance and articles are not limiting.

PPSE was also instrumental in filling research gaps by bringing to light problems that needed immediate attention of research and development. In general, great strides have been made in plant protection since the birth of the PPSE. A major contribution of PPSE is that it brings together almost all crop protection workers in Ethiopia once a year, which has made it possible for all concerned individuals to know one another and to exchange ideas, information and experiences. It is the forum to present and discuss results of research and development in the area of plant protection.

I will feel incomplete if I do not mention some of the challenges that encountered the discipline. It is needless to mention to you that equally important, with improved agricultural technologies, is the protection of crops from insect pests, plant diseases, weeds and rodents. However, the attention given to the discipline has not been adequate in terms of resources. The problem started with the commodity approached which dissolved the department of crop protection. Consequently, the interdisciplinary interaction among crop protection professionals was lost. The system also denied the discipline many things of which research budget is the most important one. We have been raising the problem in many forums since its commencement, and we will keep on doing so until we see meaningful changes. We appreciate that improvements are being made in this line and we hope it will continue further.

As some of us may remember, the first conference on crop protection research conducted in this country was organized by IAR in February 1985. It was 19 years after the inception of the IAR. This conference is being held 21 years after the first one. So, one can imagine how late we are in organizing this workshop. I am saying this just to emphasize on the importance of this gathering. Otherwise, this event is more timely than late because we are doing it in the eve of the new millennium. As such this meeting stands as a milestone in PPSE`s history.

Over the years, research on insect pests, plant diseases, and weeds has resulted in a massive body of information, but much of it remains scattered. The objectives of this conference are therefore to bring together this information and to indicate the gaps in our knowledge of plant protection. When the gaps are filled, they might lead to the efficient control of the problems.

In the coming four days, we will cover 37 papers: 11 on entomology, 10 on plant pathology, 10 on weed science, 6 on general plant protection and 1 on policy and regulatory aspects of plant protection in the country. Recommendable and indicative research results will be presented and discussed. Moreover, one paper entitled *Prevention of Accumulation of Obsolete Pesticides* and another *Introduction of IPM-FFS (farmers' field school) in Southern Ethiopia* will be presented by one of our donors.

Before I invite His Excellency to make the opening speech, allow me to thank all who contributed to the success of convening this conference. On behalf of the PPSE and EIAR, the organizing committee and myself I would like to express our gratitude to His Excellency Dr. Abera Deressa not only for taking time out of a very busy schedule to be with us this morning, but also for his kind involvement in the fund raising activity. The largest share of the cost of this conference was secured through his office.

We are also sincerely grateful to our donors for their generous financial support without which the attempt of organizing this event would have been a failure. We also thank the MoARD with funds from the United States Agency for International Development (USAID) and the Belgian Technical Cooperation (BTC), the Ethiopian Institute of Agricultural Research (EIAR), Chemtex PLC, Upper Awash Agro-Industry Enterprise (UAAIE), Bale Agricultural Development Enterprise, Metahara Sugar Factory, Golden Rose Agrofarms Ltd, Amhara Regional Agricultural Research Institute (ARARI), Axum Green Line Trading PLC, Ethiopian Science and Technology Agency (ESTA), Sasakawa Global 2000, Haramaya University and the Ethiopian Seed Enterprise (ESE).

In addition, I would also like to acknowledge all those who have devoted their time and energy to make this conference a success. I would like to thank the group leaders and their partners for taking the huge task of reviewing over two decades backlog. I personally would like to express my heartfelt gratitude to the group leaders who encouraged me at times when I was on the verge of giving up hope. I am also indebted to the Holetta Research Center, especially to the Crop Protection Research Division, for allowing me to travel as frequent as needed to organize this conference as well as for other activities concerning PPSE. I am also grateful to the PPSE executive committee and to the conference organizing committee whose contributions have made it possible for this conference to happen. Above all, I would like to thank the Almighty God who deserves all the credit for the success achieved.

With that, may I take the honour to request His Excellency, Dr. Abera Deressa, State Minster, Ministry of Agriculture, and Rural Development (MoARD) to deliver the opening address.

Thank you.

Opening Speech

His Excellency Dr. Abera Deressa
State Minister, MoARD

On behalf of the Ministry of Agriculture and Rural Development of the Federal Democratic Republic of Ethiopia and on my behalf, it is a great pleasure for me to welcome you all to this historical gathering to asses, analyse and review the achievements of the last two decades and plan for the future of plant protection research in Ethiopia.

Over the years, research on insects, plant diseases, weeds and rodents has resulted in a large body of information, i.e., for the most part, recorded in progress reports. Since 1985 these were not compiled in one document to make available to stakeholders for use.

This conference, although overdue, is a landmark in the history of plant protection research in Ethiopia. It is being held at the time when this country is struggling to achieve food security; the Government is focusing on increasing attention on agriculture as means of development, and at the time when we are approaching towards the new millennium. I think it is a wise thing to evaluate our achievements, assess the gaps and challenges and plan the future before the end of the millennium. I hope this will apply to all societies or institutions.

As it is known, the agricultural production practice experienced by our farmers is characterized by perhaps the lowest productivity in the world. This results from a number of factors including the use of traditional farm tools and implements; the low level in the use of improved agricultural inputs such as fertilizers, improved seeds, and pest control technologies; the inadequate level of post-harvest technologies; the natural resource degradation; the population pressure; and the biotic factors like insects, diseases, weeds, rodents, birds and other vertebrate pests. These factors slow the growth of agricultural production in general and of food grain production in particular. Thus, they greatly contribute to food insecurity.

In the world of globalization, survival is based on competition. To remain victorious in the competition, use of effective technologies is crucial. Therefore, suitable technologies should be imported or adapted and generated and/or updated as frequently as possible to fit into the frequently changing world market system. Much is expected from you on this regard.

Without transformation of the subsistence agriculture, it is impossible to realize this and our strategy of poverty reduction as well as the over all economic growth of the country. For agriculture to continue serving as an engine of economic growth in the coming years, there has to be a progress in terms of commercialization, with more intensive farming, increased proportion of marketable outputs and correspondingly decreasing ratio of production for own consumption.

At national level, efforts are underway to increase agricultural productivity through the endeavour to food security, to supply enough raw materials to domestic industries and to produce export commodities for foreign exchange earnings. The government has also introduced specific policies and provided technical and institutional support to farmers, in its drive to increase food production through intensive cultivation. These interventions included supplies of fertilizers and improved seeds, development of small-scale irrigation schemes, conservation of natural resources, strengthening of agricultural research and extension works as well as creating conducive marketing mechanisms.

Such a target can not, and will not, be realized without the firm support of experts like you and others who are involved in safeguarding agricultural products right from sowing until they reach consumers.

Practices from countries that have undergone agricultural transformation indicate that 'modernization of agriculture' would result in increased pest problems that require increased use of pesticides. In light of pesticide resistance development by many plants and animals and the harmful effects of chemicals on the environment, it is now acknowledged that pesticides are not a panacea for protecting crop life. Control strategies for crop pests incorporating a variety of complementary technologies have proved to offer much better chances of success than exclusive reliance on single method such as synthetic pesticides.

In this regard, Integrated Pest Management is an approach that involves selecting, integrating and applying control methods for crop pests based on predictions of the economic, ecological and social effects. This integrated approach should take into account the concerns associated with the use of toxic chemicals in the natural environment. We are required to address the environmental challenges while at the same time combating poverty and promoting socio-economic development.

With this in mind, Mr. Chairman, I would like to emphasise that the pesticide industry in Ethiopia should be encouraged to introduce and screen those safer products, with particular emphasis on the so-called green industry technologies (such as microbial pesticides and pesticides of botanical origin) for registration and use. These products have been widely tested and used in neighboring countries and elsewhere, and therefore, they should not be required to undergo the rigorous test requirements of pesticide registration; only adaptive trials should be adequate to provide information on their efficacy under local conditions. This, of course, should be done without excluding synthetic pesticides that are compatible with IPM programs.

Therefore, a huge task lies ahead of you plant protection professionals in devising best pest management systems for the diverse needs of agriculture and forestry and providing producers with the information they need. The best management system is of a limited value if timely information is not available to users.

It is doubtless that professional societies, like PPSE, play a significant role in the national development efforts. They are umbrellas for individual scientists and technologists with specialized knowledge, experience and expertise that can be mobilized to accomplish specific tasks. I believe that PPSE plays a pivotal role in the process of identifying research and development needs that would enhance national agricultural development programs and strategies.

It is my sincere hope that this conference will discuss relevant issues on how to improve the transfer of already available plant protection technologies to farmers on the one hand and consider and give direction to future plant protection research activities in the country on the other.

Finally, on behalf of my Ministry and myself I would like to thank PPSE for taking the initiative and Ethiopian Institute of Agricultural Research (EIAR) for co-organizing this extremely important conference. I would also like to thank all those who have contributed for the success of this conference, especially, the USAID - Ethiopia, the Belgian Technical Cooperation Addis Ababa Office, Chemtex PLC, Upper Awash Agro-Industry Enterprise, Bale Agricultural Development Enterprise, Metehara Sugare Factory, Golden Rose Agrofarms Ltd, the Amhara Regional Agricultural Research Institute (ARARI), Axum Green Line Trading PLC, the Ethiopian Science and Technology Agency (ESTA), Sasakawa Global 2000, Haramaya University and the Ethiopian Seed Enterprise (ESE) for their generous financial and technical supports for this conference to be a reality. With this remark and wishing you every success in your deliberations, I declare the conference is officially opened.

Thank you.

Keynote Address

Tessema Megenasa

Introduction

Culture and tradition as possible links to productivity

Some points to consider

- **I** would like to express my appreciation to the organizers of this meeting and in particular to Dr. Abraham Tadesse for inviting me to participate at this important forum on Crop Protection Research, Past, Present and the Future;
- I may also hasten to remind you that I have been outside of the system for most of the last 20 years and that I have not been fully involved in crop protection matters at the local level. Therefore, please pardon my oversights in case I express opinions that may not reflect real or current situations;
- The focus of crop protection research, I hope you will agree with me, is mainly improved food security; and
- Therefore, my short presentation is going to revolve around this particular point and that it will, I hope, dominate our discussions in relation to crop protection research.

We all agree that crop protection science and related human power development in the sector has scored a dramatic improvement in recent years. Nevertheless, there is a consensus that the discipline has not been able to achieve its critical objectives judging from the persistent food insecurity our country are facing.

Therefore, my presentation will be (1) an overview of social, historical and cultural influences which may have a bearing on our attitudes and productivity and (2) progress report on some specific areas of research in which I have been a partner.

The problems of food production from historical and cultural perspectives

- We should remember that the problems of food insecurity may not be attributed to any one particular cause. Let me venture to say that the influences of culture may have had an impact to a degree;

- History tells us that famines have repeatedly come and gone throughout the long struggle for survival of our people through the centuries;
- Crop failures were frequent, caused by climate change, by wars, by epidemic diseases, by epizootics of cattle, pests, etc;
- Records show that cholera, human influenza, and conflicts either decimated or incapacitated the working population that indirectly affected food production.
- Historians mention at least 25 major famines in the two and half centuries between 1540 and 1800 (Pankhurst, 1996);
- I should also refer to the plagues of the desert locust which used to be more common and widespread then than at present. They say the locust turned the green landscape into the desert overnight. The earliest documented evidence goes back 600 years to the year 1410 [Pankhurst 1966]. Northern Ethiopia, particularly Tigray, Gonder, parts of Shewa, Wello, and Hararghe were subjected to repeated invasions, which led to famines and mass migrations.
- The African armyworm has been another formidable enemy. The earliest record of this pest on the continent comes from Ethiopia. In 1520, a priest was reported to have told a foreign visitor, “If it was not for the worms, we would have enough harvest to last us for years” [Pankhurst 1996];
- Apart from natural causes, traditional practices of cultivation were not known for their appreciable surpluses;
- For instance, storage structures were generally small, and they afforded little protection against insects and rodents; and
- Also due to frequent wars, storing large quantities of food was discouraged because they attracted militias and soldiers which lived by plundering villages.
- Let me remind you that it is not my intention here to go through the history of famines in Ethiopia. It is the possible consequences I am trying to draw your attention to.

Could we have gradually adapted to food shortages: Through the centuries?

- As a consequence of centuries of suffering from repeated food deficit, it appears as though we have inherited this legacy of scarcity or a culture of shortages or “Sekeken”, or a tolerance to food deficit;
- This culture manifests itself and seems to persist in our attitudes in our daily lives today;
- For instance, eating less is generally regarded as a virtue or respectable. We seem to be permanently haunted by a ghost of lurking hunger which raises its head periodically;
- This ancestral enemy, as it were, has given us such expressions as “Ehil Atabakin”, “Tur yihonal”, (don’t waste food) “Hod Endasayut Naw”. It is as if food is mined like gold or some precious scarce mineral;

- Consequently, it seemed we have acquired a culture of self-denial by abstaining from eating as much as possible. We frequently subject ourselves to recurrent periods of fasting; and
- I hope you may also agree with me that some what consistent with the shortages, we seem to have undergone a form of physical adaptation:

    - We spend more time sitting than working. (as if to save energy);
    - We are typically small in physical stature. (Look at our football players);
    - Our hands are small and delicate;
    - We work less because we eat less and say **"temesgen";**
    - Is it far fetched to suppose whether the present generation has adapted these cultural attitudes? We should examine this carefully in the interest of our future; and
    - Has that attitude affected our work ethics and productivity? [We will return to this later in our discussions.]

Traditional agriculture and the transition to cash crop in relation to crop protection research

- Typically, rural Ethiopia is characterized by clusters of villages, tukuls, next to small plots of a mosaic of subsistence crops. Apart from sporadic attacks of migratory pests, statistics are lacking regarding the amount of crop loss attributed to endemic pests. These pests fluctuate in incidence and intensity. Because of lack of resources, or lack of exposure, the farmer often endured and collected whatever harvest was left over from pest attack. The farmers' attitude to pests in a way may not have been much different from his attitude to climate. They are both regarded as unavoidable;
- Needless to say, in most countries around the world it is the farmers who feed their nations. They do this with different degrees of efficiency;
- In the developed world, the number of farmers in relation to the rest of the populations is shrinking, whereas in poor countries, the number is rising with corresponding fragmentation of individual landholdings and decreasing output.
- In what ways is this traditional sector expected to respond to technology delivery under such a constraint?
- A few of you older ones may remember that the first important step to modernize Ethiopian agriculture was taken by the Americans in 1950s;
- Training, research and extension were perceived as the key to transforming the traditional system;
- The continuous output of trained human power, which joined schools, research stations, state and private farms and the NGOs, opened up a promise of a new approach to production and development in general; and
- The late 1960s and early 1970s were a milestone when a few young entrepreneurs went into large-scale cash crop sector, e.g., beans and cotton were the leading early enterprises when suddenly the new Ethiopian Socialism loomed large on the horizon.

The rise of new pests, pesticides, resistance and integrated pest management: some specific examples

- The state farms and the new Ethiopian entrepreneurs, Like AMBASH, were not necessarily the earliest ones in opening up cotton enterprises in the Awash Basin. The Mitchel Cotts at Tendaho and Montenari in upper Awash were some of the early examples to go in with the technology of crop protection. The new technology comprised mainly of improved varieties, fertilizers and pesticides.
- The rise of the African bollworm to prominence, followed by the red spider mite and the white fly, could largely be attributed to the increasingly heavy use of DDT and related chemicals by these early entrepreneurs;
- They were mainly responsible for the emergence of resistant pests to insecticides, the depletion of natural enemies and the coming of secondary pests, such as the red spider mites;
- It was reported that Montenari used DDT to an extent of up to 10 sprays per season, and applied it with a heavy dose of 5 kg ha^{-1};
- The increase in application was a response to the build-up in resistance to the chemical by the pests, though this phenomenon was not well understood or appreciated at the time;
- The public at large was not also aware or informed of the more insidious, immediate dangers to humans or the long-term impact on environment;
- There was a shift at some point from the Organochlorines to Organophosphates, not because it was realized that, for example, DDT had a harmful side effect, but all was because the organophosphates acted faster and wiped out more insects;
- Like the insecticides, concern for environment was a concept that was imported from outside. So was the concept of integrated pest management. After more than thirty years, we are still discussing how to implement it;
- Today one can register synthetic pesticides faster than non-synthetics or bio-pesticides;
- Today the Desert Locust Control Organization exclusively uses synthetic insecticides for the control of migrant pests;
- I have already mentioned earlier the Desert Locust and the African Armyworms, which are managed almost entirely by synthetic chemicals.;
- The role of multinational insecticide companies cannot be underestimated in frustrating the development of IPM;
- We cannot ignore the contributions of NGOs in the distribution and build up of obsolete pesticides;
- I should also mention the weaverbird or Quelea which is more regular or seasonal than the locust or the African Armyworm. These birds have been sprayed with one insecticide, Fenithion, for many years. It is also known as Queleatox. It is banned in the country of its manufacture;
- The spraying is done after sunset by aircraft when the birds and their predators are roosting. Up to ten, fifteen to twenty million birds are killed seasonally in

such operations. Other non-target animals are also killed directly or are affected through the food chain;

- Quite often, the sprays are directed at wetlands such as the Zwai swamps which are connected to the main body of water;
- Fishing for human consumption is also done here;
- Only one study on the effects of Queleatox on non-target animals has been done. The Denver Wild Life Group conducted the study in eastern African including Ethiopia around 1984/85;
- No follow-up study has been done since then; and
- There were instances where eagles, other birds of prey, ground scavengers such as jackals were killed. This is not an isolated case, because the spraying is done at several sites within Ethiopia which include Konso, the lake districts, Shewa Robit, Babile, etc., where the weaverbirds and other wild life overlap.

Progress towards the understanding of pest dynamics management and obstacles

- Between 1986 and 1989 huge locust outbreaks engulfed North Africa, the Sahel and eastern Africa. It threatened the livelihoods of several African countries;
- To stop the looming advance and destruction from the locusts, the United States and the European Union contributed more than 300 million dollars in cash and chemicals for aerial and ground operations;
- The quantities of insecticides sprayed and/or dusted across the continent was staggering, particularly in the Sudan;
- In response to the potential harm that the insecticide residues would leave behind, the United Sates Government initiated and provided funds to support research on Development of Bio-pesticides for Control of Grasshoppers and Locusts in Sub-Saharan Africa. Several partner institutions in Africa, Europe and the United Sates were invited to work on the project;
- The objective of the program was to develop one or two bio-pesticide products to be commercialized in five years. The project was started in November 1997;
- The activities consisted of field search and isolation of fungal pathogens from dead or live, infected locusts and grasshoppers within the habitats of the Desert Locust in the Horn of Africa;
- There were eight institutions which pooled their expertise and took part in the program; some of the centers have more advanced staff and facilities than others;
- You may have heard about the Green Muscle, a bio-pesticide product that was developed earlier by Lubilosa in West Africa. Green Muscle is based on fungal pathogen of the locust Metarhizium anisopliae var. acridum;
- Out of more than 100 strains which we isolated, not less than 5 were found to be equal to or better than Green Muscle;
- More than 120 thousand dollars worth of equipment was purchased and installed at DLCO-EA ranging from isolation of the pathogen to mass production;

- In the last two years of the project life, we were able to mass-produce some of the strains for field tests. We worked in close collaboration with Addis Ababa University;
- Some people from FAO EMPRES and Rome, however, were not in favor of our project; apparently, we were duplicating the efforts of Green Muscle. One way to discourage or stop our efforts was to discourage support or indirectly curtail the employment of the research staff of DLCO-EA; and
- On the other hand, FAO readily funded field tests on Green Muscle in Ethiopia with the exclusion of our local material. To make the long story short, our five years endeavor came to a dead end as far as field tests, production and commercialization were concerned. Or to put it mildly, it is still pending.

Registration of pesticides

- Registration was an important component and prerequisite if a product came to a stage when it has to be marketed in eastern African countries because of the restrictions to conduct cross-border operations against the locust using unregistered product.We also needed to harmonize the registration procedures among the different guidelines;
- Every country in the region has its own separate procedure to deal with issues of registration. Some countries had no guideline for the registration of bio-pesticides. Some countries were resistant to harmonization efforts due to stiff requirements. For instance, some countries demand that efficacy tests of a bio-pesticide should be carried out locally even though a strain of a bio-pesticide could have come from both sides of a political boundary;
- We therefore organized a number of workshops on capacity building, reconciliation of differing data requirements, networking with Sahelian countries, which were already in an advanced state of harmonization. We initiated linking up with Southern and Eastern Africa Regional Committee on Harmonization (SEARCH). Therefore, again to make the long story short, we started but we did not finish; another dead end on both counts: on field tests and on harmnized registration;
- A similar concern as the one with the desert locust was expressed by the Regional Armyworm Project (DLCO-EA) and the European Union to develop some alternatives to the widespread use of synthetic chemicals to control this pest;
- Like that of the desert locust, we collected the virus from the cadavers of the dead larvae and multiplied them on artificial media. We were ready to mass-produce for field testing by setting up a modern and expensive laboratory facility provided by the donors;
- At this time, financial contributions from some of DLCO-EA's sponsoring governments had plummeted to an extent that even staff were not getting salaries on time; and
- The European Union became aware of the weakening support to DLCO-EA from African governments. They decided that they need to see an improvement

in contributions from the member countries", before they commit more funding". The money was stopped. Another dead end for IPM of the African Armyworm.

The Sorghum Chafer

Sorghum chafer (*Pachnoda interrupta)* has been a serious sporadic pest for many years. Some of its important biological features have not been understood for many years. These included its source and over seasoning habits.

The population of the beetle, as many of us have noticed, goes up and down with short and at times long intervals. The pest reemerged and became serious in the early ninties. As the name implies it is a serious pest of sorghum although a very large number of both economic and wild host plants form the list of its potential hosts.

In response to the economic threat posed by the beetle, especially in northern Shewa, joint FAO and Ministry of Agriculture project was launched in the early 2000 to clarify some of the mysteries surrounding the field biology of the beetle. At present (2006-2007) the beetle remains in a recession.

Some of the important findings of the study revealed that the beetle lives almost exclusively in the bush. It has nothing to do, as was frequently supposed in the past, with manure heap. Underneath the bush, the average temperature is close to 20 ^{0}C. Inside the manure heap, on the other hand, the temperature goes up to 40 ^{0}C, where no beetles at any stage were found.

The beetle has been associated mostly with the Afar Region; not because of the shelter or abundance of manure or compost, rather the Afar Region has more bush which offers refuge for the over seasoning beetles. So, one could assume that the invasion of sorghum fields in the Amhara Region has its origin in the Afar Region. This finding is important in a sense that it narrows down our area of focus on the sorghum chafer.

Progress in monitoring the African Armyworm Community Participation

Early warning is a key to managing the African armyworm that at times causes disastrous losses to the precarious food supply of rural communities, because the pest appears suddenly in over whelming density. That is why monitoring and early warning are critical and integral parts of combating the pest. Monitoring involves trapping the male moths in advance of larval outbreak and predicting whether pest occurrence is likely or not. The trapping and recording of moth numbers has been done by trained trap operators of the Ministry of Agriculture. In this practice, previously, the target communities were not involved. They had no idea of what the trap operator was doing although the technology and procedure were simple. Another important problem with this approach was that monitoring does not cover all armyworm prone agricultural communities. The trap operators who were already in short supply frequently changed jobs, or were transferred leaving monitoring sites unattended.

As a way out of this difficulty, a pilot project sponsored by USAID was initiated to train trap operators from among resident farmers in affected communities. The new trap operators are among the elite who can read and write, record the information, communicate and drive communities into action. One important advantage is that because communities are connected, information and techniques are passed much more easily than is formerly supervised by extension agents.

A pilot program initiated at two sites in southern Ethiopia at Knoso and eastern Ethiopia at Feeds have given promising possibilities as more sustainable procedure for monitoring and forecasting the pest.

The way forward

- Earlier in my talk, I made a brief reference to some of the cultural and/or historical influence that may have influenced our attitudes and our productivity;
- We have, many times, pointed our fingers at some of the possible reasons as to why we start programs but we do not finish; or if we did finish, our achievements have not translated into tangible and productive results;
- We are now going to review our performances over the last 20 years. More likely, we are going to enumerate our in-actions and frustrations and pass the blame on to some real or imagined hindrance blocking our progress;
- Speaking of hindrances, for instance, we should ask ourselves “how librated are we from those age-old debilitating cultural influences or are we part of the problems?” or is it a combined force of the past and present institutional structure which is affecting our ability to deliver?
- Have the quality of research and researcher declined over the years?
- Are we wasting resources on wrong priorities?
- Examining some of the crop protection reports, I came across the following which are perceive to be probable reasons for research not being able to make an effective link with the farmer:

    - Research activities or results are often not relevant to the real problems;
    - Resources allocated to the researcher are not adequate;

- There are no incentives to motivate a researcher to stay on the job and sustain continuity;
- Therfore, there is a problem of continuous turnover of staff; and
- There has been decentralization and consequent fragmentation of research capacity.

- Policy has been blamed in blanket terms. Could it be a problem of lack of capacity on the part of policy markers? This is because a deliberately negative or a wanton policy does not benefit anybody. Policy makers have to have proper insights to act on desired policies. Those insights have to come from researchers.
- Is there fear of decisions? This is a deep-rooted culture, I suppose, in our working relationships;
- Is there lack of coordination between departments, say, between crop protection research, crop production (and the farmer) resulting in needless duplication of efforts due to lack of communication? and
- There could be many more obstacles faced by each of us that need to be correctly diagnosed and dealt with to avoid perpetuation of the past mistakes.

References

Abate, T. and Fantahun Assefa, 2003.

Azage, Tsehay. 2005. Working system of the pesticide registration and control. MoARD (Report).

Belayneh, Bayou. Pesticide Imports and Forecasts for the years 1996-2010.

Fankhurst, R. 1996. Some factors depressing the standard of living of peasants in traditional Ethiopia. (Source: Institute Ethiopian Studies)

MoARD-UNDP-P1. Plant Protection and Pesticide Registration and Control Perspectives.

Review of Policy and Regulatory Aspects of Plant Protection in Ethiopia

Fikre Markos
MoARD, Crop Protection Department, Addis Ababa

Introduction

Crop protection as a discipline aims to reduce or minimize crop losses due to insect pests, diseases, noxious weeds and other vertebrate pests. To achieve its goal, it is prudent that a clear direction is put before hand by the responsible body. The direction must address all related activities including research, extension and the regulatory aspect of crop protection. This paper reviews the policies related to crop protection and its regulatory functions that exist or implemented in Ethiopia to date.

Moreover, in this review, effort is made to collate and analyze the international policy instruments relevant to crop protection. In both cases, the implications and gaps to be filled are suggested.

The overall objective of this review is to gather the relevant and available information in crop protection policies and analyze the implications with regard to the Research and Development efforts being exerted in the country.

In specific terms, the review will target to:

- identify the policy instruments Ethiopia has formulated nationally and those that has been adopted from the various international fora to perform its crop protection activities;
- analyze their appropriateness and relevance to the current Ethiopian situation; and
- propose areas of concern for future investigation or amendment.

Crop protection policies and regulatory functions

Crop protection as a discipline covers a range of functions such as crop protection research, crop protection extension, and regulatory aspect of crop protection

Conceptually, all of the above functions need to have a policy guidance to be implemented in concurrence with what the government wants to accomplish. Before proceeding into the subject it is imperative that a clear definition and/or understanding of what the terms" policy" and "regulatory" are meant.

Policy

Policy is usually and fully comprehended when it is presented with its corresponding strategy or strategies because, principally, policy refers to setting the direction of a particular subject or issue and strategy elaborates the mechanism how to go about to implement the policy. Simply policy is a statement or a comprehensive document expressing one's intent (government's, company's NGO's, etc., intent) to address an issue. Usually in the case of government, policy is formulated by the executive organ of the government and approved by itself or by the legislative body. Similarly, in private firms, policies are formulated by the owners of the company supported by the executives of the firm. In both cases participation of stakeholders and professionals is given due emphasis; however, final decision is made by the policy makers.

Policies could be a general or specific one. For example, the Ethiopian economic policy encompasses the policies on Rural Development. Similarly, the Agriculture Development Led Industrialization (ADLI) strategy of Ethiopia has under its umbrella the rural development strategies. Agriculture policy and strategy can be formulated in detail. Even a more detail one like the crop protection policy, the livestock marketing policy, the extension policy, the dairy development policy, breeding policy and so on could be referred to as specific policies within the general policy and strategy framework.

Under the Ethiopian Federal system, policies are approved at various levels depending on their significance, i.e., at parliament, council of ministers and ministry level. In other words, laws, regulations, guidelines are policy instruments used to implement a given policy. Hence, they can be considered as part of the policy. Laws and regulations are published in the Negarit Gazette;

guidelines issued by ministries are signed and circulated and need not be published in a gazette. There are also some institutes, which are given by law the authority to issue guidelines. The regional governments have similar arrangements for policy approval.

Regulatory

The term "Regulatory" is understood by some people to mean any activity performed to avoid any unwanted situation from occurring using established laws, regulations or any kind of legislation as an instrument, whereas others conceive it without giving any importance to legislative or established rule and usually is equated with the term control. A relevant example in crop protection could be mentioned: If a field is infested with unwanted pest (insect, weed, or any other agent), the farmers are advised to control them on time to help them minimize the damage by such pests. This is not a regulatory activity as it is not done under the power of legislation; it is rather part of the extension activities. On the other hand, if an exotic pest is intercepted on entry into the country and the consignment is denied entry based on a legislative power, then this becomes a regulatory activity. Therefore, an activity is considered regulatory only if it is performed based on legislation or established rule.

The above background relating to policy and regulatory functions have been highlighted to assist the understanding of the crop protection policies and regulatory activities in Ethiopia reviewed below.

Crop protection research policy

As indicated in the Plant Protection Strategy of the Ethiopian Agricultural Research Organization (July 2000), there is no separate policy for crop/plant protection other than the general Agricultural Research Policy and Strategy. This, however, is not to rule out the existence of interrelated policy instruments and institutional guidelines (guideline for testing pesticides) being used as the bases for research activities.

The National Agricultural Research Policy and Strategy issued in October 1994 states that the Plant protection Research to be conducted in the country need to be in the following manner:

- That plant protection research will minimize adverse effects of pesticides on the environment;
- That plant protection research will focus on pest resistant variety development; and

- That plant protection research will put effort in finding solutions to frequent pest outbreaks

From this general direction, one may suggest that the policy of crop protection research is focused on integrating some of the options in crop protection technologies, which may then imply to the preferred policy of IPM (integrated pest manangement).

In the Plant Protection Strategy of the Agricultural Research Organization, plant protection policy issues are highlighted as having constrained the research agenda, which the following were notably cited.

- The absence of regulation to import biological control agents;
- The failure of the Plant Quarantine Regulation to stop entry of exotic quarantine pests;
- The importation of hazardous pesticides; and
- The absence of domestic quarantine that regulate movement of pests to pest free areas

An in depth looks into each of the above points raises a query whether all the issues are of policy nature or whether some are issues of enforcement. It is agreeable that the absence of regulation to import Biological Control Agents and the absence of domestic quarantine that regulates movement of pests to pest free areas are policy issues but the rest are enforcement issues.

Crop protection extension policy

Like in the crop protection research, there is no separately approved policy for crop protection extension. However, in July 1980 a circular was issued by the Agriculture Development Department (Ref. No. 92/0-7/3) regarding the responsibility of the Ministry of Agriculture in the management of pests. Under this guideline, pests were categorized into migratory and non-migratory or regular pests.

Under the migratory pests category desert locust (*Schistocerca gregaria* Forskal, 1775), armyworm (*Spodoptera exempta* Walker), grain eating bird (*Quelea quelea*) and aphids are included. All other pests were regarded as non-migratory pests. Based on this categorization, the government was responsible to control the migratory pests covering costs of pesticides, sprayers and protective clothing, while all other pests (recurrent pests) were to be controlled using the individual producer's expenses. The government will be involved in providing technical assistance to the producers including the smallholder farmers.

In June 1981 (Ref. 3010-7/3) the 1980 guideline mentioned above was amended by justifying the categorization of pests into two categories. It also included definitions of key terms like pest, migratory pest epidemics and recurrent (regular) pests. The guideline also determined that desert locust, armyworm and quelea bird only to be included in the migratory pest category, the change being the deletion of aphids from the migratory group.

Consequently, government's responsibility changed accordingly. Through the guideline, an inter-institutional committee with a mandate of reviewing the pest situation in the country was established. Member institutions were the Ministry of Agriculture, Ministry of State Farms, Ministry of Coffee and Tea Development, Relief and Rehabilitation Commission and Institute of Agricultural Research.

The 1981 guideline also introduced one item to the previous guideline, i.e., if due to man-made or natural disaster in a given area constrains the control or management of regular pests, then it should be possible to use sprayers, protective clothing and pesticides allocated for migratory pests on credit bases.

Currently, the government is honoring this arrangement and covers all costs related to the three migratory pests. In fact, the government is also supporting farmers in the control of regular pests when they occur at an epidemic level such as the recent control of sorghum chaffer, Wello-bush cricket, stock borers and various grasshoppers.

Constraints with the departmental guideline

Neither on the currents setting nor in the previous government was there any authority provided to issue a guideline to a department. The minister only was empowered to issue a guideline. Therefore, although the content of the guideline is acceptable and relevant to the condition of the country and the government is implementing it, there is an urgent need to issue the guideline at a ministerial level to accord it a full legal power. Moreover, the technical committee that was set by drawing members from different institutions need to be updated together with the other elements mentioned in the guideline regarding previous government's set up.

The regulatory activities of crop protection and its relevant policies

The regulatory activities, as explained earlier are those that are performed with a legislative power for enforcement. In Ethiopia, policies enforced relating to regulatory aspect of plant protection are policies which are issued directly to set the direction of the plant protection and are implemented by the ministry, and policies that have significant bearing in crop protection but are issued together with environmental or other issues.

The policies that are covered under number (1) include

- The plant Protection Decree No. 56 of 1971;
- Council of State Special Decree No. 20 of 1990 for the Registration and Control of Pesticides; and
- The Plant Quarantine Regulation No. 4 of 1992

A highlight of each of the above legislation is presented below.

Plant protection decree no. 56/71

The Decree gives power to the Minister of Agriculture to regulate the import and export of plant and plant products. This means that the minister will have the power to prohibit, restrict and regulate the importation into and the exportation from the country of any plants, plant products and any other articles and plant pests known to be or likely to be injurious to agriculture or to inflict or infest any plants (Article 3(1).

The MOARD is accorded the power by regulations issued to

- require import permit;
- require inspection;
- issue phytosanitary certificate;
- require the treatment of infested or infected plants, plant products and other articles including conveyances;
- specify entry points;
- retain and dispose of; and
- require phytosanitary Certificate (PC) from exporting country

The Minister of Agriculture was also authorized to delegate his power contained in the decree with the exception of Article 10 (power to issue regulation) of the decree.

Major drawback of the decree

- Does not cover the main principles enshrined in the IPPC;
- Dealt mainly on the powers accorded to the Minister; and
- Penal Provisions were too small to deter the violation of the Decree

Council of ministers plant quarantine no. 4/1992

The regulation among other things covered the following:

- Quarantine Control–All imported plants, plant products and other articles, which are liable to carry plant pests, are subject to plant quarantine;
- Import Restriction on Plants–Specified list (schedule I) which require import permit;
- Import Prohibitions – Specified list (schedule II) which are prohibited from entry into Ethiopia; and
- Waiving Quarantine Requirement – Upon presentation of evidence that the plants have been certified by a known institute using special techniques and are intended for research and scientific studies; or upon being convinced that the plants, plant products, and other articles in transit are packed and secured to an acceptable standard the inspector can waive quarantine requirements.

The regulation provides power to the Minister of Agriculture to charge fees for the various services rendered such as inspection of plants, plant products and other articles, disposal of infested/infected plants, plant products and other articles. List of fees for plant quarantine services is attached as schedule III to the regulation.

Drawbacks of the regulation

The major drawbacks with the Plant Quarantine Regulation No.4 of 1992 are

- It does not identify import and export requirements separately. That is plants, plant products and other regulated articles destined for export need to fulfill the requirement of the importing country and not of the exporting country;
- The list of restricted and prohibited plant, plant products and other articles is not exhaustive;
- The conditions of entry for the restricted plants should have been prepared based on risk analysis and attached with the regulation;
- The quarantine pest list is not prepared based on pest risk analysis and is not complete. It is not part of the regulation

Council of state Special Decree No. 20 of 1990 for the registration and control of pesticides

Among the various inputs used in agriculture, pesticides are in a class of commodities that require proper regulation because if not properly handled could result in disaster. According to the Special Decree, prohibitions authorization of registration, certification (renewal and cancellation included), packaging, labeling, storage, and disposal are provided for pesticides. The Special Decree established an advisory committee with its members drawn from:

- An official to be designated by the minister;
- A representative from the Ministry of Health;
- An official of the Ministry in Charge of Pesticide Affairs ;
- An official of the Ministry of State Farms Development;
- A representative from the Ministry of Coffee and Tea Development;
- A representative of the Valleys Development Studies Authority;
- A representative of the Ethiopian Standards Authority; and
- A representative of the Ethiopian Institute of Agricultural Research

The committee's responsibilities include

- Prepare a list that would help facilitate registration by collecting and evaluating data relating to pesticides recognized to be efficacious through domestic reserach, past us or otherwise;
- Consider pesticides submitted for registration and advise the minister as to their compliance with the requirements specified in the regulation; and
- Advise the minister on the implementation of this special decree and drectives issued according to this decree

The advisory committee is forced to operate with limited members, mainly because of the member instititions have been dissolved and/or amalgamated while few have seized participating for unknwn reasons.

The decree provides for the powers of inspectors as follows:

- Enter and search any workplace during working hours; and
- Require production of data or examine books of records relating to pesticides

The ultimate goal of pesticide registration and control is to contribute to the achievement of a clean environment and to guarantee safer agricultural produce to domestic and export supply through:

- the use of register, relatively safe and locally effective pesticides;
- provision of competence assurance certificate to persons handling pesticide production, distribution and trade; and
- the promotion of sound pesticide manangment

Drawbacks of the Special Decree

The Special Decree, however, the following drawbacks:

- There was a gap in deleneating the mandate of pesticide control;
- There was a shortfall in providing the power of the inspectors;

- The role of the advisory committee was not sufficiently indicated in the decree; and
- It failed to address issues indicated in other internationally concluded agreements

General provisions related to the regulatory functions of plant protection

The Constitution of the Federal Democratic Republic of Ethiopia Proclamation 1/1995

Article 44 (1) reads as: "All persons have the right to a clean and healthy environment."

Article 92 (1) states, "Government shall endeavor to ensure that all Ethiopians live in a clean and healthy environment."

Article 92(4) provides for as follows: "Government and citizens shall have the duty to protect the environment."

How are these provisions related to crop protection?

In crop protection, pesticides of different toxicity are used to protect crops from the damages of crop pests including insects, pests, weeds, rodents, and disease causing microorganisms. Pesticides, if used improperly, could result in a serious health hazard to human beings, plants and the general environment. Therefore, in order for all persons to have the right to a clean and healthy environment the government and the citizens shall have the duty to protect the environment from the effects of misused pesticides. As crop protection technologies are being provided to the smallholder farmer by the government, endeavor by the government to protect the environment from pollution by crop protection chemicals is of utmost importance. Moreover, some pesticides are categorized as hazardous substances and hence should not be used in contravention with the provisions of the constitution. To that end, the government had allocated a substantial amount of budget to clean up and dispose of obsolete pesticides stocks since 2000. Until this year, about 2000 metric tone of obsolete pesticide stocks have been shipped abroad for incineration.

The Criminal Code of the Federal Democratic Republic of Ethiopia

In the Criminal Code of the Federal Democratic Republic of Ethiopia Proclamation No.414/2004 various issues are covered which relate to the protection of human health, plants, animals and the environment. Among which the following are considered relevant to crop protection.

Article 516 Propagation of an Agricultural or Forest Parasite states that whoever intentionally or by negligence propagates a parasite or germ harmful to agricultural or forest crops is punishable with simple imprisonment or fine.

Where the criminal has acted maliciously or has intentionally caused substantial damage, the punishment shall be simple imprisonment for not less than three months or where the crime is committed negligently, the punishment shall be simple imprisonment not exceeding six months or fine

Article 520 Mismanagement of Hazardous Wastes and other Materials

Whoever fails to manage hazardous wastes or materials in accordance with the relevant laws; or fails to label hazardous wastes or materials; or unlawfully transfers hazardous wastes or materials, is punishable with fine not exceeding Birr 5,000, or rigorous imprisonment not exceeding three years, or with both

Article 521 Acts Contrary to Environmental Impact Assessment (proclamation No.299/2003) - Whoever, without obtaining authorization from the competent authority, implements a project on which an environmental impact assessment is required by law or makes false statements concerning such assessment is punishable with simple imprisonment not exceeding one year.

International Policy Framework Related to Crop Protection

Policy instruments

Several international policy instruments have been adopted mostly since the 1980's. Among which the following are notably cited:

- UNEP London Guidelines for the Exchange of Information on Chemicals in International Trade;
- FAO International Code of Conduct for the Distribution and Use of Pesticides;

- ILO 1990 Convention on Safety of Chemicals at the Workplace (No. 170);
- The Montreal Protocol on Substances that Deplete Ozone Layer;
- Various conventions adopted under the auspices of the UN;
    - The International Plant Protection Convention
    - The Rotterdam Convention on Prior Informed Consent Procedures
    - The Stockholm Convention on Persistent Organic Pollutants
    - The Basel Convention
- The Bamako Convention;
- Code of Conduct for the Import and Release of Exotic Biological Control Agents; and
- International Code of Conduct on the Distribution and Use of Pesticides

All policy instruments were introduced and established with one common goal, i.e., to facilitate the establishment of national plant protection programs in all countries. Some of the policy instruments are reviewed below.

The International Plant Protection Convention – IPPC

The IPPC is a multilateral treaty that was deposited with the Director General of the Food and Agriculture Organization of the United Nations in 1951. It came into force in 1952 and was amended twice in 1979 and 1997 (FAO 1997). The revised version of the IPPC has entered into force since 24 February 2004.

Ethiopia ratified the IPPC Convention of 1951 on 20th June 1977 and the current revised version on 25th August 2005. The IPPC is designed to promote international cooperation in controlling pests of plants and plant products and in preventing their international spread with special emphasis on their gaining access to endangered areas. The scope of the IPPC is not limited to crops or agricultural plants only, but covers all including wild plants.

The sanitary and phytosanitary agreement (SPS Agreement) of the World Trade Organization (WTO) in order to establish which measures are necessary, it relies on the work of three international standard setting organizations, concerning food safety, plant health and animal health. The IPPC has been designated in the SPS Agreement as the relevant international organization for the plant health field.

The IPPC recognizes the rights of every country to have sovereign authority to use phytosanitary measures to regulate the entry of plants and plant products and other objects or materials capable of harboring plant pest. However, in applying phytosanitary measures, contracting parties have obligations to comply with the convention's principles of necessity, technical justifications and transparency.

Code of conduct for the import and release of exotic biological control agents

The code of conduct is prepared by the Secretariat of the International Plant Protection Convention as part of the UN/FAO's global Program of Policy and technical assistance in plant quarantine. The Code of Conduct for the Import and Release of Exotic Biological Control Agents is prepared as part of the International Standards for Phytosanitary Measures – ISPM. This standard was endorsed by the 28th Session of the FAO Conference in November 1995 and is subject to periodic review and amendment.

The issue of Biological Control Agents is addressed under the IPPC convention particularly under the phytosanitary measures, which clearly indicates that the regulation of import and release of Exotic Biological Control Agents is justified by the quarantine threat it poses. In the code of conduct, "Biological Control Agent" is defined as follows:

Biological Control Agent means a natural enemy, antagonist or competitor and other self-replicating biotic entity used for pest control. This definition distinguishes the difference between its closest phrase "Biological pesticide" or "Biopesticide" which is defined as:

"A generic term, not specifically definable, but generally applied to biological control agents, usually a pathogen, formulated and applied in a manner similar to a chemical pesticide, and normally used for the rapid reduction of a pest population for short-term pest control".

The major difference is that biological pesticide is formulated like a chemical pesticide while biological control agent is not formulated. Therefore, the biological pesticide, in addition to the quarantine threat it poses, has additional concern that relates to efficacy and proprietorship as a pesticide. An example of a biological control agent could be:

- The parasitic wasp (*Pauesia juniperorum)* against cypress aphid (*Cinara cupressivora*); and
- While *Mehtaryzium anisoiplae* is used for the control of termites or *Bacillus thuringiensis* (Bt) for the control of various lepidopterous larvae/caterpillars are formulated biological pesticide. If the formulated biological pesticides are

exotic, then they become part of this Code of Conduct. In general terms, as it is difficult to determine whether the agent in a biological pesticide is exotic or not, it is usually treated as exotic.

The code does not deal with pest control techniques such as autocidal methods, resistant host plants, and toxic products of microbes used as pesticides which cannot reproduce and which are similar to conventional chemical pesticides. These are addressed or covered under the "International Code of Conduct on the Distribution and Use of Pesticides".

The code of conduct for the Import and Release of Exotic Biological Control Agents deals with

- the import of exotic biological control agents for research;
- the import and release of exotic biological control agents for bio- control; and
- the import and release of exotic biological control agents for use as biological pesticides where those products incorporate organisms which can multiply

The Code is non-legally binding, but serves as a means to introduce procedures of international standard; particularly where national legislation to regulate the use of biological control does not exist or is inadequate.

Ethiopia being a member of UN/FAO has the right to use and implement the Code of Conduct for the Import and Release of exotic biological control agents prepared by FAO in a situation where the national legislation is found inadequate. However, the Ministry of Agriculture and Rural Development decided to address the subject based on its national laws and drafted a separate regulation for the import and release of exotic biological control agents in addition to the Plant Quarantine Regulation No. 4/1992 and the State Council Special Decree No. 20/1990 for Pesticide Registration and Control. Unfortunately, this was not approved by the appropriate body.

The drafted regulation was not comprehensive enough to cover the issues indicated in the Code of Conduct. Beyond and above, there was no valid reason to establish a separate legislation for the importation and release of exotic biological control agents while it could be included in the quarantine regulation.

The Rotterdam Convention on Prior Informed Consent (PIC) Procedure for Hazardous Chemicals and Pesticides in International Trade

The production and the use of chemicals both industrial chemicals and pesticides raised both public and official concern about the potential risks. The concern is much higher in countries and societies lacking adequate infrastructure to monitor the import and use of such chemical.

Because of this growing concern, UNEP and FAO introduced the 1989 Prior Informed Consent (PIC) procedure. This in return led to the mandatory control of certain hazardous chemicals and pesticides through finalization of the text of the convention on the Prior Informed Consent Procedure for certain hazardous chemicals and pesticides in International Trade in March 1998. The convention entered into force on 24 February 2004, and as of September 15 there were 109 countries and the EC had deposited instruments of ratification. Ethiopia ratified the convention and made it part of its law by promulgating proclamation No 278/2002.

The Rotterdam Convention was initially inspired by North-South dilemma in which wealthier countries with bans on certain life threatening chemicals continued to sell them abroad. In recent years, however, South-South trade has increased between newly emerging economies. In both instances, less advantaged importing countries often lack the means to manage hazardous chemicals throughout their life cycle, from importation through use and safe disposal.

The Rotterdam convention is an early warning system that empowers poorer nations to make their own informed decisions on toxic chemical imports by providing:

- information on other countries' decisions to ban or severely restrict certain chemicals;
- information on other countries' experiences with severely hazardous pesticide formulation;
- information on which to base their own bans/restrictions and to announce them internationally;
- the means to stop unwanted imports; and
- the requirement that exporting countries respect other countries' decisions on imports

The Rotterdam convention also encourages nations to help each other build capacity to manage chemicals throughout their life cycle (from cradle to grave).

The convention listed in its Annex about 27 chemicals at the beginning to be subjected to the PIC procedure. However, through the consecutive Conferences of the Parties, the list has grown to 39 up until October 2006.

The Stockholm Convention on Persistent Organic Pollutants (POPs)

The Persistent Organic Pollutants were identified to pose significant threats to human, animal health and the environment that on 22nd May 2001, the world's governments met in Sweden and adopted an international treaty aimed at restricting and ultimately eliminating their production, use, release and storage. The convention entered into force on 17 May 2004; as of September 2006, there were 130 parties to the convention. It started by targeting at 12 particularly toxic POPs for reduction and eventual elimination.

While the risk level varies from chemical to chemical, by definition all of the POPs share four properties.

- They are highly toxic;
- They are persistent, lasting for years/decades before degrading into less dangerous forms;
- They evaporate and travel long distances through air and through water; and
- They accumulate in fatty tissue.

The convention recognizes these toxic chemicals as the worst POPs ever created (dirty dozen). Nine of them are pesticides, which include Aldrin, Chlordane, DDT, Dieldrin, Endrin, Heptachlore, Hexachlorobenzene, Mirex, and Toxaphen

The Convention also targets two industrial chemicals. One is hexachlorobenzene **(**HCP) which is also used as a pesticide (kills fungi that affect food crops) and can be a by-product of pesticide manufacture, and the second are class of industrial chemicals known as PCBs or polychlorinated biphenyl (notorious for human health scandals-rice oil contamination in Japan in 1968 and Taiwan in 1979).

The last two chemicals covered in the convention are unintentional chemical by-products known as poly-chlorinated dioxins and furans. These chemicals have no commercial use; they result from the incomplete combustion and from industrial process such as the production of pesticides, polyvinyl chloride and other chlorinated substances.

Dioxins and furans are the most potent carcinogenic chemicals and received worldwide attention since the 1990s when they were found contaminating chicken in Europe. Ethiopia has ratified the convention through proclamation No. 279/2002.

The Basel Convention

This convention was negotiated in 1989. It deals with the Control of Tansboundry Movements of Hazardous Wastes and their Disposal to ensure safety to the environment.

Ethiopia ratified the Basel Convention through the proclamation No.356/2003.This has enabled Ethiopia to send abroad its obsolete pesticide stock for incineration.

The Bamako Convention

Another very similar convention to the Basel one but with a continental perspective done in 1991 is the OAU solicited Bamako convention .It deals with the ban of the import into Africa and the control of tansboundry movements and management of hazardous wastes within Africa. Ethiopia ratified the convention through the proclamation No.355/2003

Other voluntary or none legally binding initiative is also negotiated and put in place. Among which the Strategic Approach to Chemicals Management (best known by its abbreviation SAICM is worth mentioning because it provides a wide scope of chemical pesticide management.

Gaps and challenges

As facts reveal the policy gaps in plant protection research, extension and the regulatory activities do not seem to constrain largely the practical application of crop protection technologies in the country, but having an articulated policy on each of the major functions will be an added advantage in terms of clarity rather than a determining factor. However, the national policy instruments of the regulatory aspect of crop protection (Plant Quarantine and Pesticide Control legislations) need to be updated in such a way that the importation and release of biological control agents can best be addressed.

The obvious challenge before us, however, is the lack of capacity particularly the capacity to manage chemical pesticides and bio pesticides according to the internationally set rules and procedures.

Establishment of accredited laboratory facilities for determining maximum residue levels (MRL) and capacity to manage bio-safety related issues are critical challenges to implement appropriately the available policy instruments.

The way forward

In line with capacity, building efforts the Ethiopian Institute of Agriculture in its capacity to coordinate the National Research System should generate the Plant Protection Research Policy and get it approved to enhance research program implementation.

In similar manner the Ministry of Agriculture and Rural Development has to update the departmental guideline and get it approved by the minister to accord it legal status. Moreover, the ministry has also to update the available legislation with special emphasis on the import and release of biological control agents and pesticide management.

In conclusion, overarching policy and strategy are very vital tools in research and development but unless supported with needed capacity they will remain on paper. Hence, capacity development should receive equal attention if not more.

Bibliography

The Basel Convention on the control of the Trans boundary movement of Hazardous Wastes and their Disposals Adopted by the conference of the plenipotentiaries on March 22, 1985 and entering into force in May 1992.

The Stockholm Convention on Persistent Organic Pollutants (POP) entering into force on May 17, 2004.

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade entering into force on February 24, 2004.

Plant Protection Decree number 56 of 1971.

Council of State Special Decree number 20 of 1990 for Registration and Control of Pesticides.

The Plant Quarantine Regulation number 4 of 1992.

The Constitution of the Federal Democratic Republic of Ethiopia Proclamation number 1/1995 Addis Ababa, Ethiopia.

The Criminal Code of the Federal Democratic Republic of Ethiopia, Proclamation number 414/2004.

Environmental Impact Assessment Proclamation number 299/2003.

FAO International Code of Conduct for the Distribution and Use of Pesticides

The Plant Protection Convention of 1951.

FAO, November 1995: Code of Conduct for the Import and Release of Exotic Biological Control Agents.

The Bamko Convention of 1991.

Agricultural Development Department Circular Ref. number 92/0-7/3 of 1980.

Ethiopian Agricultural Research Organization, Crop Protection Research Organization, Crop Protection Research Strategy, July 2000.

Institute of Agricultural Reserch (IAR) Proceedings of Annual Research Seminar, 25-27 October 1972. IAR, Addis Ababa. 1973.

Two Decades of Research on Insect Pests of Grain Legumes

Kemal Ali[1], Mekasha Chichaybelu[1], Tsedeke Abate[1], Tadele Tefera[2] and Mohamed Dawd[1]
[1]Ethiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia
[2]Haramaya University P.O. Box, 138, Dire Dawa

Introduction

Grain legumes are an important component of agriculture and food systems in practically all over the world, and they serve to complement the cereal crops in several aspects (Graham and Vance, 2003). In Ethiopia, pulses are important crops next to cereals. They are cheap sources of protein, and play modest role in export market. In terms of hectarage, these include faba bean or broad bean (*Vicia faba*), haricot bean or common bean (*Phaseolus vulgaris*), field pea (*Pisum sativum*), chickpea (*Cicer ariethenum*), grass pea (*Lathyrus sativus*), lentil (*Lens culinaris*) and soybean (*Glycine max*) (FAO, 2006). The Central Statistical Agency (CSA) of Ethiopia puts fenugreek (*Trigonella foenumgraecum*) and lupine (*Lupinus albus*) in the category of grain legumes. Other less known grain legumes, grown especially in the low and mid-altitudes (less than 1800 m), include cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*) and mung bean (*Phaseolus mungo*).

Current area of cultivation is estimated at approximately 1.35 million ha with a total production of about 1.3 million metric tons per annum; nearly 9.7 million households are engaged in grain legume production in Ethiopia (CSA, 2005). Cultivated area and production of grain legumes, particularly those for export (such as haricot bean, chickpea and lentils), are expected to increase significantly in the coming years due to the emphasis provided by the government on market-oriented production.

National average yields of grain legumes in Ethiopia are estimated at 0.8 t ha^{-1} (Figure 1). Yields have remained below the one metric ton level throughout the 1990s. Whatever increases obtained in production were met by expansion of an area rather than increases achieved from yield per unit area.

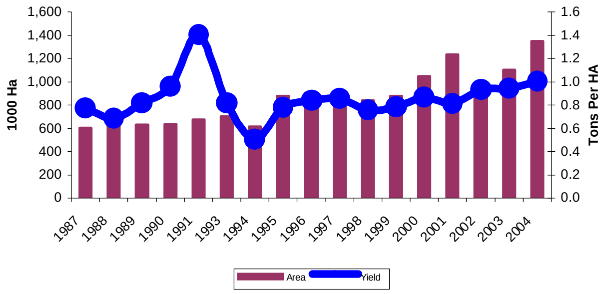


Fig. 1. Cultivated area and yield of grain legumes in Ethiopia

This yield level is very low compared to the achievements on experimental plots and on-farm demonstrations. Arthropod pests are among the most important limiting factors in grain legume production in this country. A large number of insect and mite pests attack grain legumes both in the field and in stores (Tsedeke et al., 1982; 1985). Notable among the pests in the field are the bean stem maggots (*Ophiomyia* spp.) on haricot bean, the African bollworm (*Helicoverpa armigera*) on chickpea, and the pea aphid (*Acyrthosiphon pisum*) on field pea, lentil and grass pea. The red spider mite (*Tetranychus cinnabarinus*) is also important on commercially grown snap beans in the Upper Awash and the Central Rift Valley areas. The pea bruchid (*Bruchus pisorum*) has also become a major pest of field pea in recent years in North and Central Ethiopia. The objective of this review is, therefore, to compile research findings between 2003 and 2007.

Research findings

Field pea and faba bean

Insect pests

Field pea and faba bean are grown in a wide range of environments and are subject to attack by various insect species. Only few of them are economically important. Severeal factors including crop type, variety and environment affect the occurrence and importance of these pests (Table 1).

Table1. Insect pests affecting faba bean and field pea

Crop	Common Name	Scientific name	Status
Field pea	Pea aphid	*Acyrthosiphon pisum*	Major
	Pea bruchid	*Bruchus pisorum*	Major
	African bollworm	*Helicoverpa armigera*	Major
	Common cutworm	*Agrotis segetum*	Minor
	Adzuki bean beetle	*Callosobruchus chinensis*	Major
	Bean bruchid	*C. maculatus*	Minor
Faba bean	Groundnut aphid	*Aphis craccivora*	Minor
	Black bean aphid	*Aphis fabae*	Undetermined
	African bollworm	*H. armigera*	Major
	Common cutworm	*A. segetum*	Minor
	Adzuki bean beetle	*C. chinensis*	Major
	Bean bruchid	*C. maculatus*	Minor
	Thrips	*Caliothrips impusus*	Undetermined
	Shiny cereal weevil	*Nematocerus brachyderes*	Undetermined

Source: Birhane, 2002; MARC, 2005; Seid and Tebkew, 2002

Pod borer, *Helicoverpa armigera* (Hubner) is sporadically active causing widespread damage and loss of pods and grains. Black bean aphid is also a sporadic pest in some regions where the crops are grown. The infestation causes severee distortion of the apical leaves and pods, but their development is greatly influenced by environmental conditions.

Pea aphid (*A. pisum*) is commonly found in peas grown in mid-altitude areas (1800–2200 m). The seriousness of the pest depends on weather (mostly temperature and rainfall) conditions that prevail during the cropping season. Their incidence diminishes to insignificance level at higher altitudes; the cool temperature and high rainfall slows down their development and spread. Pea bruchid *(Bruchus pisorum*) is the only pest added to the list of the previous survey report (Worku, 1998). The surveys conducted in the Amhara Region have revealed that the pea bruchid is widely distributed with often high incidence (Birhane et al., 2001)

Pea bruchid in the Amhara Region

The pest was reported in 1988 in West Amhara Regional State around Ebinat, Belesa, Wegera and Jan Amora weredas of North Gonder Zone. Then, it invaded West and East Gojam, South Gonder and South Wello severeely damaging on field peas with substantial yield losses. Very recently, the pest has been discovered from field pea seeds collected around Debre Zeit-Mojo areas. This new pest is slowly spreading throughout the country that could threaten the future of field pea in Shewa and Arsi. The spread of the pest with seed materials makes it more rapid and difficult to control.

Pea bruchid in Central Ethiopia

More recently, surveys on the distribution and abundance of pea bruchid were carried out in northern and central Ethiopia (HARC, 2004; Mohamed et al., 2005; Tesfaye et al., 2005). The adult pea bruchid count per 25 sweeps at the time of flowering and podding stages in Central Shewa showed the highest at Kurkura (12 adults per 25 sweep). No bruchid was recorded at Holetta. The lowest counts were recorded at Debre Zeit-Ziquala and Debre Zeit-Mojo areas.

From the 50 pod samples from each field, the number of larvae counted after dissecting the pods varied from 130 at Kurkura to none at Holetta. The number of pea bruchid adults that emerged from 500 g seeds is shown in Table 2. Over 1000 adults emerged from seeds collected around Kurkura with seed weight loss of 13.5%. The pest was generally observed to be more important in mid-altitude areas than the high altitudes (HARC, 2004).

Table 2. The adult pea bruchid count that emerged from seeds collected at different sites after harvest

Location	Variety	Number of adult bruchids	Seed weight loss (%)
Gode-1	Nach Ater	255	2.1
Gode-2	Nach Ater	144	2.8
Gode-3	Nach Ater	242	2.7
Gode-4	Nach Ater	628	5.7
Gode-5	Nach Ater	198	2.1
Gode-6	Nach Ater	241	3.3
Dukem-1	Dongolo	644	3.6
Dukem-2	Dongolo	729	3.0
Dukem-3	Dongolo	556	4.2
DZ market-1	Engliz	70	1.4
Kurkura-1	Mohandefer	540	3.7
Kurkura-2	Tegegnech	158	6.6
Kurkura-3	DZ local	1105	13.5
Kurkura-4	Holetta	753	9.7
Golo-1	Dube	331	1.0
Golo-2	Engliz	50	1.6
Golo-3	Dube	88	0.8
Dire	Nach Ater	58	2.2
Dibaya	Dube	123	3.0
Ude	Nach Ater	100	2.6
Mojo-1	Nach Ater	86	2.9
Mojo-2	Dongolo	61	0.3

Source: HARC, 2004

Surveys carried out in farmers' fields and stores in Amara and Tigray regional states during 2001–2003 revealed that seed damage in field pea due to *B. pisorum* reached 79% in Hgereselam (Gonder), 66% in Kimbaba (Bahir Dar) and 53% in Temben.

Pea weevil infestation in Tigrai

Pee bruchid infestation is very common in southern and central Tigray. Based on samples collected in the markets of Mekelle, Maichew and Mehoni, percent of seed damage ranged from 7 to 12% (Tesfay, 2005). The damage level in these areas was lower than the Amhara Region (80–85%) for Sekota and 50-60% for Achefer (Anon, 2004). The highest level of infestation was recorded from Boraselawa in the southern Zone of Tigrai (Tesfay, 2005).

Economic importance

Insect pests attack field pea in the field and in storage, causing considerable losses. Field pea is grown under very variable rainfed conditions in the country mainly in mid-altitude areas (1800–2200 m), with average rainfall of 740 mm and high altitude areas (> 2200 m), with average rainfall of 900 mm.

Pests have been of considerable economic importance in the production of peas, lentil and grasspea throughout Ethiopia. Since the 1980s, aphid infestations of varying intensity have been recorded, particularly in the mid-altitude areas. Pea aphid colonies aggregate in the upper canopy of the plants and feed on the growing tips of leaves and cause yellowing, stunting and even plant death.

In Ethiopia, avoidable yield loss caused by pea aphid in field pea reached 70%, with an average of 37% in different regions and under different farming systems (Kemal 1997; 2002; Lemma et al., 1996; Shambel et al., 1998).

Pea bruchid is becoming a serious pest of pea. It was first observed in Sekota during 1994 and has since become one of the most destructive pests with recorded yield losses of up to 85% (Worku, 1998). An infestation level of 85% was recorded in Sekota in 2002 (PPRC 2002).

Economic threshold level (ETL)

An economic threshold level is the level of pest population, which causes significant crop losses, and at which the pest control measures will give economic return. A reliable method of sampling pest population densities is an essential aspect for the ETL in IPM program. In pulses, ETL has been studied against *A. pisum* infesting field pea and lentils.

At Kulumsa field trials were conducted to relate infestation levels with yield losses to establish economic threshold level using improved and farmers' varieties. Pirimicab was applied at different infestation levels. The maximum yield was obtained from fully protected plots for both cultivars. Considering the economics of pesticide application, the highest net benefit was obtained from one spray at 35% level for cv. Mohandefer. Therefore, optimum threshold levels for the improved variety (Mohanderfer) and farmers' variety were about 30–35% infested leaflets coinciding with one or two applications, averaged over three years for each (Kemal, 1997).

Basic studies

Biology

Pea aphid (*Acyrthosiphon pisum*)

Recently, Kemal (2002), Melaku et al. (2000), Tebekew et al. (2002) provided a detailed account of many aspects of *A. pisum* biology. The biology of pea aphid under Ethiopian conditions was studied in some detail (Kemal, 2002). The study was carried out in an insectary under natural photoperiod with mean temperature during the experiment of 22.7 ^{0}C (day) and 15.5 ^{0}C (night) and relative humidity of 70–94%.

The pre-reproductive period ranged from 10.1 to 11.1 days. A parthenogenic female produced between 74.9 to 95.4 nymphs with an average of 84.7. The adult reproductive and post-reproductive periods were 15.5 and 10.6 days, respectively. Average maximum and mean daily fecundity were 10.9 and 5.5, respectively. The life span of the pea aphid ranged from 30.7 to 32.4 days with a generation time of 14.2.

Melaku et al. (2000a) studied the biology of pea aphid on faba bean, field pea, lentil and grasspea under minimum and maximum temperatures of 6.3 and 25.3 ^{0}C. They reported mean nymphal period of 9.4 days on faba bean, 9.4 on field pea and lentil and 9.3 on grass pea. Mean total fecundity was significantly different among the legumes used in the experiment (Table 3). Average total fecundity was 78.9 nymphs. The highest was on lentil (115 nymphs) and the lowest was on field pea (58 nymphs). Mean reproductive period ranged from 9.8 days on faba bean to 17.4 days on lentil. The life span was 20-35 days with mean generation time of 14.3 days to 18.1 on faba bean and lentil, respectively. It is clear from the studies that the growth and development of pea aphid is temperature dependent.

Table 3. Mean reproductive period (days), lifetime fecundity, mean daily reproduction and life table parameters of *A. pisum* reared on different food legumes.

Crop species	Reproductive period (days)	Nymphs/day/ female	Total fecundity	Life span (days)	Mean generation time (days)	Intrinsic rate of increase (r)
Faba bean	9.8	6.2	59.7	20.1	14.3	0.286
Field pea	9.8	5.3	57.9	22.7	16.0	0.256
Lentil	17.4	6.7	115.1	34.9	18.1	0.257
Grass pea	14.3	5.4	82.9	24.6	16.0	0.276
LSD value	0.91	1.03	16.8	3.89	-	-

Source: Melaku et al., 2000

In another study, Melaku et al. (2003a) investigated the effect of aphid density on fecundity and survival under greenhouse conditions. The environment in which the experiment was carried out was similar to the above study. Reproductive capacity and survival of four levels of aphid density (2, 6, 10, and 14 nymphs per seedling) were tested on faba bean, field pea, lentil and grass pea. The results showed that the number of nymphs produced per female decreased with increasing aphid density (Table 4). At the lowest density of 2 aphids per plant, they produced significantly more nymphs per aphid (37.3) than at 6, 10 and 14. Aphids fed on faba bean produced the lowest number of nymphs than the remaining host plants. Survival rate decreased with increasing aphid density similar to that of nymphiposition.

Table 4. Number of nymphs produced per female on faba bean, field pea, lentil and grass pea.

Aphid density (number/plant)	Number of nymphs/aphid				
	Faba bean	Field pea	Lentil	Grass pea	Mean
2	29.7a	32.0b	47.0a	40.7a	37.3a
6	21.3bc	40.3a	24.3c	36.0a	30.5b
10	24.7b	29.7b	30.3b	29.3b	28.5b
14	17.7c	23.0c	22.3c	22.7c	21.4c
Mean*	23.3y	31.2z	31.0z	32.2z	29.4z

*Means followed by different letters within a column are significantly different from each other (P = 0.05); * Grand means of each crop species followed by different letters (y and z) within the last row are significantly different from each other (P = 0.05).*

Source: Melaku et al., 2003

A. pisum clone variability

Two laboratory experiments were conducted to investigate the genetic variability of the pea aphid found on different host plants and those geographically separated populations on field pea. Four clones of *A. pisum* collected from pea, lentil, grass pea and faba bean were reared in seedling of the respective crops. Aphids were also collected in field pea fields around Holetta, Denbi, Kulumsa, Awassa, and Adet. The reproductive biology of these aphids was studied on the seedling of three moderately resistant and one susceptible line. Parameters measured for making inference were fecundity, nymphipositional period; mean maximum number of nymphs produced in a single day, mean number of nymphs produced per day and longevity.

Experiment 1: The result showed that there was no variability in all parameters when reared on the four lines of field pea. The pea aphids collected on four-pulse crops reproduced abundantly (mean= 89.1, range 76–106) on all genotypes, without distinct deviation (Table 5). The pea aphid clones reared on pea produced higher number of nymphs compared to the remaining three crops. This clearly indicated that there are no biotypes of pea aphid infesting the four crops (HARC, 2004).

Table 5. Mean fecundity of *A. pisum* infested with four clones from four pulse crops

Genotype*	Field pea	Faba bean	Lentil	Grass pea
Holetta-90	99.2	81.2	80.7	74.7
305-Ps 210900	96.5	81.7	83.2	79.8
Tegegnech	88.0	82.8	78.2	90.8
Np-874 UK	89.8	80.3	81.7	75.8
Mean	93.4	81.5	80.9	80.3
Significance	a	a	a	a

***** *There was no significant difference among genotypes in fecundity*
Source: HARC, 2004

Experiment 2: The analysis of variance of the total fecundity of the pea aphid showed that the effect of genotypes was not significant. The mean square for clones was higher than that of genotypes, indicating that there was more variation among pea aphid clones collected from distant locations than among genotypes.

The sum of mean square for genotype was only 1.8% of the sum square due to genotype x clone interactions (66.1%). This indicates that the contribution of genotype x clone interactions to variability was very high and does suggest the existence of distinct biotypes in *A. pisum* from geographically distant populations of field pea fields.

The highest fecundity (total nymph production over the entire aphid life span) was observed on cv. Holetta-90 for Debre Zeit (104.3) and Adet (116.1) clones and the lowest for Kulumsa (78.2) and Holetta (79.6) (Table 6). Adet clone was more fecund on while Kulumsa clone was more fecund on the susceptible genotype (NEP 874 UK).

Table 6. Mean total fecundity of *A. pisum* on four field pea genotypes infested with five clones collected from different locations

Genotypes	Pea aphid clones from five locations				
	Debre Zeit	Adet	Kulumsa	Awassa	Holetta
Holetta-90	104.3	116.1	78.2	83.4	79.6
305PS 210900	82.3	99.1	96.4	86.7	89.6
Tegegnech	87.6	104.3	94.0	86.0	92.0
NEP 874 UK	94.6	99.8	106.1	74.8	93.2

CV (%) = 22.06; LSD (5%) = 18.02
Source: HARC, 2004

Pea bruchid

The biology of pea bruchid was studied at Ebinat and Adet in 1999 and 2000 by Birhane (2002). According to the preliminary results in the field, a female laid up to 60 eggs on a single pod and the young larvae hatched within a week of entry into the seed. Four larval instars were reported and the adult bruchid emerged from the seed after ten days. Only one adult managed to emerge from a single seed.

Population dynamics

Pea aphid (*A. pisum*)

Population fluctuation of pea aphid was studied in peas at Denbi and Kulumsa for three consecutive years (Kemal, 1999). Two peaks were observed: one in late August and the other in mid-September. The study described seasonal changes in abundance of pea aphid in field pea.

Every year, aphids first appeared in early August. Aphid densities remained low throughout July and then increased to a peak in the later half of August or first week of September. This pattern was observed at both locations and in all the three years. However, the population of aphids was influenced primarily by differences in temperature and rainfall among seasons.

The period of increase in aphid density in September (40–50 days after crop emergence) coincided with flowering and podding of the crop. The population decline coincided with the period when the leaves on the last 25% of the nodes were senescing and pods were beginning to dry. In another study carried out at Adet and Zema, Melaku (2002) showed that pea aphid population peaked in August at Adet, and mostly in September at Zema. The author also reported a positive correlation with maximum temperatures and negative correlation with weekly rainfall, although level of significance was not shown.

The occurrence of pea aphid on wild, annual and perennial leguminous plants was studied at two locations (Adet and Wondata) in West Gojam Zone, in 1999 to 200. Plants encountered in the study areas were closely monitored for the presence of pea aphid (Melaku et al. 2003). The results showed that the pest infested annual legumes such as the wild clover (*Trifolium ruepellaiunum*) and vetch (*Vicia* spp.). The later carried more aphids load than the former. Vetch was attacked more in September and clover in October. From the perennial legumes, pigeon pea (*Cajanus cajan*) was the most susceptible plant with the peak infestation in September and October. High plant density had more aphid number than the lower. Sole vetch plant suffered higher damage than mixed with other crops or with weeds suggesting the advantages of intercropping to reduce pea aphid infestations (Melaku et al., 2003b).

Control Measures

Cultural Control

The use of cultural control practices is an important pest control method that has tremendous scope in IPM. Efforts have been made to asses the influence of various agronomic practices on pest incidence for utilization in pest management programs.

Mixed cropping

The effect of mixed cropping of field pea with faba bean, wheat and Ethiopian mustard on the population dynamics of pea aphid and its natural enemies was studied at three locations during 2000 and 2001 seasons (Kemal et al., 2007).

Over the two years and at all the three locations, the highest incidence and size of aphid colonies was recorded on the field pea monoculture than in the three mixtures. At Holetta, average aphid density per plant on monoculture field pea was significantly higher ($P<0.05$) than those of mixed cropping. At Denbi, there were significantly more aphids per plant in sole field pea plots (17.2) than in mixtures with wheat (14.1) and mustard (9.7). Among the mixtures, field pea + mustard had significantly fewer aphids. The pea aphid densities were different among the locations: lower in the cool and high rainfall site at Holetta than the warm, mid-altitude sites, Denbi and Kulumsa, respectively. *A. pisum* was more abundant at Denbi and Kulumsa, peaking from September 15 to 20, *i.e., at* flowering. This is a critical time that the heavy aphid load halts grain production. *A. pisum* populations were about 2–3 times higher at Denbi and Kulumsa than at Holetta.

From the observation, the cropping system did not affect the degree of parasitization by *Aphidius* spp. in both years. However, the percentage of *A.*

pisum parasitised by parasitoid varied among locations. There were more parasitised aphids in field pea/faba bean mixtures at Holetta (9.0%) and Denbi (8.7%) than monoculture field pea plots.

Significant treatment effects were observed for field pea grain yield at all the locations and seasons. Yields were reduced when mixed with mustard. The mean grain yield of field pea in pure stand was higher at Holetta (1640 and 1695 kg ha^{-1}) than at Denbi (395 and 450 kg ha^{-1}) and Kulumsa (1231and 1312 kg ha^{-1}) in 2000 and 2001, respectively. Field pea grain yield at Denbi was lower than at Holetta and Kulumsa due to a higher incidence of ascochyta blight and pea aphid damage. Among the intercrops, the pea yield on the field pea/wheat intercrop was higher than other treatments at Holetta and Kulumsa, and was significantly higher than field pea/mustard mixtures at Holetta in both years. Mixed crops in 2000 gave mean seed yields of 2108 kg ha^{-1}(ranging from 1354 to 3221 kg ha^{-1}) at Holetta. The mean yield at Denbi was 1891 kg ha^{-1} (ranging from 911 to 3853 kg ha^{-1}), and 2046 kg ha^{-1} (1432 to 3081 kg ha^{-1}) at Kulumsa. In 2001, the yields were 2876, 2166 and 2321 kg ha^{-1} at Holetta, Denbi and Kulumsa, respectively.

Land equivalent ratio (LER) values calculated from grain yields were above unit in the field pea/mustard intercrop at all locations and years. Field pea intercropped with mustard gave higher mean LERs of 1.70, 1.37 and 1.27 at Holetta, Kulumsa and Denbi, respectively.

In economic return, the highest mean net benefit of Birr 10451, 13494 and 10219 ha^{-1} was obtained when a mixture of field pea and mustard was grown at Holetta, Denbi and Kulumsa, respectively. Monoculture field pea at Denbi gave the lowest net benefit. Higher LER value is associated with net benefit.

Overall, and at the two locations, incidence and size of aphid colonies were the highest in monoculture field pea plots than was the case in mixture. The mean grain yield of filed pea was the highest at Adadi (1455 kg ha^{-1}) and the lowest at Debre Zeit (1100 kg ha^{-1}). Grain yield of 1420 and 1640 kg ha^{-1} were recorded in Debre Zeiet at site one and two, respectively. However, the overall grain yield was much higher at Adadi with 2110 and 2560 kg ha^{-1} in the two sites in that order. Field pea/ mustard mixture gave the maximum yield at both locations.

Date of sowing and fertilization

Adjusting planting time and fertilizer applications can help to escape pest damage and thereby keep pest numbers below economic damage level. Effect of staggering the planting date, variation in fertilizer and cultivars on damage to plants was studied in field trials over three locations (Kemal, 2002). A field trial was carried out to investigate the effect of sowing date and fertilizer application (18 kg N and 46 kg P_2O_5 ha^{-1}) on pea aphid infestation levels using three cultivars at three locations. The experiments were carried out at Holetta, Denbi and Kulumsa.

The probability values for the partial ANOVA indicated that fertilizer application significantly influenced the density of pea aphid population at Holetta. Fertilizer, sowing date and field pea variety interactions were not significant, indicating that the three factors acted independently of each other. Pea aphid population density was not significantly affected by either fertilizer application or by sowing date, at both Denbi and Kulumsa (Table 7). However, fertilizer and sowing date interaction was significant for aphid infestation. Differences were significant among treatments for each factor: fertilizer application, varieties and location.

Table 7. Probability values for the partial ANOVA on the effect of fertilizer to pea aphid population on three field pea varieties at Denbi and Kulumsa

Source	DF	Aphid/plant
Replication (R)	3	0.0184
Fertilizer (F)	1	NS
Sowing date (SD)	1	NS
F x SD	1	0.01811
Variety (V)	2	NS
F x V	2	0.0647
SD x V	2	NS
F x SD x V	2	NS
Location (L)	1	0.00001
F x L	1	NS
SD x L	1	NS
F x SD x L	1	NS
G x L	2	NS
F x V x L	2	0.0697
SD x V x L	2	NS
F x SD x V x L	2	NS
Error	69	
CV(%)		43.1

DF = degree of freedom; NS = not-significant
Source: Kemal, 2002

Field experiment to identify appropriate planting time in relation to pea aphid populations was carried out at Adet and Zema, north-western Ethiopia for three years. At Adet, grain yield of field pea was observed to increase as planting was delayed from mid-May to late June (Melaku, 2002). The highest grain yield of 0.63 t ha^{-1} was obtained from June 30 planting. A mean of 0.32 t ha^{-1} more yield was recorded from planting at the end of June compared to May and up to the second week of June. This indicates that the best time for planting field pea at Adet is from mid- to late June. Unlike Adet, grain yield generally decreased with delay in planting at Zema. Planting during the first two weeks of June gave the highest yield of 1.07 t ha^{-1}.

Biological control

The effect of predator, *Hippodamia variegata* (Coccinelidae), and an entomopathogenic fungus *Beauveria bassiana* in regulating pea aphid populations on field pea cv. Mohanderfer was evaluated in field cages (Kemal, 2002). Caged plants were inoculated with the same initial density of aphids (one aphid per plant), and the predator or fungus biocontrol agents were introduced when the population reached 10-12 aphids per plant.

Three weeks after coccinellid introduction, aphid incidence was significantly reduced in the *H. variegata* treatments than in the *Beauveria* and infested control treatments. Coccinellid-treated plots had fewer aphids (52 per sampling unit). The fungus-treated and infested plots had (102 and 108 sampling unit. The results indicated that coccinellid applied at one adult per 200 pea aphids provided the best control and optimum grain yield. The yield in the fungus treated plots was comparable to the infested untreated plots.

Ethiopian isolates of *Beauveria bassiana* and *Metarhizium anisopliae* along with two rates of Nimbecidine 0.03% EC neem formulation and Pirimor 50% WP were tested against A. *pisum* infesting field pea at Denbi for two consecutive seasons (2004–2005).

Results of two consecutive years revealed that Pirimor 50% WP treated plots supported lower aphid numbers than the remaining treatments. Unlike in 2005, there was no significant difference in grain yield among the treatments in 2004. The lowest grain yield was obtained from the lowest rate of nembecidine compared to pirimor and *Beauveria* treated plots. The results of the two seasons were inconsistent and one cannot draw a conclusion. Hence, further investigation is required (HARC, 2005).

Host plant resistance

Extensive screening for resistance to pea aphid has been carried out at Kulumsa, Denbi, Adet' and Sinana research centers. Despite intensive screening efforts, it was difficult to find substantial levels of host plant resistance against pea aphid. However, the progress we made to find tolerant plants is encouraging. At present, no insect resistant cultivars of this crop have been released to growers.

Efficient field and greenhouse evaluation for resistance to pea aphid have been developed. Screening of large number of germplasm accessions is more efficiently accomplished in the field where the pest pressure is high. Evaluation of host plant resistance to pea aphid is largely based on the number of aphids per plant. Although considerable differences in susceptibility of field pea genotypes have been found, few genotypes were identified as low to moderately tolerant to this pest (Kemal, 2002).

Screening of germplasm to pea aphid

From the evaluation, under field conditions, of more than 1000 germplasm accessions and breeding lines in 1990-2000, 16 pea aphid resistant lines were identified (Kemal et al., 2005). These selected lines together with released cultivars from Ethiopia and South Africa were further tested in greenhouse under no-choice conditions. After two weeks, seedlings of test materials were infested with newly emerged adults. In 7, 14 and 21 days after infestation, aphid populations on each entry were visually scored and seedling mortality was recorded after 3 weeks.

Genotypes differed significantly in terms of pea aphid incidence at individual scoring dates and overall means. By the third week, most of the plants had scores of 6 and were thus all within the susceptible range. This indicates that the length of time of the test was sufficient to detect damage. Furthermore, none of the 30 genotypes investigated in the study showed a high level of resistance.

Six lines, i.e., Holetta Local-90, 305ps210689, 061K-2P-2/9/2, 061K-2P-14/7/1, JI898 and 304WA1101937 and one susceptible line NEP874UK were selected from screening test based on their performance and were subjected to more intensive tests to ascertain their resistant traits. Components and mechanisms of resistance in these lines to pea aphid were investigated in a greenhouse under natural photoperiod with mean temperature during the experiment of 22.7 ^{0}C (day) and 15.8 ^{0}C (night) and relative humidity of 70-94% (Kemal et al., 2005).

Pea bruchid (*Bruchus pisorum*)

A total of 45 genotypes (28 breeding lines and 17 released varieties) were screened for resistance to pea aphid and pea bruchid under field conditions depending on natural infestation at Denbi. Mean aphid count per plant and number of pea bruchid larvae per 100 seeds are presented in Table 8.

Table 8. The reaction of field pea genotypes to pea aphid/pea bruchid preliminary screening at Denbi-2004/05.

Genotype	Aphid/plant	No. of damaged seeds	No of larvae/100 seeds
Dundil	18.3	11	12
Wolmera (R)	17.6	0	0
Dadimos (R)	7.3	17	18
Helina	20.4	40	43
PIS384/77x310392-2	3.0	2	2
Wa pea 2013 Kooki	38.3	18	24
Tuludimtu (R)	17.9	13	14
Wa pea 2013 Helina	2.8	15	15
305 PS 210900	7.6	19	19
Sv 88269	8.7	23	27
NEP 874 UK	22.2	2	2
Holetta (R)	13.4	5	5
061K2P 14/71	12.0	3	3
Local sel 1690	11.5	15	15
PARIRA No 11	7.7	18	19
88 P 022-6	7.9	25	26
304 WH 110/937	21.2	13	13
Hassabe (R)	23.0	8	8
305 P 188	10.9	5	6
DMR	2.3	15	17
89 P 109-11	3.1	4	4
Sefinesh (R)	8.3	20	20
Milki (R)	13.4	10	10
Adi (R)	17.3	10	10
NEP 874 UK	16.8	5	5
Markos (R)	17.7	15	17
Tegegnech (R)	11.7	6	6
Mohanderfer (R)	1.8	23	26
FP EX DZ (R)	15.8	9	9
NC 95 Haik (R)	11.8	4	4
G 22763 2C (R)	2.4	2	2
JP 888	31.7	13	10
Tulushenen (R)	4.7	10	13
Hursa (R)	8.6	1	1
PGRC/E 32641-1	13.3	1	1
32426 1	13.5	0	0
EH 90019 1	9.3	5	0
EH 90007 1	13.9	8	8
EH 90006 2 (R)	13.3	13	26
EH 90020 1	2.9	17	15
EH 90025 1	17.8	20	22
EH 90016 1	0.6	6	6
EH 90010 1	0.9	11	12
EH 90013 1	13.2	13	15
EH 90021 1	17.1	16	18

Source: HARC, 2005

There were variations of the pest population densities among the genotypes tested. Six genotypes sustained little aphid damage with less than three aphids per plant, while the other half were severeely damaged (> 20 aphids per plant). Seven entries showed the highest seed damage by pea bruchid; the two of which Mohanderfer and EH 90006 2 were released cultivars. Two entries (Wolmera and 32426 1) were free of bruchid seed damage (HARC, 2005).

Melaku et al. (2002) screened 336 field pea genotypes against pea bruchid under field conditions at Ebinat depending on natural infestations. Variations in infestation level among tested entries were noted. However, most of the genotypes were susceptible and only 13 were found to be less susceptible with fewer than 10 eggs per 5 plants. Three of the 336 genotypes had 100 to 200 eggs per 5 plants while the majority had 30 to 40.

Mechanisms of resistance

Antibiosis: Studies on antibiosis involved rearing cohorts of apterae aphid on the cultivars and comparing them in respect of the number of aphids surviving to adulthood, the fecundity, the duration of nymphiposition, the net reproductive rate, the intrinsic rate of increase, the finite rate of increase and doubling time. The results indicated that lines 061K-2P-2/9/2 and 304WA1101937 had significantly lower antibiosis than Holetta Local-90, 305ps210689 and 061K-2P-14/7/1. The number of nymphs produced ranged from an average of 95.4±9.1 from adults fed on line 304WA1101937 to 74.9±9.0 from adults fed on line Holetta Local-90 (mean 84.7±7.5).

The r_m (intrinsic rate of increase) of *A. pisum* on all lines was not significant, indicating that separation of lines is not possible having the various combinations of antibiosis. Mean generation and doubling time were similar among aphids reared on the seven genotypes (Table 9).

Table 9. Demographic statistics derived from the life table study of individual pea aphids confined on seven lines of field pea from Holetta, 2000.

Entry	r_m[a]	λ[b]	T[c]	DT[d]
Holetta Local-90	0.292	1.24	14.3	2.4
305PS 210687	0.291	1.34	14.3	2.4
061K-2P-2/9/2	0.304	1.35	14.0	2.3
NEP 874 UK	0.284	1.33	14.8	2.4
061K-2P-14/7/1	0.293	1.32	14.5	2.5
JI-898	0.305	1.35	14.0	2.3
304 WA 1101937	0.318	1.38	13.5	2.2
Mean	0.300			
CV (%)	8.21			

[a] Intrinsic rate of increase; [b] Rate of increase per female per day (finite rate of increase); [c] Mean generation time, days; [d] Doubling time
Source: Kemal *et al*., 2005

Antixenosis: *A. pisum* used in these tests were adult *Apterous viviparae* from the same colony as for the antibiosis experiment. This study consisted of a free-choice experiment to examine antixenosis properties of the genotypes.

The test indicated that the pea aphids required only 24 hours selecting a preferred line (Table 10). There was significant difference among the seven entries for antixenosis. Twenty-four hours after release, line 304WA1101937 had a significantly higher number of aphids (10.2±1.9) than the remaining lines, except line 061K-2P-14/7/1. The numbers of adults per plant 48 hours after release ranged from 8.4±2.5 on line 304WA1101937 to 5.1±1.0 on line Holetta Local-90 and were significantly different. After 72 hours, very few aphids left the plants, resulting in a negligible decrease in aphids per plant on all entries. Line 304WA1101937 consistently sustained the highest number of aphids for settling and development. This shows the involvement of antixenosis (non-preference) as a mechanism of resistance to the pest in field pea. Correlation ratings between 48 and 72 hours were higher and highly significant ($r = 0.62$, $P < 0.001$).

Table 10. The mean number ± SEM of *Acyrthosiphon pisum* per plant at 24, 48 and 72 h after infestation.from Holetta, 2000.

Entry	Number of *A. pisum*		
	24 h	48 h	72h
Holetta Local-90	4.8±1.5**c**	5.1±1.0**b**	4.9±1.8**cd**
305PS 210687	7.4±2.4**bc**	6.5±2.2**ab**	6.2±1.4**bcd**
061K-2P-2/9/2	6.2±2.7**bc**	5.4±2.2**b**	4.3±1.3**d**
NEP 874 UK	6.9±2.0**b**	6.9±1.8**ab**	7.5±1.3**ab**
061K-2P-14/7/1	8.3±2.0**ab**	7.2±1.5**ab**	7.3±1.5**ab**
JI-898	7.7±1.4**b**	6.5±2.1**ab**	8.3±2.2**a**
304 WA 1101937	10.2±1.9**a**	8.4±2.5**a**	8.4±2.1**a**
Mean	7.4±0.75	6.6±0.69	6.7±0.63
CV (%)	30.33	31.25	28.39

Note: abc means without letters in common differ significantly.
Source: Kemal et al., 2005

Tolerance: In this test, each of the seven entries was planted in plastic pots in a randomised complete block design with five replications. Significant differences were noted among uninfested tolerant test entries in plant growth, number of leaves, fresh and dry biomass at the end of the test, indicating that the genotypes were not similar in these parameters. Stunting was very severe among the field pea lines; some resistant lines were more stunted (or equal) stunted than the susceptible line. The average plant height of all uninfested test entries was 68.0 cm, whereas the corresponding infested plants were 21.4 cm. Growth of infested entries ranged from 16.1 cm in line NEP 874 UK to 27.6 cm in line 061K-2P-2/9/2, with an overall test average of 21.4 cm. In the infested plants, line 061K-2P-2/9/2, 061K-2P-14/7/1 and JI-898 significantly grow taller than the remaining lines. Differences in percent of plant height confirmed that pea aphids caused significant reduction in plant height.

Genotypes significantly varied in the number of leaves between infested and uninfested lines. Similarly, the leaf number on infested entries ranged from 14.0 in line 305PS 210687 to 30.6 in line 061K-2P-2/9/2. Number of leaves was significantly lower in infested plants of lines Holetta Local-90 and 305PS210687, than in lines 061K-2P-2/9/2, 061K-2P-14/7/1 and 304WA1101937.

Genotypes also varied significantly in biomass. Line 061K-2P-2/9/2 had fresher biomass in all entries with the exception of line 061K-2P-14/7/1. The fresh plant mass of infested entries ranged from 0.43 g in line Holetta Local-90 to 1.55 g in line 061K-2P-2/9/2 , with a mean of 0.92 g.

Table 11 shows the normalized indices for the three components of resistance. The data indicate that lines Holetta Local-90, 305PS 210687 and NEP 874 UK are more resistant than the remaining lines. The most susceptible lines appeared to be 061K-2P-2/9/2, 061K-2P-14/7/1, JI-898 and 305PS 210687, although these lines were not as resistant in these tests as they were in the field. In part, this lack of resistance appears to have been resulted from low antibiosis.

Table 11. Normalized indices and overall resistance index (RI) to *Acyrthosiphon pisum* in eight field pea lines at Holetta, 2000.

Entry code #	Normalized index			
	Antibiosis (x)	Antixenosis (y)	Tolerance (z)	PRI*
Holetta Local-90	0.78	0.54	0.66	3.6
305PS 210687	0.81	0.74	0.66	2.5
061K-2P-2/9/2	0.98	0.59	1.00	1.7
NEP 874 UK	0.91	0.79	0.63	2.2
061K-2P-14/7/1	0.80	0.84	0.86	1.7
JI-898	0.92	0.83	0.83	1.6
304 WA 1101937	1.00	1.00	0.66	1.5

**PRI = 1/(xyz); indices calculated using x, y and z indices.*
Source: Kemal et al., 2005

The performance of these tolerant field pea cultivars was assessed in large plots (10 X 10 m) on farmers' fields at Debre Zeit, Kulumsa and Adadi areas for two consecutive seasons. The mean pea aphid populations on unsprayed plots were higher at all locations (3 sites each at DZ and Kulumsa) than the sprayed ones. The highest mean seed yield recorded from sprayed plots was 956 kg ha^{-1} (Tegegnech) and the lowest was 724 kg ha^{-1} (farmers' variety). The cv. Tegegnech was found to be tolerant to the pest damage and gave the high seed yield of 860 kg ha^{-1} combined over three locations without insecticide treatment and with the lowest yield loss of 10.0% at Debre Zeit in 2003/04 cropping season.

At Kulumsa, the pea aphid population on randomly selected plants was higher in unsprayed plots with the highest on farmers' variety (62 aphids per plant). The mean grain yield pooled over locations was higher on sprayed plots. Tegegnech gave the highest mean grain yield under both sprayed (1795 kg ha^{-1}) and unsprayed plots (1461 kg ha^{-1}), whereas Holetta Local-90 (1143 kg ha^{-1}) and the farmers variety (1156 kg ha^{-1}) were similar under unsprayed conditions in the same season.

Similar trend was also observed in 2004/05 cropping season at Debre Zeit, Adadi and Kulumsa areas. At Debre Zeit, the mean aphid count per plant in unsprayed plots were high on farmers variety (14.1) followed by Holetta Local-90 (12.4) and Tegegnech (10.4), whereas the mean counts on sprayed plots were much lower. The highest grain yield from unsprayed plots was recorded from Tegegnech (1140 kg ha^{-1}) combined over four locations. At Adadi, the maximum yield of 1955 kg ha^{-1} and 2015 kg ha^{-1} was obtained from unsprayed and sprayed plots from cv. Tegegnech, respectively. This proves that the variety can overcome aphid damage and produce good yield. Similarly, the mean yields of the cultivars at three locations under unsprayed conditions were 1560 kg ha^{-1} (Tegegnech), 1248 kg ha^{-1} (Holetta Local-90) and 957 kg ha^{-1} (farmers' variety) at Kulumsa.

It is very clear from the results that cv. Tegegnech can tolerate the pest damage and give high yield without aphicide sprays at all locations and seasons. Farmers were convinced to plant this cultivar and they are multiplying the seeds to be distributed among them.

Chemical control

Although insecticides have been used as an important method of pest control, economic and environmental issues discourage their continued use in pest control especially in developing countries. Chemical control of pea aphid with selective insecticides and neem seed extract in field pea was carried out at Denbi for two years (1996-1997). Pirimicarb 50% wp (the standard check) gave the best aphid control with a mean number of 5.7 and 3.1 of aphids per plant in 1996 and 1997, respectively (Kemal, 1998a and 1998b). The highest rate of Gaucho (300 g per 100 kg seed) significantly reduced the pest populations compared to neem and promet treatments. The seed-dressing chemicals failed to control aphids that appeared in high densities late in the season when the crop flowered and set pods.

Grain yields were also statistically different at 5% significance level. Pirimicarb (2 sprays) resulted in the highest yield, 809 kg ha^{-1}, and 779 kg ha^{-1} in the two years respectively, followed by the highest rate of Gaucho.

In the greenhouse studies, the effect of neem seed kernel extract aqueous solution and commercial neem product Multineem® on metamorphosis, longevity, and fecundity of pea aphid exposed to young nymphs and adults to treated plants and topical spray was used (Kemal and Louw, 2005). A significantly reduced rate of increase of *A. pisum* populations, comprised of nymphs and adults, was recorded at 10 days after treatment on plants applied with > 20 mg/l (multineem) and neem seed extract (NSE) than was observed on control water spray.

The exposure of the nymphs to Multineem® treated field pea plants significantly reduced the number of molts, longevity and fecundity that had been reared on treated field pea plants (Table 12). The molting process was completely disrupted at the two levels of SE, less than one molt average. The average number of offsprings produced by a female over a lifetime was 69.8 in the control group and only 3.4 in the group exposed to 100 pmm Multineem® from birth (Table 12).

Table 12. Effects of neem insecticide formulations on *Acyrthosiphon pisum* exposed as newborn nymphs to treated field pea plants

Treatment	No. of molts (± SEM) [a]	Longevity (± SEM) [a] (days)	Number of offspring (± SEM) [b]
0 mg azadirachtin/l	4.0 ±0.0a	29.4±2.9a	69.8± 9.3a
10 mg azadirachtin/l	3.9 ±0.3ab	24.8±6.4ab	29.0± 4.3b
20 mg azadirachtin/l	3.6 ±0.4abc	19.9±9.2bc	15.8± 3.1c
40 mg azadirachtin/l	3.1 ±0.8cd	14.4±8.5cd	9.9± 2.3cd
60 mg azadirachtin/l	3.2 ±1.1bcd	14.1±7.9cd	9.0± 2.6cd
80 mg azadirachtin/l	2.7 ±1.3d	11.9±7.1d	4.7± 1.4d
100 mg azadirachtin/l	2.6 ±0.6d	10.2±5.1d	3.4± 1.2d
5 % SKE	0.5 ±0.7e	4.2±1.3e	0.0± 0.0d
10 % SKE	0.7 ±0.8e	4.1±1.7e	0.0± 0.0d
CV (%)	15.2	22.1	52.5

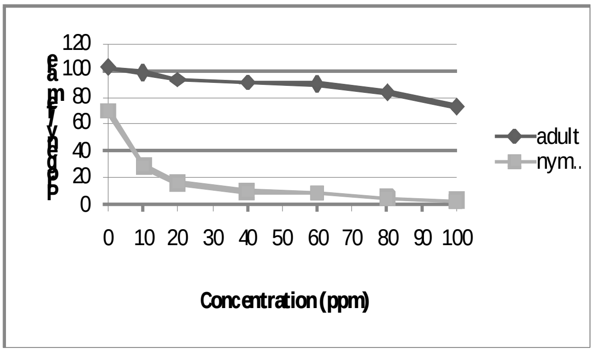
a, Means within a column followed by the same letter are not significantly different (P= 0.05)..
Source: Kemal and Louw, 2005

When adult aphids were exposed to plants treated with different concentrations of the neem formulations, the survival and fecundity declined with increasing dosage (Table 13). The longevity ranged from 16.8 to 24.0 days in treatments, while it was 24 days in control. In the 20 ppm or less treatments, minimal effects were observed on survival of adults. Their number of offspring also declined in response to pesticide exposure in the population exposed as adults. Significantly, fewer offsprings were produced at the highest concentration of Multineem® (80 and 100 ppm) and SE than other treatments. However, the reduction in progeny number was much less dramatic than aphids exposed to treated plants from birth (Figure 2).

Table 13. Effect of neem insecticide formulations on adult pea aphid exposed to treated field pea plants.

Treatment	Longevity (± SEM) (days)	Number of offspring (± SEM) [b]
0 mg zadirachtin/l	23.7±3.1ab	101.7±10.9a
10 mg zadirachtin/l	24.2±3.2a	97.8±8.8ab
20 mg zadirachtin/l	21.5±3.0abc	93.2±12.0ab
40 mg zadirachtin/l	21.7±1.9abc	91.3±8.2ab
60 mg zadirachtin/l	21.0±2.1bcd	89.6±17.4ab
80 mg zadirachtin/l	21.0±3.1bcd	84.4±9.8bc
100mg zadirachtin/l	19.0±3.8cd	73.1±13.7cd
5 % SKE	18.5±2.3de	67.9±14.6d
10 % SKE	16.8±2.6e	40.7±15.0e
CV (%)	13.6	17.3

b, means with out letters in common differ significantly, (P= 0.05)
Source: Kemal and Louw, 2005



Source: Kemal and Louw, 2005.
Figure 2. Fecundity of *A. pisum* exposed to different concentrations of Multineem® from birth and as adults.

When applied topically, the neem formulations significantly reduced longevity and fecundity of adult aphids. Life span of individuals treated with 100 ppm and 10% SE were, respectively, 29 and 40% shorter than those of the control. The mean fecundity over the lifespan of an adult was 81.1 nymphs for control aphids, compared with 44.8 nymphs for 100 ppm and 25.1 for aphids sprayed with 10% KSE. The 12-day LC_{50} for individuals exposed from birth was 49.3 mg azadirachtin per liter while the 12-day LC_{50} for adults was 440.94 mg per liter. The LC_{50} value for adults topically sprayed was 60.20 mg (Table 14).

Table 14. Toxicity of Multineem® to *Acyrthosiphon pisum* reared on field pea as newborn nymphs or adults or applied topically.

Stage initially exposed	Day	Slope (SE)	LC50 (95% FL) mg azadirachtin liter^{-1}
Exposed to treated plants			
Nymphs	12	1.85 (0.21)	49.29 (31.58 – 81.60)
Adults	20	1.33 (0.31)	55.54 (28.39 – 125.60
Adults (topically applied)	20	2.14 (0.31)	60.2 (39.8 – 102.5)

Source: Kemal and Louw, 2005

On-farm and on-station trials at Ebinat were carried out to determine critical time of insecticide application in relation to crop growth stages against pea bruchid using trichlorfon 85% wp at a rate of 1.5 kg ha^{-1} (Melaku et al., 2002). The results of the two years experimentations showed that the insecticide failed to control both adults and eggs. They suggested screening severeal other potential insecticides with ovicidal property to kill eggs laid on pods.

An attempt was also made to control the pea bruchid with solar heat using polyethylene sheet at regular intervals after threshing (Melaku et al., 2002). The result showed that there was no significant difference among the treatments. However, the immediate heating after threshing was better in terms of larval penetration sites and total number of windows. The heating and Pirimiphos-methyl 2% dust had no effect on adult bruchid.

The effectiveness of dried flower powders of pyrethrum on pea bruchid adults soon after emergence from the seeds was evaluated at Mekelle University. Pyrethrum flowers were dried under shade and ground and then applied at 1%, 5%, and 9% W/W and untreated control on pea bruchid adults. All treatments were able to knock-down the pea bruchids 4 hours after treatment and all were found dead 12 hours later. There was no difference among the different rates of application. This shows the suitability of the Mekelle area for pyrethrum growing and that flowers contain the required level of pyrethrins to kill the pest.

Faba bean

Faba bean has relatively few insect pest problem compared with field pea. Hence, research was focused on pod borer. Surveys carried out in farmers' fields by Tadesse and Bayeh (1989) revealed that the pod damage due to pod borer ranged from 1 to 72% in northern Shewa. Results of verification trial on aphid control in faba bean showed that Pirimor 50% WP 500 g a.i ha^{-1} gave the highest yield of 2.2 t ha^{-1} with the highest net benefit of Birr 1265 ha^{-1} (Hailu and Tadesse, 1989).

Aqueous extracts of seeds of *Azadirachta indica*, *Croton macrostachyus* and *Millettia ferruginea* at the rate of 10% concentration, applied twice, at flowering and podding stage, significantly reduced the number of larvae per plant as effectively as Carbaryl 85% WP (Hussien, 2003). Effect of sowing date on pod borer (*H. armigera*) infestation in faba bean was studied at Axum and no conclusive results were obtained (MkARC, 2000).

IPM

Insecticides have played an important role in increasing yields of many crops, including pulses. However, cost and environmental concerns have prompted reaction against the liberal use, and stimulated research on alternatives. Most resource-poor farmers hardly use any control measures. Consequently, pea crop in this sector sustain extensive damage from pea aphid and pea bruchid. The widespread recognition of IPM is relatively recent. Pesticides will continue to have an important role in IPM. The first step in most successful IPM initiatives has been the realization that insecticides should be used according to need rather than as routine. For IPM to become effective, suitable components of pest control will have to be developed. Major emphasis needs to be centered on host-plant resistance and cultural methods.

The most important considerations in small-scale agriculture are tackling a number of multifaceted problems, i.e., economic, human and sustainability. Thus, any strategy on IPM must provide satisfactory answers to these considerations. Therefore, one has to strive to develop IPM strategies that are effective, economical, safe, and compatible with other crop management practices.

Chickpea and lentil

Research findings

Pests recorded

The spectrum of insect pests of chickpea is shown in Table 15. Pod borer, *Helicoverpa armigera*, is the major field pest on chickpea (Tsedeke et al., 1982; Kemal and Tibebu, 1994; Mekasha and Geletu, 1999; AdARC, 2002). About 52.2% of the farmers also perceived the pest to be the first priority (Mekasha and Geletu, 1999). Very recently 84 and 69% of the farmers consider pod borer and cut worm (*Agrotis* sp.) as important field pests of chickpea (Mekasha and Geletu, 1999). Though cutworm is considered as minor pest of chickpea, since it is sporadic, its damage is serious during its occurrence. Percentage of seedling damaged by this worm varied between 4.5% at Shenkora and 8.3% at Tefki, and it was more prevalent in plain areas that could retain moisture for longer duration (DZARC, 1993). Mekasha and Geletu (1999) reported that cutworm is considered as an important pest by about a quarter (24.7%) of the sample farmers. It was also reported to cause substantial damage in Merto Lemariam and Ginde Woin areas of northwestern Ethiopia (AdARC, 2002). Detailed studies were not conducted on cutworm due to its sporadic nature.

Table 15. Insect pests recorded on chickpea in Ethiopia

Common name	Scientific name	Status
Pod borer	*Helicoverpa armigera*	Major
Cutworm	*Agrotis* sp	Minor
Mendi termite	*Macrotermes subhualinus*	Undetermined
	Delia cilicrura	Minor
	Gonocephalum simplex	Minor
Lesser army worm	*Spodoptera* sp	Undetermined
Pea aphid	*Acyrthosiphon pisum*	Minor
Black bean aphid	*Aphis fabae*	Record
Azuki bean beetle	*Callosobruchus chinensis*	Major

Source: AdARC, 2002; DZARC, 2000; Ferede and Tsedeke, 1986; Geletu et al., 1996a, Tsedeke et al., 1982; MARC, 2005

Table 16 shows the pest spectrum of lentil. Pea aphid, *Acyrthosiphon pisum*, is the most serious threat to lentil production (DZARC, 1993; Kemal and Tibebu, 1994; DZARC, 1996; Geletu et al, 1996b; AdARC, 2002). Pod borer, *Helicoverpa armigera*, is also considered as a major pest of lentil and its damage is becoming serious in some lentil producing areas like Gimbichu district. Other pests of minor importance in lentil crop include thrips and black aphids.

Table 16. Pest spectrum of lentil in Ethiopia

Common name	Scientific name	Status
Pea aphid	*Acyrthosiphon pisum*	Major
Thrips	*Caliothrips impurus*	Minor
Bean flower thrips	*Taeniothrps* spp	Undetermined
African bollworm	*Helicoverpa armigera*	Major
Epilachna	*Epilachna* spp	Minor
Cow pea aphid	*Aphis craccivora*	Minor
Azuki bean beetle	*Callosobruchus chinensis*	Major

Source: AdARC, 2002; DZARC, 2000; Ferede and Tsedeke, 1986; Geletu et al., 1996a;Tsedeke et al., 1982; MARC, 2005

Economic Importance

Pea aphid

Assessments made to determine the economic significance of pea aphid revealed the importance of the pest. Aside from the direct damage, the loss caused by viral disease transmission is of paramount importance. Economic analysis of the relative response between sprayed and unsprayed treatments in 1984/85 indicated that losses in the range of 13 to 33% occurred due to pea aphid attack. Similar results were also obtained from a continuation work conducted in 1986/87 season where 15.6 to 33% losses (Figure 3) have been recorded from four varieties evaluated under sprayed and unsprayed conditions (DZARC, 1987). Surveys conducted in different lentil growing areas in Shewa between 1991 and 1994 confirmed the importance of the pest (DZARC, 1995). Later, comparison of insecticide treated and untreated plots showed losses ranging from 69 to 75% (DZARC, 1998).

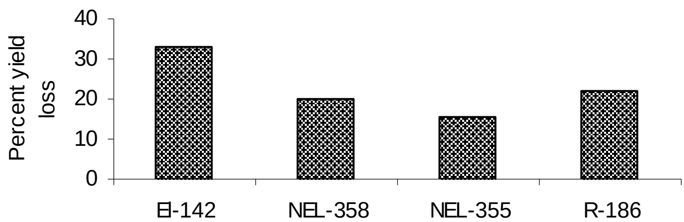


Figure 3. Yield loss (%) of lentil cultivars due to pea ahid evaluated under insecticide treated and untreated condition at Debre Zeit (DZARC, 1987)

Pod borer

Pod borer threatens chickpea from early seedling stage until maturity. Young caterpillars of different ages scrape the undersurface of leaves, causing premature defoliation. They also nibble flowers and young buds. Later they bore into green pods and eat away ripening seeds.

Severeal surveys were conducted to assess the importance of pod borer on chickpea in major growing regions of Ethiopia. In earlier assessments, the pest was recorded in all the surveyed localities except in some parts of northern Shewa: Sendafa, Aleltu and Sheno (DZARC, 1994; 1996; 1997). However, the pest was recorded to cause some damage in these areas in recent surveys (DZARC, 2003). These and other recent works revealed that the pest causes more damage in the central part of the country; i.e., western and eastern Shewa than other areas. Mekasha and Geletu (1999) reported that about 39.7, 22.0, 13.2 and 10.9% of the farmers in some major chickpea growing regions considered the pest to cause very severe (76–100%), severe (51–75%), substantial (25–50%) and very little (<25%) damage, respectively.

Though the pest was found to cause low damage in northern Shewa, pod damages of 11.9 and 15.0% were recorded exceptionally in Enewari and Jihur areas in 2001/02 season and in Woyra Amba in 2002/03, respectively. Pod borer was also reported to cause low damage in northwestern Ethiopia: eastern and western Gojam areas (DZARC, 1999; 2001; 2002; 2003). Other reports, on the other hand, indicated that in this region particularly in some localities of Yilmana Densa and Mota, the pest caused as high as 99% and at Achefer complete pod damage (AdARC, 2002). On-farm surveys conducted from 1999/2000 to 2002/03 revealed pod damage of 0.7–32.7% (Tebekew, 2004).

Basic studies

Biology

Pea aphid

Biology of pea aphid was studied on four legumes: faba bean (variety CS-20DK), field pea (variety Mohandefer), lentil (variety EL-142) and grass pea (accession LS-8246) by Melaku et al. (2000). Their result revealed that the number of molts and the nymphal period required by each nymph were similar on all crops while reproductive period, post reproductive period and lifespan of aphids raised on lentil were longer than those raised on other pulses, which resulted in its higher total reproduction on lentil (Table 17).

Table 17. The bionomics of *A. pisum* on different food legume crops

Life table parameters	Crop species			
	Faba Bean	Field Pea	Lentil	Grass Pea
Development period (days)	9.4	9.8	9.8	9.3
Pre-reproductive period (days)	0.9	1.2	1.1	0.9
Reproductive period (days)	9.8	9.8	17.4	14.3
Post reproductive period (days)	1.0	1.3	2.1	0.7
Total lifespan (days)	20.1	22.7	34.9	24.6
Net reproduction/female	59.40	62.59	103.56	82.90
Mean generation time	14.27	16.04	18.07	16.02
Intrinsic rate of increase	0.286	0.256	0.257	0.276

Source: Melaku et al., 2000

Tebekew et al. (2002) studied the biology of two strains of pea aphid – Debre Zeit (DZ) and Goettingen (GOE) strain – originated from Ethiopia and Germany, respectively, at a constant temperature of 21 °c and relative humidity of 50–70% on four lentil genotypes (Table 18). According to their findings, on the average, the GOE strain required relatively longer developmental period and longer post reproductive period than the DZ strain. However, the commencement of reproduction was not affected by the different lentil varieties due to the ability of the aphids to compensate for the delay in reproduction by shortening the pre-reproductive period or compensate for pre-maturity by extending the pre-reproductive period. The net reproduction of both strains was closer to the total reproduction on Chalew and Flip-88-12L, whereas it was low on Alemaya and ILL-8006. The mean intrinsic rate of increase (r_m) of DZ strain was 0.33 compared to 0.321 for GOE strain, which indicates the absence of variation in this regard.

Table 18. Bionomics of two strains of *A. pisum* on different lentil genotypes

Genotypes	Development period (days)**			Pre-reproductive period(days)*		Reproductive period (days)**			Post reproductive period (days)°		Longevity (days)°	
	Strains			Strains		Strains			Strains		Strains	
	DZ	GOE	Mean	DZ	GOE	DZ	GOE	Mean	DZ	GOE	DZ	GOE
Alemaya	8.76	8.78	8.77[a]	1.22	1.54	17.18	16.86	17.02[a]	5.50	12.35	32.26	39.53
Chalew	8.36	8.52	8.44[bc]	1.29	1.84	17.26	16.75	17.01[a]	8.08	12.92	34.99	40.03
Flip-88-12L	8.13	8.54	8.34[c]	1.29	1.58	14.35	14.54	14.45[b]	7.29	13.37	31.06	38.03
ILL-8006	8.5	8.81	8.65[ab]	1.24	1.36	14.83	16.00	15.42[b]	7.39	14.40	31.96	40.57
Mean*	8.44[a]	8.67[a]	-	1.26[a]	1.58[a]	15.91[a]	16.04[a]	-	7.07[b]	13.26[a]	32.67[b]	39.54[a]

°= Mann-whitney U-test, significance at $p<0.05$
*= means followed by the same letter with in a column or row are not statistically different at $p=0.05$
**= means followed by the same letter with in a column are not statistically different at $p=0.01$
Source: Tebkew *et al*. 2002

Economic threshold

Studies were conducted at Debre Zeit and Akaki from 1999/2000 to 1992/93 to determine the economic threshold level of pea aphid on lentil. Nine levels of aphid infestations were used, at which Pirimor 50% at the rate of 1 kg ha^{-1} was applied. Though the results obtained varied from one season to the other and in some seasons the aphid population did not reach all the treatment levels, the highest net return was obtained at two to three sprays at aphid population level of about 25 per 130 cm^2 board at Akaki. Hence, this value could be taken as economic threshold level for launching control action against pea aphid on lentil until further information is made available (DZARC, 1994).

Population dynamics

Pea aphid

The seasonal population dynamics of pea aphid was studied at Debre Zeit from 1993/94 to 1996 on lentil grown through out the year. Although the aphid infests the crop during both the common growing and non-growing periods, pest population incidences varied from year to year. In 1993/94 season, for instance, the population reached its maximum of 19.5 aphids per 130 cm^2 board on the last week of May. In 1995 the highest numbers of pea aphid – an average of 41.8–47.4 aphids per 130 cm^2 board were recorded throughout October, but in 1996 peaks of 16–27.33 aphis per 130 cm^2 board were encountered (DZARC, 1996; 1997; 1998). Such incidence of the pest throughout the year might suggest that it over seasons in active form on alternate hosts or volunteer host plants.

Pod borer

Studies on population dynamics of pod borer have been conducted for three years (1987/88, 1988/89 and 1991/92) at DZARC using pheromone and light traps. Year round moth flights were recorded during all monitoring periods, which resulted in two distinct peaks (DZARC, 1990; 1991). Seid and Tebekew (2002) attribute this to the high correlation of moth catch with rainfall that resulted in the first peak after the small rainy season, Belg peak, and the second peak after the main rainy season, Meher peak. These peaks are characterized by temporal shifts from one season to the other and there is high year-to-year fluctuation in the seasonality of this pest (Seid and Tebkew, 2002). Similar activities have also been conducted at Debre Zeit and Akaki during 1998/99-2000/01 and 1998/99-1999/2000, respectively.

Pod borer moth attraction effect of honey, molasses, orange squash, ‘tej’ and ‘tela’ was evaluated in comparison with frozen synthetic septa at Debre Zeit (DZARC, 2003). The efficacy of the tested food lures varied from one season to the other. Less than one moth was caught per trap per day in food lures while up to seven male moths were caught per trap per day with old frozen septa. These food lures attracted both male and female pod borer moths with moths and other moths and butterflies.

Control methods

Cultural methods

Studies have been conducted at Debre Zeit Research Center to assess the potential of planting time and plant density against pod borer on chickpea. Plant populations (17, 25, 33, 50 and 65 plants m^{-1}) and sowing dates (early August, mid August and early September) were considered in the study during 1988-1992 (DZARC, 1989; 1990; 1991; 1992). Unfortunately, conclusive results could not be obtained due to the low natural pest infestation pressure. However, the general trend showed that early sown chickpea with high plant population suffered relatively higher percent of pod damage than the late sown ones. Because of the substantial yield advantage of early sowing, Geletu et al. (1996a) recommended early planting with insecticide application to reduce pod borer damage.

Investigations were made to determine the effect of sowing date on the incidence of pea aphid and lentil yield. In general, early planted lentils suffered higher aphid infestation. In earlier studies where sowing dates of as early as June 20 were used, grain yield of early planting treatments were lower than the late planted ones (DZARC, 1987; 1991; 1992). Later evaluations were made for four years (1993 to 1996) at Debre Zeit and three years (1994 to 1996) at Akaki by pushing the earliest planting dates to July 19 and June 30, respectively (DZARC, 1993; 1996; 1997; 1998). At Debre Zeit, aphid population declined with delay in sowing date. High aphid incidence on earlier planted materials might have been favored by the relatively high relative humidity and warm temperature of late September and early October. During this period, early-planted lentils flower to pod set, the most vulnerable stage to aphid attack. In contrast, early-planted lentil produced better grain yield compared to late planting. The low yield of early plated treatments of the earlier evaluation might, therefore, be attributed to the confounded effect of waterlogging, which is the common problem of most Vertisols. In general, higher yields were obtained from planting in July. This, therefore, indicates that planting lentil early around mid-July with insecticide supplement during seasons of high aphid incidence is worth practicing.

The potential of adjusting plant density (seed rate) for the management of pea aphid on lentil was assessed on four elite varieties: EL-142, Ada (Flip-84-78L), Gudo (Flip-86-41L) and Chekol (NEL-2704) at Debre Zeit and Akaki for four seasons (1996/97–1999/00). Five seed rates (40, 70, 100, 130 and 160 kg ha^{-1}) were used. At Debre Zeit the seed rates used did not affect the initial incidence of pea aphid on the crop. However, at flowering stage, marginally significant pea aphid population difference was obtained among the seed rates for three consecutive years, except 1999/2000 cropping season. In all the years, aphid population increased with an increase in seed rate with the exception of highest seed rate (160 kg ha^{-1}) in 1996/97 and 1997/98 cropping season. Nonetheless, the increment in aphid infestation did not affect the grain yield at various seed rates. Similar trend was also observed at Akaki except for the low aphid population recorded compared to Debre Zeit.

Biological control

In Ethiopia, so far, research efforts towards biological control of pod borer and other pests are minimal, though the work was started in 1947. Some natural enemies of pod borer were recorded on different crops, though their potential as biological control agent was not studied. Seid and Tebkew (2002) reported that Ichneumonid wasps in Wello were found to cause 5–10% mortality of the pest. Tsedeke (1995) reported eleven natural enemies that attack pod borer in bean and cotton fields in the Rift Valley. Tachinids (*Voria ruralis, V. capensis* and *Periscepsia carbonaria*) and the wasp, *Tiphia sjostedti,* were observed attacking pod borer in haricot bean fields (Tsedeke, 1995). Furthermore, survey work done at Ambo Research Center has shown that assasin bugs, Tachnicds, Ichneumonid wasps (*Charos* sp), spiders and egg parasitoids (*Trichogramma* sp) were found attacking this pest in different crops (Seid and Tebkew, 2002).

Limited survey results on entomopathogens attacking insect pests were conducted and pathogenic fungi and viruses were found to be naturally infecting pod borer. Among these, nuclear polyhedrosis virus (NPV) was isolated from diseased larvae. On a survey made to assess entomophathogens no ill-looking or dead pod borer larvae were found (DZARC, 2002).

Host plant resistance/tolerance

The use of resistant/tolerant cultivars is a potentially cheap and yet effective means of pest control to obtain better yield. However, no chickpea cultivar has been identified to be resistant to pod borer. Germplasm screening activities undertaken at Debre Zeit on local collections and introductions from early eighties until recently did not come up with conclusive results partly due to the low incidence of the pest (DZARC, 1988; 1989; 1990; 1991; 1992). Large-scale verification of chickpea lines that were promoted from earlier screening phases due to their low-level pod of damage proved the same result (DZARC, Unpublished data).

Quite a large number of lentil germplasm were evaluated for resistance to pea aphid since the early 1980s. It was reported in DZARC (1987) that none of the 360 evaluated accessions were free of attack and infestation with pea aphid. Twenty-four accessions were found to be relatively tolerant. Later in 1992/93 and 1995/96 genotypes were tested at Akaki and thereafter screening activities were carried out at Debre Zeit Center. Concerning, the level of infestation among the tested genotypes, all have different level of pea aphid infestations. After frequent selections, 12 out of the 32 promising genotypes that gave better yield under the prevailing aphid infestation pressure were further evaluated under insecticide treated and untreated conditions in 2000/01 and 2001/02. Significant differences in aphid infestation were observed at pre-spray counts of Chalew and R-186 in 2000/01 and Chalew, Flip-87-75L and R-186 in 2001/02, but variations were observed at later counts (DZARC, 1993; 1997; 1998; 1999; /2000). In another screening study, FLIP-86-17L and LL-57 were found to be promising and reached verification level and were evaluated with a susceptible check, i.e. EL-142, at Debre Zeit. However, they were found to be susceptible as the check (DZARC, 2005).

Botanical methods

The effect of neem oil, neem seed powder (NSP), *endod* seed powder (ESP), animal waste (cow dung, CD, and cow urine, CU), insecticides (endosulfan, ES, at half and full recommended dose) and their paired combination against pod borer on chickpea was evaluated at Debre Zeit (DZARC, 1999; 2000; 2001). Pod damage and grain yield responses of neem seed powder from Melka Werer alone or in combination with *endod* seed powder or animal wastes highly reduced pod damage by pod borer as compared to neem oil and untreated check. Water extract of nine plant materials were evaluated in comparison with neem oil in the laboratory against pod borer larvae. The treatments were applied twice on single second or third instar larva feeding on chickpea leaves on petri-dishes in two replications. Of these, sisal leaf and neem seed extracts effectively killed the whole test larvae followed by endod seed and *Chines mole* leaf extract (DZARC, 2002).

Several botanicals were evaluated against pea aphid in 2001/02 and 2002/03 cropping seasons at Debre Zeit. Significant difference was not observed among the tested plant species in reducing aphid number, although aphid population showed continuous decrease on plots treated with alashume (dried), amphar,. *Argemone* seed and *Argemone* leaf and stem (fresh) extract. There were marginally significant differences in grain yield among the various treatments. Plots treated with extract of alashume, Argemon seed, oleander, tagetus and *Yefereng zigita* gave better yield than the others (DZARC, 2003).

Chemical control

The scope for wide-scale use of insecticides in managing pod borer on pulse crops is generally limited because the subsistence farmers cannot afford to buy it (Seid and Tebkew, 2002). Mekasha and Geletu (1999) also reported that the most farmers in some major chickpea growing areas do not use control measures except a few farmers who spray insecticides and some use traditional means to control pod borer. With the virtue of selecting effective ones, several insecticides were tested at Debre Zeit against the pest on chickpea. Cypermethrin 20% (Ripcord 20), cypermethrin 25% (Cymbush 25%), cythalothrin-k 25% and DDT 25% were evaluated at manufacturers' application rates. The results of these studies revealed that single application of cypermethrin 20% (Ripcord 20), cypermethrin 25% (Cymbush 25%) at peak flowering of the crop gave the least pod damage due to pod borer (DZARC, 1987; 1989; 1990). Kemal and Tibebu (1994) also reported that single application of cypermethrin or endosulfan at similar growth stage of the crop was found effective in controlling the pest and application of insecticides at full pod setting resulted in a significantly high pod damage compared to the applications at peak flowering and mid pod setting stages.

Various insecticide evaluation studies have been conducted at different times. Results of the screening activities conducted in 1986 and 1989 did not show significant difference among insecticides due to low aphid infestation. In 1990, significant difference was observed among the 14 insecticides evaluated and all of them sharply reduced pea aphid population. Particularly, ekatin 25% EC, metasystox R 250 EC, sumithion 40% EC, pirimor 50% WP, dursban 48% EC, and perfekthion 40% EC effectively controlled the pest. These insecticides, however, did not result in significant yield difference probably due to the low pest pressure to cause economic damage (DZARC, 1991). Similar screening conducted at Akaki in 1992, however, showed significant difference among insecticides in suppressing aphid population and increasing grain yield. Primicarb 50% WP, pirimiphos-methyl 50% EC, ofunak 40% EC and dimethoite 40% EC sharply reduced aphid population and gave better yields (DZARC, 1993).

Grass pea

The extensive plain around Lake Tana, especially the Vertisols is traditionally planted grass pea (Melaku, 2004). Farmers' know that they will not get any yield unless they use insecticides against pea aphid. The yield loss due to the pest is 100% and farmers harvest the straw to feed their livestock. But growing the crop has advantage, even with the pea aphid not allowing any grain to form, than feeding animals, i.e., they use it for crop rotation. Without it grown every year, the soil nutrients are highly depleted that other crops cannot grow.

Therefore, growing grass pea is obligatory, not a choice. In so doing, they can benefit in more than one way: harvesting some grain by applying insecticides or other control methods while they maintain soil fertility making the field ready for the subsequent crop, mainly a cereal.

Grass pea is the most susceptible host of pea aphid in the warm areas of the Tana basin around Bahir Dar. To test potentially more sustainable and harmless alternatives to the commonly used pesticides, some botanicals (neem, garlic and hot pepper), soap, kerosene and the aphiccide pirimicarb were teasted against pea aphid at Wondata village, close to Bahir Dar from 1999 to 2002 (Melaku, 2004). After pirimicarb, hot pepper was consistently the most effective botanical in controlling the pest and higher grain yield compared with the untreated control. There was up to 83 and 55% lower aphid population on pirimicarb and hot pepper treated plots, respectively. The yields were also 93 and 54% more than the control, respectively. Soap was less effective, while kerosene caused severe phytotoxicity (Melaku, 2004). Percent of parasitism of aphids was higher (40%) on pirimicarb treated plots due to density dependent nature of the parasitoids than other plots (<20%)

A separate study on the efficacy of using polyethylene sheets to heat infested plants led to some burning of the plants but at the same time driving the pea aphids to hide away from the leaves (Melaku et al. 2000). The aphids hide around the base of the plant and in the soil. Some three days later, they reinfested the plants.

Lowland pulses

Research findings

Pests recorded

Although a large number of arthropod pests have been recorded on major lowland pulse crops, only a few of them are of economic importance (Table 19). The bean stem maggot (*Ophiomyi*a spp.) is the most important pest of beans (Ferede and Tsedeke, 1986). The African bollworm is also an important pest of beans in the Rift Valley and other drier parts of Ethiopia (Tsedeke and Adhanom, 1981; Tsedeke et al., 1985a).

Table 19. Arthropod pest species recorded on selected lowland pulses in Ethiopia

Crop	Common name	Scientific name	Status	Reference*
Haricot bean	Bollworm	*Helicoverpa armigera*	Major	72,75
	Bean stem maggot	*Ophiomyia phaseoli*	Major	70, 24
		O.spencerella	Major	70
		O. centrosematis	Minor	70
	Groundnut aphid	*Aphis craccivora*	Minor	74
	Pea aphid	*Acyrthosiphon pisum*	Minor	74
	Bean aphid	*Aphis fabae*	Unknown	74
	Peach ahid	*Myzus persicae*	Unknown	74
	Tobacco white fly	*Bemicia tabaci*	Minor	74
	Cotton bud thrips	*Frankliniella schultzei*	Unknown	74
	Spotted bean borer	*Maruca testulalis*	Minor	74
	Lesser armyworm	*Spodeptera exigua*	Sporadic	74
	Bean thrips	*Sericothrips occipitalis*	Unknown	74
	Spider mite	*Tetranychus* sp.	Major	74
	Flea beetle	*Pdagrica* sp.	Minor	74
Soybean	Green stink bug	*Nezera verdula*	Unknown	74
	Groundnut aphid	*Aphis craccivora*	Minor	74
		Acyrthosiphon pisum	Unknown	74
	Cotton aphid	*Aphis gossypii*	Unknown	74
	Bean pod weevil	*Apion sp. varium?*	Minor	74
	Greasy cut worm	*Agrotis ipsilon*	Minor	74
	Pineapple mealybug	*Dysmicoccus brevipes*		74
Mung bean	Bean pod weevil	*Apion sp. varium?*	Major	74
	Green stink bug	*Nezera verdula*	Unknown	74
	Pod borer	*Heliothis peltigera*	Minor	74
		Maruca testulalis	Minor	74
		Helicoverpa armigera	Minor	74
	Pod borer	*Etiela zinckenella*	Minor	74
Pigeon pea	Cluster bug	*Agonoscelis pubescens*	Minor	74
	Spiny brown bug	*Clavigralla tomentosicollis*	Unknown	74
	Pod borer	*Etiela zinckenella*	Minor	74
	African boll worm	*Helicoverpa armigera*	Major	72,75
	Pod bugs			
	Cotton bud thrips	*Frankliniella schultzei*	Unknown	74
	Cottony cushion scale	*Icerya purchasi*	Sporadic	74
Cowpea	Groundnut aphid	*Aphis craccivora*	Minor	74
	Bruchids	*Callosobruchus* spp.	Major	74
	Cotton leaf worm	*Spodeptera exigua*	Minor	74
	Cotton leafworm	*Spodeptera littoralis*	Major	74
	Flower thrips	*Taeniothrps* spp	Minor	74
	African bollworm	*Helicoverpa armigera.*	Major	72,75
	Pod borer	*Etiela zinckenella*	Minor	74
	Spotted bean borer	*Maruca testulalis*	Minor	74

* Numbers in the 'reference' column indicate the position of the referenses in the reference list

Basic studies

Bean stem maggot (*Ophiomyia* spp.)

Population dynamics studies

This study was conducted at Awassa and Areka between 1991 and 1993. The result obtained indicated that *O. phaseoli* was the dominant species in bean plots sown between early May and mid-June. In contrast, *O. spencerella* constituted 60 to 100% in plots sown during the cooler and wetter months of July and August. At Areka, *O. spencerella* ranged from 73% to 100% in 1992 and from 57 to 100% in 1993. Here, *O. phaseoli* was found in considerable numbers only in plots sown during the warmer and relatively drier months of February to May (Tsedeke, 1995).

Host range studies

Studies conducted so far indicated that bean stem maggots (BSM) are restricted to the plant family Leguminasae. These include, in descending order, haricot bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), the wild host (*Crotalaria laburnifolia*), and soybean (*Glycine max*) (Tsedeke, 1990)

Ecological studies

From the ecological studies of BSM carried out by Tsedeke (1995), three species (*Ophiomyia phaseol*i, *O. spencerlla* and *O. centrosematis*) were identified in Ethiopia. *O. phoseoli* and *O. spencerella* are the most widely distributed and abundant of the three species. *O. centrosematis* occurs rarely and represents less than 2% of the total BSM population. The incidence of BSM species is influenced by one or a combination of environmental factors and cultural practices, including altitude, sowing date, growth stage and type of the host plant. *O. phaseoli* and *O. centrosematis* are more prevalent in warmer areas (<1800 m), whereas *O.spencerella* is dominant at higher altitudes and cooler, wetter environments. The pest intensity (as measured by BSM per 10 plants) and species composition vary with location and sampling date (or sowing date). Sample of bean plants collected at Welenchiti, Bulbula, Ambo, Hirna, Chelenko, Kunai, Kulubi, and Abelti and Seka did not yield BSM, although they showed characteristic symptoms by this insect. BSM intensity at some areas, such as Kersa, Wakmolie, Yabete Anbessa, Melkassa, Shashemene, Metu, Bonga, and Jimma is relatively low, suggesting that this insect may not be a limiting factor in haricot bean production in these areas.

Loss assessment studies

Tsedeke (1995) showed data on losses due to major insect pests to different lowland pulses. Crops losses ranged from 9 to 100%. Loss assessment studies due to some commonly occurring insect pests of cowpea conducted for two seasons at Nazret indicated that there was no significant difference in yield among the chemicals used at different crop stages. However, two applications of endosulfan, i.e., at seedling and flowering stages gave relatively higher yield. The estimated crop loss was 9.5% (Ferede and Tsedeke, 1987a).

Control measures

Bean stem maggot

Cultural methods

Cultural control studies on the management of BSM consisted of determining the effect of sowing date and plant density, and of habitat management. Planting date and plant density have significant effect on BSM intensity, crop damage and yield (Tsedeke, 1990a). The effect of sowing date is location specific. At Awassa, seedling mortality and the resulting yield did not follow any specific trend among sowing dates, whereas at Melkassa seedling mortality increased and seed yield increased with delays in sowing (Tables 20).

Table 20. Sowing date and plant density effects on seed yield of haricot bean at two locations during the 1987 and 1988 crop season*.

Factor	Awassa		Melkassa		Mean
	1987	1988	1987	1988	
Sowing date					
1st	2488b	3657a	867a	2592a	2388a
2nd	2738b	3028b	574ab	2364a	2176b
3rd	2885a	3165b	482bc	2294a	2195b
4th	2322c	2746c	323c	1386b	1694c
Plant density					
100,000 ha^{-1}	1943b	2526c	428a	1476c	1602c
200,000 ha^{-1}	2562a	3107b	486a	1842bc	1999b
300,000 ha^{-1}	2860a	3401a	617a	2213ab	2273a
400,000 ha^{-1}	2838a	3449a	635a	2593a	2379a
500,000 ha^{-1}	2776a	3224ab	641a	2616a	2314a

. Means followed by the same letter with in a column or row are not statistically different at p=0.05
Source: Tsedeke, 1990

The effect of spacing on the infestation of haricot bean by some insect pests was studied at Melkassa during 1984/85–1985/86. Results of these studies indicated that contrary to pod borer and bug damage increase in plant densities significantly reduced the percent of bean fly damage (Ferede and Tsedeke, 1987b).

The study on the effect of spacing on the infestation of two cowpea varieties by some insect pests was carried out for two consecutive seasons at Nazret. The results indicated that cv. White Wonder Trailing (WWT) had significantly lower percent of bean fly and pod bugs damage than cv. Black-eyed bean Ex DZ. However, the latter were better in pod borer damage than WWT. Plant population had little effect on the percent damage by any of the pests studied (Ferede and Tsedeke, 1987).

The effect of sowing dates and planting densities on ABW, pod weevils, leafhoppers and predators were evaluated in haricot bean fields at two locations

(Awasa and Melkasa). In general, the overall mean percentage pod damage increased with increasing plant density. Sowing date did not have a significant effect on pod weevil numbers, whereas plant density effects were significant. Leafhopper numbers of the two locations and seasons were different. The number of predators (*Orius*) increased with late seeding. Plant density had no effect (Tsedeke, 1992).

Studies on host plants, insect pests and parasitoids interactions in haricot bean were carried out at Mekelle Research Center for two years (MkARC, 2000). In the study, 10 bean varieties were included. Bean maggot larvae, pupa, crop mortality, yield and yield components were recorded. Four lines (TESB-8, Cr-3-22, TESB-12 and Cr-3-19) had less than 10% mortality while the most susceptible line was TESB-6. In terms of grain yield, lines TESB-8, TESB-12 and Cr-3-22 were found to be better than others were.

African bollworm

A study on African bollworm (ABW), *Helicoverpa armigera,* focused on trap-cropping, strip-cropping and habitat management in general. It has been shown that pod damage by ABW was lowest and seed yield was the highest in haricot bean stripped-cropped with maize (Tsedeke, 1988). In another experiment, where the effects of strip-cropping beans with maize under weedy and weed free conditions were tested. Natural enemy (including the tachinids *Voria ruralis, V. capensis*, and *Periscepsia carbonaria*; the wasp *Tiphia sjostedii)* numbers were significantly higher in the diverse weedy and intercropped plots than in bean monoculture (Tsedeke, 1995).

The use of trap crops (maize) and insecticide application were tested against pod borer at Melkassa during 1984/85 and 1985/86 seasons. Results of the 1984 showed significant differences between counts of pod borer in insecticide treated and untreated main plots. Significantly, higher yields of haricot bean were also obtained from insecticide treated plots. Insecticide application had no effect on the yield of maize. No significant yield differences of either crop were observed among the treatments. In 1985 season, significant differences in pod borer damage were obtained between treated and untreated main plots. None of the other parameters was significant. It was recommended that strip-cropping maize with haricot bean at about 10 m intervals must be practiced in the IPM of pod borer (Tsedeke and Ferede, 1987).

Biological control

Studies on the biological control of BSM were directed at delineating natural enemies that occur in Ethiopia. Seventeen species of parasitoids have been identified from surveys carried out so far (Tsedeke, 1990; 1995). Of these, the braconid (O*pius phaseoli)* was the major parasitoid on *O. phaseoli* on haricot bean. Average parasitism at Awassa was roughly 78% and at Melkassa it was about 38% (Tsedeke, 1990). Seeding rate did not influence *Opius* number, whereas sowing date had significant effects (parasitoids numbers increased with an increase in BSM numbers).

The Pteromalids *sphegigaster stepicola* and *S.brunneicornis* were also common but they accounted for about 5% of the total parasitism in haricot bean. In contrast, they were the major parasitoids of BSM on the wild host *crotalaria laburnifolia* where the average parasitism reached about 26%.

Host plant resistance

Bean stem maggot

Several genotypes with resistance to BSM and high seed yield have bean identified from studies conducted between 1986 and 1988 (Tsedeke, 1990). Crosses of some of these materials have been made with commercial varieties in the bean improvement program and their progenies are evaluated for BSM and disease resistance, grain yield, and food and cooking quality which resulted in the release of two varieties: Melko and Beshbesh.

In another study, preliminary screening of 48 cowpea lines for resistance to bean stem maggot was carried out at Mekelle Research Center for three consecutive years (1995–1997). Twenty-three lines were moderately resistant/tolerant. These lines were advanced to a replicated trial and tested for two seasons under natural infestation. Results of the two seasons showed that entries IT86D-400, IT87-D-1010, IITA VAR-91-12, TVU 1977ODI, IT85F-26-87, IT82-889, IT84D-666 and White Wonder Trailing had low level of infestation, and they matured early and gave better grain yield (MARC, 1998).

African bollworm

Fifty-three cowpea lines were evaluated for their resistance at Melkassa from 2003 to 2005 (MlARC, 2005). The lines IT87D721, IT95K1098-5, IT84D449 and 85D-3517-2 gave lower percentage of damaged pods than the remaining lines.

Chemical Control

Bean stem maggot

Insecticidal control studies have been conducted at Kobo, Mekelle, Melkassa, and Awassa primarily to replace aldrin (Ferede and Tsedeke, 1996; Tsedeke, 1990). Although seed dressing with carbofuran (35% liquid formulation) significantly reduced BSM infestation at Kobo and Mekelle, it was phytotoxic, especially in low rainfall areas (Tsedeke et al., 1985a, b). Experiments at Melkassa and Awassa demonstrated that an effective control of BSM can be obtained with endosulfan seed dressing at the rate of 5g a.i. kg^{-1} of seed (Tsedeke, 1990)

Conclusion and Recommendations

Pea aphid, pod borer, pea bruchid and bean stem maggot are the major field insect pest that threatens pulse crops production. Cut worms, *Agrotis* sp. is also sporadic pest of pulses causing serious damage in some regions. Wide ranges of insecticides were recommended for the control of these pests. Pea aphid is an important pest of lentil, field pea and grass pea, primicarb 50% WP, pirimiphos-methyl 50% EC, cofunak 40% EC and dimethoite 40% EC sharply reduced aphid population and gave better yields. Single application of cypermethrin 20% and endosulfan 35% were recommended for the control of pod borer. Though effective insecticides for the control of these pests are available, their utilization by the subsistence farmers is generally limited mainly due to high prices.

Growing concern over the impact of agrochemicals on food safety and the environment necessitates that integrated pest management (IPM) must be practiced with minimum reliance on pesticides. This approach also takes into consideration the pest control needs of the resource-limited farmers in most developing countries, particularly in Africa, by emphasizing biointensive pest management (BPM). Within this framework, host plant resistance, comprising the use of pest tolerant cultivars, forms the focus and is supported by other pest management components. These are, among others, biological controls (deploying predators, parasitoids and microbes), botanical (natural) pest control (the use of derivatives of locally available plants with pesticidal properties) and cultural control and supportive tactics (such as pest monitoring, loss assessment and establishment of ETL). Control by synthetic pesticides is only used as a last resort when other strategies fail to curb pest eruptions.

A long-term solution to the legumes insect pest problem is only possible through the integration of the control strategies mentioned above. Based on results of the previous researches summarized in this paper, the strategy rests on integrated pest management that takes into account the needs and circumstances of individual farmers, be it the commercial farming or low-input small-scale farming. Farming systems differ widely in the area, i.e., the type of land cultivated the cropping systems, wealth and farming objectives. The objectives of subsistence farmers, for instance, are vastly different from those of commercial farmers. Overall, however, farmers of any group are concerned with generating a food supply on a profitable basis.

Synthetic, and to a certain extent natural insecticides, probably remain the key factors in managing for commercial farmers in the near future. This program is based on the judicious use of environment-friendly insecticides and cognizant of economic threshold levels (ETL), supplemented by host plant resistance and cultural control methods whenever possible. Previous research in this regard has indicated that timely and correct application of insecticides could result in substantial yield increases. Information for pesticide use should be based on sampling during critical periods of crop development, and treatment decisions should be based on pest densities or severity so that unnecessary treatments are avoided and maximum ecological selectivity is encouraged.

Cultural control practices can have a profound influence on insect and disease survival, their persistence in a particular environment and damage levels on the crop, and each practice needs to be seen as part of the total crop production system. The development of a sound pest control strategy requires an understanding of the principles underlying the fluctuation of populations that make up the ecosystem. Population densities of pests generally fluctuate significantly under monoculture conditions and are more stable under polyculture conditions. From the viewpoint of pea aphid management, it would be desirable to rather practice intercropping than monoculture. Intercropping is a common practice in many parts of the world, particularly in small-scale farming in the developing world. Overall, the development of an IPM model for resource-poor farmers in developing countries should be geared towards maximizing the use of safe, cheap and simple pest management methods. Moreover, incorporating those traditionally used by third world farmers and integrating them with the use of the safest possible chemical pesticides when necessary should also be encouraged.

Gaps and Challenges

The scope of insect pest survey was limited and not coordinated to get the national significance in legumes. It did not consider, in most cases, the effect of crop diversity, farmer's management practices and the effect of new technologies in pest development. Ecological studies are limited and need to be strengthened to aid in forecasting. The genetic variability in the germplasm of indigenous and exotic sources is not fully utilized. Moreover, the durability and mechanisms of resistance of resistant genotypes are determined in research.

The effect of crop rotation, straw management, and tillage system on the management of legume pests is not adequately investigated. The indigenous knowledge of farmers to manage legume pests is not systematically well documented and exploited by research. Moreover, the emphasis given to biological control (parasitoids and predators) research is insignificant and their potential use is not explored. IPM as sustainable pest management options in legumes lacks attention by most researchers and users. The limited research done by different research centers are not well coordinated in the country.

Most of the laboratories, green houses and other facilities in research centers are below the minimum standards to carry out satisfactory plant protection research. The facilities, chemicals and other supplies are critically limited. Modern tools (e.g. molecular marker) for biotype analysis are lacking. Such facilities need to build as soon as possible. Future research relies on molecular biology.

Low infestation level of the regular pest in some seasons and sporadic nature of pests like the cut worms were the major challenges that hampered the research work. Controlled experiments in the laboratory which are not affected by the environment should be encouraged. Basic knowledge such as the biology, behaviour and chemical ecology of the pests in relation to the host crops and the relation of the pest with major environmental elements such as temperature and rainfall are minimal. Studies on cultural, biological and physical control methods were not conclusive.

Future prospects

Insect pests are major constraints to pulses production; yet there has been relatively little research investment, particularly outside of the developed countries, into the ecology and management of the pests and their natural enemies. To some extent, research has concentrated on host plant resistance, cultural and chemical control. Chemical control of the pea aphid and pod borer has been the only option for many growers and will remain so for some time. Knowledge of the impact, dynamics and ecology of the pest and its natural enemies is essential before effective control strategies can be developed. It should be stressed that understanding plant-pest-natural enemy interactions is essential to the successful integration of plant resistance with biological control for optimal IPM results. These must focus on cropping systems, as the crops are frequently one component of a complex farming system. There is no short cut to reduce losses due to pests immediately. Progresses will be incremental and in the short term, the greatest impact may come from improving pesticide application and developing safe alternatives that have potentials to replace the toxic pesticides. The incompatibility between chemical and biological control has in fact been the main force behind the evolution of IPM. Strategy for medium term should concentrate on developing improved cultivars that combine high yield, disease and insect-resistance with good agronomic characters. A longer-term solution to insect pest problem in field pea must focus on ways to enhance natural control processes by enhancing the effectiveness of endemic species.

Exploitation of under utilized natural enemies, development of novel bio-pesticides and management of resistance are all tactical options to enrich IPM strategies. All the aforementioned control tactics yield the best results when they are a component of the IPM strategy. IPM should be given the highest priority as a pest management strategy for developing countries, including Ethiopia. The way it is developed accentuates the need for focused research on all components of IPM.

The gaps in our knowledge of different methods needed for effective IPM in field pea and haricot bean have been indicated above. Future research efforts should address these gaps. The need for technology development has been emphasized in this paper. To achieve this, the national capabilities for research on integrated control aspects will need strengthening. Developing national networks dedicated particular pests will have to be created and a general awareness have to be developed among farmers and agricultural personnel in the country. Finally, a group action will be required at the national level to coordinate the research activities in IPM.

References

1. Anonymous. 2004. The pea weevil, *Bruchus pisorum* (L.). Crop Protection Society of Ethiopia. Addis Ababa, Ethiopia.
2. AdARC (Adet Agricultural Research Centre). 2002. Summary of research achievements, 1987-2001, Bahir Dar, Ethiopia.
3. Birhane Assayehegne. 2002. The biology and ecology of pea bruchid (beetle) (*Bruchus pisorum* L.), (Coleoptera: Bruchidae) Paper presented during the pea weevil workshop, 25-27 November 2003. Bahir Dar, Ethiopia.
4. Birhane Assayehegne, Awgechew Kidane and Libawit Haile Michael. 2001. Abundance and distribution of pea weevil (*Bruchus pisorum*) in field pea growing areas of West Amhara Region. Paper presented in the 14th African Association on Insect Scientists and the 9th Crop Protection Society of Ethiopia Joint Conference, June 4-8, 2001, Addis Ababa, Ethiopia.
5. CSA (Central Statistical Authority) 2005. Agricultural sample survey 2004/05: Report on area and production of crops (Private peasant holdings for Meher season). Vol. 1, Statistical Bulletin 331.
6. DZARC. 1987. Debre Zeit Agricltural Research Center. Annual Report for 1985/86.

7. DZARC. 1988. Debre Zeit Agricltural Research Center. Annual Report for 1986/87.
8. DZARC. 1989. Debre Zeit Agricltural Research Center. Annual Report for 1988/89.
9. DZARC. 1990. Debre Zeit Agricltural Research Center. Annual Report for 1989/90.
10. DZARC. 1991. Debre Zeit Agricltural Research Center. Annual Report for 1990/91.
11. DZARC. 1993. Debre Zeit Agricltural Research Center. Annual Report for 1991/92.
12. DZARC. 1994. Debre Zeit Agricltural Research Center. Annual Report for the period 1992/93.
13. DZARC. 1996. Debre Zeit Agricltural Research Center. Annual Report for 1993/94.
14. DZARC. 1997. Debre Zeit Agricltural Research Center. Annual Report for 1994/95.
15. DZARC. 1998. Debre Zeit Agricltural Research Center. Annual Report for 1996/97.
16. DZARC. 1999. Debre Zeit Agricltural Research Center. Annual Report for 1997/98.
17. DZARC. 2000. Debre Zeit Agricltural Research Center. Annual Report for 1998/99.
18. DZARC. 2001. Debre Zeit Agricltural Research Center. Annual Report for 1999/2000.
19. DZARC. 2002. Debre Zeit Agricltural Research Center. Annual Report for 2000/01.
20. DZARC. 2003. Debre Zeit Agricltural Research Center. Annual Report for 2001/02.
21. DZARC. 2004. Debre Zeit Agricltural Research Center. Annual Report for 2002/03.
22. Emana Getu, Ahmed Ibrahim and Firdisa Iticha. 2006. Review of lowland pulses in insect pest research in Ethiopia. pp. 274-277. *In*: (Kemal et al. (Eds.) Food and forage legumes of Ethiopia: Progress and progresses. Proceedings of the workshop of food and forage legumes, 22-26 September 2003. Addis Ababa, Ethiopia.
23. FAO.2006. Agricultural Database: Available at http://apps.fao.org/page/collections?subset=agriculture
24. Ferede Negasi and Tsedeke Abate. 1986. Studies on the control of bean fly, *Ophiomyia phaseoli* ,(Tryon) (deptera: Agrromyzidae). *Ethiop. J. Agric. Sci.* 8:47-59.
25. Ferede Negasi and Tsedeke Abate. 1987. The effect of spacing on the infestation of haricot bean by some insect pests. *PP*.410-412. Proceedings of the 18th National Crop Improvement Conference. 24-26 April 1986, Nazret, Ethiopia.
26. Ferede Negasi and Tsedeke Abate. 1987a. Loss assessment studies in cowpea due to some insect pests. PP. 407-408. Proceeding of the 18th National Crop Improvement Conference. 24-26 April 1986. Nazret, Ethiopia.
27. Ferede Nagasi and Tsedeke Abate. 1987b. The effect of spacing on the infestation of cowpea by some insect pests. PP. 404-406. Proceedings of the 18th National Crop Improvement Conference. 24-26 April 1986. Nazret, Ethiopia.
28. Geletu Bejiga, Million Eshete and Yadeta Anbesa. 1996a. Improved cultivars and production technology of chickpea in Ethiopia. Research bulletin No. 2. DZARC, AUA, Debre Zeit, Ethiopia.
29. Geletu Bejiga, Million Eshete and Yadeta Anbesa. 1996b. Improved cultivars and production technology of lentil in Ethiopia. Research bulletin No. 3. DZARC, AUA, Debre Zeit, Ethiopia.
30. Graham, P.H. and C.P Vance. 2003. Legumes: Importance and constraints to greater use. *Plant Physiology* 131: 872-877.
31. Hailu Beyene and Tadesse Gebremedhin. 1989. On farm verification of aphid control on faba bean and field pea. PP. 22-23 In Research results on cool season food legumes in Ethiopia. Nile Valley Regional Program during 1989 crop season. IAR, Addis Ababa.
32. HARC (Holetta Agricultural Research Centre). 2004. Progress report for 2003/04 season.
33. HARC (Holetta Agricultural Research Centre). 2005. Progress report for 2004/05.
34. Hussien Fetene. 2003. Evaluation of seeds of some pesticidal plants in controlling African bollworm, *Heliothis armigera* on faba bean (*Vicia faba* L.) in Wolo. MSc thesis. Alemaya University, Ethiopia.

35. Kemal Ali. 1997. Economic threshold for pea aphid. *Pest Management Journal of Ethiopia* 1-2: 63-68.
36. Kemal Ali. 1998a. Chemical control of pea aphid with selective insecticides and neem seed extract in field pea. *In:* Nile Valley and Red Sea Regional Program on Cool Season Food Legumes and Cereals. Annual Report 1995/96. ICARDA/NVRSRP.
37. Kemal Ali. 1998b. Chemical control of pea aphid with selective insecticides and neem seed extract in field pea. *In:* Nile Valley and Red Sea Regional Program on Cool Season Food Legumes and Cereals. Annual Report 1996/97. Ethiopia, ICARDA/NVRSRP.
38. Kemal Ali. 1999. Population dynamics of *Acyrthosiphon pisum* (Homoptera: Aphididae) and its natural enemies on *Pisum sativum*. *Pest Mgt J. Eth.* 1-2: 23-29.
39. Kemal Ali. 2002. An integrated approach to pest management in field pea, *Pisum sativum* (L.), with emphasis on pea aphid, *Acyrthosiphon pisum* (Harris). PhD thesis.University of the Free State, Bloemfontein, South Africa.
40. Kemal Ali. 2006. Insect pest management research of faba bean and field pea in Ethiopia. pp. 247-259. *In* (Kemal *et al*. (Eds.) *Food and forage legumes of Ethiopia: Progress and progresses*. Proceedings of the workshop of food and forage legumes, 22-26 September 2003. Addis Ababa, Ethiopia.
41. Kemal Ali and Tibebu Habtewold. 1994. Research on insect pests of cool-season food legumes, PP. 367-396. *In:* Asfaw Telaye, Geletu Bejiga, M.C. Saxena and M..B. Solh (eds). *Cool Season Food legumes of Ethiopia*. Proceedings of 1st National Cool-season Food Legumes Review Conference. Addis Ababa, Ethiopia.
42. Kemal Ali and S.vdM. Louw.2005. Effect of neem insecticide formulations on pea aphid (*Acyrthosiphon pisum Harris*) development and reproduction on field pea in *Ethiopia. Ethiop. J. Agric. Sci.* 18(1): 73-88.
43. Kemal Ali, S.vdM. Louw and W.J Swart. 2005. Components and mechanisms of resistance in selected field pea lines to pea aphid (*Acyrthosiphon pisum* Harris) in Ethiopia. *International Journal of Tropical Insect Science* 25(2): 114-121.
44. Kemal Ali, S.vdM. Louw and W.J Swart. 2007. Effect of mixed cropping of *Pisum sativum* L. on *Acyrthosiphon pisum* (Harris) infestation and ascochyta blight in Ethiopia. *Pest Mgt. J. Eth*.11:69-79
45. Lemma Ebsa, Asrat Kelbesa and Arfasa Kiros. 1996. Yield loss assessment of field pea due to pea aphid in Bale region. Sinana Agricultural Research Centre Progress Report for the period of 1996.
46. MkARC (Mekele Agricultural Research Centre). 1998. Progress report for 1997/98.
47. MlARC (Melkasa Agricultural Research Centre). 2000. Progress report for 1999-2000.
48. MlARC (Melkasa Agricultural Research Centre). 2005. Progress report for 2000-2004.
49. Mekasha Chichaybelu and Geletu Bejiga. 1999. Farmers' perception of the importance and management of chickpea insect pests in Ethiopia. NVRSRP Newsletter. 2:35-37.
50. Melaku Wale. 1989. Effect of weeding on pea aphid infestation in field pea. Nile Valley and Red Sea Regional Program Newsletter 2:32-34.
51. Melaku Wale. 2002. Population dynamics of the pea aphid, *Acyrthosiphon pisum* (Harris) (Homoptera: Aphididae) on field pea (*Pisum sativum* L.) in northern Ethiopia. *Insect Science and its Applications*. 22(2): 131-137.
52. Melaku Wale. 2004. Relative efficacy of botanicals, detergent and kerosene in controlling the pea aphid, A. *pisum* (Harris) (Homoptera: Aphididae) on grass pea *Lathyrus sativa. International Journal of Tropical Insect Science* 24(2): 143:149).
53. Melaku Wale, Bekele Jembere and Emiru Seyoum. 2000a. Biology of the pea aphid, *Acyrthosiphon pisum* (Harris) (Homoptera: Aphididae) on cool season food legumes. *Insect Science and its Applications*. 20(3): 171-180.

54. Melaku Wale, Bekele Jembere and Emiru Seyoum. 2000b. Effect of solar heat produced by polyethylene sheeting on the contact of pea aphid on grass pea in Ethiopia. Lathyrus Lathyrism Newsletter 1:32.
55. Melaku Wale, Bekele Jembere and Emiru Seyoum. 2003a. Effect of density on reproduction and survival of pea aphid on cool season food legumes. *Pest Mgt. J. Eth.* 7: 63-69.
56. Melaku Wale, Bekele Jembere and Emiru Seyoum. 2003b. Occurrence of the pea aphid, *A. pisum* (Harris) (Homptera: Aphididae) on wild leguminous plants in West Gojam, Ethiopia. *Sinet: Ethiopian Journal of Science* 26(1):83-87.
57. Melaku Wale, Birhane Assayehegne and Dereje Andarge. 2002. Research attempts on the management of pea weevil (*Bruchus pisorum* L.) on field pea. Paper presented during the pea weevil workshop, 25-27 November 2003. Bahir Dar, Ethiopia.
58. Mohammed Dawd, Shimeles Getinet, and Kemal Ali. 2005. Distribution and abundance of field pea weevil, *Bruchus pisorum*, in different parts of Amahara Region. Paper presented in the second national workshop on alien invasive weeds and insect pest pests, 6-8 June, 2005, Bahir Dar, Ethiopia.
59. PPRC (Plant Protection Research Centre). 2002. Progress Report for 2001.
60. Shambel Kumbi, Lema Ebsa and Asrat Kelbesa. 1998. Yield loss assessment trial of field pea to pea aphid. Sinana Agricultural Research Centre Entomology Progress Report for the period of 1998.
61. Seid Ahmed and Tebkew Damte. 2002. African Bollworm (*Helicoverpa armigera* (Hubner): A key pest affecting pulses production in Ethiopia. African boll worm management in Ethiopia. Proceedings of the National Workshop, 17-19 April 2002 held at the Plant Protection research Center, Ambo, Ethiopia.
62. Tadesse Gebremedhin and Bayeh Mulatu. 1989. Survey of field insect pests of faba bean. *In:* results of research report on cool season food legumes in Ethiopia. Nile Valeey Regional Program during 1989 crop season. IAR, Addis Ababa.
63. Tebekew Damte. 2004. Importance of pod borer in some chickpea growing regions of Ethiopia. *Pest Mgt. J. Eth*. 8:105-110.
64. Tebekew Damte, Ulber, B. and Vidal, S. 2002. Biology and Biotype of two strains of pea aphid (*Acyrthosiphon pisum,* on lentil. *Pest Mgt. J. Eth.* 6: 13-21.
65. Tebekew Damte and Mohamed Dawd. 2006. Chickpea, lentil and grass pea insect pest research in Ethiopia: a review. pp. 260-273. *In* (Kemal *et al*. (Eds.) *Food and forage legumes of Ethiopia: Progress and progresses*. Proceedings of the workshop of food and forage legumes, 22-26 September 2003. Addis Ababa, Ethiopia.
66. Tesfay Belay, Hailu Terefe, Berhanu Abraha, and Feseha Bezabih. 2005. Pea bruchid (*Bruchus pisorum* L.) infestation and control in field pea (*Pisum sativum* L.) in Tigrai. Paper presented in the second national workshop on alien invasive weeds and insect pest pests, 6-8 June, 2005, Bahir Dar, Ethiopia.
67. Tsedeke Abate. 1988. Experiments with trap crops against African bollworm, *Heliothis armigera*, in Ethiopia. *Entomol. Experi. Appli.* 48:135-140.
68. Tsedeke Abate. 1990. Studies on genetics, cultural and insecticidal control against the bean fly, *Ophiomyia phaseoli* (Tryon) Diptera: Agromyzidae), in Ethiopia. PhD thesis, Simon Fraser University, Burraby, BC, Canada. 177pp.
69. Tsedeke Abate. 1992. Sowing date and plant density on pest and predator numbers in haricot bean fields. *Ethiop. J. Agric. Sci.* 13:30-36
70. Tsedeke Abate. 1995. Pest management in lowland pulses: progress and prospects. Pp 181-194. In: Proceedings of 25th anniversary of Nazret Research Center, 22-23 September 1995, Melkassa, Ethiopia. 319pp.

71. Tsedeke Abate.and Adhanom Negasi. 1981. Chemical control of African bollworm (*Helicoverpa armigera*) (Hubner) with ultra- low volume sprays. *Ethiop. J. Agric.Sci*.3:49-55.
72. Tsedeke Abate and Adhanom Negasi. 1985. Current state of stored product pest management research in Ethiopia. pp. 645-652 *In: A review of crop protection research in Ethiopia*,. Tsedeke Abate (ed.). IAR: Addis Ababa.
73. Tsedeke Abate and Ferede Negasi. 1987. The use of trap crops for the Control of African bolworm on haricot bean, Part II. PP.413-415 Proceeding of the 18th National Crop Improvement Conference.. 24-26 April 1986, Nazret, Ethiopia.
74. Tsedeke Abate,. Tadesse Gebremedhin and Kemal Ali. 1982. Arthropod pests of grain legumes in Ethiopia: Their Importance and distribution. IAR, Addis Ababa, Ethiopia.
75. Tsedeke Abate, Ferede Negasi.and Kemal Ali.1985a. A review of grain legume pest management.Research in Ethiopia. In: a review of crop protection research in Ethiopia, ed.Tsedeke Abate, pp 327-44, Institute of Agricultural Research, Addis Ababa, 685 pp.
76. Tsedeke Abate, Gashawbeza Ayalew and Ammanual Tamiru. 1985b. Ecology of bean stem-maggots in Ethiopia. Paper presented at the 2nd International Crop Science Conference, eastern and southern Africa, Malawi, 19-24 February 1995.
77. Worku Teka. 1998. New insect pest on field pea. *Gibrinachen* 1: 13-14 (Amharic Edition), 1 (1): 13-14. Bureau of Agriculture, Bahir Dar, Ethiopia.

Review of Research on Diseases Food Legumes

Negussie Tadesse[1], Seid Ahmed[1], Dereje Gorfu[2], Tesfaye Beshir[3], Chemeda Fininsa[4], Adane Abraham[3], Melkamu Ayalew[5], Abiy Tilahun[6], Fekede Abebe[7] and Kiros Meles[8]

Introduction

In Ethiopia, crops are grown annually on approximately 7.9 million hectares of land. Of these, 1.2 million hectares is appropriate to pulses (411,719 ha to faba bean, 224,326 ha to field pea, 203,644 ha to haricot bean, 154,032 ha to chickpea, 83,039 ha to grass pea, 60,046 ha to lentil, 19,667 ha to fenugreek, 12,715 ha to lupine and 1,523 ha to soybean). Annual productions are about 446,850 t, 179,362 t, 165,083 t, 137,218 t, 85,701 t, 37,472 t, 11,899 t, 4,577 t and 662 t for faba bean, field pea, haricot bean, chickpea, grass pea, lentil, fenugreek, lupine and soybean, respectively (CSA, 2006). Cultivation of faba bean, field pea, lentil, grass pea, fenugreek and lupine is generally limited to the mid and higher altitudes (1800–3000 m) where the mean annual rainfall ranges from 650 to 1500 mm. Haricot bean and soybean, however, are commonly grown in low to mid altitude areas.

These pulse crops have diverse roles to play in the country. They are cash crops, important sources of dietary protein, and they correct important amino acid deficiencies in cereals. They help to improve soil fertility through biological nitrogen fixation and reduce the dependence on external fertilizer input. Nevertheless, the national average seed yields of these crops are lower (less than1 t ha^{-1}) than the crop yields elsewhere. The major technical constraints to the production of these crops are diseases, insect pest attacks, poor agronomic practices, and lack of improved cultivars and crop protection technologies. In addition, poor popularization of the recommended crop protection technologies following participatory approach is one of the main socio-economic reasons for low productivity of these crops.

Root and foliar diseases may reduce attainable, if not potential, yields of food legumes grown in Ethiopia to a considerable degree. Some information on diseases of these crops has been documented in the first review of crop protection research in Ethiopia (Tsedeke, 1986). An up-to-date understanding of pathogen development as dependent on host plant, the environment, the time and the human (cultural) practice is important in planning and execution of useful disease management practices. The aim of this review is thus to give a concise description and review of new records and research results obtained on diseases of the food legumes in Ethiopia since 1986 and to give future directions.

Chickpea

In Ethiopia, 16 diseases were reported on chickpea (*Cicer arietinum* L.). About 50% and 38% of these diseases are caused, respectively, by fungal and viral pathogens. The remaining diseases are caused by nematodes and mycoplasma-like organisms. The major threats to the production of the crop are diseases of fungal origin such as *Fusarium* wilt and dry root rot (Table 1).

Table 1. List of pathogens causing diseases of chickpea in Ethiopia

Pathogen	Disease	Status	Reference
Fusarium oxysporum f.sp. *ciceris*	*Fusarium* wilt	Major	11, 42, 102, 125, 128
Rhizoctonia bataticola	Dry root rot	Major	do
Fusarium solani	Black root rot	Intermediate	do
Rhizoctonia solani	Wet root rot	Intermediate	do
Sclerotium rolfsii	Collar rot	Intermediate	do
Ascochyta rabiei	*Ascochyta* blight	Major	102
Meloidogyne spp.	Root knot	Minor	11, 103
Leveillula taurica cv. Arn)	Powdery mildew	Minor	do
Uromyces cicer-arietini (Gorgn.) Jacz and Boyer	Rust	Minor	do
Mycoplasma-like organisms	Phyllody	Minor	16
Beet Western Yellows Virus (BWYV)	Stunt	Intermediate	45,127,128
Alfalfa mosaic virus (AMV)	Alfalfa mosaic	Minor	45
Broad bean mosaic virus (BBSV)	Broad bean mosaic	Minor	45
Pea seed borne mosaic virus (PSbMV)	Pea seed borne mosaic	Minor	127
Faba bean necrotic yellows virus (FBNYV)	Faba bean necrotic yellows	Minor	127
Broad bean wilt virus (BBWV)	Broad bean wilt	Minor	127

Wilt/root rots

Economic significance

Wilt/root rots diseases that are caused mainly by *Fusarium oxysporum* f.sp. *ciceris* (FOC [*Fusarium* wilt]), *Rhizoctonia bataticola* (dry root rot), *Fusarium solani* (black root rot), *Rhizoctonia solani* (wet root rot) and *Sclerotium rolfsii* (collar rot) are the most important diseases worldwide. In Ethiopia, these diseases occur in the main chickpea growing areas – the major ones being *Fusarium* wilt and dry root rot (AARC, 1992; Beniwal et al., 1989; Stewart and

Dagnachew, 1967; Tadesse et al., 1998a). When conditions are favorable for disease development, wilt/root rots causes up to 50% yield losses (Mengistu and Negussie, 1994).

Ecology and epidemiology

Most wilt/root rots pathogens occur simultaneously on a plant and infect roots and stems (vascular bundles). However, there are variations in the progress of epidemics. Collar rot (*S. rolfsii*) and black root (*F. solani*) and wet root rot (*R. solani*) occur much earlier in the crop growth stages causing death of seedlings. The initial conditions such as undecomposed organic matter (cereal straw like wheat) in the soil are favorable for quick multiplication of *S. rolfsii*, and the pathogen is can sooner infect and kill chickpea seedlings to a large extent. Dry root rot (*R. bataticola*) prevails at later stages of growth, whereas *Fusarium* wilt relatively occurs throughout the life of the crop (Negussie, unpublished data; Mengistu and Negussie, 1994).

The development of wilt/root rot causing pathogens is strongly associated with soil temperature and moisture, as well as inoculum level of the specific pathogen in the soil and crop age. Optimum temperatures for development of the pathogens were determined [25 °C for *F. oxysporum*, *R. solani* and *F. solani*, and 30 °C for *R. bataticola and S. rolfsii* (Negussie 1989a). *Rhizoctonia bataticola* is favored by low soil moisture, whereas *S. rolfsii* and *R. solani* are prevalent in wet soils (Mengistu and Negussie, 1994). An inoculum level of 33 FOC propagules g^{-1} of soil is the damaging level for growth and development of the wilt susceptible chickpea cultivar JG-62 (Negussie, 1989b).

Disease control

Cultural practices

Cultivation methods involving the destruction of inoculum pool in undecomposed fresh organic matter such as wheat stubble (an excellent medium for *S. rolfsii*) at the time of seedbed preparation offers effective results in the control of collar rot (Ahmed and Ayalew, 2006).

Host plant resistance and race pattern

Varietal differences exist in chickpea genotypes with respect to resistance to wilt/root rots pathogens (Ahmed et al., 1990; Bejiga and Anbessa, 1994; Bejiga et al., 1998; Negussie, 1995). Most of the chickpea cultivars distributed nationwide possess resistance mainly to *Fusarium* wilt (Bejiga et al., 1996;

Daba et al., 2005; NAIA, 2003). These include cultivars Arerti (FLIP-89-84C), Chefe (ICCV 92318), Akaki (DZ-10-9-2) and Worku (DZ-10-16-2).

The existence of races of FOC (races 1, 2, 3 and two unkonowns "Shire and Azezo") was first reported by Tadesse et al. (1998b). Chickpea improvement program needs to look ahead in releasing varieties that should carry resistance to known races of FOC depending upon the objective of the release (wide or narrow). Later using known differentials, four races, namely 0, 2, 3 and 4 were identified from farmers' fields and wilt/root rots sickplot in the central highlands (Meki, 2004). Race 4 was found in a restricted area. On the contrary, race 3 was found in Shewa and Gojam both on farmers' fields and the sickplots at Adet and Debre Zeit. This suggests that the race might be predominant in Ethiopia. Race 0 is non-pathogenic to *desi* cultivar JG-62 that is susceptible to all other (six) races of the pathogen reported worldwide (Haware and Nene, 1982; Jimenez-Diaz and Trapero-Casas, 1990). This is suggestive of considering the use of Kabuli cultivars such as P-2245 as a susceptible check together with JG-62 (early wilter) and K-850 (late wilter) in resistance screening work.

Biological control

Biological control offers an alternative method of plant disease control. Hence, a glasshouse experiment was conducted to test the efficacy of native *Trichoderma* spp. for the control of chickpea wilt. The results indicated that the test species has the potential to control *Fusarium* wilt in chickpea (ARARI 2000). Some species of *Penicillium* and *Aspergillus* were also found to be antagonistic to *F. oxysporum* f.sp. *ciceri* (AARC, 1992). In addition, a preliminary study was made to determine the effect of neem seed extract in reducing the incidence of wilt/root rots of chickpea (Meki, 2004).

Antagonists or botanicals' anti-fungal powers hold out promise for the development of control potions, especially against wilt/root rots of chickpea that have also seed-borne nature such as *F. oxysporum* f.sp. *ciceris*. Despite the fact that some promising results have been generated, it is crucial to recognize that the work is at its immature state and scaling-up the technology is not an easy task. Therefore, further research and scientific evaluations of the bio-agents from various perspectives are necessary.

Chemical control

Given the current demand for chickpea continues to increase, chemical treatments are likely to go well with chickpea production technology in the future. A combination of fungicides Vitavax and Thiram offers a good protection against *Fusarium* wilt, dry root rot, wet root rot and collar rot (DZARC, 1994; DZARC, 2005; Mengistu and Negussie, 1994).

Integrated wilt/root rots management

Substantial reductions in plant mortality due to wilt/root rots were recorded when a combination of moderately resistant varieties, drainage methods, i.e., raised beds (ridge, broad bed and furrow), and recommended seed rate was used, compared to flat planting. Other factors (fungicide and fertilizer) tested were not effective (AARC, 1996; AARC, 2000; DZARC, 1994). This is a step forward in the development of integrated wilt root rots management (IWRRM) approach. However, a combination of the techniques proved to be effective needs to be pilot tested on larger plots if farmers have to adopt the approach to manage wilt root rots of chickpeas.

Ascochyta blight

Economic significance

Blight caused by *Ascochyta rabiei* was reported to occur in the major chickpea growing areas of Ethiopia (AARC, 1992; Ahmed and Ayalew, 2006; Mengistu and Negussie, 1994). In Ethiopia, the results obtained in trials with early sowing dates have shown that chickpea can give seed yield as high as 4 t ha^{-1} since the plant can make a better use of soil moisture, compared to the traditional sowing date on residual moisture that reduce plant population and expose the crop to terminal drought (Bejiga and Anbessa, 1994). However, early chickpea sowing using drainage system on Vertisol has an increased risk of outbreaks of *Ascochyta* blight leading to heavy losses of yield. Therefore, *Ascochyta* blight is one of the major limiting factors for chickpea production in the main cropping season, i.e., June – August.

Ecology and epidemiology

The habitat for *A. rabei* includes all the above ground parts of the host. It survives in infected plant debris and infected and/or contaminated seeds. The disease attacks seedling and adult plants. The disease symptoms appear a week after inoculation on ICCX-9101 and ILC-3633. The rate of blight development is rather high resulting in a maximum disease severity, killing the host, in about four weeks signifying a short duration epidemic nature (Negussie, Pers. Obs.).

Disease control

Cultural practice

The use of healthy or treated seeds can contribute in preventing the blight from establishing itself in an area. This defensive approach needs to be applied in chickpea production system including seed exchange. The measures in this regard contain seed health testing, use of seed dressing fungicides and standard seed multiplication scheme. Removal and destruction of infected plant debris and a 3-year crop rotation reduce the blight (Negussie, personal observation).

Host plant resistance

Less priority has been given to *Ascochyta* blight in the past. However, the current desire of reaping the advantage of early sowing and maximizing the production particularly with *kabuli* chickpeas for export market as well as introduction of chickpeas to non-traditional areas have changed the mindset. This is because the disease poses a huge threat to the production of early-planted chickpeas. Hence, a consolidated blight control research undertaking has been recently launched at the Debre Zeit Agricultural Research Center (DZARC) in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) for the development of blight resistant varieties with desirable plant type/agronomic traits.

Most *desi* genotypes tested in *Ascochyta* blight screening nurseries and yield trials by the national program were susceptible to the blight. On the contrary, the success rate of finding resistance source in *kabuli* types was rather high (Ahmed and Ayalew, 2006). Therefore, more emphasis should be given to kabuli types in the short term until resistant and high yielding desi types are available in *Ascochyta* blight prone areas. In the long-term, however, chickpea materials developed through introgression between desi and kabuli chickpea should be tested to develop blight resistant desi type varieties. The genetic variability of the blight causing pathogen and existence of mating types need to be known to guide the breeding program and make effective and agronomic practices and seed treatment based blight management.

Numerous genotypes resistant to *Ascochyta* blight were identified in Ethiopia (Ahmed and Ayalew, 2006; Mengistu and Negussie, 1994). As a result, three *kabuli* chickpea cultivars (Arerti, Chefe and Habru) that are resistant to *Ascochyta* blight were released for large-scale production. These three cultivars are also resistant to wilt/root rots.

Chemical control

Seed dressing with a mixture of thiabendazole (Tecto) and benomyl (Benlate) was reported as effective means of controlling seed-borne inoculum (Mengistu and Negussie, 1994). Foliar applications of chlorothalonil-based fungicides (Bravo-500® and Daconil 75% WP®) starting at the appearance of the disease symptom repeated two to three times at 15 days interval substantially reduce the disease (DZARC, 2005b; DZARC, 1997).

Viral diseases

Stunt (Beet Western Yellows Virus)

Incidence and economic significance

Chickpea stunt ([shortening of internodes, browning and yellowing of the foliage and narrowing of leaflets and stiffness of branches; yellowing and wilting in kabuli types] DZARC, 1994) was first reported in Ethiopia in 1976 from Shewa (Arsi Neghelle, Debre Zeit) and Gonder (DZARC, 1976). Since then the disease has been observed in Gojam (Araya, 1990), Tigray and Wello (Ahmed and Ayalew, 2006). Of the several viruses identified, beat western yellows (BWYV) is the most prevalent with the highest incidence in Ethiopia (Berhanu et al., 2005; Tadesse et al., 1999a; Tadesse et al., 1999b). Beet western yellows virus is the most frequently used name for the causal agent of chickpea stunt in Ethiopia although some researchers disagree (Abraham, 2006). The argument is mainly based on the non-specificity of the monoclonal antibody PVAS-647. The other viruses reported include alfalfa mosaic (AMV), broad bean mosaic (BBMV), pea seed borne mosaic (PSbMV), faba bean necrotic yellows (FBNYV) and broad bean wilt (BBWV) (Berhanu et al., 2005; Tadesse et al., 1999a; Tadesse et al., 1999b) (Table 1).

Ecology and epidemiology

Knowledge of various aspects of the field biology and epidemiology in chickpea plantings *vis-à-vis* the presence of virus-infected hosts and systematic yield loss assessment in chickpea is non-existent.

Disease control

Host plant resistance

Attempts have been made in the past to identify sources of resistance at the Debre Zeit Agricultural Research Center in field trials using standard screening technique. Results indicated that eight ICC-lines showed a high level of resistance (Mengistu and Negussie, 1994). No information is available, however, on the fate of the lines.

Other diseases

The occurrences of root knot nematodes (*Meloidogyne* spp.), powdery mildew (*Leveillula taurica* cv. Arn) and rust (*Uromyces cicer-arietini* [Gorgn.] Jacz and Boyer) have also been reported in the country (AARC, 1992; Mengistu and Negussie, 1994). Rust severity (as high as 60%) and incidence of root knot nematode (20%) have been recorded (Ahmed and Ayalew, 2006; Mengistu and Negussie, 1994). The rust disease gets severe on chickpeas, especially *kabuli* types, at flowering time, and when grown during the off-season (Feb. to April). The root knot nematode incidence was high on chickpea grown on sandy loam soil. Nematodes could be problematic if chickpeas are pushed in irrigated lowlands. Previous observation showed that chickpea grown on sandy soil in the lowlands were severely infected by root knot nematodes (Mengistu and Negussie, 1994).

In the 1999/2000 cropping season, phyllody (probably caused by *Mycoplasma*-like organisms) was observed on some chickpeas planted in the irrigated cotton belt in the Awash Valley with less than 5% incidence. The infected plants did not flower and no pod was formed. Though there are evidences that some Kabuli genotypes can be produced during the off-season in the Valley, the situation of the phyllody and its vectors needs a close follow up (Ahmed and Ayalew, 2006).

Lentil

A number of diseases caused by fungi, nematodes and viruses were reported on lentils (*Lens culinaris* Medik.) in the country. Of these, rust and wilt are the major diseases of the crop and the remaining are of either intermediate or minor importance (Table 2).

Rust

Economic significance

Rust (*Uromyces fabae*) disease is, economically, the most important disease on a country-wide scale causing complete yield loss (Abashamo et al., 2000; Bejiga and Yadeta, 1999; Negussie, 2004). Every 1% increase in rust severity reduces seed yield by 8.39%. Rust severity $\geq$ 4.7% at the critical stage, early flowering, substantially reduces seed yield (Negussie, 2004).

Table 2. List of pathogens causing diseases of lentil in Ethiopia

Pathogen	Disease	Status	References*
Alernaria alternata	*Alternaria* blight	Minor	103
Fusarium oxysporum f.sp. *lentis*	*Fusarium* wilt	Major	16, 103, 126
Rhizoctonia bataticola	Dry root rot	Minor	do
Rhizoctonia solani	Wet root rot	Minor	do
Sclerotium rolfsii	Collar rot	Intermediate	do
Ascochyta fabae f. sp. *lentis*	*Ascochyta* blight	Intermediate	18
Colletotrichum destructivum	Leaf spot	Minor	103
Meloidogyne spp.	Root knot	Minor	118, 126
Tylenchus spp.	Root disease	Minor	103, 118
Tylenchorynchus spp.	Root disease	Minor	103, 118
Oidium spp.	Powdery mildew	Minor	103
Sclerotinia spp.	Stem blight	Minor	103
Uromyces vicie-fabae (synonymous: *U. fabae*)	Rust	Major	113, 126
Beet western yellows Virus (BWYV)	Stunt	Intermediate	45, 127, 128
Bean yellow mosaic virus (*BYMV*)	bean yellow mosaic	Minor	do
Broad bean mottle virus (*BBMV*)	broad bean mottle	Minor	do
broad bean stain virus (BBSV)	broad bean stain	Minor	do
Soybean dwarf virus(SbDV)	soybean dwarf	Minor	do
Pea seed borne mosaic virus (*PSbMV)*	Pea seed borne mosaic	Intermediate	8, 45, 127, 128
Faba bean necrotic yellows virus (FBNYV)	Faba bean necrotic yellows	Minor	45, 127, 128

Ecology and epidemiology

The disease attacks leaves, stems and pods of lentil plants. The pathogen survives in infected plant debris and a contaminant with the seeds. In Ethiopia, the disease occurs every year, although its outbreak is strongly dependent on environmental conditions. Lentil farmers vividly still remember the rust epidemic in November – December 1997 that has completely wiped out an area of 2500 ha planted to farmers' varieties of lentil in Gimbichu *Wereda* alone (Bejiga et al., 1998; Negussie et al., 1998).

The fungus grows optimally at 20 °C; and at this temperature infection can occur after leaf wetness of only three hours (Negussie et al., 2005a). Hence, during the growing season, growth of the epidemic is governed by atmospheric relative humidity and temperature. Lentil rust is of a short duration epidemic type with high apparent infection rate, > 0.05 per day on susceptible cultivars, reaching an epidemic proportion in about a month (Negussie, 2004).

Disease control

Cultural practices

Removal and destruction of rust-infected plant debris in the field as well as mixed with the seed might help reduce the rust (Negussie, Personal observation).

Host plant resistance

In Ethiopia, the most important means of lentil rust control involves the use of resistant varieties. Most of the officially recommended lentil cultivars are resistant to rust (Bejiga et al., 1996a). There is an enormous genetic variability, in lentil genetic stock at DZARC, for rust resistance (Bejiga and Yadeta, 1999; Bejiga et al., 1995; DZARC, 1994). A large number of genotypes were evaluated in the field under natural infection from 1995–2005 at rust “hot-spot” areas: Akaki, Sinana and Chefe Donsa. From the evaluations, many resistant lines with useful agronomic traits were selected and advanced to yield trials. At present, some of these lines are released either at local or national level. A case in point is FLIP-88-46L, which is released for Bale highlands under the name *Assano* in 2003 (MoARD, 2005). Recently, two more rust resistant varieties *Alem Tena* (FLIP 96-49L) and *Teshale* (FLIP 96-46L) were released for low- to mid-altitude and mid- to high-altitude areas, respectively (MoARD 2005).

There is no information on the genetics of rust resistance in the cultivars released so far. An experiment conducted to determine inheritance of the trait using 18 crosses involving direct, reciprocal and backcrosses between susceptible (*Chekol* and EL-142) and resistant (*Alemaya* and *Adaa*) varieties, as well as Precoz x PGRC/E-7 indicated that the resistance is governed by a single dominant gene (Abebe, 2005). This means that incorporation of resistance into an agronomically desirable background may be rather simple. However, Negussie et al. (2005b) reported the existence of partial resistance to rust in lentil cultivars such as FLIP-87-66L, a phenomenon that implies a quantitative inheritance. Moreover, a report by Chahota et al. (2002) indicated that two duplicate, non-allelic and non-linked dominant genes control the resistance. Therefore, further studies are needed to determine the number of genes conferring rust resistance in all the released lentil varieties. Inheritance studies coupled with clear picture on the physiologic race of the pathogen will have useful implications in resistance breeding and adds to our knowledge of host-parasite relationship.

There is little information on physiologic races of the rust fungus in the country and the degree of their virulence to the released lentil varieties. In the future, determination and monitoring of rust races need to be aspects worth considering. To date, about 17 races of the pathogen have been reported worldwide (Conner and Bernier, 1982; Singh, 1995).

The mechanism of rust resistance in lentil is poorly understood. Recently, the mechanism has been shown to be pre-haustorial and pre-penetration (Negussie, 2004). In determining the resistance mechanism, histo-pathology was employed, and this could be of some help in speeding up the detection of phenotypic differences in the response of lentil genotypes to rust. Moreover, Negussie and Pretorius (2005) developed a technique suitable for studying rust resistance in lentil.

Chemical control

In the event of dangerous attacks by new virulent races of the pathogen, chemical treatments might be essential. The systemic products such as tebuconazole and propiconazole offer adequate rust control (Negussie, 2004).

Ascochyta blight

Economic significance

In Ethiopia, blight caused by *Ascochyta fabae* f. sp. *lentis* is lentil's third most important disease after rust and wilt/root rots. The blight is a potential threat to the improvement of the crop. The fungus was first described (characterized) in the country by Ahmed and Beniwal (1987).

Ecology and epidemiology

The causal fungus attacks leaves, stems, pods and seeds of lentil only and not other legumes. Debre Zeit and its vicinity has become an important niche for the blight, for which the seed-borne (20%) nature of the pathogen might be the contributory factor (Ahmed and Beniwal, 1988). Moreover, severe outbreaks of the disease were observed in lentil yield trials at the Debre Zeit Agricultural Research Center in the 1986/87 and 2001/02 farming seasons (Beniwal, Seid and Negussie, Personal observation). This suggests that the blight (*Ascochyta fabae* f. sp. *lentis*) was possibly introduced through germplasm exchange.

Ascochyta fabae f. sp. *lentis* is known to be seed-borne in nature and can be primary source of inoculum to initiate epidemics under favorable conditions in the field. The pathogen was routinely isolated from infected lentil seeds stored at room temperature (at 22 °C) in the store and in refrigerator at 5°C (Ahmed and Beniwal, 1998). This finding indicates that the pathogen could survive and initiate epidemic in the field.

Disease control

Cultural practices

Since the pathogen survives in the seed, it could easily initiate epidemic in the field and be introduced to new areas in the country through germplasm exchange from gene bank or research centers. Therefore, during germplasm exchange, there is a need to treat seeds with fungicides or seed should be produced during the dry season using irrigation. Removal and destruction of blight-infected plant debris prevent spread of the disease (Negussie, Personal observation)

Physical measures

Thermotherapeutic treatment of the seed with hot water or solar heat is the commonly practiced direct control measure. Experiments conducted on this line between 1986 and 1991 produced some of the most encouraging results. Hot water and dry heat treatments at 55 °C for 25 min and 70 °C for 24 h, respectively, partially inhibited fungal growth from seed (Ahmed and Beniwal, 1991). Sun drying of lentil seeds effectively controlled seed-borne *A. fabae* f. sp. *lentis*, the most effective treatment being the treatment with a polyethylene sheet cover that provided 96% control (Beniwal et al., 1989). However, one major drawback of the technique is a decrease in seed germination, which ranges from 18 to 59% depending upon the heat source and duration of exposure, indicating that the technique needs further improvement.

Chemical control

Field spray of chemicals offers adequate blight control. Chlorothalonil, benomyl and a mixture of tridemorph and maneb provide excellent disease control and the highest yields. Nevertheless, more research is still required to determine optimal timing of application and cost-effective rate of each fungicide. Dressing lentil seeds with thiabendazole effectively eradicated the seed-borne inoculum (DZARC, 1997; Ahmed, 1987).

Wilt and root rot diseases

Economic significance

Wilt (*Fusarium oxysporum* f.sp. *lentis*), collar rot (*Sclerotium rolfsii*), wet root rot (*Rhizoctonia solani*) and dry root rot (*Rhizoctonia bataticola*) are the soil-borne diseases affecting lentil production and productivity in Ethiopia, the major one being *Fusarium* wilt (Ahmed and Ayalew, 2006; Mengistu and Negussie, 1994; Stewart and Dagnachew, 1967).

Ecology and epidemiology

Fusarium wilt attacks the roots and water conductive tissue, xylem, whereas the remaining hit either the collar region of the plant (collar rot) or the roots (dry and soft rots). The fungi survive in infected plant debris and in the soil as chlamydospores or sclerotia. The information on various aspects of epidemiology is non-existent.

Disease control

Host plant resistance

Measure that has been found to be effective is host resistance. In an effort to identify resistance, an effective field screening technique, sick-plot for wilt, has been developed at Debre Zeit, and many lines have been identified as resistant (Bejiga et al., 1996b; DZARC, 2005a). Of course, it is important to identify sources of resistance, but what is more important is to use the sources to combine resistance with high yield or other desirable traits. Lentil breeding in this direction is in progress at Debre Zeit.

Some attempts were made to study the variability of lentil wilt pathogen using some lines and released cultivars of lentil. The results obtained from 11 isolates show some degree of pathogenic variability (ICARDA, 2006). Similarly, data from past experiment gave evidence of the existence of variability in *Fusarium* wilt of lentil (Tadesse et al., 1998a). In a recent study, nine pathogenic groups have been identified using five released lentil cultivars (Adaa, Alemaya, Chalew, Gudo and R-186) and ILL-590 as differentials (Table 3). Virulent group FOL 6 is the most aggressive of all. All the differential cultivars are resistant to FOL 25/64.

Table 3. Reaction of lentil varieties to nine isolates or pathogenic groups of *Fusarium oxysporum* f.sp. *lentis*

variety	FOL 1	FOL 2	FOL 3	FOL 4	FOL 6	FOL 9	FOL 25/64	FOL 65	FOL 85/100
Adaa	–*	+	+	+	+	+	–	–	+
ILL 590	–	+	+	–	+	–	–	–	–
Alemaya	–	–	–	+	–	+	–	–	–
R-186	–	–	+	+	+	+	–	–	+
Chalew	+	–	+	–	+	–	–	–	–
Gudo	+	+	–	+	+	–	–	+	+

** – = resistant (R or MR reaction) and + = susceptible (S reaction).*
Source: Habtu et al., 98

Other diseases

A number of diseases of minor importance have been reported to occur in association with lentils in Ethiopia. These included powdery mildew (*Oidium* spp.), leaf spot (*Colletotrichum destructivum*), *Alternaria* blight (*Alernaria alternata*), stem blight (*Sclerotinia* spp.), and diseases caused by nematodes (*Tylenchorynchus* spp., *Tylenchus* spp., *Meloidogyne* spp.) and viral diseases (Mengistu and Negussie, 1994).

Over the past decade, a lot has been published concerning the identity of viruses infecting lentil crops in Ethiopia. Seven viruses identified as pea seed borne mosaic (PSbMV), beet western yellows (BWYV), soybean dwarf (SbDV), faba bean necrotic (FBNYV), broad bean stain (BBSV), bean yellow mosaic (BYMV) and broad bean mottle (BBMV) were isolated from naturally infected lentils in different parts of the country (Abraham and Albrechtsen, 1998; Berhanu et al., 2005; Tadesse et al, 1999a; 1999b). PSbMV is the most prevalent of all. Studies on the health status of hundreds of farmer-saved lentil seed lots as well as some germplasm resources indicated that PSbMV is widely associated with lentil seeds sown in the country (Abraham and Makkouk, 2002).

Fenugreek, grass pea and lupine

Fenugreek

Powdery mildew (*Oidium* sp.) was prevalent on fenugreek (*Trigonella foenum-graecum* L.) in the central highlands with an incidence of about 95%. The severity ranges from 20 to 80%. The mildew was observed to attack both seedling and adult plants, but it was less severe on the seedling than on the adult stage. Leaf chlorosis and wilt symptoms have also been recorded

(DZARC, 2005a). Powdery mildew was also reported from northwestern Ethiopia as being the major disease of the crop (AARC, 1993). Two other fungal diseases of minor importance, namely, leaf spots (*Ascochyta* sp. and *Cercospora traversiana* [Sacc]) and rust (*Uromyces anthyllides* [GrevSchroet]) on fenugreek have been reported from north western part of the country (AARC, 1996). Of all these, powdery mildew and leaf spots are the major diseases of fenugreek that need immediate attention. Recently, a mildew resistant fenugreek variety *Chala* (FG-47-01) has been developed and released for mildew-risk areas (MoARD, 2005).

Natural infection of fenugreek with beet western yellows (BWYV) and soybean dwarf (SbDV) was reported first by Berhanu et al. (2005) in Bale, Ethiopia. In addition, faba bean necrotic yellows (FBNYV) has been reported. Apparently, these viruses were not severe on fenugreek from Bale. The overall mean incidence reported was 3.7% for the luteoviruses (BWYV and SbDV) and 0.7% for FNYV (Berhanu et al., 2005) (Table 4).

Table 4. List of pathogens causing diseases of fenugreek, grasspea and lupine in Ethiopia

Crop	Pathogen	Disease	Status
Fenugreek (*Trigonella foenum-graecum* L.)	*Oidium sp.*	Powdery mildew	Major
	Ascochyta sp.	Leaf spot	Minor
	Cercospora traversiana (Sacc)]	Leaf spot	Minor
	Uromyces anthyllides (Grev) Schroet]	Rust	Minor
	Beet western yellows virus (BWYV)	Beet western yellows	Minor
	Soybean dwarf virus (SbDV)	Soybean dwarf	Minor
	Faba bean necrotic yellows virus (FBNYV)	Faba bean necrotic yellows	Minor
Grasspea (*Lathyrus sativus*)	*Odium sp.*	Powdery mildew	Major
	Ascochyta lathyri	Leaf spot	Minor
	Fusarium oxysporum f. sp. vasinfectum	Wilt	Minor
	Uromyces fabae (Pers) de Bary	Rust	Minor
	Beat western yellows virus (BWYV)	Beat western yellows	Minor
	pea seed-borne mosaic virus (*PSbMV*)	pea seed-borne mosaic	Minor
	Bean yellow mosaic virus (*BYMV*)	bean yellow mosaic	Minor
	Faba bean necrotic yellows virus (*FBNYV*)	Faba bean necrotic yellows	Minor
Lupine (*Lupinus albus* L.)	*Fusarium* sp.	Root and stem rot	Minor
	Pleiochaeta setosa (Kirchn) Hughes	Leaf spot	Minor
	Uromyces occidentalis (Dietel)]	Rust	Minor

Source: Abraham and Lencho, 2000; AdARC, 1992; 1993; 1996; 2001; Birhanu et al., 2005; DZARC, 1994; Mengistu et al., 1994

Grass pea

Powdery mildew (*Pseudomonas* sp.), leaf spot (*Ascochyta lathyri*), wilt (*Fusarium oxysporum f. sp. vasinfectum*), rust (*Uromyces fabae* [Pers] de Bary) are some of the fungal diseases reported on grass pea (*Lathyrus sativus*) from Ethiopia (AARC, 1992; Ahmed and Ayalew, 2006; DZARC, 2005a). Currently, only powdery mildew appears to have the potential to ravage the crop.

Disease control

Host resistance

Grasspea genotypes were evaluated for their resistance to powdery mildew at Debre Zeit. Almost all genotypes tested were susceptible to powdery mildew. However, the local collections with high neurotoxin (β-ODAP) contents, although showed high severity, had minimal yield reduction compared to the introduced genotypes. The disease evaluation work helped in the identification of the best level of mildew-resistance that could be achieved. Therefore, a low β-ODAP (0.08%) variety *Wasie* (ILAT-LS-LS-B2) with average reaction to powdery mildew has recently been released (MoARD, 2005).

Viral diseases

Berhanu et al. (2005) first reported the natural occurrence of beat western yellows (BWYV) and pea seed-borne mosaic (PSbMV) in Gojam and Gonder, as well as bean yellow mosaic (BYMV) in Gonder. However, the overall incidence of viral infection was less than 10%. Faba bean necrotic yellows (FBNYV) producing severe stunting and yellowing in grass pea was first reported by Abraham and Lencho (2000) from Ambo area, Ethiopia. Since then the virus has been observed in Gojam, Gonder, Wello and Arsi (Abraham and Lencho, 2000; Berhanu et al., 2005). Early infected plants die prematurely. In later infections, stunting is less conspicuous but leaf symptoms are visible. The virus particles are isometric, 20 nm in diameter (Abraham and Lencho, 2000). The host range of this virus appears to include leguminous plants such as faba bean, field pea, lentil, fenugreek and cowpea. The virus is vectored by *Acyrthosiphon pisum* Harris and *Aphis craccivora* Koch, and it is not sap-transmissible. Presumably, the disease is serious in the most important grass pea producing areas of the country (e.g., Wello [incidence ca. 25% around Haik]).

Lupine

Diseases reported on lupine (*Lupinus albus* L.) include root and stem rot (*Fusarium* sp.), leaf spot (*Pleiochaeta setosa* [Kirchn] Hughes) and rust (*Uromyces occidentalis* [Dietel]). When ranked, the first one has intermediate status, whereas the remaining hold minor position (AARC, 1992).

At Debre Zeit, the sweet varieties (alkaloid-free lupines) are severely infected by powdery mildew and collar rot but the bitter varieties (lupines that contain a toxic alkaloid) are resistant. Therefore, some control measures need to be developed for sweet lupine diseases (Ahmed and Ayalew, 2006) (Table 4).

Common bean

A host of diseases has been recorded on beans (*Phaseolus vulgaris* L.). Of these, anthracnose, rust, common bacterial blight, web blight and angular leaf spot are the major ones. The remaining are either of intermediate or minor importance (Table 5).

Table 5. List of pathogens causing diseases of common bean in Ethiopia

Pathogen	Disease	Occurrence/ distribution	Status	Reference
Colletotrichum lindemuthianum	Anthracnose	Wide	Major	29, 30, 31, 32, 126
Uromyces appendiculatus	Rust	Wide	Major	do
Xanthomonas campestris Pv. Phaseoli	Common bacterial blight	Wide	Major	do
Rhizoctonia solani (=Thanatephorus cucumeris)	Web blight	Limited	Major	do
Phaeoisariopsis griseola	Angular leaf spot	Limited	Major	do
Phoma exigua var. diversispora	Leaf blight	Limited	Intermediate	do
Pseudomonas syringae pv. phaseolicola	Halo blight	Limited	Intermediate	do
Mycovellosiella phaseoli	Floury leaf spot	Limited	Intermediate	do
Bean common mosaic poty virus	Bean common mosaic virus	Limited	Intermediate	do
Rhizoctonia solani, Fusarium oxysporum, Sclerotium rolffsii	Root rots and wilts	Unknown	Minor	do

Common bacterial blight

Economic significance

Common bacterial blight (CBB) (*Xanthomonas campestris* pv. *phaseoli* [Erw. Smith] Dowson) is among the main constraints to common bean production in Ethiopia (Abiy et al., 2006; Fininsa, 1996; 2001; Habtu and Abiy, 1995; Habtu et al., 1996). In eastern Hararghie, in the 1999 and 2000 cropping seasons, an actual yield loss of 21% was due to this disease. The type of cropping system and crop growth stage influence CBB severity and the amount of yield loss. In broadcast and mixed intercropping, for example, for each increase in CBB severity, about 5.2 and 9.1 kg ha^{-1} seed yield loss, respectively, occurred at physiological maturity. However, the same disease level in sole cropping at earlier growth stages, for instance 73 days after planting, results in an overwhelming seed yield loss (ca. 39 kg ha^{-1}). In general, intercropping (common bean-maize) systems tend to lower yield, and 100-seed weight losses due to CBB than common bean sole cropping system (Fininsa, 1996).

Ecology and epidemiology

CBB attacks leaves, stems, pods and seeds. It survives in the soil, infected plant debris and seeds (Fininsa, 1996; Fininsa, 12001). A number of factors influence temporal spread of the disease including cropping systems. Fininsa and Yuen (2002) reported that CBB develops more rapidly in sole stand of common bean crops than those intercropped with maize. According to the authors, intercropping delays CBB epidemic onset; reduces disease progress rate and area under the disease progress curve, as well as final disease incidence and severity.

Primary inoculum source plays a vital role in determining the level of CBB development and its effect on yield as well as seed quality. Results of studies made in eastern Ethiopia revealed that primary inoculum from infested debris is relatively more damaging than other inoculum sources, causing early epidemic development and yield reduction (Fininsa and Tefera, 2001; 2002). Seed-borne nature of CBB in common bean has been established, and even some seeds without the disease symptoms were found to have infection from 10 to 12% (Tefera, 2001). This suggests that visual assessment or direct inspection alone is not good enough to conclude on the magnitude of seed infection occurring in a particular seed lot. Therefore, the appraisal should include other appropriate seed health testing methods if realistic quantifications of seed infections have to be made.

Disease control

In line with the above epidemiological findings, CBB management options should include components that reduce initial inoculum such as field sanitation, crop rotation whenever feasible, planting healthy seed, early incorporation of bean debris into soil, burning of crop residues and effective seed treatment, in addition to developing resistant cultivars.

Host resistance

The various research centers in the country have managed to develop and release numerous haricot bean varieties that possess good level of CBB-resistance (MoARD, 2005; 2004; NAIA, 2003).

Cultural practices

Reports on the efficacy of varietal mixture in the control of CBB in common beans are available from eastern and western Hararghie areas, Ethiopia (Fikire, 1998; Fikire, 2004). For instance, varietal mixtures with the resistant variety, Gofta (G-2816), consistently reduce CBB incidence, severity, area under disease progress curve (AUDPC), and disease progress rate on the susceptible cultivar (Red Wolaita). Generally, disease development decreased as the proportion of the resistant cultivar in the mixture increased (Fikire, 2004). The mixture had a maximum of 27% efficacy for CBB control. Therefore, cultivar mixtures can be used as a component of integrated disease management scheme for food type's common bean. Bean-maize intercropping could also be component of CBB integrated disease management (Fininsa, 1996).

Anthracnose

Economic significance

Bean anthracnose caused by *Colletothricum lindemuteianum* is a wide spread destructive disease of haricot bean in Ethiopia. In seed multiplication program on farmers' field, the released variety Roba-1 failed to give seed due to anthracnose in 2002 cropping season (BARC, 1997). The disease can inflict a huge yield loss in susceptible varieties. For example, Tesfaye (1997) has recorded a yield loss of about 67% in the susceptible bean variety Mexican-142 with anthrcnose severity of 77%. Cost-benefit analysis demonstrated that net gains obtained from anthracnose control Birr 2376 ha^{-1} on-station and Birr 1915 ha^{-1} under on-farm conditions.

Ecology and epidemiology

The initiation of anthracnose epidemics from primary inoculum sources (infected seed, infested debris and soil) and their effect on seed yield and quality were studied by Fininsa and Tefera (2001; 2002). The primary inoculum sources had differential effect on levels of disease development assessed at flowering and podding, yield and seed quality compared to treated seeds. The primary inoculum from infested debris was relatively more damaging than other inoculum sources, causing early epidemic development and yield reduction.

Disease control

Cultural

Growing common bean in cultivar mixture is one strategy of controlling anthracnose. Growing cultivar mixtures containing at least 50% of a resistant cultivar can control the disease (Tesfaye, 2003). The level of control achieved depends upon the proportion of the resistant cultivar in the mixture, i.e., the higher the percentage of the resistant cultivar in the mix the lower the disease.

Host resistance

Glasshouse and field experiments were carried out to identify bean genotypes that are resistant to the Ethiopian isolates of *C. lindemuthianum*. As a result, genotypes *Widusa*, *GLP X 1132*, *A 482*, *A 193*, *G-7*, *HAL 5* and *G 2333* were identified as valuable sources of anthracnose resistance (Tesfaye, 2003). In addition, genotypes *RAZ-18* and *REN-20* posses field resistance to anthracnose and angular leaf spot (BARC, 1998).

Some knowledge was gained during the past few years on the degree of variability in the pathogen. Tesfaye (2003) gave an account of eight races of *C. lindemuthianum,* namely 65, 73 128, 296, 511, 589, 961, 63, 68, 81, 465 and 1027 from Ethiopia and compared them to races 3, 6, 81, 323, 390 and 593 from Southern Africa. Races 128 and 511 were the most frequent constituting more than 50% of all the isolates characterized. Considering reaction of the differential cultivars used for race identification, G 2333 was resistant to all races in Ethiopia, and to AB 136, G 2333, Kaboon, Cornell 49-242 to all races in South Africa (Tesfaye 2003; 1999b).

Chemical control

Chemotherapy has a role to play in the control of anthracnose, particularly in large-scale bean production. Data generated from efficacy trials on fungicides revealed that a combination of dressing common bean seeds with benomyl and a foliar spray of bean plants with difenoconazole or foliar application of difenoconazole alone adequately protects common beans against anthracnose (Tesfaye and Pretorius, 2005).

Integrated disease management

Anthracnose management options should include components that reduce initial inoculum such as field sanitation, crop rotation whenever feasible, planting healthy seed, early incorporation of bean debris into soil, burning of crop residues and effective seed treatment, in addition to developing resistant cultivars (Fiininsa and Tefera, 2001; 2002).

Rust

Economic significance

Rust (*Uromyces appendiculatus* Pers. Ung.) is one of the major common bean diseases occurring in most parts of Ethiopia (Fininsa, 1996; Habtu et al., 1998). The yield loss in common beans due to the disease could reach as high as 85% (Habtu et al., 1997; 1998). The loss is mainly related to the reduction in the number of pods per plant (Habtu and Zadoks, 1995a). According to Habtu et al. (1998), the seed yield loss for each unit increase in rust severity ranges from 2.6% to 7.8% for every unit increase in rust severity.

Ecology and epidemiology

The intensity of *U. appendiculatus* is influenced by cropping system, geographical area, altitude and season. Good indications are found in many common bean growing areas of Ethiopia (Fininsa and Yuen, 2001; Habtu et al., 1996). In the Hararghe highlands, for instance, rust incidence and severity, respectively, are reduced by about 25% and 16% in intercropping when compared to sole cropping (Fininsa and Yuen, 2001). Similarly, varietal proportion (susceptible: resistant) in a bean crop and geographic area play a role in determining the spread of the disease over space. Depending upon the location, the speed with which spores of *U. appendiculatus* travel in a bean crop with a mixture of 20% susceptible variety and 80% resistant variety is about 2.5 to 5 times slower than in a bean crop with a pure susceptible variety (Habtu, 1994).

Disease control

Host resistance

Genetic variability exists among common bean genotypes, for resistance, rust (Habtu, 1994; Habtu and Zadoks, 1995b). Many of the genotypes exhibit multiple resistances (resistance to two or more of the major diseases): rust, CBB, anthracnose, angular leaf spot and web blight. These include *HAL-5, Atndaba, Awash Melka, Pan-173, A-197, TY-3396-1, Zebra, A-409, Bat-73, Bat 24, Bonita nigra, Redlands pioneer, Xan-175, Emp-87, Emp-110, Hal-5, Pvad-1022, Pan 173, Pva-1145, Xan-41, Pan-64, Ica-15541, Icapijas, Xan-162, Zaa-84057, TY-3396-16, Bat-1629, G-3124, G-11044, G-19428 and G-19792.* Rust resistant bean varieties such as *Negro Mecentral* are available in Ethiopia. Most of the recently released varieties are resistant/moderately resistant to rust and two or more of haricot bean diseases. These comprise AFR-722 (*Ibado*), RWR-719 (*Omo-95*), Dicta-105 (*Nasir*), DOR-554 (*Dimtu*) and *Batagonia* (MoARD, 2005; NAIA, 2003).

Habtu and Zadoks (1994) reported the existence of partial resistance (PR) to rust in some of the genotypes listed above. This is a kind of durable resistance that ensures stable performance of genotypes across the various growing conditions and environments of common beans in Ethiopia. Habtu and Zadoks (1994) suggested criteria for selecting bean genotypes with PR to rust, as well. Therefore, PR may be a trait worth utilizing in bean breeding program.

Other diseases

Presently, a spectrum of fungal, bacterial and viral diseases of beans is known to occur in Ethiopia. Some of these are add-ons to those reported in the first review of crop protection research in Ethiopia (Tsedeke, 1986). Though not comparable with common bacterial blight, rust and anthracnose, it known that powdery mildew, white mold, angular leaf spot, web blight, halo blight, floury leaf spot, bean common mosaic virus, *Ascochyta* blight, brown spot, root rots, vascular wilts and grey mold diseases affect haricot beans in some agro-ecologies of the country (Abiy et al., 2006; AARC, 1992; Fekede and Kedir, 1998; Habtu et al., 1996).

Mohamed (2005) identified 13 seed-borne fungi of different genera from major *Phaseolus* bean seed samples collected from several agro-ecologies of Ethiopia. Among others, *Colletotrichum lindemuthianum, Phaeoisariopsis griseola* and *Ascochyta phaseolorum* were the most widespread fungal pathogens associated with *Phaseolus* bean seed in Ethiopia.

Bean common mosaic necrosis, potyvirus, serotype *A*, causing systemic necrosis called black root was also recently isolated from infected plants at experimental sites (Lencho et al., 1998). Perhaps, this virus was imported with infected seeds (Abraham and Habtu, 2000). Viruses were also detected in other lowland pulse crops: soybean mosaic potyvirus in soybean and peanut mottle potyvirus in cowpea (Abraham and Habtu, 2000). However, information on economic importance, epidemiology and control measures of any of the viruses reported on lowland pulse crops are lacking.

Soybean, pigeon pea, cowpea, lima bean and mung bean

Particulars of fungal, bacterial and nematode diseases of lowland pulse crops (soybean, pigeon pea, cowpea and lima bean) grown in Ethiopia. Information on various aspects (distribution, economic significance and control) of the diseases in the listing is lacking. Therefore, emphasis should be given to the key diseases of these crops in the future since they are integral components of the cropping systems in the dry agriculture of the country (Table 6).

Table 6. List of pathogens causing diseases of soybean, pigeon pea, cowpea and lima bean in Ethiopia

Crop	Pathogen	Disease	Status
Soybean (*Glycine max*)	*Pyrenochaeta glycines*	Leaf spot	Major
	Pseudomonas syringaei pv. *gycinea*	Bacterial blight	Medium
	Xanthomonas phaseoli pv. *sojense*	Bacterial pustule	Major
Pigeon pea (*Cajanus cajan*)	*Cercospora cajani*	Leaf spot	Major
Cowpea *(Vigna unguculata*)	*Ascochyta phaseolorum*	Ascochyta blight	Major
	Meloidogyne spp.	Root knot	Minor
	Synchytrium dolichi	False smut	Medium
	Phoma bakeriana	Leaf spot	Medium
Mung bean (*Phaseolus aureus*)	*Pseudomonas phaseolicola* *Ascochyta boltshauseri* *Fusarium* sp.	Halo blight Leaf spot Root rot	- - -
Lima bean (*Phaseolus lunatus*)	*Phoma exigua* var. *diversispora*	Blight	Major
	Uromyces appendiculatus	Rust	Medium
	Pseudomonas syringaei pv. *Phaseolicola*	Bacterial blight	Medium

Source: BARC, 2002; 1997; 1998; 1999; Singh et al., 1995

Faba bean

Numerous diseases are affecting faba bean (*Vicia faba* L.), but only a few of them have either major or intermediate economic significance. These include chocolate spot, rust, black root rot, foot rot and necrotic yellow (Table 9).

Chocolate spot (*Botrytis fabae)*

Economic significance

Chocolate spot, caused by *Botrytis fabae,* is one of the major diseases of faba bean nationwide (Berhanu et al., 2006; Dereje and Tesfaye, 1994a; MRC 2002). Derege and Beniwal (1988) recorded yield losses of up to 61% for susceptible genotypes and 34% for tolerant genotypes. Yet, complete crop failure due to the disease is commonly encountered when a long-lasting favorable environment for disease development prevails in an area (Dereje et al., 1994). In Negash areas, Tigray, in 2000 seed yield loss of 62% was due to this disease (MRC, 2002).

Ecology and epidemiology

The pathogen infects the leaf tissue, petioles, stems and seeds (Dereje, 1996a). It survives as sclerotia in infected plant debris for more than a year. According to Dereje (1999a), sclerotia of *B. fabae* stay alive for about two years under Holetta conditions on the surface of the ground and die in four months when buried 20 cm deep. The fungus *B. fabae* was recovered from infected debris strored in Nitosol after 12 months, but not from that stored in Vertisol (Dereje, 1999a). Apparently, soil type and depth at which infected plant residues are located have an effect on the biology of the fungus, and this might have practical implications on disease management.

Humid (≥ 70% relative humidity, especially in the mornings), warm (10-23 °C) and rainy (frequent rain) weather conditions are favorable for the growth of chocolate spot epidemic (Dereje, 1993a). With this environment, the epidemic grows with apparent infection rates ranging from 0.142 to 0.164 disease units per day, which means several chocolate spot generations within a single growing season (Dereje, 1993a). This is an indication to rapid and dangerous spread of the disease. Obviously, if the pathogen falls short of the above-mentioned weather variables, it will be forced to have short infection period, and this is significant in spread of an epidemic.

Disease Control

Cultural practice

Considerable hold-up and shortening of chocolate spot epidemic and thereby reduction of attack can be achieved by late sowing of faba bean as the conditions suitable for development of the disease do not exist for a sufficiently long period of time (Dereje, 1993a). However, seed yield harvest from late sown crop is considerably less than that of early sown crop.

Deep plowing of faba bean fields with high chocolate spot infection immediately after harvest reduces the risk of disease development. In addition, early sowing, use of improved cultivars and fungicide protection (chlorothalonil at a rate of 2.5 kg a.i. per hectare once or twice after disease infection reached 30%) avoid the occurrence of chocolate spot disease at epidemic proportions (Dereje, 1993a).

Planting faba bean in mixture with field pea in a ratio of 1:2 drastically reduces epidemic development of chocolate spot in faba bean (Amare, 1996; Dereje, 1999b). Studies carried out at several locations in the Northwest part of the country by Adet Agricultural Research Center confirmed the advantages of mixing faba bean and field pea in different proportions in reducing chocolate spot severity (AARC, 2001). Other advantages that would be obtained by applying this practice include weed suppression, physical support of field pea by faba bean, increased land productivity and higher seed yield (Dereje, 1999b). However, mixed cropping culture might not be feasible in large-scale production of faba bean. The value of growing faba bean in mixture with field pea regarding reduction of chocolate spot infection in faba bean is contentious (Gemechu et al., 2006). Perhaps what is in order may be verification of these results in large plots.

Chemical control

Many fungicides, both systemic and protectant were tested for control of chocolate spot in the past (Habtu and Dereje, 1986; IAR, 1985). Among these, chlorothalonil, benomyl and benomyl + manacozeb were effective against chocolate spot. Cholorothalonil completely protected faba bean plants from infection when applied at weekly intervals, but extended intervals more than 15 days were less effective. Faba bean producers can realize the benefit of early planting, increased seed yield, by planting improved cultivars at the beginning of the growing season and spraying the crop with chlorothalonil at a rate of 2.5 kg a.i. per hectare once or twice after disease infection has reached 30% severity level (Dereje, 1993a). In an experiment where three to four sprays were applied, mancozeb at a rate of 0.7 kg per hectare proved even more effective than chlorothalonil (AARC, 1996). According to the concept of integrated disease management, chemical treatment should only be applied as supplement to combat chocolate spot risk.

Host resistance and pathogenic variability

Great differences exist between local and exotic genotypes with respect to resistance or tolerance (Dereje et al., 1987; Dereje et al., 1988; Dereje and Beniwal, 1986; Dereje and Tesfaye, 1994a; Dereje et al., 1993; Yitbarek, 1990), which could be exploited to breed chocolate spot resistant faba bean varieties. However, breeding and selection programs should utilize as many virulent isolates of the pathogen as possible from different regions.

Dereje (1996a) reported that cultural and pathogenic variability exists among isolates of *B. fabae* collected from agro-ecologically different areas. According to the report, the most virulent isolate was collected from Enewari. He also observed special interaction of isolates from Enewari, Kulumsa and Holetta with host genotypes Kuse and S83103-1-1 (Table 7). Dereje (1996a) also reported artificial media preference by individual isolates of the pathogen. Among the media used, Faba Bean Dextrose Agar was the most suitable medium for laboratory propagation of this fungus, which is widely used in many laboratories at present. On this medium, however, *B. fabae* produced only sclerotia and very few conidia.

Table 7. Reaction of ten faba bean genotypes to nine isolates of *Botrytis fabae*

Genotype	Isolate				
	Group 1	Group 2	Group 3	Group 4	Group 5
KUSE	S	S	S	R	R
S83103-1-1	S	R	R	S	R
CS 20 DK	R	S	R	R	R
NC 58	S	R	R	R	R
BPL 112-1-1	S	R	R	R	R
BPL 261-2-1	R	S	R	R	R
BPL 1179-3-1	R	R	R	R	R
Coll 30-77-1	R	R	R	R	R
BPL 1821-1	R	R	R	R	R
BPL 710-7-1	R	R	R	R	R

Note: R = Resistant, S = Susceptible. Group 1 = Enwari; Group 2 = Kulumsa 1; Group 3 = Bekoji 2; Group 4 = Sinana 1 and Debretabor; Group 5 = Bekoji 1, Kulumsa 5, Gindeberet and Holetta.

Source: *Dereje, 1993b*

Rust

Incidence and economic significance

Rust, (*Uromyces viciae-fabae*), is widely distributed in Ethiopia (AARC, 1996; Berhanu, 2006; Dereje and Tesfaye, 1994a; MRC, 1994). In the central, western and eastern zones of Tigray, for example, in a survey conducted in 1994, incidences of 5–50% were recorded (MRC, 1994). Depending on the severity of rust infection, the seed yield loss ranges from 2 to 15% for lower altitudes and 14-21% for intermediate altitudes (Dereje and Tesfaye, 1994a). The rust has no significant effect in the highland areas of the country.

Ecology and epidemiology

It is endemic in lower and intermediate altitudes (<2300 m.a.s.l) and off-season crops. The rust usually comes late in the season. Wind is of importance in disseminating the pathogen; faba bean rust spreads at a wave velocity of ca. 0.1 m per day implying that dissemination of faba bean rust epidemic occurs mainly over relatively short distances (Negussie, 1991). A single infection (point infection) or a focus within an area is not sufficient for build up of a general epidemic.

Leaf age or crop growth stage and inoculum level are also of significance in the growth of the faba bean rust epidemic. Younger faba bean leaves are more susceptible to rust than older leaves, and spore production increases as inoculum level decreases (Teame, 2000). These epidemiological aspects are worth considering in disease control programs, especially the breeding of resistant varieties.

Disease Control

Chemical control

When faba bean was grown during off-season (from February to April) or in lower and intermediate altitude areas (≤2300 m), it might be necessary to control rust disease in faba bean. Growing resistant varieties and fungicide application might be useful methods to control the disease and prevent a rust epidemic. In areas where rust regularly prevails, several sprays are necessary for adequate disease control. Spraying mancozeb (Dithane M-45) at a rate of 2.5 kg a.i. ha^{-1} at weekly intervals controls rust. The protection should start at about 5% infection level. The spraying is beneficial when the crop is at flowering or at early pod setting. Late grain filling stage is not affected by rust (HARC, 2000).

Although foliar application with fungicides has limited scope at present, combining one to two sprays of mancozeb (700 g ha^{-1}) with any of the mixtures reduces the disease largely. Mixed cropping has been reported to reduce disease severity. This includes 34: 16 and 28: 17 faba bean to field pea proportion (AARC, 2000; AARC, 2001).

Host resistance

In the past, a large number of genotypes were evaluated for resistance to rust by various research centers in the country (AARC, 1996; AARC, 2000; Dereje et al., 1987; Dereje et al., 1988; Dereje and Beniwal, 1986; Dereje et al., 1993; Yitbarek, 1990). Moreover, sources of resistance were also identified from time to time. However, maintenance of resistance for utilization in varietal development program was a problem. Perhaps, this is attributed to the high out-crossing nature of the crop.

Black root tot (*Fusarium solani*)

Economic significance

The fungus *Fusarium solani* has been encountered on a large number of hosts in Ethiopia, including on faba bean causing black root rot (PPRC, 1998). Black root rot (BRR) is the second most important disease of faba bean. Complete crop losses could occur in severe infection conditions and when favorable conditions prevail. In farmers' fields, a yield loss of about 45% was estimated due to this disease (PPRC, 1996).

Ecology and epidemiology

The disease exclusively occurs in black clay soils (Vertisols) where waterlogging is severe. Waterlogging is a key factor that predisposes faba bean to this disease. Since the disease develops slowly, infected plants show chlorosis and dark black roots, which finally disintegrate. Pulling out of plants with symptoms of BRR becomes easy and the black discoloration of the whole root is easily observed. Death of the plant follows severe rotting (Dereje and Tesfaye, 1994a; PPRC, 1996).

Disease control

Cultural practice

Planting crops that are not hosts of *Fusarium solani*: noug (*Guizotia abyssinica*), rapeseed (*Brassica napus*) and linseed (*Linum usitatissimum*) (PPRC, 1996) in rotation with faba bean may reduce inoculum level in the soil. However, it is still not known to what extent would this inoculum reduction suppresses BRR. The time interval occurring between the repeated cultivation of faba bean (or another susceptible crop such as chickpea) is not determined, as well. As waterlogging is a key factor in predisposing plants to this disease, proper drainage of faba bean fields is essential to minimize the effect of this disease (Dereje and Tesfaye, 1994a).

Biological control

The role of *Trichoderma viride* in protecting plants from BRR infection has been tested on faba bean under glasshouse conditions (Tesfaye, 1999a). The results of this study suggest that the biological control agent *T. viride* can play a role in a strategy for the control of BRR in faba bean.

Host resistance

The National Faba bean Improvement Program at Holetta Agricultural Reserch Center and Ambo Plant Protection Research Center, and Regional Research Center, Sheno, made efforts to identify sources of resistance to BRR (Tesfaye, 1995; PPRC, 2003) and thereby develop BRR-resistant varieties possessing high yield. These efforts resulted in the development and release of four BRR-resistant varieties of faba bean: Wayu (Wayu 89-5), Selale (Salale Kasim 91-13), Lalo (Selale Kasim 89-4) and Dagm (Grarjarso 89-8) (NAIA, 2003). The first two varieties perform well under waterlogged conditions and have been released for general cultivation in the country in 2002, and the remaining have been released for North Shewa areas where BRR is a problem every year.

Studies to obtain a full picture of the pathogenic variability in the country are needed if stable resistance to black root rot is to be achieved. Some information has come through NVRSRP/IFAD research on variation in the fungus isolates (ICARDA, 2006). Based on pathogenic behavior of eight isolates collected from infected faba bean plants in central Ethiopia, five “pathogenic groups” (2/12/17, 14/19, 13, 16 and 20) have been identified using 10 released faba bean varieties (Table 8). The differences in reaction of varieties are clear that it could be possible to suggest a set of four of the varieties (Mesay, Degaga, Selale and Kuse) to be used as a differential set for identification of races in *Fusarium solani*. None of the pathogenic groups attacks varieties Wayu, Tesfa, Bulga, Kasa, CS 20 DK and Holetta.

Table 8. Reaction of faba bean cultivars to eight isolates of *Fusarium solani*

Variety	Isolate 4	Isolate 13	Isolate 16	Isolate 19	Isolate 20	Isolate 2/12/17
Mesay	R	R	R	R	S	R
Degaga	R	S	S	R	R	R
Selale	R	R	S	R	R	R
Kuse	S	R	R	S	R	R

Source: IAR, 1985

Cultural practices

Planting of either the released faba bean cultivar Wayu (moderately resistant) or local cultivar (susceptible) with improved drainage system, broad bed and furrow (BBF), reduce black root rot incidence and thereby increase seed yield (ICARDA, 2006). A group action by all farmers of a region, however, is essential if adoption of specific cultural practices such as BBF is to help in disease control.

Foot rot

Economic significance

Foot rot of faba bean is caused by *Fusarium avenaceum* reduces faba bean seed germination by 23%, germination energy by 35% and seedling emergence (stand establishment) by 55% (Dereje, 1996b). The disease may also reduce seed size, and if seeds from severely infected plants are used, emergence can be delayed.

Ecology and epidemiology

Fusarium avenaceum survives as mycelium on diseased seeds and infected plant debris. Development of foot rot is favored by acidic soils. However, key environmental conditions that favor foot rot epidemics have not been determined in Ethiopia.

Disease control

Cultural practice

Liming of acidic soils is likely to negatively affect the pathogen, *F. avenaceum*. Rotation of faba bean with *Brassica spp.* would help in controlling the disease by reducing initial inoculum level (HARC, 1995). Destroying volunteer faba bean plants and weeds belonging to genera, *Setaria, Phalaris, Cayluses, Polygonum, Spergolla,* and *Avena,* which serve as host plants to *F. avenaceum* could also help reduce the risk of an early build up of inoculum.

Viral diseases

A new luteovirus, tentatively named as chickpea chlorotic stunt (CpCSV), is the major virus associated with stunting and yellowing symptoms of faba bean, chickpea and almost all other cool-season food legumes in Ethiopia (Abraham, 2005; Abraham, 2006). The genomic RNA of CpCSV-FB (the faba bean isolate of CpCSV) measures 5900 nts in length with a genomic organization similar to poleroviruses. The virus is transmitted persistently by *Aphis craccivora* Koch; it is not transmitted by *Myzus persicae* Sulzer, *Acyrthosiphon pisum* Harris and *Aphis fabae* Scopoli.

Stunting and yellowing of faba bean caused by faba bean necrotic yellows (FBNYV) has been reported first by Abraham et al. (2000) in Shewa and later by Berhanu et al. (2005) in Bale, Gojam and Gonder, Ethiopia. The results of serological and molecular studies on several ssDNA of a FBNYV isolate from Holetta revealed that the virus is a distinct nanovirus species as compared to those in other countries (Abraham, 2005). Two other nanoviruses, namely, faba bean necrotic stunt (FBNSV), and a new nanovirus tentatively named as faba bean yellows (FBYLV), have also been reported in the country (Abraham, 2005).

Natural infection of faba bean with soybean dwarf (SbDV) was reported first by Berhanu et al. (2005) from Bale (incidence $\leq$ 2%), Gojam and Gonder (incidence $\leq$ 0.19%), Ethiopia. Additionally, pea seed-borne mosaic (PSbMV) was detected in leaves and/or seeds of faba bean (Abraham and Albrechtsen, 1998).

Fungal seed-borne diseases

Awgechew (1999) reported several fungi associated with seed of local and improved faba bean varieties collected from Arsi, Bale, Gojam, Gonder and western Shewa. The major fungi isolated were *Ascochyta fabae* (11%), *Botrytis fabae* (7%), *Fusarium avenaceum* (3%), *F. oxysporum* (2%) and *F. culmorum* (5%). Most of these fungi cause major diseases of faba bean in Ethiopia. The majority of the fungi (ca. 60%) were isolated from the improved faba bean cultivars CS20DK and Kusse.

Other diseases

There are a large number of diseases of minor importance recorded on faba bean in Ethiopia (Table 9).

Table 9. List of pathogens causing diseases of faba bean in Ethiopia

Pathogen	Disease	Status	Reference*
Alternaria tenuis	Black spot	Minor	64
Ascochyta fabae	Blight	Minor	27, CMI 241843
Bean leaf roll virus	Leaf roll	Minor	9
Bean yellow mosaic virus	Mosaic virus	Minor	9
Beet western yellows virus	Virus	Minor	9
Botrytis fabae	Chocolate spot	Major	126
Broad bean stain virus	Stain virus	Minor	9
Broad bean true mosaic virus	Mosaic virus	Minor	9
Cercospora zonata	Zonate leaf spot	Minor	126
Chickpea chlorotic dwarf virus	Chlorotic virus	Minor	9
Erysiphe polygoni	Powdery mildew	Minor	126
Faba bean necrotic yellows virus	Necrotic yellow	Medium	9
Fusarium avenaceum	Foot rot	Medium	HRC 5054, CMI 241885
Fusarium solani	Black root rot	Major	61, HRC 933
Macrophomina phaseolina	Dry root rot	Minor	HRC 3690, 3698
Meloidogyne incognita	Root knot	Minor	118
Mycoplasma-like organisms	Phyllody	Minor	64
Ovularia schwarzia	Leaf spot	Minor	126
Pea seedborne mosaic virus	Mosaic virus	Minor	9
Pratylenchus sp.	Root lesion	Minor	118
Rhizoctonia solani	Root rot	Minor	HRC 933
Sclerotium rolfsii	Collar rot	Minor	126
Trychothecium sp.	Orange leaf spot	Minor	64
Tylenchus sp.	Root lesion	Minor	118
Tyrenchorchynchus sp.	On roots	Minor	118
Uromyces viciae-fabae	Rust	Major	126

**HRC = Herbarium number at Holetta Agricultural Research Center and CMI = Herbarium number at the Commonwealth Mycological Institute, Kew, England.*

Field pea

Many diseases of field pea *(Pisum sativum*) were recorded in Ethiopia; yet, powdery mildew and blight/spot are the most important menace to the crop (Table 10).

Table 10. List of pathogens that cause diseases on field pea in Ethiopia

Pathogen	Disease	Status*	References*
Ascochyta pisi	Leaf/pod spot	Minor	126
A. phaseolorum	Leaf spot	Minor	65
Bean Yellow Mosaic Virus	Mosaic	Minor	123
Cochliobolus bicolor	Collar discoloration	Minor	65
Colletotrichum pisi	Spot	Minor	65
Erysiphe poligoni [*Oidium* sp. (imporfect stage)]	Powdery mildew	Major	126
Fusarium solani	Fusarium root rot	Minor	65
Helycotylenchus sp.	On roots	Minor	65
Mycosphaerella pinodes [*Ascochyta pinodes* (anamorph)]	Spot/blight	Major	65
Pea Early Browning Virus	Browning disease	Minor	123
Pea Leaf Roll Virus	Leaf roll	Manor	65
Pea Mosaic Virus	Mosaic	Manor	126
Pea Seedborne Mosaic Virus	Mosaic	Minor	123
Peronospora viciae	Downy mildew	Manor	65
Phoma medicaginis	Stem lesion	Inter.	65
Pratylenchus sp.	Root lesion	Minor	65
Pseudomonas pisi	Leaf spot	Minor	65
Rhizoctonia solani	Root rot	Minor	65
Sclerotium rolfsii	Collar rot	Minor	65
Septoria pisi	Blotch	Inter.	65
Tylencorhynchus sp.	On roots	Minor	65
Tylenchus sp.	Root lesion	Minor	118
Uromyces pisi	Rust	Minor	126

*Status indicating Inter. = Intermediate.

* Numbers in the 'reference' column indicate the position of the references in the reference list

Ascochyta blights (*Ascochyta* spp.)

Incidence and economic significance

Among the three *Ascochyta* spp. causing blights on field *Ascochyta pinodes* [teleomorph = *Mycosphaerella pinodes*] is a major disease of field pea in Ethiopia (Dereje and Tesfaye, 1994b; HARC, 1995). Blight infection is as high as 85% around Dembi East Shewa and a mean infection of 18.7% for all areas surveyed (Ada, Adaberga, Selale, Welmera, Weliso, and Chelia) were reported (HARC, 1995). A complete loss of yield due to *Ascochyta* blight is common, especially in hot-spot areas such as Dembi where there is high natural infection of the disease (Habtu and Dereje, 1986). Severe infection of *Ascochyta* blight causes a substantial seed yield reduction in field pea amounting 22% (Dereje, 2000; Dereje and Tesfaye, 1994b). A mean seed yield reduction of 0.37 t ha^{-1} (ranging from 1.31 to 1.68 t ha^{-1}) was recorded as the final disease score increased from 14 to 66% (Dereje, 2000). The disease mainly causes defoliation that eventually affects pod set and seed size more than any other yield component. A complete loss of yield due to *Ascochyta* blight is common, especially in blight hot-spot areas such as Dembi where there is high natural infection of the disease (HARC, 1995).

Ecology and epidemiology

The pathogen infects all the above ground parts. It is also found in seeds. The pathogen attacks the foliage, which causes spotting and blighting mainly on field peas grown in the wetter parts of the country. Seed infection serves as primary sources of inoculum for new crop, and this pathogen has up to 86% transmission efficiency from seed to seedlings (Dereje, 2004; Dereje and Sangchote, 2005). That means there could be a direct invasion of young plants by the fungus when infections originate from the seed.

The main fungus *A. pinodes* that causes blight in field pea survives as sclerotia (thickened mycelia), chlamydospores or pycnidia on straw fragments and in the soil (Lawyer, 1984), and as infection in the seed and conidia adhere on seed surface (Dereje, 2004). It colonizes pea straw on the surface and in the soil, and it competes well as a saprophyte with other soil microflora. When temperatures decrease and sufficient moisture is available under Ethiopian conditions, old pycnidia mature, new pycnidia, perithecia develop, and their spores are released. During wet weather, spores are produced on infected plants, and transferred on to healthy plants by wind and rain splash. Early sowing and use of infected seeds increase the incidence of the disease.

Disease control

Cultural practice

In many field pea-producing areas of Ethiopia, faba bean and field pea are grown in mixed cropping for weed suppression and physical support of field pea by faba bean. The major advantage, however, is suppression of foliar diseases (Dereje, 1999b). Other advantages include higher seed yield and increased land productivity. Dereje (1999b), Gemechu et al. (2006) and AARC (1996; 2000) reported the importance of mixed cropping of faba bean and field pea to reduce *Ascochyta* blight. After three seasons study at Holetta and Dembi, Dereje (1999b) found the lowest disease pressure and maximum yield from a 2:1 faba bean to field pea mixture. Final disease severity dropped from 93 to 70% as field pea proportion in the mixed cropping decreased from 100 (pure stand) to 32%.

Use of clean seed is also advisable, as infected seeds are important sources of inoculum, where other sources are not important (Dereje, 2004). In the absence of seed treatment, however, seed should be held over at least for one year when seed infection is known to be less than 10% (Dereje, 2004; Lawyer, 1984). Pea refuse should be disked and ploughed under immediately after harvest before the fungus can be generally dispersed by wind and rain splash.

Host resistance

The level of resistance to *Ascochyta* blight in field pea genotypes tested (after screening over 800 accessions) is low to be of practical value in the development of resistant varieties (HARC, 2000). The choice of moderately or partially resistant varieties might prove effective, and sources/genotypes with these types of resistance already exist in Canada (Ali-Khan et al., 1974) and Australia (Ali et al., 1978).

Different alternative to *Ascochyta* blight control is offered by host plant tolerance. Certain differences are found in tolerance of field pea cultivars to infection with *M. pinodes*. These differences are of practical value and hence should be exploited. Most landraces and existing improved cultivars are tolerant to the disease and provide reasonable yield under moderate blight pressure (HARC, 1995).

Chemical control

Several fungicides were reported as effective for seed dressing or foliar application. Seed treatment with carbendazim provides early protection of seedling infection from the seed source (Dereje and Sangchote, 2003). Foliar application of chlorothalonil, benomyl, thiophanylmethyl and metalaxyl could also control *Ascochyta* blight in field pea and increase the seed yield reasonably (HARC, 1995). Field pea crop intended for seed production should be sprayed with chlorothalonil and metalaxyl at the rates of 2.5 and 1 kg a.i./ha, respectively. However, the economics for grain production is questionable.

Chemical spray is recommended if wet and warm weather is likely to prevail for two weeks following foliar application of the crop at or before flowering stage (HARC, 1995). Beyond this crop stage, the benefit obtained from yield increase due to protection against the blight might not justify fungicide spray.

Powdery mildew

Economic significance

Powdery mildew [*Erysiphe polygoni* (*Oidium* sp.)] is the second most important disease of field pea in distribution and damage to the crop (Dereje and Tesfaye, 1994b; HARC, 1995; HARC, 2002). Severe pod infection could result in a gray-brown discoloration of the seeds. These seeds may have an objectionable flavor that reduces the quality of the grain. Under severe infection conditions, yield losses of 37.7% were recorded (Dereje and Tesfaye, 1994b).

Ecology and epidemiology

The disease is severe in the dry season and on late sown field pea crops. Leaves, stems and pods may all become infected causing the whole plant to wither. Infected plants show a white powdery film and severely affected foliage looking blue-white. Tissue below infected areas may be purplish. In heavily infected crops, clouds of spores could be shaken from the plants and easily observed under compound microscope.

In Ethiopia, no information on the epidemiology of powdery mildew has appeared in the literature. Nevertheless, there is enough general knowledge that enables to manage powdery mildew at present. The disease is favored by dry and hot days followed with cool nights that allow dew formation. Kulumsa Research Center is a good place for this disease as the chilling wind (weather) blows from Mount Chilalo in nights, and the days are often dry and hot.

Disease control

Cultural practice

Powdery mildew is most damaging when it occurs late in the season at a time when dew formation is common. So, early sowing and/or harvesting may reduce the effect of the disease. However, early sowing also has severe *Ascochyta* blight problem. These two diseases occur at different time of the season, early and late due to their requirements of contrasting environments, which needs proper planning of field pea production.

There are reports of major gene resistance to powdery mildew disease (Reiling et al., 1984). In Ethiopia there is little success in resistance breeding to this disease, despite the availability of immense gene pool for complete resistance. Preliminary reports indicate that there is a possibility of getting genotypes with complete resistance to this disease from local and international collections (Dereje and Tesfaye, 1994b). Until resistant varieties are available, spraying benomyl at a rate of 2 kg a.i./ha every two weeks constitute a measure for mildew control. The spraying should start when infection reaches about 5%.

Other diseases

Several fungal diseases of minor or intermediate importance have been reported on field pea in Ethiopia (Table 5). These include *Septoria* blotch (*Septoria pisi*), stem lesion (*Phoma medicaginis*) (Dereje and Sangchote, 2005), *Fusarium* root rot (Dereje and Tesfaye, 1994b) and *Fusarium* wilt (Berhanu et al., 2006; HARC, 2002). Of these, *Septoria* blotch appears to be devastating in the North, particularly eastern and southern Tigray (MRC, 1994; MRC 2002).

In a biological control study, *T. viride* has proved effective against *Fusarium oxysporum* (a wilt causing fungus in field pea) (PPRC, 1995). With regard to host plat resistance, four field pea germplasm accessions (Acc. No. 832781, 032801, 173/77 and 48/73) were identified as resistant under glasshouse and field conditions at Ambo (PPRC, 1995).

Dereje (2004) and Dereje and Sangchote (2005) studied the seed mycoflora of field pea and reported 16 fungi species associated with pea seeds that include *Alternaria alternata*, *Ascochyta pinodes*, *Ascochyta pisi*, *Aspergillus niger*, *A. flavus*, *Aspergillus* spp., *Cladosporium cladosporioides*, *Chaetomium funicola*, *Curvularia brachyspora*, *Fusarium oxysporum*, *Fusarium avenaceum*, *Monilia* spp., *Penicillium* spp., *Phoma medicaginis*, *Rhizoctonia solani and Trichoderma* spp. Among these, *A. pinodes*, *C. cladosporioides* and *Penicillium* spp. were most frequent with mean occurrence of 7.1, 6.6 and 3.9%, respectively, whereas the others were with less than 1.3% frequency. Surface sterilization of seeds excluded most fungi except *A. niger*. *A. pinodes*, *A. pisi*, and *P. medicaginis*. *A. pinodes* was located in the seed coat while embryo infection was incidental. Removal of the seed coat blocked transmission of this fungus from seed to seedling. *A. pinodes* found to be a highly seed transmissible pathogen with mean transmission efficiency of 86%. Blotter and potato dextrose agar methods could be used as methods of detecting this pathogen. Fungal fragments adhered on the surface of seed have the capability of surviving a standard surface disinfection treatment (disinfecting seeds with 1% NaOCl for 5 min).

Although frequencies were low, *Alternaria* and *Culvularia* attacked shoots of field pea at early stage, whereas *Aspergillus* completely killed the seed before germination takes over during incubation (Dereje, 2004). Of the many seed treatment fungicides tested by Dereje and Sangchote (2003), carbendazim, iprodione and chlorothalonil completely eradicated seed fungi, including *Ascochyta* blight. However, only carbendazim and iprodione greatly reduce development of *Ascochyta* blight in field pea at early epidemic stages.

Viral diseases

Pea seed borne mosaic (PSbMV), bean yellow mosaic (BYMV), pea enation mosaic (PEMV) and pea early browning (PEBV) were present at low rate (≤ 3%) in seed samples from the important field pea-producing areas of Ethiopia (Abraham and Albrechtsen, 1998; PPRC, 1995). This indicates that viral diseases, especially seed-borne viruses, are at the moment not a threat to field pea production in the country. Natural infections of pea with SbDV and FBNYV have been reported by Berhanu et al. (2005) in Bale, Ethiopia. Other viruses of minor importance include pea leaf roll (PLRV) (Dereje and Tesfaye 1994b) and pea mosaic (PMV) (PPRC, 2000) (Table 10).

Conclusion

In the past two decades, enormous progresses have been made in terms of developing practical disease management options. For instance, the successful adoption of lentil production technology in Gimbichu district and the neighbouring areas of Bereh and Aleltu and its impact on the livelihoods of those involved in lentil value chain is largely the development of rust resistant lentil cultivars such as Alemaya. In a nutshell, diseases had a compelling position in the generation and adoption of food legume technologies in Ethiopia, and the present review has documented this and similar situations that have been taking place since 1986.

Although, commendable outcomes have been scored through pulse pathological research in the country during the past, there is still a lot remains to be done in the years to come. In addition, some of these issues have been highlighted in the final chapter of this review document, future directions. It is our conviction that the current status of food legumes research has laid a strong foundation for the one ahead, and is of practical value in the country’s endeavor towards the attainment of national food security and food self-sufficiency.

Future research directions

Field pea

- Survey should concentrate on quantitative data to map the relative distribution and importance of field pea diseases in different agro-ecological zones.
- Search for resistance gene against *Ascochyta* and powdery mildew should continue. Workable field and laboratory screening techniques for powdery mildew and *Ascochyta* diseases need to be worked out.
- Survival, host range and variability of *Ascochyta* should be studied.
- Appropriate management options should be worked out by considering the unique agronomic-feature of the crop and farmers' production circumstances.

Faba bean

- Survey should concentrate on quantitative observation to map the relative distribution and importance of faba bean diseases in different agro-ecological zones
- Losses should be quantified for different infection regimes for diseases. Search for resistance genes should continue for major diseases (chocolate spot, rust and black root rot)
- *Trichoderma viride* must be mass-produced and tested in farmers' fields where the incidence of *Fusarium solani* and *Fusarium oxysporum* are high.
- Integration of cultural, varietal, biological, chemical, etc. options should be considered

Chickpea, lentil, grass pea, fenugreek and lupine

The future direction should focus on the following issues:

- In depth study on the pathogenic variability of the *Fusarium* spp causing wilt diseases of lentil and chickpea and rust pathogens and biological race analyses should be supported by molecular pathotyping;
- Although major diseases of chickpea and lentil are known, emphasis should be given to know the status of diseases of fenugreek, grass pea and lupine since these crops are given less emphasis in research and development. In addition, more emphasis should be given to manage powdery mildew of fenugreek and grass pea;
- Multiple disease resistance for foliar and soil-borne diseases should be given priority in the five legumes;
- Due to unreliability of the onset of the rain in the nation, farmers started growing legumes like mung bean, haricot bean, chickpea, fenugreek and lentil

in sorghum and maize belts of the lowlands. Since the small rain and the temperature favor foliar disease like rust and ascochyta blight, there must be a strategy that addresses this emerging cropping system by developing early maturing and resistant genotypes to foliar diseases;

- *Cropping system:* New agronomic practices like zero tillage are being demonstrated for farmers. One of the candidate crops for zero tillage are legumes like chickpea and wilt and root rots will be emerging problems and efforts should be made to design control methods;
- The central highlands practice crop rotation with pulses and the level of straw left in the field is observed to have a bearing on soil borne diseases affecting subsequent pulse crops. For example, when lentil follows wheat where straw is not well decomposed, lentil crops were observed to be killed by collar rot compared with lentil that follows tef where the limited straw is completely decomposed. Hence, such type of study needs to be initiated;
- *Integrated disease management:* Most of the research efforts on chickpea and lentil disease management focused on host plant resistance. However, the integrated disease management approach should be strengthened;
- The screening technique (wilt/root rot sick plots) should be supplemented with pot screening since pathogen dynamics change with changes in moisture and temperature during the cropping season. This was a problem during the period under review;
- *Germplasm enhancement:* Most of the materials in the breeding program are exotic sources. The local land races are susceptible to wilt/ root rots, but have special character for export like the Gondar type chickpea. Hence, there must be efforts to transfer disease resistance genes to the local types;
- The role of ODAP in relation to disease susceptibility should be studied in grass pea;
- Genetics of host plant resistance to rust, *Ascochyta* blights and powdery mildew should be strengthened;
- There is a strong interest to introduce sweet lupine and the disease situation of powdery mildew and collar rot needs to be considered;
- Development of differentials for lentil rust and *Fusarium* wilt pathogen characterization should be developed;
- *Ascochyta* blight and anthracnose on lentil need some attention; otherwise they will devastate the existing cultivars. Hence, it is worthwhile to devise a control strategy;
- Epidemiological aspects of the major diseases should be studied to devise appropriate control methods; and
- Identification of molecular and biochemical markers to enhance marker assisted selection

Haricot beans and other lowland pulse crops

Emphasis should be given to

- Breeding for multiple disease resistance;
- Biological disease control methods and antagonists;
- Developing model integrated disease management;
- Develop information on disease dynamics (race occurrence, varietal susceptibility). Conventional and molecular techniques may be used to study pathogen variability;
- Determining occurrence and importance of diseases on lowland pulse crops with special emphasis to soybean, cowpea, mung bean and pigeonpea;
- Identification of molecular markers to enhance marker assisted selection;
- Use of GIS to map the distribution of major diseases; and
- Epidemiology, economic importance and control options of viral diseases need to be worked out.

References

1. Abashamo L., Shambel, K. and Wondu, G. 2000. Preliminary identification of rust resistant lentil genotypes in southeastern Ethiopia. *NVRSRP* Newsletter 3and 4: 5-6.
2. Abebe, G. 2005. Inheritance of resistance to rust (*Uromyces fabae*) in lentil (*Lens culinaris* Medik,). MSc. Thesis, Addis Ababa University, 64 pp.
3. Abiy, T. Fekede, A. and Chemeda, F. 2006. Lowland pulse diseases research in Ethiopia. Pp 228-237 Proceedings of Food and Forage Legumes of Ethiopia: Progress and Prospects (Ali, Kemal; Keneni, Gemechu; Ahmed, Seid; Malhotra, Rajendra; Beniwal, Surendra; Makkouk, Khaled; and Halila, M.H.(eds.). The workshop on Food and Forage Legume, 22-26 September 2003, Addis Ababa, Ethiopia. Sponsors: EIAR and ICARDA. International Center for Agricultural Research in the Dry Areas (ICARDA) Aleppo, Syria.
4. Abraham, A. 2005. Characterization and genome organization of new luteoviruses and nanoviruses infecting cool-season food legumes. Ph.D. Thesis. Georg-August University of Geottingen, Germany. 146 pp.
5. Abraham, A. and Albrechtsen, S.E. 1998. Seed-borne viruses infecting some important crops in Ethiopia. Pest Management Journal of Ethiopia 2:94-101.
6. Abraham, A. and Habtu, A. 2000. Virus and virus like diseases of plants in Ethiopia. *Pest Management Journal of Ethiopia*. 4: 1-10.
7. Abraham, A. and Lencho, A. 2000. Grass pea severe stunt virus disease in Ethiopia. *Pest Management Journal of Ethiopia* 4(1and2): 85-88.
8. Abraham, A. and Makkouk, K.M. 2002. The incidence and distribution of seed-transmitted viruses in pea and lentil seed-lots in Ethiopia. *Seed Science and Technology (Switzerland)* 30(3): 567-574.
9. Abraham, A., Makkouk, K.M., Dereje, G., Lencho, A., Kemal A. Nigusie T. A Yusuf and A Lencho. 2000. Survey of faba bean (*Vicia faba* L.) virus diseases in Ethiopia. *Phytopathol. Mediterr*. 39: 277 – 282.
10. Abraham, A.D., Menzel, W., Lesemann, D.-E., Varrelmann, M. and Vetten, H.J. 2006. Chickpea chlorotic stunt virus: A new polerovirus infecting cool-season food legumes in Ethiopia. *Phytopathology* 96:437-446.

11. Adet Agricultural Research Center (AARC). 1992.Progress Report.
12. Adet Agricultural Research Center (AARC). 1993. Progress Report.
13. Adet Agricultural Research Center (AARC). 1996. Progress Report.
14. Adet Agricultural Research Center (AARC). 2000. Progress Report.
15. Adet Agricultural Research Center (AARC). 2001. Progress Report.
16. Ahmed, S. and Ayalew, M. 2006. Chickpea, lentil, grasspea, fenugreek and lupine disease research in Ethiopia. Pp 215-220. *In:* Proceedings of Food and Forage Legumes of Ethiopia: Progress and Prospects (Ali, Kemal; Keneni, Gemechu; Ahmed, Seid; Malhotra, Rajendra; Beniwal, Surendra; Makkouk, Khaled; and Halila, M.H., eds.). The workshop on Food and Forage Legume, 22-26 September 2003, Addis Ababa, Ethiopia. Sponsors: EIAR and ICARDA. International Center for Agricultural Research in the Dry Areas (ICARDA) Aleppo, Syria.
17. Ahmed, S. and Beniwal, S.P.S. 1988. Seed-borne nature of *Ascochyta lentis* in lentils in Ethiopia. *Lens Newsletter*15:30-31.
18. Ahmed, S. 1987. Ascochyta blight of lentil (*Lens culinaris* Medik): Identification of the causal fungus and its seed transmission and controlM.Sc. Thesis, Alemaya University of Agriculture, Alemaya, Ethiopia. 70pp.
19. Ahmed, S. and Beniwal, S.P.S. 1991. Ascochyta blight of lentil and its control in Ethiopia. *Tropical Pest Management* 37(4):368-373.
20. Ahmed, S. and Beniwal, S.P.S. 1998. Survival of Ascochyta fabae f. sp. lentis on infected lentil seeds. *Lens Newsletter* 22 (1&2): 8-10.
21. Ahmed, S., Beniwal, S.P.S. and Tadesse, N. 1990. Field screening of chickpea for resistance to wilt/root rots in Ethiopia. International Chickpea *Newsletter* 22:34-36.
22. Ali, S.M., Nitschke, L.F., Dube, A.J. Krause, M.R. and Cameron, B. 1978. Selection of pea lines for resistance to pathotypes of Ascochyta pinodes, Ascochyta pisi, and Phoma medicaginis Var. pinodella. Aust. *J. Agric. Res.* 29: 841-849.
23. Ali-Khan, S.T., Zimmer, R.C. and Kenaschuk, E.O. 1974. Reaction of pea introductions to *Ascochyta* foot rot and powdery mildew. *Canadian Plant Disease Survey*. 53: 155-156.
24. Amare, G. 1996. Mixed cropping of faba bean and field pea in Ethiopia. Pp 56-63. *In:* Proceedings of first Agronomy and Crop Physiology Society. Addis Ababa.
25. Amhara Regional Agricultural Research Institute (ARARI). 2002. Summary of research achievements, 1987-2001. 87 pp.
26. Araya, W., Tsegaye, S. and van Rheenen, H.A. 1990. A rapid survey of chickpea cultivation: I. Gojam, Ethiopia 1989/90. *International Chickpea Newsletter* 23:27-29.
27. Awgechew, K. 1982. Additional index of plant diseases in Ethiopia. IAR, Addis Ababa.
28. Awgechew, K. 1999. Evaluation of faba bean varieties for the major seed-born diseases in Ethiopia. *NVRSRP Newsletter* 2: 27-29.
29. Bako Agricultural Research Center (BARC). 2002. Bako Research Center; Crop protection division progress report for 2001/2. Bako Agricultural Research Center, Bako Ethiopia.
30. BARC. 1997. Bako Research Center; Crop protection division progress report for 1996/97. Bako Agricultural Research Center, Bako Ethiopia.
31. BARC. 1998. Bako Research Center; Crop protection division progress report for 1997/98. Bako Agricultural Research Center, Bako Ethiopia.
32. BARC. 1999. Bako Research Center; Crop protection division progress report for 1998/99. Bako Agricultural Research Center, Bako Ethiopia.
33. BARC. 2000. Bako Research Center; Crop protection division progress report for 1999/2000. Bako Agricultural Research center, Bako Ethiopia.
34. Bejiga, G., Abebe, T. and Seifu, S. 1995. Effect of sowing date and seeding rate on the yield of chickpea (*Cicer arietinum* L.). *Ethiopian Journal of Agricultural Science* 14 (1-2): 7-14.

35. Bejiga, G. and Anbessa, Y. 1994. Genetics and breeding research in chickpea. Pp 138-161. *In:* proceedings of Cool-season Food legumes of Ethiopia (Asfaw Tilaye, Geletu Bejiga, Saxena, M.C. and Solh, M.B., eds.). The First National Cool-season food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia: ICARDA/Institute of Agricultural Research. ICARDA: Aleppo.
36. Bejiga, G. and Yadeta, A. 1999. Development of rust resistant lentil cultivars in Ethiopia. *Lens Newsletter* 26(1&2): 33-34.
37. Bejiga, G., Abebe, T., Tsegaye, S., Ahmed, S. and Abessa, Y. 1995. Evaluation of lentil genotypes for resistance to rust. *Petria* 5:189-194.
38. Bejiga, G., Eshete, M. and Anbessa, Y. 1996a. Improved cultivars and production technology of chickpea in Ethiopia. Research Bulletin No. 2. Debre Zeit Agricultural Research Center, Alemaya University of Agriculture, Debre Zeit, Ethiopia.
39. Bejiga, G., Eshete, M. and Anbessa, Y. 1996b. Improved cultivars and production technology of lentil in Ethiopia. Research Bulletin No. 3. Debre Zeit Agricultural Research Center, Alemaya University of Agriculture, Debre Zeit, Ethiopia.
40. Bejiga, G., Tadesse, N. and Anbessa, Y. 1998. Evaluation of chickpea accessions for resistance to *Fusarium* wilt in Ethiopia. *NVRSRP Newsletter* 1:9.
41. Bejiga, G., Tadesse, N. and Erskine, W. 1998. We fixed rust! Next, wilt and root rots. ICARDA, *CARAVAN* 9:12 and 14.
42. Beniwal, S.P.S., Ahmed, S. and Gorfu, D. 1992. Wilt root rot diseases of chicklpea in Ethiopia. *Tropical Pest Management* 38(1):48-51.
43. Beniwal, S.P.S., Ahmed, S. and Tadesse, N. 1989. Effect of sun drying of lentil seeds on the control of seed-borne Ascochyta lentis. *Lens Newsletter* 16(2):27-8-51.
44. Berhanu, B., Getachew, M., Teshome, G. and Temesgen, B. 2006. Faba bean and field pea diseases research in Ethiopia. Pp 221-227. *In:* Proceedings of Food and Forage Legumes of Ethiopia: Progress and Prospects (Ali, Kemal; Keneni, Gemechu; Ahmed, Seid; Malhotra, Rajendra; Beniwal, Surendra; Makkouk, Khaled; and Halila, M.H., eds.). The workshop on Food and Forage Legume, 22-26 September 2003, Addis Ababa, Ethiopia. Sponsors: EIAR and ICARDA. International Center for Agricultural Research in the Dry Areas (ICARDA) Aleppo, Syria.
45. Berhanu, B., Kumari, S.G., Ali, K., Yusuf, A., Makkouk, K.M., Aslake, M., Ayalew, M. Girma, G. and Hailu, D. 2005. Survey of viruses affecting legume crops in the Amhara and Oromiya regions of Ethiopia. *Phytopathology*. Mediterr. 44:235-246.
46. CSA. 2006. Report on the preliminary results of area, production abd yield of temporary crops. Central Statistical Authority (CSA), Addis Abb, Ethiopia.
47. Chahota, P.K., Gupta, V.P. and Sharma, S.K. 2002. Inheritance of rust resistance in lentil. *Indian J Genet Plant Plant Breeding* 62:226-227.
48. Conner, R.L. and Bernier, C.C. 1982. Race identification in Uromyces viciae-fabae. *Phytopathol* 72:687-689.
49. Daba, K., Bejiga, G., Anbessa, Y., Gaur, P.M., Kumar, J. and Rao, B.V. 2005. Chefe (ICCV 92318) – A new kabuli chickpea variety for Ethiopia. *International Chickpea and Pigeonpea Newsletter* 12:15-16.
50. Debre Zeit Agricultural Research Center (DZARC). 1976. Research Progress Report for the period 1975/76. DZARC, Debre Zeit, Ethiopia.
51. Dereje G. 1999a. Survival of Botrytis fabae Sard. Between seasons on crop debris in field soils at Holetta, Ethiopia. *Phytopathol. Mediterr*. 38: 68–75.
52. Dereje G. 2004. Seedborne nature of Ascochyta and its significance on disease development and yield of field pea. Ph.D. Thesis. Kasetsart University, Bangkok, Thailand..
53. Dereje G., Beniwal, S.P.S. and Tesfaye, B. 1987. Screening of faba bean research done on faba bean in Ethiopia for the 1986 crop season. Pp 85-94 in IAR Conference Papers:

Results of Research Done on Faba bean in Ethiopia for the 1986 Crop Season (S.P.S. Beniwal, ed.). IAR, Addis Ababa.

54. Dereje G., SPS Beniwal and Alem Berhe. 1988. Screening of faba bean lines for chocolate spot and rust resistance. IAR progress reports on faba bean. Pp90-94.
55. Dereje, G. 1993a. Studies in the epidemiology of chocolate spot (*Botrytis fabae* Sard.) of faba bean (*Vicia faba* L.). M.Sc Thesis, Alemaya University of Agriculture.
56. Dereje, G. 1993b. Yield loss of faba bean caused by foot rot (*Fusarium avenaceum*). *FABIS* 33:24-27.
57. Dereje, G. 1996a. Morphological, cultural and pathogenic variability among nine isolates of *Botrytis fabae* from Ethiopia. *FABIS* 38/39: 37-41.
58. Dereje, G. 1996b. Effect of foot rot on faba bean. *Seed Science and Technology* 25: 19-23.
59. Dereje, G. 1999b. Effects of mixed cropping of faba bean and field pea on disease development and yield. *Pest Management Journal of Ethiopia*. 3(1and2): 61-67.
60. Dereje, G. 2000. Yield loss of field pea due to *Ascochyta* blight in central Ethiopia. *Pest Management Journal of Ethiopia.* 4: 89-95.
61. Dereje, G. and Beniwal, S.P.S. 1986. Evaluation of faba bean lines for chocolate spot and rust resistance. Paper presented on the 7th Annual Coordination Meeting of ICARDA/IFAD Nile Valley Project on Faba Bean, 23-27Sep 1986, Addis Ababa.
62. Dereje, G. and Beniwal, S.P.S. 1988. Yield losses caused by chocolate spot in faba bean. *Ethiopian Plant Pathology Newsletter* 13: 16-20.
63 Dereje, G. and Sangchote, S. 2003. Effects of seed treatment fungicides on *Ascochyta pinodes* on field pea under controlled and field conditions. *Kasetsart Journal (Natural Science)* 37: 429-444.
64. Dereje, G. and Sangchote, S. 2005. Fungi associated with field pea seeds from Ethiopia and seed transmission of *Ascochyta pinodes*. *Seed Science and Technology* 33: 387-396.
65. Dereje, G. and Tesfaye, B. 1994a. Faba bean diseases in Ethiopia. Pp 328-345. *In:* Cool Season Food Legumes of Ethiopia (Asfaw Telaye, Geletu Bejiga, Mohan C. Saxena and Mahmoud B. Solh, eds.). Proceedings of the First National Cool season Food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia.
66. Dereje, G. and Tesfaye, B. 1994b. Field pea diseases in Ethiopia. Pp 317-327. *In:* Cool Season Food Legumes of Ethiopia (Asfaw Telaye, Geletu Bejiga, Mohan C. Saxena and Mahmoud B. Solh, eds.). Proceedings of the First National Coolseason Food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia.
67. Dereje, G. and Yaynu, H. 2001. Yield losses of crops due to plant diseases in Ethiopia. *Pest Management Journal of Ethiopia* 5: 55-67.
68. Dereje, G., Mengistu, H. and Tadesse, G.M. 1994. Influence of weather factors on infection rate of chocolate spot of faba bean. Pp 33-34 *In:* Proceedings of Crop Protection Society of Ethiopia, 26-27 April 1994. Addis Ababa, Ethiopia.
69. Dereje, G., Yitbarek, S. and Truwork, A. 1993. Screening of faba bean for chocolate spot and rust resistance. Pp 60-66 in Research Results, 1991 Crop Season, IAR, Addis Ababa.
70. DZARC (Debre Zeit Agricultural Research Center). 1994. Annual Research Report 1991/92. Debre Zeit, Ethiopia.
71. DZARC. 2005a. Annual Research Report 2004/05. Debre Zeit, Ethiopia.
72. DZARC. 2005b. DZARC in half a century (Golden Jubilee: 1955-2005). Getachew, B., Alemu, Y., Negussie, T. and Senait, R. (eds.). DZARC, Debre Zeit, Ethiopia. 74 p.
73. DZARC. 1997. DZARC: From Where to Where? “Research with a Mission” (1953-1997. Mesfin Abebe and Tekalign Mamo (eds.)DZARC, Debre Zeit, Ethiopia. 146 p.

74. Fekede, A. and Kedir, W. 1998. Disease and pest recommendations for Western Ethiopia.PP 145-150. Beyene Seboka and Aberra Deressa (eds.) 1998. Agricultural Research and Technology Transfer Attempts and Achievements in Western Ethiopia. Proceedings the Third Technology Generation Transfer and Gap Analysis Workshop. 12-14 November 1996, Nekemt, Ethiopia.
75. Fikire, L. 1998. Effect of bean (*Phaseolus vulgaris* L.) cultivar mixtures on development of bean rust and common bacterial blight. MSc Thesis, Alemaya University of Agriculture, Alemaya.
76. Fikire, L. 2004. Effect of intercropping and cultivar mixtures on bean diseases and yield. *Pest Management Journal of Ethiopia* 8: 71-81.
77. Fininsa, C. 1996. Effect of intercropping bean with maize on bean common bacterial blight and rust diseases. *International Journal of Pest Management* 42: 51-54.
78. Fininsa, C. 2001. Epidemiology of bean common bacterial blight and maize rust in intercropping. PhD Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweden.
79. Fininsa, C. 2003. Relationship between common bacterial blight severity and bean yield loss in pure stand and bean-maize intercropping systems. *International Journal of Pest Management* 49: 177-185.
80. Fininsa, C. and J. Yuen. 2002. Temporal progression of bean common bacterial blight (Xanthomonas campestris PV. Phasseoli) in sole and intercropping systems. *European Journal of Plant Pathology*. 108: 485-492.
81. Fininsa, C. and Tefera, T. 2001. Effect of primary inoculum sources of bean common bacterial blight on early epidemics, seed yield and quality aspects. *International Journal of Pest Management* 47: 221-225.
82. Fininsa, C. and Tefera, T. 2002. Inoculum sources of bean anthracnose and their effect on epidemics and yield. *Tropical Science* 42: 30-34.
83. Fininsa, C. and Yuen J. 2001. Association of bean rust and common bacterial blight epidemics with cropping systems in Hararghe highlands, eastern Ethiopia. *International Journal of Pest Management* 47: 211-219.
84. Gemechu K., Musa, J., Tezera, W. and Million, B. 2006. Faba bean and field pea mixed-cropping: potential and limitations. Research Report No. 66. EIAR, Addis Ababa.
85. Habtu, A. 1994. Epidemiology of bean rust in Ethiopia. Ph.D. Thesis. Wageningen Agricultural University. Department of Phytopathology. The Netherlands.118 pp.
86. Habtu, A. and Abiye, T. 1995. Disease management in lowland pulses: progress and possibilities for an integrated approach. Pp.141. *In:* proceedings of the 25th Anniversary Conference of Nazareth Agricultural research center: 25 years of experience in lowland crops research. Nazareth/Melkassa, Ethiopia, 20-23 September 1995.
87. Habtu, A. and Dereje, G. 1986. Review of pulse disease research in Ethiopia. Pages 347-401 *In:* A review of Crop Protection Research in Ethiopia (Tsedeke Abate, ed.). Proceedings of First Ethiopian Crop Protection Symposium, 4-7 Feb. 1985, Addis Ababa, IAR, Ethiopia.
88. Habtu, A. and Zadoks, J.C. 1995a. Crop growth, disease and yield components of rusted Phaseolus beans in Ethiopia. *Journal of Phytopathology* 143: 391-401.
89. Habtu, A. and Zadoks, J.C. 1995b. Components of partial resistance in Phaseolus beans against an Ethiopian isolate of bean rust. *Euphytica* 83: 95-102.
90. Habtu, A., Abiye, T. and Zadoks, J.C. 1997. Analyzing crop loss in bean pathosystem: I. Disease progress, crop growth and yield loss. *Pest Management Journal of Ethiopia*. 1(1and2): 9-18.
91. Habtu, A., Sache, I. and Zadoks, J. C. 1996. A survey of cropping practices and foliar diseases of common bean in Ethiopia. *Crop protection*. 15: 179-188.

92. Habtu, A., Zadoks, J.C. and Abiye, T. 1998. Analyzing crop loss in a bean rust pathosystem. II. Severity-damage relationship. *Pest management Journal of Ethiopia*. 2(1&2): 1-13.
93. HARC. 1995. Research progress report. Plant Pathology Section, Holetta Agricultural Research Center.
94. HARC. 2000. Faba bean and field pea pathology Research Progress Report, Holetta.
95. Haware, M.P. and Nene, Y.L. 1982. Races of Fusarium oxysporum f.sp. ciceri. *Plant Dis*. 66:809-810.
96. Holetta Agricultural Research Center (HARC). 2002. Faba bean and field pea pathology research progress report. Holetta.
97. Institute of Agricultural Research (IAR). 1985. Crop protection department progress report. IAR, Addis Ababa. Ethiopia.
98. International Center for Agricultural Research in the Dry Areas (ICARDA). 2006. NVRSRP/IFAD Project – Progress Report 2004-2005.
99. Jimenez-Diaz, R.M. and Trapero-Casas. 1990. Improvement of chickpea resistance to wilt and root rot diseases. Options Méditerranéennes – Série Séminaires – Numéro 9:65-72.
100. Lawyer, A.S. 1984. Foliar diseases caused by fungi: Diseases caused by Ascochyta spp. *In:* D.J. Hegdorn, ed. Compendium of pea diseases. *The American Phytopathological Society*. St. Paul, Minnesota.
101. Lencho, A., Abraham, A. and Matias, A. M. 1998. Necrotic strain of bean common mosaic virus in Ethiopia. *Pest management journal of Ethiopia*. 1: 110-112.
102. Mekele Research Center (MRC). Progress Report for the Period 1994.
103. Meki, S. 2004. Pathogenic variability of Fusarium oxysporum f.sp. ciceris, causing chickpea wilt and its control using Trichoderma isolates in central Ethiopia. MSc. Thesis Alemaya University. 75 pp.
104. Mengistu, H. and Negussie, T. 1994. Chickpea and lentil diseases research in Ethiopia. Pages 346-366 in proceedings of Cool-season Food legumes of Ethiopia (Asfaw Tilaye, Geletu Bejiga, Saxena, M.C. and Solh, M.B., eds.). The First National Cool-season food Legumes Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia: ICARDA/Institute of Agricultural Research. ICARDA: Aleppo.
105. Ministry of Agriculrure and Rural Development (MoARD), Crop Development Department, Ethiopia. 2005. Crop variety register. Issue No. 8.
106. MoARD, Crop Development Department, Ethiopia. 2004. Crop variety register. Issue No. 7.
107. Mohammed Yesuf. 2005. Seedborne Nature of Colletotrichum lindemuthianum and Its Epidemic on Common Beans in the Major Bean Growing Areas of Ethiopia. Ph.D. Thesis, Kasetsart University, pp.142.
108. MRC. Crop Protection Division Progress Report for the Period 1995-2002.
109. National Agricultural Input Authority (NAIA), Ethiopia. 2003. Crop variety register. Issue No. 5.
110. Negussie, T. 1989a. Effect of temperature on the growth of important wilt and root rot fungi of chickpea. Page 24 in Abstracts of The 14th Annual Meeting of the Ethiopian phytopathological Committee, 30-31 March, 1989. Ambo, Ethiopia.
111. Negussie, T. 1989b. Studies on the threshold levels of *Fusarium oxysporum* f.sp. ciceri in chickpea. Pp 24-25 in Abstracts of the 14th Annual Meeting of the Ethiopian Phytopathological Committee, 30-31 March, 1989. Ambo, Ethiopia.
112. Negussie, T. 1991. Expansion of rust focus in faba beans (*Vicia faba* L.). Wageningen Agricultural University, Wageningen, The Netherlands.
113. Negussie, T. 1995. ICC 6045: A kabuli chickpea resistant to wilt and root rots in Ethiopia. *International Chickpea and Pigeanpea Newsletter* 2: 17-19.

114.Negussie, T. 2004. Epidemiology of lentil rust in Ethiopia with special reference to disease progress and yield loss assessment. Ph.D. Thesis, University of the Free State, Bloemfontein, South Africa.
115.Negussie, T., Bejiga, G. and Million, E. 1998. Lentil rust outbreak called the attention of farmers to variety 'Dimma'. *AgriTopia* 13(1):11.
116.Negussie, T. and Pretorius, Z.A. 2005. A settling tower for quantitative deposition of urediniospores of Uromyces viciae-fabae. *S. Afr. J. Plant Soil* 22(3):141-144.
117.Negussie, T., Pretorius, Z.A. and Bender, C.M. 2005a. Effect of some environmental factors on In Vitro germination of urediniospores and infection of lentils by rust. J. Phytopathol 153:43-47.
118.Negussie, T., Pretorius, Z.A. and Bender, C.M. 2005b. Components of rust resistance in lentil. Euphytica 142:55-64.
119.O'Banen, J.H. 1975. Nematode Survey. FAO Working paper (ETH/74/002/IAR), Rome.
120.Plant Protection Research Center (PPRC). 2003. Progress report for the period 2002/2003. Ambo.
121.PPRC. 1995. Highland Pulses. Annual report for the period of 1994/1995, Ambo.
122.PPRC. 1996. Progress report for the period 1995/96. Ambo.
123.PPRC. 1998. Progress report for the period 1997/98. Ambo..
124.PPRC. 2000. Progress report for the period 1999/2000. Ambo.
126.Singh, K., Rawl, H.S., Singh, S. and Gumber, R.K. 1995. Physiologic specialization in Uromyces fabae causing rust of lentil. *Lens Newsl* 22:46-47.
127.Stewart, R.D. and Dagnachew, Y. 1967. Index of plant disease in Ethiopia. Experiment Station Bulletin No. 30. HSIU, College of Agriculture. Debre Zeit.
128.Tadesse, N., Ali, K., Gorfu, D., Yusuf, A., Abraham, A., Ayalew, M., Lencho, A., Makkouk, K. and Kumari., S.G. 1999a. Survey for chickpea and lentil virus diseases in Ethiopia. *Phytopathol. Mediterr*. 38: 149-158.
129.Tadesse, N., Ali, K., Gorfu, D., Yusuf, A., Abraham, A., Ayalew, M., Lencho, A., Makkouk, K. and Kumari., S.G. 1999b. First report of soybean dwarf virus infecting lentil and beet western yellows virus infecting lentil and chickpea crops in Ethiopia. Plant Dis. 83: 589.
130.Tadesse, N., Bejiga, G. and Ayalew, M. 1998a. Survey and identification of major organisms causing wilt and root rots and their relative importance in chickpea and lentil in Ethiopia on Cool-season Food Legumes and Cereals. Regional Networks Annual Report 1997/98. Cairo, Egypt.
131.Tadesse, N., Bejiga, G. and Ayalew, M. 1998b. Fusarium wilt of chickpea and lentil in Ethiopia: Race identification and pathogen variability. Pp 35. *In:* Nile Valley and Red Sea Regional Program on Cool-season Food Legumes and Cereals. Regional Networks Annual Report 1997/98. Cairo, Egypt.
132.Tadesse, N., Yusuf, A. and Makkouk, K.M. 1999c. Natural occurrence of Beet Western Polerovirus on chickpea and lentil in Ethiopia. *NVRSRP Newsletter* 2:32.
133.Teame, G. 2000. Effects of leaf age of faba bean and inoculum level of Uromyces viciae-fabae on pustule development and spore production. *Pest Mgt. J. Eth.* 4(1and2): 41-49.
134.Tefera, T. 2001. Seed transmission of bean common bacterial blight and its influence on yield. *Tropical Science* 41: 185-191.
135.Tesfaye, B. 1995. Evaluation of faba bean cultivars for resistance to black root rot (Fusarium solani). Proceedings of The Third Annual Conference of The Crop Protection Society of Ethiopia, 18-19 May, Addis Ababa, Ethiopia. Pp. 201-206.
136.Tesfaye, B. 1997. Loss assessment study on haricot bean due to anthracnose. *Pest Management Journal of Ethiopia*. 1(1and2): 69-72.

137. Tesfaye, B. 1999a. Evaluation of the potential of Trichoderma viride as biological control agent root rot diseases, Fusarium solani, of faba bean. *Pest Management Journal of Ethiopia*. 3:91-94.
138. Tesfaye, B. 1999b. Determination of diversity of Colletotrichum lindemuthianum in Ethiopia. *Pest Management Journal of Ethiopia*. 3 (1&2) 77-82.
139. Tesfaye, B. 2003. Biology and control of bean anthracnose (*Colletotrichum lindemuthianum*) in Ethiopia. Ph.D. Thesis, South Africa, Free State University, pp.145.
140. Tesfaye, B. and Pretorius, Z.A. 2005. Seed treatment and foliar application of fungicide for the control of bean anthracnose. *Pest Management Journal of Ethiopia.* 9: 57-62.
141. Tsedeke, A. (Editor). 1986. A review of Crop Protection Research in Ethiopia (Tsedeke Abate, ed.). Proceedings of First Ethiopian Crop Protection Symposium, 4-7 Feb. 1985, Addis Ababa, IAR, Ethiopia.
142. Yitbarek, S. 1990. Screening of faba bean for chocolate spot and rust. Pages 29-30 in Nile Valley Regional program on Cool Season Food Legumes, Annual Report 1989/90. Ethiopia. ICARDA/NVRP-DOC-001.

Review of Weed Research in Highland and Lowland Pulses

Rezene Fessehaie[1] *and Kedir Nefo*[2]
[1]*Ethiopian Institute of Agricultural Research, P.O. Box 2003*
[2]*Oromia Agricultural Research Institute*

Introduction

Pulse crops are the most widely cultivated grain legumes in the Ethiopian farming systems. They are essential part of the dietary requirement of most Ethiopians. The edible seeds of food legumes serve as an important protein supplement in the cereal based Ethiopian diet. Pulses also form a significant export commodity group and help earn important hard currency for the country. According to Central Statistics Authority (CSA) between September 2001 and August 2002, 123,000 t of pulses valued at Birr 352 million were exported to different countries (CSA, 2002).

Pulse crops are not widely grown as cereals in the country in terms of area and cultivation. The contribution o these crops in 2001/2 crop season in terms of area and production to the country's total crop area and production was about 13% and 9%, respectively. Faba bean, chickpea, haricot bean and field pea are the major pulse crops that are produced in terms of area and production (CSA, 2002).

Faba bean and lentil are very sensitive to weed competition from seedling establishment to early flowering stages. Field peas are not as sensitive to early weed competition as many of the other legumes. However, yield reduction can occur if there is no attention to weed control. Chickpea is sensitive to early weed competition and is less competitive than lentils. However, because it is sown late in the season and grown in residual moisture, it seldom encounters much weed competition (Rezene, 1994)

The results across different crops, years and locations invariably showed that lowland pulse crops are especially sensitive to weed competition in the first four weeks after sowing. One timely, early weeding at 25 days after emergence resulted in 70% yield increase of haricot bean and up to 300% increase in cowpea compared to the control (no weeding). Similar results were also obtained on soybean

Hand weeding is the major weed control method used in pulses production and is labor intensive and slow compared to other manual weeding operations and is usually delayed until the weeds are tall enough to be firmly held in the hand. Thus, these crops suffer from the adverse effects of early weed interference because of delayed weeding. Generally, herbicides are not recommended for subsistence agriculture at this time unless grown for large scale commercial production.

Past weed research activities in highland and lowland pulses were reviewed by Rezene (1986; 1994). The aim of this paper is to give a broad view of recent information in weed research in pulse crops that have been accumulated in Ethiopia since the last two decades.

Research findings

Composition of the weed flora

Available survey records indicated that there are about 61 species in 53 genera and 21 plant families known to be problematic weed species in highland and lowland pulses. Species of *Asteraceae* are the most common followed by *Polygoniaceae*, *Poaceae* and *Solanaceae*. The weed species reported to cause major problems in pulse crops production (Appendix 1).

Basic studies

Weed surveys

Major surveys carried out during this period include

- Occurrence of broomrapes *(Orobanche spp.*) and dodder (*Cuscuta spp.)* in high land pulses (HP);
- Distribution and economic importance of *Orobanche* spp. in North and Northwestern Ethiopia;
- Qualitative and quantitative determination of faba bean weeds in West and Northwestern Shewa; and
- Weed survey in major field pea and faba bean growing areas of Bale highlands

Occurrence of broomrapes and dodder

The survey methodology applied under this report allowed rapid data collection on the occurrence of the target parasites and was found to be useful as indicative tool for future work. The survey was carried out to identify broom rapes (*Orobanche* spp) and dodder (*Cuscuta* spp) species attacking HP and their associated hosts and to determine the geographical distribution and hot spot areas. Questionnaires were sent to cooperators at various research centers, Regional Bureaus of agriculture, agricultural colleges and plant health clinics to supply specific information on the distribution, host range and economic importance of *Cuscuta* and *Orobanche* species in cultivated lands of their respective areas.

.

This survey covered all HP growing areas of Ethiopia with the exception of Benshangul Gumuz Region. Results indicated that out of the 3 species reported, *Orobanche crenata* was found to be an actual and potential threat to HP production particularly with more pronounced effect in faba bean fields in Kedijo and Haroye-Flagober (Tables 1 and 2).

Table 1. Records of species composition, distribution and host range of *Orobanche* species in HP surveyed areas

Species	Host crops	Distribution	Hot spot areas
Orobanche minor	Extremely wide ranges of hosts: Faba bean, clovers, including non-crop hosts in Compositae, Solanaceae and Umbeliferae and wild Trifolium	Widely spread through out the high land pulses growing areas under report	None
Orobanche ramose	Faba bean, chickpea, lentil, field pea, clovers including long list of wild hosts in *Chenopodiaceae, Amaranthaceae, Rubiaceae, Oxalidiaceae, Lineaceae, Polygoniaceae, Labiatae* and *Plantiginaceae*	Some localized situation of highland pulses growing areas of Arsi, West Shewa in Chelia wereda (neighboring localities of Guder).	None
Orobanche crenata	- Chickpea, faba bean, lentil, and field pea. The crop most affected was reported to be faba bean. Non crop hosts reported were members of *Leguminosae*, *Umbeliferae*, and *Compositae*	North Welo, South Gonder and and South Tigray	Kedijo, Geter(Gerado) SE of Dessie; Kutaber North of Dessie; Dara and Tatch Gayint (South Gonder) and Korem area (southern Tigray)

Source: HARC, 2001

Table 2. Results of questionnaire survey on the occurrence of *Orobanche* and *Cuscuta spp.* in HP surveyed areas of Ethiopia

District / *wereda*	Zone	Crop(s)	Status *Orobanche* spp		
			Species	Importance[a]	Spread[b]
Dita darmallo	North Omo	Fb	*Orobanche sp*	x	L
Kobo	North Wello	Fb, Cp	*O. minor*	xx	M
All districts	Sidama	Fb	*O. minor*	x	M
Habru	North Welo	Fb, Cp, Ln,	*O. minor*	x	M
Tehule Dere	South Welo	Fb, Cp, Ln,	*Orobanche sp*	x	M
Ambassel	South Welo	Fb, Cp, Ln,	*Orobanche sp*	xx	M
Dessie Zuria	South Welo	Fb	*O. crenata*	xxx	W
Woldeya	South Welo	Fb	*Orobanche sp*	x	L
Babile	East Harerge	Fb	*Orobanche sp*	xx	L
Chilga	North Gonder	Fb, Cp, Ln	*Orobanche sp*	xx	M
Gonder Zuria	North Gonder	Fb, Cp, Ln	*Orobanche sp*	xx	M
Belessa	North Gonder	Fb, Cp, Ln	*O. minor*	x	M
Dara	South Gonder	Fb, Cp, Ln	*O. crenata*	xxx	W
Tatch Gayint	South Gonder	Fb, Fp	*O. crenata*	xxx	W
Meseia	West Hararge	Fb	*Orobanche sp*	x	L
Darolabu	West Hararge	Fb	*Orobanche sp*	x	L
Boke Habro	West Hararge	Fb	*Orobanche sp*	x	L
Quni	West Hararge	Fb	*Orobanche sp*	x	L
Guba Koricha	West Hararge	Fb	*Orobanche sp*	x	L
Alamata	South Tigray	Fb	*O. crenata*	xxx	W
Korem	South Tigray	Fb	*O. crenata*	xxx	W
Raya Azebo	South Tigray	Fb	*Orobanche sp*	x	L
Adwa Zuria	South Tigray	Fb	*Orobanche sp*	x	L
Tahtay Keraro	Tigray	Fb	*Orobanche sp*	x	L
Wekero	Tigray	Fb, Cp, Ln	*O. minor*	x	L
Afla	Tigray	Fb	*Orobanche sp*	x	M
Inda Mehoni	South Tigray	Fb	*Orobanche sp*	x	M
Indetrta	Central Tigray	Fb	*Orobanche sp.*	x	M
Mekele	Central Tigray	Fb	*O. minor, O. ramosa*	xx	M
Wajrat	Tigray	Fb	*Orobanche sp*	x	M
All districts	East Welga	Fb	*O. minor*	xxx	W
All districts	West Welga	Fb	*O. minor*	xxx	W
All districts	Arsi and Bale	Fb, Fp, Cp	*O. minor, O. ramosa*	xx	M
All Districts	East Gojam	Fb, Cp, Ln	*O. minor*	xx	L
All Districts	West Gojam	Fb, Cp, Ln	*O. minor*	xx	M
All Districts	Bahr Dar Zuria	Fb, Cp, Ln	*O. minor*	xx	M
All Districts	West Shewa	Fb, Cp, Ln	*O. minor, O. ramosa*	xx	M
All Districts	East Shewa	Fb, Cp, Ln	*O. minor, O. ramosa*	xx	M
All Districts	North Shewa	Fb,Fp	*O. minor*	x	L

[a]*Importance:*
[b]*Spread: L = Localized; M = Moderately spread; W = Widely spread, xxx = Very serious (heavy yield loss); xx = Serious (moderate yield loss); x = Not serious (present but no effect on crop).*
Fb = Faba bean, Fp = Field pea, Cp = Chickpea, Ln = Lentil
Source: HARC, 2001

There are already pocket areas in Dara and Tach Gayint in South Gonder and Alamata in South Tigray where severe infestation of this species has been recorded. Thus, there could also be a real danger for the HP production areas of Northern and Northwestern Ethiopia to be invaded by *O. crenata* (Rezene, 1998).

All cooperators did not indicate the incidence of *Cuscuta* spp. But, this by no means could be considered to reflect the real situation as all HP were reported among the host range checklist of this parasite.

Distribution and importance of *Orobanche* in faba bean production areas

The discovery of crop damaging species of *Orobanche* in cool season food legumes in Ethiopia indicated the hazard of the spread of this parasite and the necessity of precautions against its spread. In earlier reports (Rezene, 1986; 1994) *Orobanche* was not often considered a problem for subsistence farming systems of highland food legumes production areas. Asefa and Endale (1994) reported that *O. crenata* was observed as a new invader in faba bean fields at two localities in South Welo: Kedijo Geter (Gerado), and Kutaber. At that time even though the introduction of this species was questionable, no follow up has been made to confirm the existence of the parasite in these localities. Later, specific follow up surveys were conducted at two locations in *Orobanche* infested areas of selected districts of Gojam, Gonder and Wello during 1998-2001 (Besufikad et al., 1999; AARC, 2002).

Orobanche survey results in Gojam and Gondar are summarized in Table 3. Results indicated that the average prevalence (percentage of crop fields infested) by the parasite across all surveyed districts was higher in field pea than faba bean. However, the highest infestation level of *Orobanche* species was recorded for faba bean at Tatch Gayint followed by field pea in the same district. Data herein confirmed the earlier report by Adugna et al., (1998) where crop-damaging species of *Orobanche* was observed in faba bean fields of Dara and Tatch Gayint of South Gonder.

Table 3. Prevalence (percent of infested crop fields) and infestation levels of *Orobanche* on faba bean and field pea in Gojam and Gonder

Locations	Faba bean		Field pea	
	Prevalence	Intensity Level [a]	Prevalence	Intensity Level [a]
Mecha	-	-	-	-
Yilmana Densa	0	0	-	-
Bahir D. Zuria	66.7	1	-	-
Machakel	0	0	-	-
Gozamin	25	1	0	0
Baso-Liben	0	0	33	2
Bibugne	0	0	0	0
Awabel	0	0	25	1
Goncha-Siso	14.3	1	100	2
Debark	0	0	-	-
Dabat	0	0	-	-
Estie	0	0	-	-
Tatch-Gayint	68.2	5	53.8	3
Lay-Gaint	30.8	2	30	2
Simada	63.6	1	23.5	1
Farta	27.3	1	16.7	1
Ebenat	-	-	-	-
Prevalence by crop	19.7	-	31.3	

[a]*Intensity of infestation in faba bean fields were estimated using the following scale: Level 0 = no Orobanche; Level 1 = Orobanche sporadically present; Level 2 = Orobanche present in the entire field; Level 3 = Majority of the host plant with up to two Orobanche shoots; Level 4 = All host plant with more than two Orobanche shoots --- the field retains the character of faba bean fields; Level 5 = Faba beans are barely visible --- (the field resembles an Orobanche field); Level 6 = Field completely destroyed by Orobanche: (no yield expected)*

Source: AARC, 2002

In South Wello, the prevalence and distribution of the parasite is extremely high at Kedijo than Flagober (Tables 4 and 5). Owing to this problem, large faba bean farms have already been replaced by wheat and oil crops. The undulating topography of the area (3–5% slope); along with dispersal agents of wind and flood, contribute to the spread and possible contamination of grazing areas by the parasitic weed.

Table 4. *Orobanche* shoot count and infestation level at Kedijo peasant association.

Surveyed plot No.	Area (ha)	Weed prevalence score (0-6 scale)	live* faba bean shoots/m^2	Dead** faba bean shoots/m^2	Weed count (t/m^2)	*Orobanche* shoot plant^{-1} (mean)
1	0.03	6	0	67	248	14
2	0.06	4	30	6	69	6
3	0.06	4	17	33	115	5
4	0.05	4	17	51	108	7
5	0.02	4	8	28	55	4
6	0.09	5	9	59	149	6
7	013	6	0	18	127	9
8	0.50	4	14	24	150	14
9	0.50	3	16	15	41	2
10	0.13	4	4	34	164	6
	Total	3-6	115	335	1226	2-14
	Mean	4	11.5	33.5	122.6	7

**Infested faba bean shoots with harvestable green pods*
***Dead faba bean shoots (no harvestable product)*
Source: Besufekad et al.., 1999

Table 5. *Orobanche* shoot count and infestation level at Haroye - Flagober peasant association.

Surveyed plot No.	Assessed farm size (ha)	Weed prevalence level (0-6 scale)	Live* faba bean (shoots/m^2)	Dead** faba bean (shoots/m^2)	*Orobanche* species (count/m^2)	Shoots/faba bean plant (mean)
1	0.13	5	8	46	119	6
2	0.02	4	21	0	109	6
3	0.03	5	10	27	301	8
4	0.25	5	9	25	108	8
5	0.13	5	0	58	148	11
6	0.20	5	7	33	154	5
7	0.13	4	28	49	57	5
8	0.25	3	26	39	88	4
9	0.25	4	30	19	43	4
10	0.25	1	8	26	120	5
Total		1-5	147	322	1247	4-11
Mean		4	14.7	32.2	124.7	6

**Infested faba bean shoots with harvestable green pods*
***Dead faba bean shoots (no harvestable product)*
Source: Besufekad et al.., 1999

At both locations, the practice of harvesting green pods is becoming customary so as to prevent further yield loss by the weed. According to farmers, crop loss could reach as high as 75–100% (Besufikad et al., 1999).

Farmers in Kedijo area indicated that the weed appeared for the first time in 1983 in Dehit area (Goshim locality). But they were not familiar with the weed and could not realize the potential threat at the time. This area seems to have been the source of infestation for all other areas in Kedijo. The way in which the weed was introduced into the country at large is still unknown. There was an erroneous speculation that the species occurring in the area was *Orobanche crenata* brought in with imported crop seeds (Assefa and Endale, 1994).

Farmers continually uproot the weed, 4–5 times, with a local implement called '*Ankase*' (an implement with sharp pointed end) and mattock. The removal of the weed by hand pulling is laborious as new flushes of the weed appear every 2–3 days after weeding. In the effort to prevent the weed by hand pulling much labor is wasted which otherwise could be used for other farm activities. There are conflicting ideas among farmers concerning the impact of soil fertility on the weed. Some farmers suggested that the application of manure reduces the damage and hence helps the crop to resist the attack. Others suggested that cattle manure aggravates the infestation as it can contain weed seeds.

In Haroye - Flagober peasant association, *Orobanche* existed in the area since 1980 in the low elevations (2690–2710 m) growing among shrubs and bushes. Farmers of both high and low elevations were using the weed to treat wounds and sores. Farmers pointed out that the primary sources of infestation were neighboring lowland areas, from where farmers have brought the weed to their area as a medicinal plant. Furthermore, the weed was thought to have been introduced from Kedijo area by means of farm tools and planting materials (seeds) (Besufikad et al., 1999).

During the assessment it was noticed that the weed was as tall as and sometimes even taller and more vigorous than the faba bean crop. Frequent hand weeding (on average five times) is the usual practice that creates shortage of labor for the other farm activities. At Haroye-Flagober, one can observe severe infestation of *Orobanche* from flowering up to the harvesting period of faba bean. Seeds of the weed that shatter become the source of infestation for subsequent seasons.

All surveyed faba bean fields (range 0.02–0.25 ha) were infested. The average prevalence level was four with more than two shoots per faba bean plant. On a 1 x 1 m area, 43–301 *Orobanche* shoots were counted. From the same sample area, an average number of 125 *Orobanche* shoots and 15 live but parasitized faba bean plants were recorded. The average of *Orobanche* shoots on a single faba bean plant was six.

Qualitative and quantitative determinations of weeds

Qualitative and quantitative determinations of weeds in faba bean fields were conducted in 9 and 5 *weredas* of West and Northwest Shewa zones, respectively, during 2000–2001. The frequency, abundance, dominance and species composition of weeds occurring in faba bean fields were determined (HARC, 2002).

In West Shewa Zone, the frequency and dominance level of individual weed species ranged from 0.48% to 60.09% and 0.01% to 8.36%, respectively. Similarly, the respective order of frequency and dominance level of individual weed species for North Shewa Zone of Oromiya Region were 12.03% to 86.57% and 0.49 % to 15.43 % (Beyenesh, 1989).

Only weed species which has frequency and infestation levels greater than 25% and 2.5%, respectively were considered as major weeds because they constituted more than 30% of the total weeds infesting faba bean fields. In this regard, the most frequent, abundant and dominant weed species for both zones were *Guizotia scabra, Cerastrium octandrum, Plantago lanceolata, Phalaris paradoxa, Polygonum nepalense, Medicago polymorpha,* and *Spergula arvensis* (Tables 6 and 7). Similarly, major weeds for West Shewa Zone were *Corrigiola capensis, Avena fatua, Setaria pumila and Snowdenia polystachya* (Table 6). For North Shewa *Galium spurium, Alchimela* sp., *Bromus pectinatus, Juncus bufonius, Galinsoga parviflora, Commelina benghalensis, Athraxon quantinanus* were determined as major weed species (Table 7). Forty weed species were identified which belong to 18 plant families. Overall, *Poaceae* and *Asteraceae* contributed nine and six species, respectively. Most weed species important to faba bean belong to these families, although there are other families with a single species that cannot be ignored. All faba bean fields were severely plagued by '*meskel'* flowers (*Bidens pachyloma, B. peristenaria* and *Guizotia scabra*) (Beyenesh, 1989).

Table 6. Major weeds of faba bean recorded in West Shewa

Species	Characteristics[1]			F[2]	D	A
Amaranthus hybridus	a	d	rs	1.44	0.03	0.01
Bidens pachyloma	a	d	rs	12.98	1.47	0.43
Galinsoga parviflora	a	d	rs	13.46	1.91	0.56
Gnaphalium unionis	a	d	rs	12.98	1.43	0.42
Guizotia scabra	a	d	rs	60.09	5.81	1.70
Launea cornuta	p	d	rs/rv	1.92	0.41	0.12
Capsella bursa-pastoris	a	d	rs	0.48	0.003	0.001
Raphanus raphanistrum	a	d	rs	0.48	0.003	0.001
Cerastium octandrum	a	d	rs	31.25	3.45	1.01
Corrigiola capensis	a	d	rs	46.63	12.83	3.75
Spergula arvensis	a	d	rs	33.65	3.01	0.88
Commelina benghalensis	a/p	m	rs/rv	14.90	1.19	0.35
Cyperus rotundus	p	m	rs/rv	2.88	0.27	0.08
Satureya paradoxa	a	d	rs	18.26	1.84	0.54
Medicago polymorpha	a	d	rs	40.38	3.38	0.99
Oxalis latifolia	p	d	rs/rv	11.05	1.30	0.38
Plantago lanceolata	b	m	rs/rv	36.0	3.08	0.90
Athraxon quartinianus.	a	m	rs	1.92	0.34	0.10
Avena fatua	a	m	rs	37.01	3.32	0.97
Bromus pectinatus	a	m	rs	17.30	1.23	0.36
Cynodon dactylon	p	m	rs/rv	2.40	0.17	0.05
Digitaria scalarum	p	m	rs/rv	10.09	1.02	0.30
Eragrostis spp.	a	m	rs	2.40	0.17	0.05
Lolium temulentum	a	m	rs	5.76	0.41	0.12
Panicum sp.	a	m	rs	17.78	2.12	0.62
Phalaris paradoxa	a	m	rs	26.44	2.50	0.70
Setaria pumila	a	m	rs	35.57	3.59	1.05
Snowdenia polystachya	a	m	rs	28.36	4.14	1.20
Polygonum aviculare	a	d	rs	13.46	0.99	0.29
Polygonum nepalense	a	d	rs	25.0	2.80	0.82
Rumex bequartii	p	d	rs/rv	12.98	0.85	0.25
Anagalis arvensis	a	d	rs	3.36	0.13	0.04
Caylusea abyssinica	a	d	rs	4.32	013	0.04
Galium spurium	a	d	rs	4.80	0.34	0.10

[1]a = annual; p = perennial; b = biennial
d = dicot; m = monocot; rs = reproduction by seed; rv = reproduction by vegetative means
[2]F= Frequencey; D = Dominance; A = Abundance.
Source: HARC, 2002

Table 7. Major weeds of faba bean recorded in North Shewa.

Species	Characteristics[1]			F[2]	D	A
Anthemis tigreensis	a	d	rs	36.57	4.18	0.93
Bidens pachyloma	a	d	rs	12.03	1.03	0.23
Galinsoga parviflora	a	d	rs	27.31	2.16	0.48
Gnaphalium unionis	a	d	rs	19.44	1.89	0.42
Guizotia scabra	a	d	rs	25.46	1.93	0.43
Cerastium octandrum	a	d	rs	33.79	3.69	0.82
Corrigiola capensis	a	d	rs	21.75	2.20	0.49
Spergula arvensis	a	d	rs	25.00	2.43	0.54
Commelina benghalensis	a/p	m	rs/rv	24.53	2.16	0.48
Cyanotis barbata	a/p	m	rs/rv	7.87	0.49	0.11
juncus bufonius	p	m	rs/rv	32.40	7.38	1.64
Satureya paradoxa	a	d	rs	4.62	0.81	0.18
Medicago polymorpha	a	d	rs	86.57	15.43	3.43
Plantago lanceolata	b	m	rs/rv	27.31	2.79	0.62
Athraxon quartinianus.	a	m	rs	22.22	3.75	0.75
Avena fatua	a	m	rs	22.68	1.57	0.35
Bromus pectinatus	a	m	rs	34.72	4.41	0.98
Eichinocloa colona	a	m	rs	6.01	0.67	0.15
Lolium temulentum	a	m	rs	7.40	0.81	0.18
Panicum sp.	a	m	rs	12.96	2.83	0.63
Phalaris paradoxa	a	m	rs	48.61	10.17	2.26
Setaria pumila	a	m	rs	12.96	0.54	0.12
Snowdenia polystachya	a	m	rs	15.74	3.28	0.73
Polygonum nepalense	a	d	rs	68.98	13.41	2.98
Rumex bequartii	p	d	rs/rv	14.35	1.48	0.33
Alchimella sp.	p	d	rs/rv	43.98	4.72	1.05
Galium spurium	a	d	rs	38.88	4.09	0.91

[1]a = annual; p = perennial; b = biennial
d = dicot; m = monocot; rs = reproduction by seed; rv = reproduction by vegetative means
[2]F = Frequency; D = Dominance; A = Abundance
Source: HARC, 2002

The similarity index (SI) matrix of weed species in faba bean growing areas of the surveyed locations is shown in Table 8. If the index of similarity is below the threshold value, 60%, it is said that the two locations have different weed communities. This helps to use the same kind of management for the areas having similar weed communities (SI >60%) and different weed management systems for areas having different weed communities (SI < 60%).

Table 8. Indices of weed communities in faba bean fields at different locations in West and North Shewa zones.

X	WE	DE	EJ	AM	CH	WO	JE	IL	AG	SU	YD	KU	WU	DE
Welmera (WE)	100													
Dendi (DE)	29.4	100												
Ejerie (EJ)	68.6	32.1	100											
Ambo (AM)	42.2	28.6	54.5	100										
Chelia (CH)	50.0	25.0	60.9	70.6	100									
Wonchi (WO)	39.4	44.4	38.5	42.1	42.9	100								
Jeldu (JE)	24.2	37.5	26.9	35.3	38.9	42.9	100							
Illu (IL)	9.1	6.7	14.3	6.3	11.1	7.1	9.1	100						
Alemgena (AG)	30.3	27.8	36.0	50.0	28.6	53.3	21.4	7.7	100					
Sululta (SU)	60.5	45.8	57.1	50.0	55.0	66.0	42.9	8.7	40.0	100				
Y.G.&D.L (YD)	60.0	48.1	58.7	48.0	46.2	60.0	33.3	10.5	45.0	81.5	100			
Kuyu (KU)	52.6	45.5	52.0	52.4	45.8	50.0	40.9	10.0	33.3	31.5	70.4	100		
Wuchale (WU)	60.0	50.0	58.6	50.0	54.2	60.0	40.9	11.1	41.7	88.9	92.6	70.4	100	
Degem (DE)	58.8	37.5	62.9	61.9	52.0	60.6	38.1	17.4	42.9	65.5	76.0	86.4	80.8	100

Source: HARC, 2002

Weed survey in Bale highlands

The survey was conducted in field pea production areas of Sinana, Gasera and Agarfa districts during *'Belg'* season only. During the '*meher*' season both field pea and faba bean fields were surveyed at Agarfa, Gasera and Dinsho and field pea only at Sinana.

A total of 43 weed species were identified. The most important weed species in both crops were *Guizotia scabra, Galinsoga praviflora, Bromus pectinatus, Galium spurium* and *Amaranthus hybridus*. During '*belg*' season, the frequency and dominance of individual weed species ranged from 3.7 to 87% and 0.06 to 13.9%, respectively, in field pea fields. However, in the *bona* (*meher*) season, the frequency of individual weed species ranged from 5.6 to 75% and 11.1 to 88.9% for field pea and faba bean, respectively. The dominance level was 0.4 to 16.2 and 0.5 to 20.5 for field pea and faba bean, respectively. Weed species having frequency and dominance levels below 5.0 and 0.4%, respectively, were excluded since they occurred rarely and at low densities (Tables 9 and 10).

Table 9. Weed composition, frequency, and dominance in field pea in Sinana, Agarfa and Gasera in '*belg*', 1997

Botanical name	Frequency (%)	Dominance (%)
Guizotia scabra	87.0	11.60
Phalaris paradoxa	12.4	0.70
Erucastrum arabicum	16.2	0.40
Galinsoga parviflora	70.5	13.90
Digitaria scalarum	64.6	7.60
Scorpiurus muricatus	14.1	0.80
Flaveria trinevia	25.5	6.50
Tagetes minuta	21.5	1.50
Galium spurium	79.1	5.20
Bidens pilosa	31.9	6.30
Chenopodium spp.	32.3	1.10
Amaranthus hybridus	46.9	5.50
Anagalis arvensis	64.2	4.40
Plantago lanceolata	45.0	4.10
Leucas martinicensis	29.6	3.60
Corrigiola capensis	19.2	1.60
Euphorbia spp.	7.0	0.06
Fallopia convolvulus	16.2	2.20
Polygonum nepalense	7.0	0.20
Commelina benghalensis	48.4	6.40
Lolium temulentum	13.8	0.60
Chenopodium procerum	25.5	1.20
Medicago sativa	7.0	0.50
Cynodon dactylon	6.0	0.50

*a = annual; b = biennial; p = perennial
Source: Kedir et al., 1999

Table10. Weed composition, frequency, and dominance in field pea and faba bean fields of Sinana, Gasera, Agarfa and Dinsho in *'meher',* 1997

Botanical name	Frequency		Dominance	
	Field pea	Faba bean	Field pea	Faba bean
Guizotia scabra	75.0	81.5	10.1	11.3
Erucastrum arabicum	44.4	-	5.1	-
Galinsoga parviflora	47.2	88.9	6.4	20.5
Digitaria scalarum	44.4	22.1	2.3	0.8
Scorpiurus muricatus	55.6	-	10.2	-
Bromus pectinatus	41.6	44.5	16.2	6.8
Tagetes minuta	13.9	-	1.24	-
Galium spurium	50.0	79.1	8.8	5.2
Bidens pilosa	5.6	-	0.1	-
Chenopodium spp.	63.9	77.8	6.2	11.6
Amaranthus hybridus	36.1	85.2	5.0	10.9
Plantago lanceolata	13.9	45	1.51	4.1
Euphorbia spp	5.6	-	0.1	-
Polygonum nepalense	5.6	37	0.2	2.2
Commelina benghalensis	25.0	14.8	0.9	3.2
Lolium temulentum	5.6	-	0.9	-
Snowdenia polystachya	8.3	7.4	0.6	0.5
Ageratum conyzoides	8.3	11.1	6.4	9.8
Raphanus raphanistrum	8.3	32.2	0.3	0.98
Cyperus blysmoides	25.0	29.6	8.4	4.1
Medicago sativa	25.0	-	1.3	-
Cynodon dactylon	11.1	-	0.4	-
Solanum nigrum	-	25.9	-	0.83
Spergula arvensis	-	11.1	-	0.80

*a = annual; b = biennial; p = perennial; - = weed species with low density and frequency
Source: (Kedir et al., 1999)

The similarity index across locations, between the two crops and seasons were less than 60% (Tables 11), indicating the variation of weed species composition across locations, among seasons and crops. Taye and Yohannes (1998) indicated that if the similarity index among locations or between seasons is less than 60%, the weed composition of locations or seasons should be considered as different.

Table 11. Similarity index (%) of weed communities in field pea and faba bean fields at different locations in Bale highlands

A. Field pea, *meher* season, 1997

Locations	Sinana	Agarfa	Dinsho
Sinana	100		
Agarfa	45.8	100	
Dinsho	56	54.16	100

B. Faba bean, *meher* season, 1997

Locations	Gasera	Agarfa	Dinsho
Gasera	100		
Agarfa	38.8	100	
Dinsho	40.00	29.40	100

C. Field pea, *belg* season, 1997

Locations	Sinana	Agarfa	Gasera
Sinana	100		
Agarfa	47.05	100	
Gasera	60.97	58.8	100

Source: (kedir et al., 1999)

Even though the same major weed species were found in faba bean and field pea fields, the infestation level of a specific weed species in one crop was different from the other. For instance, *Galinsoga parviflora* infested faba bean fields up to 21%, but it represented only 6% of the weeds in field pea. Since farmers plough their fields more frequently for faba bean than for field pea, perennial grass weed infestation was prevalent in field pea fields. On the contrary, higher broadleaf weed infestation was observed in faba bean than in field pea fields (Kedir, 1999).

Galinsoga parviflora, *Amaranthus hybridus* and *Chenopodium* spp. were major weed species in faba bean, but they were not as common in field pea fields. However, *Digitaria scalarum* and *Commelina benghalensis* were the major weeds observed in field pea (Kedir, 1999).

Weed management methods

Research of weed management in pulse crops in Ethiopia during the past two decades were based on integrated weed management (IWM) focusing on how weed interference can be minimized by changes in crop management practices such as combined treatments of hand weeding times with mixed cropping, crop varieties with different growing habits, sequential application of hand hoeing timings with supplementary hand weeding, tillages and chemical control.

Cultural methods

Effect of time of single hand weeding

Faba bean and Field pea mixed cropping

Field experiments were carried out for three years at Holetta (1998–2000) and Denbi (1999–2000) to study the effect of time of single hand weeding on weed control in mixed cropping of faba bean and field pea. Weed control treatments were six single hand weeding timings during 2, 3, 4, 5, and 6 WAE. Farmers' weed control practice (no weeding) was also included for comparison.

Results of these experiments indicated that weed infestation levels were highly significant to reduce the combined seed yields of the companion crops (faba bean + field pea) in the untreated weedy check (the treatment which represented the local weeding practice by majority farmers in the testing locations). In contrast, weed density in all single hand weeded plots between 2 and 6 WAE was low to influence the combined seed yield of the test crops, and density of late emerging weeds was significantly lower in treatment weeded between 4 and 6 WAE. (HARC, 1999; 2000; 2001).

A participatory on-farm trial was conducted at Welmera and Chelia '*weredas'* to verify the effectiveness of single hand weeding timings coupled with the recommended mixed cropping pattern of faba bean and field pea.

Total seed yield of the companion crops (faba bean and field pea) differed significantly at Welmera and the highest yield was obtained from the single hand weeded treatment at six weeks after crop emergence (WAE) with a yield increase of 57.4% of the check yield 1113 kg ha^{-1}. The treatment weeded during the 4th WAE also significantly out yielded the check treatment resulting in a yield increase of 49.9% (Table 12). At Chelia hand weeding at 6 WAE resulted in numerically higher yield for both crops than the check treatment but differences were not significant (P = 0.05) (Table 13). Initiation of hand weeding timings at 4 and 6 WAE resulted in significantly reduced total weed biomass weight relative to the check treatment at both sites and the respective total weed biomass reduction was found to be 42.4% and 49.7% for Welmera and 8.0% and 27.7% for Chelia, respectively (Tables 14 and 15) (HARC, 2003; Rezene and Getachew, 2003).

Table 12. Effect of hand weeding treatments on weed control, Welmera, 2002

Treatment[a]	*General weed control score*[d]		Individual weed control score[d]		Weed biomass weight (kg ha^{-1})
	69 DAE[c]	113 DAE	*Guizotia scabra*	*Spergula arvensis*	
HW x 1 (4WAE)	2.7 ab[b]	2.7 b	1.3 b	2.0 b	850.0 b
HW x 1 (6WAE)	2.0 b	2.0 b	1.0 b	1.7 b	741.5 b
Farmers practice	3.7 a	4.7 a	4.0 a	3.7 a	1475.0a
CV%	18.97	16.94	24.97	13.64	12.38

[a] HW = Hand weeding; WAE = Weeks After Crop Emergence
[b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05)
[c] DAE = Days after crop emergence.
[d] Weed control score (scale 1.0 – 5.0) where: 1.0 = weeds effectively controlled and 5.0 = no effect on weed control.
Source:(HARC, 2003; Rezene and Getachew, 2003

Table 13. Effect of hand weeding treatments on faba bean and field pea yield, Chelia, 2002

Treatment[a]	Plant height (cm)		Crop biomass weight (kg ha^{-1})	Seed yield (kg ha^{-1})
	FB	FP	FB+FP	FB+FP
HW x 1 (4WAE)	109.9	152.0	2758.3	1902.9
HW x 1 (6WAE)	108.3	156.7	3425.0	2701.2
Farmers practice	113.8	156.0	3372.4	2532.2
CV%	12.01	6.49	23.61	18.67

[a] HW = Hand weeding; WAE = Weeks After Crop Emergence
Source: (HARC, 2003; Rezene and Getachew, 2003)

Table 14. Effect of hand weeding treatments on faba bean and field pea yield and yield components, Welmera, 2002

Treatment[a]	Plant height (cm)		1000 seed weight (g)		Crop biomass weight (kg ha^{-1})	Seed yield (kg ha^{-1})		
	FB	FP	FB	FP	FB+FP	FB	FP	FB+FP
HW x 1 (4WAE)	102.1	120.8	506.4	231.5	3586.5	599.0	941.5	1669.0 a[b]
HW x 1 (6WAE)	102.9	116.7	509.2	229.2	4593.5	712.5	969.0	1751.5 a
Farmers practice	106.6	120.4	509.2	236.0	3786.0	434.0	695.5	1113.0 b
CV%	5.47	2.60	4.82	3.18	20.63	28.53	23.38	14.67

[a] HW = Hand weeding; WAE = Weeks After Crop Emergence
[b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05)
Source: HARC, 2003; Rezene and Getachew, 2003

Table 15. Effect of hand hoeing and weeding treatments on weed control, Chelia, 2002

Treatment[a]	General weed control score[c]		Individual weed control score[c]			
	102 DAE[b]	119 DAE	PN[e]	SP	PP	GS
HH+HW (2+5WAE)	2.5	3.0	4.0	3.5	1.0	2.0
gHH+HW (2+7WAE)	2.0	1.5	4.0	4.5	2.0	1.0
Farmers practice	4.0	4.5	5.0	4.5	4.0	4.0
CV%	--[d]	--	--	--	--	--

[a] *HH= Hand Hoeing; HW = Hand Weeding; WAE = Weeds After Crop Emergence*

[b] *DAE = Days after crop emergence.*

[c] *Weed control score (scale 1.0 – 5.0) where: 1.0 = weeds effectively controlled and 5.0 = no effect on weed control.*

[d] *= Values are means of two trial sites and were not subjected to statistical analysis*

[e] *PN = Polygonum nepalense, SP = Snowdenia polystachya, PP = Phalaris paradoxa, GS=Guizotia scabra.*

Source: HARC, 2003; Rezene and Agajie, 2003

Comparing the recommended hand weeding treatment with their traditional practice (no weeding), host farmers in both locations said that a single hand weeding at 6 WAE is more preferable for mixed cropping of faba bean and field pea in its effectiveness in controlling late emerging weed species and reducing weed interference during early crop growth stage and time of harvesting. The same farmers also suggested that using weed control recommendation coupled with crop rotation are useful to increase crop yield and control late emerging weeds.

Effect of hand weeding timings on cow pea varieties

A hand weeding trial was conducted on two cowpea varieties with different growth habit at three sites in the Central Rift Valley area: Blackeye bean (erect type) and White Wonder Trailing (semi-erect type) (Giref and Etagegnehu, 1999). Although these varieties were morphologically different they had similar response to the timing of weeding operation. At Melkassa, one early weeding was sufficient to increase yield by three fold compared to the un-weeded control (Table 16). Cowpea showed similar response to early weeding at Welenchiti and Zeway. Their findings demonstrated that one timely early weeding could be sufficient for optimum performance of cowpea in dryland environments. Late weeding, regardless of the number of operations, did not improve crop yield.

Table 16. Effect of time of weeding on cowpea yield at Melkassa

Time of weeding	Black eye bean	White Wonder Trailing	Black eye bean	White Wonder Trailing
	1997		1998	
	Yield (kg/ha)		Yield (kg/ha)	
First trifoliate	1538	1460	1263	1968
First trifoliate + pod formation	1492	1528	1330	2010
Pod formation	596	722	655	930
Pod formation + pod filling	654	833	785	1135
Pod filling	551	592	550	820
Unweeded control	516	430	318	665
CV (%)	23		21.4	
LSD (5%)	332		340	

Source: Giref and Etagegnehu, 1999

Effect of seeding rates and weed control methods, Lentil

Field trials were conducted at Akaki to study the effects of seeding rates and weed management practices on grain yield of lentil and efficacy in controlling major weed species. The major weed flora recorded within the experimental plots was *Scorpiurus muricatus, Phalaris paradoxa, Launea cornuta* and *Plantago lanceolata* (DZARC, 1997).

Seeding rates did not show significant differences in grain yield and density of weed species except that of *Launea cornuta* where lower rates (60 and 70 kg ha^{-1}) resulted in lower count. Unlike seeding rates, weed management practices showed significant differences in seed yield, total weed biomass, and density of *Scorpiurus muricatus, Phalaris paradoxa* and *Launea cornuta*. Hand weeding twice and Topograd (2.0 ℓ ha^{-1}) gave higher yields, lower weed biomass and individual weed counts which indicated better efficacy in controlling weeds (DZARC, 1996; DZARC, 1997).

The interaction effects of seeding rates and weed management practices revealed that at all the seeding rates that used Topograd (2.0 l ha^{-1}) and hand weeding twice were better in increasing the grain yield of lentil and reducing populations of *Scorpiurus muricatus*. However, there was no significant interaction effect between the two factors in reducing total weed biomass and population of other weed species (Table 17).

Table 17. Effect of seeding rates and weed management practices on weed biomass and yield of lentil (Akaki, 1994-1996)

Treatments	Weed dry wt.		Seed yield (kg ha^{-1})	
	g m^{-2}	kg m^{-2}		
	1995	1996	1995	1996
Weeding methods				
Hand weeding x 1 30 dae*	38.0	1853	1145	1533
Hand weeding x 2 30+60 dae	13.3	906	1334	1533
Topogard	2.0	2069	1461	1494
Weedy check	19.3	2984	848	1267
LSD (0.05)	14.8	777.5	168	200
Seed rates				
60 kg/ha	25.1	195.0	1101	1467
70 kg/ha	15.0	1866	1307	1267
80 kg/ha	16.0	2016	1220	1353
90 kg/ha	16.3	1978	1160	1353
LSD (0.05)	NS	NS	NS	NS
WM x SR	**NS**	**NS**	**	**NS**

**dae = Days after crop emergence*

Source: DZARC, 1996; 1997

Effect of hand weeding and hand hoeing timings

Faba bean

A three-year study was initiated in 1998 to evaluate the influence of hand hoeing and hand weeding timings on faba bean production at Holetta and Denbi. Treatments were factorially arranged to establish interaction of initiation timings of hand hoeing and hand weeding on faba bean yield response.

When averaged over timing initiation of hand hoeing, the supplementary hand weeding treatments carried out during 5, 6, or 7 weeks after crop emergence (WAE) reduced dry matter weight weeds significantly compared to the zero supplementary hand weeding. However, differences of weed dry matter between the three supplementary hand weeding timings were not significant. As a whole, reduced weed dry matter weight associated with higher seed yield was obtained from hand hoeing at 2 WAE supplemented by hand weeding at 5-7 WAE (HARC, 1999; 2000; 2001).

Two hand weeding timings applied during 5 and 7 WAE after hand hoeing at 2 WAE were compared for maximum yield benefit of faba bean associated with effective control of early and late emerging weed species under on-farm participatory verification trials at Welmera and Chelia (HARC, 2003; Rezene and Getachew, 2003).

At Welmera biomass and seed yield of faba bean were significantly affected by weed control treatments. The treatments with supplementary hand weeding during 5 or 7 WAE yielded 44.5% or 28.7% more than the check yield (farmers practice receiving no weed control). The corresponding efficacy (i.e., percentage of weed biomass reduction) for the 5 or 7 WAE supplementary hand weeded treatments after the recommended hand hoeing (2 WAE) was 63.4% and 72.3% compared to the check treatment in that order (Table 18). At Chelia biomass and seed yield of the crop were not influenced by the weed control treatments. However, even though not at significant level the highest yield for this location was obtained from the sequential application of hand hoeing and hand weeding treatment applied during 2 and 7 WAE, respectively (Tables 19 and 20).

Table 18. Effect of hand hoeing and weeding treatments on weed control, Welmera – 2002

Treatment [a]	General weed control score[d]		Individual weed control score[d]				Weed biomass weight (kg ha^{-1})
	69 DAE[c]	113 DAE	PN[e]	SP	PP	GS	
HH+HW (2+5WAE)	2.3 b[b]	2.0 b	4.0	4.0	3.0	1.0 b	1617 b
HH+HW (2+7WAE)	1.3 b	1.3 b	3.7	3.3	3.0	1.3 b	1183 b
Farmers practice	4.3 a	4.7 a	3.7	3.3	3.0	4.0 a	4417 a
CV%	21.65	15.31	8.83	18.15	19.25	15.97	31.14

[a] HH= Hand Hoeing; HW = Hand Weeding; WAE = Weeds After Crop Emergence
[b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05)
[c] DAE = Days after crop emergence.
[d] Weed control score (scale 1.0 – 5.0) where: 1.0 = weeds effectively controlled and 5.0 = no effect on weed control.
[e] PN = Polygonum nepalense, SP = Snowdenia polystachya, PP = Phalaris paradoxa, GS=Guizotia scabra.
Source: HARC, 2003; Rezene and Agajie, 2003

Table 19. Effect of hand hoeing and weeding treatments on faba bean yield and yield components, Chelia, 2002

Treatment[a]	No. of pods plant^{-1}	No. Seed pod^{-1}	Plant height (cm)	Crop biomass wt. (kg ha^{-1})	Seed yield (kg ha^{-1})
HH+HW (2+5WAE)	12.2	2.5	119.5 b[b]	4666.7	1964.7
HH+HW (2+7WAE)	16.1	2.8	132.0 b	6041.7	2337.5
Farmers practice	13.9	2.8	139.8 a	5541.7	2012.2
CV%	13.6	6.48	3.64	26.36	41.46

[a] HH= Hand Hoeing; HW = Hand Weeding; WAE = Weeds After Crop Emergence
[b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05)
Source: HARC, 2003; Rezene and Agajie, 2003

Table 20. Effect of hand hoeing and weeding treatments on faba bean yield and yield components, Welmera – 2002

Treatment[a]	Crop stand (m^{-2})	No. of pods $plant^{-1}$	No. Seed pod^{-1}	Plant height (cm)	1000 seed wt. (g)	Crop biomass wt. (kg ha^{-1})	Seed yield (kg ha^{-1})
HH+HW (2+5WAE)	105.3	7.8	2.0	99.2	473.9	3231.7 a[b]	1362.3 a
HH+HW (2+7WAE)	114.6	5.3	2.5	90.0	478.5	2948.1 a	1213.5 a
Farmers practice	102.7	5.6	2.5	99.6	473.6	2278.3 b	942.7 b
CV%	7.99	31.32	11.35	5.57	2.98	13.89	18.03

[a] HH= Hand Hoeing; HW = Hand Weeding; WAE = Weeds After Crop Emergence
[b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05)
Source: HARC, 2003; Rezene and Agajie, 2003

Farmers in both locations believed that supplementary hand weeding during 7 WAE after the recommended hand hoeing at 2 WAE effectively controlled most late emerging weed species and improved crop performance. With regard to future use of the recommended weeding practices, 27% of 41 farmers in Chelia showed their interest to use hand hoeing with supplementary hand weeding if the hoeing implement is made available to them. However, farmers at Welmera suggested comparison of one early season hand weeding during 5 WAE without hand hoeing as alternative practice.

Effect of hand weeding timings on haricot bean

According to Tenaw et al. (1997), hand weeding significantly affected weed infestation intensity and crop yield parameters of haricot bean at Awassa (Table 21). The study revealed that preventing early competition of weeds through one manual weeding could suffice for optimum yield of haricot bean under Awassa condition. One early-weeding at 25 days after emergence reduced weed infestation from 35% to 50% and subsequently increased grain yield by 55% to 70%. The yield attributes positively affected by weeding were pods per plant and plants per square meter. The result further showed that genotype by weeding interaction was significant for grain yield (Table 22). Mexican 142 required two weedings to produce significantly higher yields than the un-weeded control, whereas one early weeding was sufficient for optimum yield performance of the other two, apparently more competitive varieties, Ex-Rico and Red Wolaita.

Table 21. Effect of time of weeding on weed control and yield of haricot bean

Treatment	Weed count no m-2	Crop					
		Leaf area (cm2)	Pods Plant-1 no.	Seeds Pod-1 no.	Seed weight g	Plants m-2 no.	Grain yield (kg ha-1)
	1992						
No weeding	270	17	8	4	13.7	5	310
Weeding at 25 DAE*	133	16	18	5	14.3	12	1160
Weeding at 25 and 55 DAE	133	15	17	5	14.8	11	1170
LSD (5%)	40	NS	2.1	NS	NS	1	130
	1993						
No weeding	379	21	6	4	16.3	9	340
Weeding at 25 DAE	247	24	11	5	17.1	12	770
Weeding at 25 and 55 DAE	252	23	13	5	16.8	13	880
LSD (5%)	33	2.8	1.8	NS	NS	1.4	130

**DAE - Days after crop emergence*
Source: Tanaw et al., 1997

Table 22. Effect of herbicides on weed infestation, yield and yield attributes of haricot bean

Treatment	Rate (l/ha)	Weed count (no/ m2)	yield			
			Pods/plant (no.)	Seeds/pod (no.)	Plants/m2 (no.)	Grain yield (q/ha)
Igran combi	4 (Pre.)	181bc	24ab	5.4a	16ab	18a
Igran combi	5 (Pre.)	105c	22abc	5.8a	15abc	18a
Igran combi	6 (Pre.)	127bc	25a	5.7a	15abc	22a
Agil 100 EC	0.75 (Post.)	358a	10d	4.3c	12cd	6b
Agil 100 EC	1.00 (Post.)	342a	9d	4.6bc	11d	3b
Agil 100 EC	1.25 (Post.)	207a	9d	4.1c	9e	3b
Alachlor	4 (Pre.)	193b	19bc	5.4a	16ab	18a
Dual 960 EC	1.50 (Pre.)	212b	17c	5.4a	17a	18a
Dual 960 EC	1.75 (Pre.)	209b	20bc	5.1ab	18a	17a
Dual 960 EC	2.0 (Pre.)	185c	19bc	5.3a	16ab	19a
Hand weeding	-	121b	20bc	5.1ab	17a	19a
Weedy check	-	349a	10d	4.6bc	13bcd	6b

[1] Pre – Pre-emergence, Post – post-emergence
[1] Means followed by the same letter are not significantly different at P = 0.05
Source: Tenaw and Mathias, 1998

At Jimma, two haricot bean varieties, Roba 1 (improved) and Jimma local, required at least two early weedings (15 and 30 days after emergence) for efficient weed control, which led to significantly higher crop yields (Tilahun, 1998). One time weeding later in the season (45 days after crop emergence) led to significantly reduced yields due to the extended exposure of the crop to weed competition. It was shown that if not weeded early, Roba 1 and Jimma local could loss up to 66% and 90% of their yield potential, respectively, depending on the season.

It was confirmed that soybean was a weak competitor with weeds compared to other pulse crops. At Awassa, exposure of the crop to prolonged weed competition resulted in up to 98% loss in grain yield (Beyenesh, 1989). Two times hand weeding at 25 and 55 days after sowing was the optimum practice to enhance crop performance. Weeding during the indicated times resulted in the highest grain yield of 1320 kg ha^{-1} and net economic return of Birr 305 ha^{-1}. Late weeding led to yield reduction and consequently negative net economic returns.

Tillage methods

Various combinations of conservation tillage, hand weeding and herbicides were compared for weed management and improvement of lentil seed yield at Debre Zeit (Nigussie et al., 1993). Generally, conservation tillage was more suitable for lentil production compared to conventional tillage (Table 23). The crop seemed to prefer less disturbed soil conditions. Hand weeding enhanced the beneficial effect of Terbutryne under conventional tillage system, but this effect was not so apparent under reduced tillage. The results further showed that 70% yield increment could be realized through integrated use of minimum tillage and twice weeding; or zero tillage, terbutryne and supplementary hand weeding (Table 24). The crop is small and fragile and thus was unable to withstand the competition with weeds and required adequate protection against weeds to realize its potential.

Table 23. Effect of tillage practices on weed control and seed yield of lentil

Tillage system	Weed dry matter yield ($g\ m^{-2}$)	Crop seed yield ($kg\ ha^{-1}$)
Conventional Tillage	305a	349b
Minimum tillage	209b	591a
Zero tillage	193b	609a
LSD (0.05)	34	60
CV (%)	47	39

Source: Nigussie et al., 1993

Table 24. Weeding and variety interaction effect on grain yield (Kg ha^{-1})

Weeding frequency	Variety		
	Ex-rico 23	Mexican 142	Red Wolayita
No weeding	2.6	3.4	4.3
Weeding at 25 DAE	9.0	5.0	9.1
Weeding at 25 and 55 DAE	10.5	7.7	8.3
LSD (5%) Weeding x Variety	3.1		

Source: Tenaw et al., 1997

Chemical

Very little work has been done on herbicides in the past two decades. Prior to 1993, 6 pre-emergence and 1 post-emergence herbicides were recommended for HP weed control. However, currently only one of these herbicides is officially registered (Rezene, 1994).

Experiments were conducted at Debre Zeit (black soil) during 1994-96 cropping seasons to evaluate terbutryn + terbutylazyn and linuron ± hand weeding (DZARC, 1996; 1997). The major weed species recorded within the experimental plots were *Commelina benghalensis, Plantago lanceolata, Scorpiurus muricatus, Amaranthus* spp. and *Cichorium intybus.*

According to the results, there was no statistical difference between the two herbicides in all the parameters considered (Table 19). The three rates of the herbicides, however, showed significant difference ($P \leq 0.05$) among themselves in reducing the dry matter accumulation of total weeds and population of most weed species – the highest rate being the best in reducing the dry matter. All the treatments, including the interaction effect did not show any significant effect on the population of *Scorpiurus muricatus* and *Amaranthus* spp. However, hand weeding once proved better for the control of all other weeds tested than the weedy check. The supplementary effect of hand weeding is clearly observed in the interaction effect between herbicides and hand weeding treatments. Better yield of lentil and lower weed biomass were obtained from plots where herbicides were coupled with hand weeding once indicating better control of the weeds.

Pre-and post-emergence herbicides in faba bean were evaluated at Holetta Nitosols during 1993-94 cropping seasons. The treatments comprised one pre-emergence herbicide *terbutryn + metolachlor* and five grass killer post-emergence herbicides (*fluazifop-buthyl, diclofopmethyl, propaquizafop,* and *fenoxaprop-p-ethyl*) applied ± broadleaf killer herbicide (*Bentazone*) (HARC, 1994; 1995).

Management of broadleaf weeds with herbicide treatments was much more variable than it was in grasses. Broadleaf and grass weeds were managed more effectively with pre-emergence herbicides than with the sequential application of *bentazone* with grass killer herbicides. The efficacy of *bentazone* against broadleaf weeds was reduced when applied sequentially with grass-killer herbicides. However, when the antagonistic effects occur, faba bean seed yields do not appear to be affected by reduced broadleaf control.

A range of herbicides was tried for weed control in lowland pulses. However, even though the chemicals were effective in suppressing weeds, it was not often reflected in terms of enhanced yield performance of the crops. In fact, some of the crops were highly sensitive to the herbicides and as a result, sustained unacceptable level of damage. Pre-emergence application of Igran combi, Dual, and Alachlor suppressed weeds effectively leading to significantly improved grain yield of haricot bean (Tenaw and Mathias, 1998).

Igran combi spray resulted in up to 4-fold increase in grain yield and 70% reduction in weed infestation (Table 20). Improved crop performance due to herbicides was accounted for by improvement in yield attributes, particularly pods/plant and seeds/pod. The post-emergence herbicide Agil was neither effective on weeds nor safe to the crop. In a further study, sole application of Terbutryne significantly reduced weed infestation in lentil at DebreZeit. However, the herbicide had to be supplemented with one hand weeding to realize substantial increase in seed yield compared to the weedy control (Nigussie et al., 1993). Terbutryne was especially effective on the major broadleaf weed species, *Galinsoga parviflora* and *Amaranthus hybridus*.

Conclusions and recommendations

As a whole, judicious application of hand weeding practice was the core component of the overall integrated weed control recommendations in pulse crops production. Results of weed control recommendations recorded in pulses during the past two decades are summarized below:

Weed control in faba bean and field pea mixed cropping

A single hand weeding applied at 6 WAE is recommended for wide-scale application in mixed cropped of faba bean and field pea in terms of its effectiveness in controlling late emerging weed species and reducing weed interference during early crop growth stage and time of harvesting.

Weed control in cowpea

A single early weeding (applied during first trifoliate crop stage) is recommended for verification in the Central Rift Valley (Melkassa, Welenchitti and Zeway areas) on two cowpea varieties with different growth habit: Blackeye bean (erect type) and White Wonder Trailing (semi-erect type).

Weed control in lentil

Two-hand weeding during 30 and 60 days after crop emergence are recommended for verification in lentil production areas in eastern Shewa and related environments.

Weed control in faba bean

Hand hoeing at 2 WAE supplemented by hand weeding at 5-7 WAE are recommended for wide-scale application in faba bean production areas for controlling early and late weed interference associated with high crop yield.

Weed control in haricot bean

Twice hand weeding applied during 15–45 days after crop emergence is recommended for verification in Mexican 142 variety of haricot bean, whereas one early weeding applied during 20–25 days after crop emergence in two other apparently more competitive varieties Ex-Rico and Red Wolaita for the Central Rift Valley areas.

In Jimma area, twice hand weeding applied during (15 and 30 days after crop emergence) is recommended for weed control verification for two haricot bean varieties: Roba 1 (improved) and Jimma local.

Weed control on soybean

Twice hand weeding applied at 25–55 days after planting is recommended for weed control verification for soybean production in Awassa area.

Gaps and Challenges

Hand weeding has remained the most widely used method of weed control in HP and has seen little modifications over the years. A work at agricultural research centers in HP has emphasized on determining the crop growth period when weeds are most injurious and when they are relatively harmless. In this regard, the efficacy of mixed cropping in reducing weed control requirements, weed surveys, interaction effects of cultural practices with weed control methods, studies on economic importance of specific weed problems and the efficacy of chemical control have all been attempted.

Perhaps the issue that has not been addressed is how intensive a control program should be implemented in order to augment the adoption of high yielding crop varieties and fertilizer use where it is recognized that weed control remains the weakest link to improved crop productivity. Therefore, we should aim at developing a weed management program that makes cultural weed control more efficient to complement ably adopted inputs like improved varieties and fertilizers and the ultimate goal should be to reduce the weed flora above ground and weed seed bank below ground as a long term strategy for minimizing weed-crop competition while reducing labor and drudgery associated with weed control.

It is now recognized that *Orobanche* is likely to constitute a problem in the northern HP production areas of the country (Gonder, Gojam, Welo, Tigray and neighboring localities of North and West Shewa). The present awareness of the problem should lead to the formulation of a national and regional programs designed to exploit the genetic possibilities of the host plants and to improve the understanding of the evolution of the parasite in the environment of the host.

Future prospects

Non-parasitic weed species

- Identification and characterization of the weed flora associated with HP need to be strengthened. Determination of quantitative and qualitative of weed species also need to be extended for areas and crops not previously covered;
- These time thresholds are the basis for the concept of flexible weed control. Accordingly, weed control measures need to be determined based on knowledge of actual or potential weed densities and their economic thresholds, rather than executed on a routine or fixed basis;
- Considering the increasing weed status and potential risks of *Parthenium hysterophorus* to HP production, there is a need to develop prevention and control measures through which an integrated management of this invasive weed can be formulated;
- There is a need to improve on the traditional weeding practices by exploring the feasibility of row seeding of HP using animal drawn seeders in conjunction with a push-type or animal drawn interrow-weeders;
- It appears that the country still has large cheap labor pool that can effectively be used for weeding. Thus, research into chemical weed control need to be emphasized for large-scale mechanized situations only; and
- Efforts should be strengthened towards integrated weed management approach that combines (cultural, mechanical, biological and chemical measures). This approach is especially important for the control of prolific annual weeds that are generally inadequately controlled by any of the methods solely.

Orobanche spp.

Research areas

- The geographical distribution of *Orobanche;*
- An inventory of host plants (wild as well as cultivated);
- Precise data on yield loss;
- Tolerance level of local varieties;

- Host/parasite interaction;
- The influence of rotation, nitrogen fertilizers, farmyard manure, tillage intercropping, date and density of sowing the crop and weeding of *Orobanche* plants;
- The influence of other weeds and rainfall; and
- The influence of soil physical and chemical characters

Awareness creation and collaborative actions

There is a need to create awareness of the *Orobanche* problem in HP among farmers, researchers, extension personnel and policy makers through information campaigns and pre-extension work on the risks of re-infestation and on the methods and systems by which *Orobanche* infestations, and the losses due to the parasite, may be reduced.

Since *Orobanche* is a serious problem in North Africa and some localities in the Nile Valley Region, it would be desirable to work out joint research project at a regional level. This would enable the member countries to make maximum use of both material and scientific resources, which in the case of small-scale program for each individual country would be difficult to achieve. Such a joint project would enable the these countries to define and evolve a strategy for *Orobanche* control in HP, and the outcome would be to enhance regional cooperation through the dissemination of information and the transfer of techniques to farmers and technicians and the training of extension workers.

Appendices

Appendix1. Major weeds of highland pulses recorded in Ethiopia.

Family	Species	Level of importance[1]							References[3*]
		FB[2]	FP	LN	CP	HB	SB	CB	
ACANTHACEAE	*Hygrophilla auriculata*	x	x	-	-	-	-	-	19,20
AMARANTHACEAE	*Amaranthus hybridus*	xx	x	xx	xx	xx	Xx	x	15,17,19,20
ASTERACEAE	*Bidens pachyloma*	xxx	xxx	xxx	xx	-	-	-	15,19,20
	Bidens pilosa	-	xx	-	-	-	-	-	17
	Cichorium intybus	-	-	xx	xxx	-	-	-	20
	Galinsoga parviflora	xx	xx	x	x	xx	xx	x	15,17,19,20
	Guizotia scabra	xx	xxx	xx	xx	x	X	-	15,17,19,20
	Launea cornuta	-	-	xx	xx	xxx	xx	xx	15,17,19,20
	Parthenium hysterophorus	xx	x	xxx	xxx	xxx	xxx	xxx	20
	Sonchus arvensis	-	-	-	x	x	X	-	19,20
	Sonchus oleraceus	x	x	x	x	-	-	-	19,20
	Tagetes minuta	xx	x	xx	xx	xxx	xx	xx	17,19,20
	Xanthium spinosum	x	x	xx	xx	xx	X	x	19,20
	Xanthium strumarium	-	-	-	-	xxx	xx	xx	20
BRASSICACEAE	*Brassica napus*	x	x	-	x	x	x	-	20
	Raphanus raphanistrum	xxx	xx	x	xx	-	-	-	15,20
CARYOPHYLLACEAE	*Cerastium octandrum*	x	x	-	-	-	-	-	15,20
	Corrigiola capensis	xxx	xxx	-	-	-	-	-	15,17,19,20
	Spergula arvensis	xx	xx	-	-	-	-	-	15,19,20
COMMELINACEAE	*Commelina africana*	xx	xx	xx	-	xx	x	x	19,20
	Commelina benghalensis	xx	x	xxx	xx	xxx	xx	xx	15,17,19,20
CONVOLVULACEAE	*Convolvuls arvensis*	xx	xx	xxx	xxx	xx	xx	x	19,20
	Cuscuta campestris	x	x	Xx	x	-	-	-	20
	Fallopia convolvullus	-	xxx	-	-	-	-	-	17
CYPERACEAE	*Cyperus esculentus*	-	-	xxx	xxx	xx	xx	xx	19,20
	Cyperus rotundus	xx	xx	xxx	xxx	xxx	xx	xx	15,1920
LABIATAE	*Satureya paradoxa*	xx	x	-	-	-	-	-	15,20
LEGUMINOSAE	*Medicago polymorpha*	xxx	xxx	Xx	xx	-	-	-	15,19,20
	Scorpiurus muricatus	xx	x	xxx	xxx	-	-	-	17,19,20
OROBANCHACEAE	*Orobanche crenata*	xxx	xx	xxx	xxx	-	-	-	3,4,14,20,21

* Numbers in the 'reference' column indicate the position of the references in the reference list

Appendix1. Continued

Family	Species	Level of importance[1]							References[3*]
		FB[2]	FP	LN	CP	HB	SB	CB	
	O. minor	xx	-	-	-	-	-	-	14,19,20
	O. ramosa	-	x	-	-	-	-	-	14
OXALIDACEAE	*Oxalis latifolia*	x	x	-	-	-	-	-	15
PAPAVARACEAE	*Argemone mexicana*	xx	xx	xxx	xxx	xx	xx	xx	19,20
PLANTAGINACEAE	*Plantago lanceolata*	xxx	xx	X	xx	-	-	-	15,17,19,20
POACEAE	*Athraxon quartinianus.*	x	x	-	-	-	-	-	15, 20
	Avena abyssinica	xxx	xxx	Xx	xx	-	-	-	19,20
	A. fatua	xxx	xxx	Xx	xx	-	-	-	15,19,20
	Brachiaria eruciformis	xxx	xx	Xx	x	-	-	-	19,20
	Bromus pectinatus	xxx	xx	X	x	-	-	-	15,19,20
	Cynodon dactylon	x	x	X	xx	-	-	-	15,17,19,20
	Digitaria scalarum	x	x	X	x	xx	X	x	15,17,19,20
	Eleusine afiricana	-	-	-	-	xx	Xx	xx	19
	E. indica	-	-	-	-	xx	xx	xx	19
	Eragrostis spp.	-	-	X	x	-	-	-	15,19,20
	Lolium temulentum	-	-	X	x	-	-	-	15,17,19,20
	Phalaris paradoxa	xxx	xxx	Xx	xx	-	-	-	15,17,19,20
	Setaria pumila	xxx	xxx	Xx	xx	-	-	-	15,19,20
	S.vericillata	x	x	Xx	xx	xxx	xx	xx	19,20
	Snowdenia polystachya	xx	xx	X	x	-	-	-	15,19,20
	Sorghum arundinaceum	-	-	Xx	xx	xxx	xx	xx	20
POLYGONACEAE	*Oxygonom sinautum*	x	-	-	x	-	-	-	19,20
	Polygonum aviculare	xx	xx	-	-	-	-	-	15,19,20
	P. nepalense	xxx	xxx	Xx	xx	-	-	-	15,17,19, 20
	Rumex abyssinicus	xxx	xxx	X	x	-	-	-	19,20
	Rumex bequartii	xxx	xxx	Xx	xx	-	-	-	15,19,20
PRIMULACEAE	*Anagalis arvensis*	x	x	X	x	-	-	-	15,17,19,20
RESEDACEAE	*Caylusea abyssinica*	xxx	xxx	-	-	-	-	-	15,19,20
RUBIACEAE	*Galium spurium*	xx	xx	X	x	-	-	-	15,17,19,20
SOLANACEAE	*Datura stramonium*	xx	xx	xxx	xxx	xxx	xxx	xx x	19,20
	Nicandra physalodes	-	-	Xx	xx	xxx	xxx	xx x	19,20
	Solanum nigrum	x	x	Xx	xx	xxx	xxx	xx x	19,20
UMNELLIERAE	*Feuniculum vulgare*	x	x	Xx	xx	-	-	-	19,20

[1]*xxx = widely spread; xx = moderately spread; x = localized.*

[2]*FB = Faba Bean; FP = Field Pea: LN = Lentil; CP = Chick Pea; HB = Haricot Bean = Haricot Bean; SB = Soya Bean; CP = Cow Pea*

* Numbers in the 'reference' column indicate the position of the referenses in the reference list

Appendix 2. Effect of hand weeding treatments on weed control, Chelia – 2002

Treatment[a]	*Weed density* (plants m^{-2})		Individual weed control score[c]		Weed biomass weight (kg ha^{-1})
	Guizotia scabra	*Snowdenia polystachya*	*Guizotia scabra*	*Snowdenia polystachya*	
HW x 1 (4WAE)	96[e]	52[e]	2[e]	3[e]	1891.7 ab[b]
HW x 1 (6WAE)	48	36	2	2	1500.0 b
Farmers practice	88	52	5	5	2075.0 a
CV%	--	--	--	--	42.03

[a] HW = Hand weeding; WAE = Weeks After Crop Emergence ; [b] Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05); [c] DAE = Days after crop emergence; [d] Weed control score (scale 1.0 – 5.0) where: 1.0 = weeds effectively controlled and 5.0 = no effect on weed control. [e] Means are values of one location only

Source: HARC, 2003; Rezene and Getachew, 2003

Appendix 3. Effect of tillage systems and weed control practices on seed yield of lentil

Treatment	Seed yield (kg ha^{-1})
CT + no weeding	233e
CT + once hand weeding (30 DAP)	311de
CT + twice weeding (30 and 60 DAP)	367cde
CT + terbutryne (2 l/ha) + once weeding (30 DAP)	396cde
CT + terbutryne (2 l/ha)	437cd
MT + no weeding	530cde
MT + once hand weeding (30 DAP)	763a
MT + twice weeding (30 and 60 DAP)	798a
MT + terbutryne (2 l/ha) + once weeding (30 DAP)	515bc
MT + terbutryne (2 l/ha)	528bc
ZT + no weeding	486bcd
ZT + once hand weeding (30 DAP)	750a
ZT + terbutryne (2 l/ha) + once weeding (30 DAP)	797cde
ZT + terbutryne (2 l/ha)	637ab
LSD (0.05)	166

[1] Means followed by the same letter are not significantly different at P = 0.05

[1] CT – conventional tillage (2 plowing + 1 harrowing), MT – minimum tillage (1 harrowing + glyphosate at 4 l/ha, applied 3 weeks before sowing), ZT – zero tillage (glyphosate at 4 l/ha)

[1] Means followed by the same letter are not significantly different at P = 0.05

[1] DAP – days after planting

Source:(Nigussie et al., 1993

Appendix 4. Effect of weed control practices on grain yield, dry weight accumulation of weeds in lentil (Debre Zeit, 1994 -1996)

Treatment	Weed dry wt.(g m^{-2})		Seed yield (kg ha^{-1})	
	1995	1996	1995	1996
Terbutryn + terbutylazyn	323.8	126.8	471.7	976.7
Linuron	331.7	164.5	531.3	1062.2
LSD(0.05)	NS	NS	NS	NS
Weedy check (W0)	451.5	200.7	276.6	886.7
Hand weeding x 1 (W1)	204.0	90.6	726.4	1152.2
LSD(0.05)	**	**	**	**
Terbutryn + terbutylazyn +W0	432.5	165.5	296.2	929.4
Terbutryn + terbutylazyn +W1	215.1	88.2	647.2	1023.9
Linuron+WO	470.6	235.8	256.9	843.9
Linuron+W1	192.9	93.1	805.7	1280.0
LSD (0.05)	NS	**	**	**

Source: DZARC, 1996; 1997

References

1. AARC (Adet Agricultural Research Center)**.** 2002. Progress report of 2001/2002. ARARI, Adet.
2. Adugna Wakijira., Amare Gizaw, Kemal Ali, Chilot Yirga and Berhanu Bekele. 1998. Crop loss assessment of 1997 in Gojam and Gonder, Amara Regional State. A survey report. HARC, IAR.
3. Assefa Admasu and Endale Berhe**.** 1994. *Orobnache crenata*: A potential threat to food legumes in Ethiopia. *EWSS Newsletter* 2:(1).
4. Besufikad Tadesse, Legesse Admasu and Rezene Fessehaie. 1999. *Orobanche* problem in South Wello. *Arem* 5: 1–10.
5. Beyenesh Zemichael**.** 1989. Estimated yield loss and relative profitability of different time of weedings in soybean and haricot bean. Pp. 47–51. *In:* Proceedings of the 7th Annual Conference of the Ethiopian Weed Science Committee. Rezene Fessehaie (ed.). Addis Ababa.
6. CSA. 2002. The 2001/2 Ethiopian agricultural sample enumeration, preliminary results, Part I. Central Statistical Authority (CSA), Addis Ababa, Ethiopia.
7. DZARC **(**Debre Zeit Agricultural Research Center)**.** 1996. Annual research report for 1995/96. DZARC, AUA
8. DZARC**.** 1997. Annual research report - 1996/97 of Debre Zeit Agricultural Research Center. DZARC, AUA.
9. Giref Sahle and Etagegnehu Gebremariam**.** 1999**.** Assessment of cowpea yield loss due to weeds in the Central Rift Valley of Ethiopia. *Arem* 5: 138–145.
10. HARC **(**Holetta Agricultural Research Center). 1994. Progress report for 1993/4.
11. HARC. 1995. Holetta Agricultural Research Center progress report for 1994/5. HARC, Holetta.
12. HARC. 1999. Holetta Agricultural Research Center progress report for 1998/1999. HARC, Holetta.
13. HARC. 2000. Holetta Agricultural Research Center progress report 1999/2000. HARC, Holetta.
14. HARC. 2001. Holetta Agricultural Research Center progress report for 2000/1. HARC, Holetta.

15. HARC. 2002. Holetta Agricultural Research Center progress report for 2001/2. HARC, Holetta.
16. HARC. 2003. Holetta Agricultural Research Center progress report for 2002/3. HARC, Holetta.
17. Kedir Nefo, Feyissa Tadesse and Tilahun Geletu. 1999. Results of a weed survey in the major field pea and faba bean growing areas of the Bale highlands. *Arem* 5:109–121.
18. Negussie Tadesse, Seid Ahmed, Mengistu Huluka and Sewalem Amogne. 1993. Evaluation of lentil weed management practices under various tillage systems. *Arem* 1: 44 – 47.
19. Rezene Fessehaie. 1986. Review of weed science research activities in pulses in Ethiopia. Pp 403-426 *In*: A review of crop protection research in Ethiopia. Tsedeke Abate (ed.). *Proceedings of the first Ethiopian crop protection symposium*. February 4-7, 1985. Addis Ababa, Ethiopia. IAR, Addis Ababa.
20. Rezene Fessehaie. 1994. Weed research in cool season food legumes. Pp. 252-275. Cool-season food legumes of Ethiopia. *In*: Asfaw Tilaye, Geletu Bejiga, MC Saxena and MB Sohl (eds.). Proceedings of the First National Cool season Food Legumes Review Conference 17-20 December 1993. Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA: Aleppo, Syria. vii+440 pp.
21. Rezene Fessehaie. 1998. Review of broom rapes (*Orobanche* spp.) in Ethiopia. *NVRSRP Newsletter* 1: 20-22.
22. Rezene and Agajie Tesfaye. 2003. On-farm verification of hand weeding timings after the recommended hand hoeing in faba bean. Progress report of Client-Oriented Research of Holetta Agricultural Research Center for 2003. HARC, Holetta.
23. Rezene and Getachew Agegnehu. 2003. On-farm verification of weed control methods in mixed cropping of faba bean and field pea. Progress Report of Client-Oriented Research of Holetta Agricultural Research Center for 2003. HARC, Holetta.
24. Taye Tessema and Yohannes Lema. 1999. Qualitative and quantitative determination of weeds in tef in West Shewa Zone. *Arem* 4: 46–60.
25. Tenaw Workayehu and Mathias Mekuria**.** 1998. Evaluation of pre- and post-emergence herbicides for weed control in haricot bean. *Arem* 4: 126–133.
26. Tenaw Workayehu, Beyenesh Zemichael and Waga Mazengia**.** 1997. Effect of variety, seed rate, and weeding frequency on weed infestation and grain yield of haricot bean. *Arem* 2 & 3: 61–69.
27. Tilahun Tadious. 1998. Weed competition study on haricot bean in the sub-humid zone of Jimma. *Arem* 4: 61–68.

Review of Entomological Research on Maize, Sorghum and Millet

Emana Getu[1], Abraham Tadesse[2], Mulugeta Negeri[2], Tadele Tefera[3], Hadush Tsaheye[4] and Asmare Dejene[5]*
[1]Addis Ababa University, Science Faculty, P.O.Box 1176; [2] Ethiopian Institute of Agricultural Research, P.O.Box 2006, Addis Ababa;[3] Alemaya University, Dire Dewa, P.O.Box 38; [4] Tigrayi Agricultural Institute, Mekele, P.O.Box; [5] Amahara Agricultural Research Institute, P.O.Box 8, Bahir Dar.

Introduction

Agriculture is the backbone of the Ethiopian economy. Crop production and livestock keeping are the major elements in the Ethiopian agriculture. Crop production includes cereals, pulses, oil crops, stimulants, fiber crops, spices, vegetables, fruits and others. Cereals cover about 82% of the land allotted for crop production. Of the cereals, maize, sorghum and millet cover 17%, 12% and 4%, respectively (CSA, 2000). This is about 40% of the land allotted for cereals. In terms of total production, over 50% of the production comes from maize, sorghum and millet. The average yield per hectare for all the cereals is 1.1 t, whereas for maize, sorghum and millet it is 1.8, 1.2 and 0.89 t ha^{-1}, respectively (CSA, 2000). Based on this, maize, sorghum, and millet are the most important crops among the crops in general and cereals in particular in Ethiopia. However, the potential of these crops is not fully realized as compared to other countries. For example, the average yield of maize in USA is about 4 t ha^{-1}. The sorghum yield is also 2 t ha^{-1} even in African countries like Nigeria (Ferdu et al., 2001).

Among the factors contributing to the low yield of these crops are herbivory by insect pests. Quite a large number of insect pests attack maize, sorghum, and millet in Ethiopia, although few of them cause economic losses. Insect pests such as stemborers can at times result in 100% crop failure (Emana and Tsedeke, 1999). The damage by termites, shoot flies, sorghum chaffer and a few others in some localities are tremendous and grain harvest is either poor or zero unless certain control measures are applied (Emana, 2002). Since the establishment of the Institute of Agricultural Research in 1966, coordinated research activities have been under taken to solve these pest problems. Entomological research activities up to 1985 were reviewed during 1985 Crop

Protection Symposium and references can be made to the proceedings of this symposium (Adhanom and Abraham, 1985; Tsedeke, 1986). The proceedings of the 1985 symposium served as a major source of local information in crop protection for developmental agents, researchers, expatriates and others who are making use of research results. As more developments have taken place in research since then, it is long overdue to compile and make avalaible useful research results for users. Moreover, new problems and new methods of problem tackling such as use of Geographic Information System (GIS), use of friendly computer softwares, use of geo-statistics, molecular biology, etc. have made the recent research findings more reliable.

In this review, entomological research activities on maize, sorghum, and millet from 1986 to 2006 are reviewed; some research activities that were done before 1986 but omitted from the 1985 review are also considered. Even if the authors worked hard to include all research activities in the review for the stated period, the review is not exhaustive. The checklists of insect pests recorded on maize, sorghum, and millet along with their natural enemies are presented. The results of basic and applied research activities of the major insect pests of the crops such as stemborers, shoot fly, sorghum chaffer, termites, sorghum midge and African bollworm are also highlighted. Avalaible research results of the natural enemies associated to these insect pests are also presented. Moreover, recommendations on readily usable research results are made. Research gaps and future research directions are also explicitly indicated.

Research findings

Insect pests and associated natural enemies

Abraham et al. (1993; 1996; 1998), Abraham and Adane (1998), Ferdu et al. (2001), and Emana et al. (2002) earlier published checklists of maize and sorghum insect pests and their natural enemies. The check lists of insect pests and their natural enemies included in the current review are broader than the previous checklists (Appendix 1-6). Over 30 insect pest species on maize (Table 1), 90 on sorghum (Table 2) and 9 on millet (Table 1) were recorded in the last two decades. Of these insect pests, only a few of them were found to be economically important. These include *Busseola fusca* (Fuller), *Chilo partellus* (Swinhoe), *Pachnoda interrupta* (Olivier), *Macrotermes subhyalinus* (Rambus), *Microtermes* spp on maize and sorghum; *Atherigona soccata* (Randani) and *Contarinia sorghicola* (Coquillett) on sorghum, and *Decticoides brevipennis* (Ragge) and *M. subhyalinus* on millet. *B. fusca* is the major insect pest of maize and sorghum at higher altitudes, higher rainfall and cooler areas, whereas *C. partellus* is the major pest in lower altitudes, low rainfall and warm areas of the country (Emana et al., 2002). *P. interrupta* was a big menace to sorghum and maize production in northenn and part of eastern Ethiopia in the early 1990s (Elias, 2003). The problem of termites on maize and sorghum has become a political issue in western Ethiopia between termite victims of the Oromo highlanders who were displaced to reclaim land in Dabuse in Buenshangul Gemuz to which Dabuse belongs (Devendra et al., 1998; Emana and Gure, 1997). Crop production in western Ethiopia is impossible due to termites unless persistent insecticides such as aldrin and other groups of chlorinated hydrocarbons, which were banned elsewhere, are applied to control the termites (Abraham et al., 1997; Emana and Gure, 1997). *A. socata* was mainly reported as seedling pest on sorghum grown in research stations (Girma and Plotnikove, 1988; Sileshi and Lakra, 1994; Sileshi et al., 1995; 1996). *Diopsis* sp. was recorded in Shewa, Arsi, and Wellega at altitudes ranging from 1660 to 2300 m as a new insect pest on sorghum and presents the same potential importance as *A. soccata*. Since the pest develops mainly in the main crop-growing season, damage was lower in early sown sorghum (SPL, 1988).

C. *sorghicola* was reported as a causal agent for flower abortion of sorghum in the1990's and now it has become an emerging major pest of sorghum in northenn, eastern and southeastern Ethiopia, where 100% crop loss was reported in some localities (Emana, pers. obs.). *D. brevipennis* was reported from northern Ethiopia as major production constraint of tef and millet (SARC, 1997; SARC, 1998; SARC, 2000).

Table 1. Insect pests recorded on millet in Ethiopia

Order, family and species	Common name	Status	Reference*
LEPIDOPTERA			
Noctuidae			
Spodoptera exemta (Wlk)	*Armyworm*	*Sporadic*	167,188
COLEOPTERA			
Chrysomelidae			
Nematocerus brachyderes Marshall	-	Minor	7
Tenebrionidae			
Lagria villosa Fabricius	Metallic leaf beetle	Minor	7
Scarabaeidae			
Phyllophaga crinita (Burmeister)	*Chafer grub*	Major	167
ORTHOPTERA			
Tettigoniidae			
Decticoides brevipennis (Ragge)	*Welo bush cricket*	Major	167
Acarididae			
Kraussaria angulifera (Krauss)	*Grasshopper*	Uncertain	167
ISOPTERA			
Termitidae			
Macrotermes subhyalinus (Rambus)	Termite	Major	167
ACARI			
Ixodidae			
Poophilus costalis (Walker)	-----------	Unknown	161

* Numbers in the 'reference' column indicate the position of the referenses in the reference list

A few insects only reach the status of economic pest in a given ecosystem mainly due to the presence of natural enemies, which can keep the density of certain species below economic threshold level (Emana, 2002). Many natural enemies were recorded on maize, sorghum, and millet (Tables 2 & 3). According to the latest information, stemborers are attacked by over 40 natural enemies (21 parasitoids, 14 predators, and 7 pathogens). Of the natural enemies recorded on stemborers, *Cotesia flavipes* (Cameron) an Asian origin endo-larval parasitoid of stemborer is the most abundant and efficient now resulting in an average of 58% parasitism. Currently, this parasitoid is under stemborers biological control program through augmentative release and conservation methods (Emana, 2005). The parasitoid has a benefit in Ethiopia as it creates new association with some populations of *B. fusca* (20%). Its rate of spread is faster as it moved over 2000 km away from its release site in Somalia in 1997 near Shebele River (Emana et al., 2001a; 2001b). Other parasitoids such as *Dolichogenidea fuscivora* Walker, *Dentichasmias busseolae* Heinrich, *Sturmiopsis parasitica* (Curran), *Pediobius furvus* (Gahan) and *Telenomus busseolae* Gahan from the guilds of larval, pupal and egg parasitoids are good candidates of natural and biological control agents of stemborers (Abiy, 2005; Amanuel, 2005; Emana, 2002). The predators and pathogens now may not seem effective though they may influence the population of stemborers. Information on the role of natural enemies on other pests of maize, sorghum, and millet are not sufficient especially in quantifying their effect which needs to be studied in the future.

Table 2. Predators recorded on maize, sorghum and millet insect pests in Ethiopia

Predators	Host species	Host stage	Reference*
DERMAPTERA			
-			
Forficula rehm	Cp, bf	Egg, larva	86, 195, 196, 197,228
Forficula senegalensis	Cp, Bf	Larva	86, 114
Diaperasticus erythrocephala	Cp, Bf	Larva	86
Euborellia sp.	Cp, Bf	Larva	86
Doru lineare	Cp, Bf	Larva	86, 200
Euborellia annulepsis	Cp, Bf	Larva	86, 199
Labia minor			
HYMENOPTERA			
Pheidole megacephala	Cp	Larva	86, 114
Cardiocondyla emeryi	Cp	Larva	86, 114
COLEOPTERA			
Coccinellidae			
Cheilomenes lunata	Cp	Larva	114, 200
Cheilomenes literata	Maize and sorghum pests	Larva	200
Cheilomenes vicina	Maize and sorghum pests	Larva	201
Cheilomenes sulphurea	Sc	Larva	86, 114, 228
Cheilomenes propinqua	Bf	Larva	86, 114
Ganocephala simplex	Bf	Larva	86
Adalia intermedia	Maize and sorghum pests	Larva	199
A. signifera	Maize and sorghum pests	Larva	195
A. areata	Maize and sorghm pests	Larva	197
Adonia variegata	Maize and sorghum pests	Larva	200
Henosepilachna reticulata	Maize and sorghum pests	Larva	
Hemiptera	Sc	Egg	86
Crysopa sp.	Sc	Egg	86

Cp = Chilo partellus; Bf = Busseola fusca; Sc = Sesamia calamistis

* Numbers in the 'reference' column indicate the position of the referenses in the reference list

Table 3. Pathogens recorded on maize, sorghum and millet insect pests in Ethiopia

Pathogen	Type	Host insect	Host stage	Distribution	Reference
Aspergillus sp.	Fungus	Cp, Bf	Larva	EE	
Beauveria bassiana	Fungus	Bf	Larva	EE	68, 76, 86
Metahrizium anisopleae	Fungus	Cp, Sc	Larva	WE	68, 76, 86
Panagro lamimus	Nematodes	Cp	Larva	SE	68, 76, 86
Hexamermis sp.	Nematodes	Cp	Larva	SE	68, 76, 86
Steinernema intermedia	Nematodes	Bf	Larva	NE	68, 76, 86
Heterorhabditis sp.	Nematodes	Sc	Larva	EE	68, 76, 86
Beaveria sp	Fungi	*P. interrupta*	Larva and adult	NE	164
Metarrhizium sp.	Fungi	*P. interrupta*	Larva and adult	NE	164

* Numbers in the 'reference' column indicate the position of the referenses in the reference list

Insect pests and natural enemies of maize, sorghum and millet

Biology and Phenology

Stemborers

Over six species of stemborers from the insect orders Lepidoptera and Coleoptera were recorded on maize, sorghum, and millet (Assefa, 1985; Emana et al., 2001a; 2001b; Emana, 2002). These include *B. fusca*, *C. partellus*, *S. calamistis*, *S. nonagrioides botanephaga*, *S. cretica* Lederer, *Pissodes dubius* and *Rhynchaenus niger* (Horn). Of these stemborers, *B. fusca* and *C. partellus* are the most important ones for which research results are available including their biology and phenology (Emana et al., 2004; 2002; 2001).

B. fusca: Biology of *B. fusca* was affected by a number of factors. Among the factors temperature, relative humidity and location are the most important ones (SPL, 1977). Biology of *B. fusca* was studied under laboratory and insectarium conditions (Assefa, 1989a; 1992; SPL, 1977). The female moth laid 236 and 169 eggs under laboratory and insectarium conditions, respectively. Eggs are laid in batches. The adult longevity and the egg-laying period were 7–6 and 4 days in the laboratory, 10, and 2.3 days in the insectarium, respectively. Larval and pupal development at an average daily temperature of 18.7 ^{0}C and relative humidity of 77% were 79 and 22.5 days, respectively. Thus, *B. fusca* requires 116.6 days to complete its life cycle under laboratory condition. Six larval instars were recorded. The sex ratio was 3:5 (female: male) (SPL, 1977; 1979). The phenology of *B. fusca* was studied at Awassa, Areka, Ziway (Assefa and Ferdu, 1996; 1994; 1997; Assefa, 1992; 1994; Ferdu, 1991; IAR, 1985), Alemaya (Kassahun, 1993), Ambo (SPL, 1979) and Sirinka (Yirga, 2006).

There are three generations of *B. fusca* per year in Awassa (Assefa, 1989a). The first generation eggs are laid from early April until the end of May, but the peak populations have been recorded in the later half of April. The first generation larvae pupate from early June until late August. The second-generation eggs are laid between the first week of July and early September. The majority of second generation larvae go into diapause and remain dormant from September to February, while a small proportion pupate in September or October and give rise to a third generation. The diapause larvae pupate in April and begin the cycle a new (Assefa, 1989a; IAR, 1985). The first generation could be destructive on maize planted in March, whereas the second generation could cause severe infestation and damage on maize planted later than April could. However, the third generation, which appears in September–October, does not cause damage to maize crop planted in April or May since the crop reaches maturity. Female moths from the first (non-diapause) generation laid significantly more eggs and lived longer than those coming from the second generation. However, most of the eggs were laid between the second and fifth nights after emergence and the rate of egg hatching declined with age of moths that laid the eggs (Assefa, 1989a; 1989b; 1994). At Hawassa, pupation of the diapausing larvae started in the last week of March. Before the end of April, more than 50% of the diapausing larvae pupated. Pupation of the diapausing larvae was completed at the end of May.

Unlike Awassa, at Areka ovipostions were observed between July and Novemeber. Three peaks of oviposition were observed indicating the presence of three generations of the insect at Areka. The highest egg mass depositions were in September-November. The study on the oviposition period of the insect at Areka showed that higher numbers of eggs were deposited by the second generation compared to the first (Assefa and Ferdu, 1997). In Ziway, ovipositions were observed between July and November with a peak oviposition in September (Assefa and Ferdu, 1997).

In the three areas (Awassa, Areka and Ziway) studied, higher oviposition were observed during later part of the growing season. This indicates that late-planted maize suffers much more than early planted maize. The highest number of eggs per unit area was observed in Awassa (Assefa, 1990; 1991; 1992).

Laboratory investigation of ecolosion, ovipoision, and mating times of *B. fusca* indicated that the great majority of male moths (about 80%) emerged between 18 and 22 hours. Emergence continued until 05 hours in the morning. In addition, it was observed that about 17% of the male emerged before complete darkness (which usually started after 19 hours) during the study period. Oviposition was observed between 17 and 06 hours in the laboratory. Howver, greater than 50% of oviposition took place between 18 and 24 hours (Assefa, 1991; 1992). The mating time experiment indicated that mating took place between 21 and 06 hours. About 70% of the mating was observed between 21 and 01 hours. It was also seen that mating could take place the same night either after emergence or after 2–7 days after ecolosion of both sexes.

Another phenology study conducted at Awassa demonstrated that irrespective of the ages of maize plants, eggs were laid on the under side of the leaf sheath (Ferede, 1991). *B. fusca* moths showed better ovipostional preference to younger maize plants and significantly fewer egg masses were laid on older plants ($r = -0.98$, $p<0.001$). A strong relationship between the age of the maize plant and the position of the egg masses was found. Ovipostion height increased with the age of the plant. During the post-tasseling stage, most of the egg masses were found below the primary ear.

Growth stages of both larvae and maize plants influenced larval movement and distribution. The leaf whorl and ears of older maize plants were identified as the primary feeding sites for early instar larvae. Larval movement from ovipostion site to leaf whorl commenced on the day of hatching. In 4 days, over 90% of the first instar larvae successfully invaded the leaf whorl. The larval population in the whorl sharply declined after three weeks. On young maize plants, signs of leaf infestation appeared within eight days after the hatching of eggs. Dead-heart injury developed after two weeks; stalk tunneling appeared after three days. However, in older maize plants (post-tasseling) larvae bored into ears and stalks of plants within eight days (Ferede, 1991; 1992).

The phenology study conducted at Alemaya indicated that *B. fusca* had two generations per year in Alemaya (Kassahun et al., 1995). The first generation began at the end of April, while early August marked the beginning of the second generation. All the second-generation larvae enter the diapause stage in about early October and termination of diapause occurs in early March. The larval stage passes through a post diapause period before the onset of pupation in about the middle of April. The onset of pupation of the diapause larvae appeared to be strongly correlated with the amount and distribution of rainfall. Larval mortality was high (up to 75%) in the second generation and it increased towards the end of the dry season (Kassahun, 1993).

Two peaks of *B. fusca* activities (June and September) were observed at Ambo showing the existence of two generations. In addition, non-diapausing individual borers were observed producing a third generation (SPL, 1979).

Diapause larvae of *B. fusca* in dry sorghum stalk pupated following the onset of rainfall (Yirga, 2006). Assefa (Assefa, 1989b) indicated that at least 80 mm cumulative rainfall is needed to intiate pupation. In Sirinka, the highest populations of diapause larvae in dry sorghum stalk were found in the top internodes including the peduncles (Yirga, 2006). *B. fusca* had three generations per year in Sirinka as witniessed by three distinct peaks of infestations in sorghum (Yirga, 2006).

C. partellus: Ovipostion by *C. partellus* female started on the first day of the moth emergence and ceased on the fourth day. Adult female of the insect laid 379 eggs on the average and eggs were laid at night. The mean durations of the different stages of the insect (egg, larva, pupa and adult) were 7, 35, 14 and 4 (for female) and 5 (for male), respectively. Complete life cycle lasted 42 to 68 days. Ovipostion started on the first day of adult emergence at night. The peak ovipostion was on the first day of emergence and declined over time. About 83% of the eggs were hatched into larvae (Firdissa and Abraham, 1998; IAR, 1991b).

Laboratory study was conducted to observe the combined effect of relative humidity and temperature on the biological features of *C. partellus* (Amanuel, 2005). The results obtained showed variation on potential and realized fecundity, the developmental time of immatures, and adult longevity due to differences in temperature, relative humidity, and their interaction. Mean duration of *C. partellus* life cycle was 70.2 days at 22 ^{0}C and 80% relative humidity, whereas it took only 26.5 days to complete its life cycle at 30 ^{0}C and 40% relative humidity. Average life span of adult *C. partellus* ranged from 6.9 to 11.1 days at 22 ^{0}C and 2.3–7.2 days at 30 ^{0}C for the different levels of relative humidity.

Six to seven generations of *C. partellus* was observed at Melkassa where cultivated and wild hosts are available all year round, but there were only three generations per year at Meiso where both wild and cultivated hosts only exist between June and October. Under Melkassa conditions, very few larvae enter diapause between November and May. At Meiso, where there was no irrigation facility and crop production is entirely dependent on rainfall, larval instars from the entire 3rd generation enter into diapause. In areas where there were growing plants (maize and/or sorghum) and dry stalks of the plants both active feeding larvae (on the growing plants) and diapause larvae (on the dry stalks) were found, indicating diapause in *C. partellus* is facultative.

Shoot fly

Lists of sorghum shoot fly species recorded in Ethiopia are *Atherigona soccata*, *Aprometopis flavofacies*, *Anatrichus pygamaeus*, *Elaciptera simplicipes*, *Mlanochaeta vulgaris*, *Oscinella nartshukiana*, *Rhopalopterum* species, *Scoliopthalmus micantipennis*, *Scoliopthalmus trapezoids*, *Steleocerellus* *tenellus*, some species of Lonchaeide and Milichidae (Sileshi, 1994). However, research results are only available for *A. soccata* and *Diopsis* sp.

A. soccata. *A. soccata* is a principal pest of sorghum occurring throughout the year without diapause at Alemaya. As many as 10 overlapping generations were recorded per year at the Alemaya condition. Seasonal abundance of the pest was significantly correlated with relative humidity, total rainfall, temperature and availability of sorghum seedlings (Sileshi, 1994).

***Diopsis* sp.** Girma and Plotnikov (Girma and Plotnikove, 1988) reported *Diopsis* sp. as a new pest of sorghum in Shewa, Arsi, and Wellega at altitudes of 1660–2300m. *Diopsis* sp. and *A. soccata* were later compared and the results indicated that both pests severely damaged especially the late sown sorghum. The economic threshold levels for *Diopsis* sp. and *A. soccata* were determined on the local variety IS-9302. *Diopsis* reproduces mainly during the rainy season and the population could be several folds more than *A. soccata*. In the early period of the season, *Diopsis* sp. is not a competitor of *A. soccata.* Preliminary observations on *Diapsis* sp when reared in the laboratory at the mean day temperature of 19.0–19.5 ^{0}C and relative humidity of 75–77%, the incubation and pupal development periods were 5.5$\pm$0.5 and 12$\pm$1 days, respectively. But, when the mean temperature and relative humidity of the day were 17 ^{0}C and 65.7%, pupal development took 14.5$\pm$0.5 days (SPL, 1988).

Sorghum chaffer

Sorghum chaffer was a big menace to sorghum in the early and mid 1970’s in Ethiopia. During that time, an attempt was made to know the biology of the pest (IAR, 1976; 1977a; 1977d). The first attempt was adult collections made in 1973. The beetles laid a few eggs from which two larvae hatched and served as reference. This was important as for the first time a larval stage of *P. interrupta* had been observed and this knowledge helped in avoiding confusion with other Scarabaeidae larvae. The biology of sorghum chaffer was studied under laboratory and field conditions during the year to identify the breeding site and workout the life history so that control measures could be targeted at vulnerable stages. Adult beetles were dissected to determine their breeding properties. Upon dissection of three hundred adults collected from Welenchiti in 1974, it was learned that the adults were not sexually mature. Some females dissected in March 1975 were also immature. It was concluded that Pachnoda become sexually mature 9–10 months after the initial post–pupal emergence (IAR, 1975; 1976; 1977b; 1977c).

The sorghum chaffer disappeared for a long time and then became one of the most important insect pests of sorghum after a lapse of almost two decades. The insect widely occurred and caused serious crop damage in parts of Afar and Amhara National Regional State. The first major recent outbreak of the sorghum chaffer occurred in 1993, although the insect has been known to farmers as a minor pest of sorghum for more than 40 years. With the general survey carried out in the 1970's, *P. inetrrupta* and P. *steheleni* were the two species of Pachnoda recorded in Ethiopia mainly on sorghum (IAR, 1977a). However, in the recent survey five species of sorghum chaffer were recorded in Kewet district of Amhara Region. These include *P. interrupta, P. abyssinica, P. crassa fairmairei, P. massajae* and *P. peregrine*. Among these, *P. interrupta* was the dominant species, constituting 99% of the total sorghum chaffer populations (Elias, 2003).

Developmental periods (eggs, larvae, pupae, and adults stages) of *Pachnoda interrupta* were studied under laboratory conditions ($28 \pm 2^{o}c$) at Ambo. Hatching period was 6 to 16 days with a mean of 11.3 days. The larval period was between 41 and 71 days with a mean of 55–57 days. Pupal stage took 11 to 26 days, the average being 18.9 days. The adult beetles could live up to 17 months under laboratory condition (Seneshaw and Mulugeta, 2002).

Yeraswork (Yeraswork, 2003) studied the biology of *P. interrupta* under different laboratory conditions. According to his report, the mean ovipostion period and the number of eggs laid were 17 and 24 days, respectively. The mean number of days for egg eclosion and the mean percent of egg eclosed were 9.1 and 88%, respectively. The mean larval size was 5.4 mm at emergence. The mean larval and pupal durations were 52 and 18 days, respectively. Number of days from egg to adult was 80 days.

Kassahun et al. (Kassahun et al., 2004) studied the field biology of *P. interrupta*. Their investigation was initiated to study temporal occurrence of the life stages and the over seasoning habits of *P. interrupta* in the Northeast and central Ethiopia. Adult flight was monitored through traps, while events such as overseasoning habits, ovipostion, and larval occurrence were studied through a series of regular soil sampling and direct field observations. *P. interrupta* is a univolitine insect, but the adults have two flight periods. The first flight period is September/October and the second flight period was June/July. The mortality rate among adults was generally low during the dry season. Survey conducted in May 2000 indicated that the aestivating/diapause beetle can be found in farmland, non-farlands (bush and woodlands), forest areas, adjacent to rivers, etc. This is at variance with the original hypothesis that the insect breeds in manure heaps. This shows the difficulty of detecting its breeding sites. Traps were installed at various locations in problem areas (northern Ethiopia) and other sites where the insect was suspected to breed.

Termites

Termites have been regarded as serious pests of agricultural crops, forest trees, and buildings in West Wellega, Ethiopia. They contribute to severe soil degradation by reducing the vegetation cover and leaving the soil surface barren and exposing it to the elements of erosion (Devendra et al., 1998; Emana and Gure, 1997). Participatory systems analysis of the termite situation carried out in West Wellega in 1998 disclosed that ecological changes resulting from increasing human activities, unsustainable land use practices, and mismanagement of natural resources are the major causes of the recent spread and intensification of the termite problem. It is also noted that past chemnical based control without incorporating farmer's indigenous coping strategies did not solve the problem (Ferede et al., 2001).

A number of termite species are involved in the infestation. Over 300 samples of termites collected from eastern, western, and southern Ethiopia were identified. They included 41 species belonging to 18 genera. Those associated with damage to crops belong to the subfamily Macrotermitinae. *Microtermes* in particular (nine species including one newly discovered species) were found in crops, attacking roots of mature plants, especially maize; *Macrotrmes subhyalinus* damaged young maize plants (Barnett et al., 1987).

Termites are serious pests of maize. In recognition to this, a consultant to the Ministry of Agriculture funded by the World Bank visited different parts of Ethiopia in January and February 1986 to assess the extent of this problem. Subsequently, courses of both immediate and long-term action were recommended (Adane and Abraham, 1998). Further visit by the same consultant was made during the early growing season (June–August 1986) to assess the particular problems occurring at the right time (AARC, 2005).

Macrotermes (and less commonly *Pseudacanthotermes*) cut the maize plant at the base from seedling to young cob stage. Observed losses on seedlings varied with location. These losses were greater in Wellega than in Sidamo and Gemu Goffa. Microtermes attack maize by penetrating roots when plants are at the tasselling or young cob stage. They continued penetration that results in excavation of the root system and base of the stem, which finally cause lodging. Millet and sorghum are also attacked (Emana, 2005b; Tadele, 2004c). Abdurahman (1992) reported that *M. subhyalinus*, *Microtermes* nr. *vadschagge* (Sjost.), *M. aethiopicus*, *Odontotermes* sp., *Pseudacanthotermes militaris* (Hagen) are species regarded to be harmful on maize and sorghum.

Damage to maize by termites was more serious when termite attack is severe enough to cause lodging or when attack occurs on lodged plants. In Wellega, 30–40% lodging and damage to maize have been substantiated. Overgrazing by livestock aggravated the termite problem. Many species recorded were harmless feeding on dead plant tissues, dung, or soil. Species with deep subterranean nests and with ability to survive on living crops and crop residues can cause severe losses. These include *Macrotermes, Microtermes, Ansistrotermes, Odontoterms* and *Pseudacanthotermes* (Abraham, 1990).

Natural enemy

Cotesia flavipes

Cotesia flavipes is native to Asian. It is an endo-larval parasitoid of stemborers highly considered in the classical biological control of *C. partellus* in eastern and southern African countries. The parasitoid has never been released in Ethiopia. However, it was for the first time recorded by Emana (Emana, 2002) and Emana et al. (Emana et al., 2001; 2003) in 1999 across the country. It was assumed that the parasitoid crossed over to the country from releases made in Somalia in 1997 by the ICIPE group. The authors arrive at this speculation since stemborers' survey reports of the previous years from Ethiopia did not report *C. flavipes*. Moreover, Cotesia complex specimens collected from Ethiopia and either deposited in the National herbarium or collection centers in Ethiopia or outside of Ethiopia like the National Museum of Kenya and/or British did not posess *C. flavipes*. Another reason for the speculation was that the highest rate of C. *flavipes* parasitism was from eastern Ethiopia, which is in close to the Somalia release site. This parasitoid has a very good potential in suppressing stemborers' population in Ethiopia, as a mean parasitism rate for 2005/2006 was 58%. Melaku et al. (2007) from their survey of 2003 and 2004 in Amhara Region of northern Ethiopia reported that *C. flavipes* was the most abundant parasitoid species in the semi-arid eastern Amhara with an overall average of around 30% parasitism, although as high as 85% parasitism was recorded in many localities.

Emana (2002) and Emana et al. (Emana et al., 2003; 2001b) reported an average rate of parasitism of 7.5% by *C. flavipes* for Ethiopia with the survey made at vegetative and maturity stages of maize and sorghum crops, although they recorded as high as 100% parasitism in few eastern Ethiopia localities.

Owing to its potential, some biological parameters on Ethiopian population were studied. Emana (2007) studied the effect of temperature and relative humidity on longevity, potential and realized fecundities of Ethiopian populations of *C. flavipes*. The longevity experiment indicated that temperature, relative humidity and their interactions significantly ($F= 38.9$, $p<0.001$) affected the survival period of the adult wasps of *C. flavipes*. Meanwhile, the interaction of temperature, relative humidity and sex did not significantly affect longevity ($F= 2.6$, $p>0.05$).

C. flavipes adult wasps significantly ($F= 66.5$, $p<0.001$) lived longer hours at the highest relative humidity (80–90%) and at the temperatures of 10, 20 and 30 ^{0}C. Relative humidity had no effect on the longevity of *C. flavipes* adult wasp at 40 ^{0}C. The longevity of the female *C. flavipes* adult wasp was significantly longer at 60–70% and 80–90% relative humidities. As temperature increases from 10 to 40 ^{0}C, the survival time of *C. flavipes* was significantly shortened. The longevity of the female *C. flavipes* adult was significantly higher at 10 ^{0}C and 20 ^{0}C. Significantly higher potential fecundity was recorded at 80–90% relative humidity followed by 60–70% relative humidity. Relative humidity did not significantly affected ($F= 1.8$, $p>0.05$) potential fecundity at 25 ^{0}C and 28 ^{0}C. Significantly ($F= 16.8$, $P<0.001$) lower potential fecundity was recorded at lower temperature (20 ^{0}C) and no significant differences were observed among the temperatures of 25 ^{0}C, 28 ^{0}C and 30 ^{0}C. Significantly ($F= 12.5$, $P<0.05$) higher realized fecundity was recorded at 80–90% relative humidity. At 25 ^{0}C and 28 ^{0}C, relative humidity had no effect on realized fecundity

Henock (Henock, 2003) studied the effect of population variation and temperature on different biological parameters of *C. flavipes* such as fecundity, longevity, and developmental time. The number of dead larvae inside the host was affected significantly by population interaction ($P=0.001$) and temperature ($P<0.0001$). The number of dead cocoon inside the host was significantly affected by population interaction ($P<0.0001$), temperature ($P<0.0001$) and the interaction of temperature and population interaction ($P<0.0001$). The highest mean longevity of *C. flavipes* went up to 97 hours for Cf Ziw (*C. flavipes* from Ziway) reared on Cp Mel (*C. partellus* from Melkassa) male at 20 ^{0}C, while the lowest was 18.8 hours for Cf Mel (*C. flavipes* from Melkassa) reared on Cp Mel male at 30 ^{0}C. Females of Cf Mel reared on both *C. partellus* populations at 28 ^{0}C lived significantly longer than males of the same population interaction at the same temperature. Females of Cf Ziw reared on both *C. partellus* population at 20 ^{0}C had lived significantly longer than males of the same population interactions at the same temperatures. Population interaction was significant with respect to the number of dead larvae inside the host ($F_3=18.39$, $P<0.0001$), number of dead cocoons ($F_3=40.85$, $P<0.0001$) and total progeny ($F_3=26.03$, $P< 0.0001$).

However, population interactions were not significant with respect to percent female progeny per host ($F_3=0.544$, $P=0.653$). Comparison of the four-population interactions for mean number of dead larvae inside the host, dead cocoon and total progeny showed that when both the parasitoid and the host are from the same location, dead larvae inside the host and dead cocoon are significantly lower and the total progeny is significantly higher. Egg to adult developmental time was significantly affected by temperature (F_3=9027.4, P< 0.0001), population interaction (F_3=89.04, P< 0.0001) and the interaction of temperature and population interaction (F_3=52.39, P< 0.0001). Comparison of the mean number of days taken from egg to adult indicated that regardless of the type of populations (both Cp and Cf) used, days taken from egg to adult is inversely proportional to temperature. The regression equation for egg to adult developmental time was Y= 52.90-1.27X, Where Y represents the developmental time and X represents the temperature in ^{0}C (Fig. 1). The R^2 and P values were 0.87 and 0.001, respectively. The regression equation shows that egg to adult development time is significantly negatively correlated with temperature. Emana (Emana et al., 2003b, 2003a; 2003c, Emana et al., 1999; 2006; 2007) studied different biological parameters such as life table, developmental time, fecundity and longevity of Asian populations of *Cotesia flavipes* under different temperature and relative humidity conditions. The information obtained from these studies helped to demarket the release site of *C. flavipes* for the successful biological control of *C. partellus*.

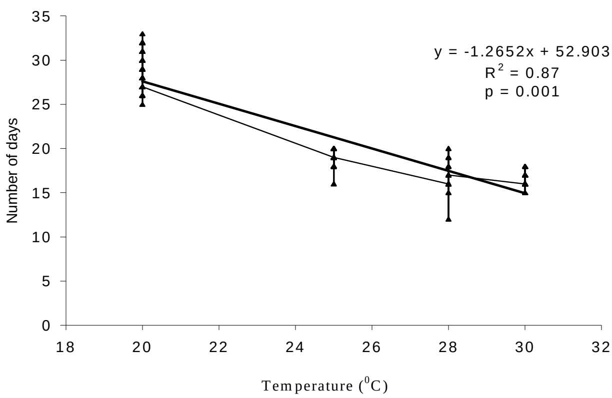


Fig. 1. Regression of egg to adult developmental time (days) as a function of temperature (after Henock, 2003)

Dolichogenidae fuscivora

Kassahun (Kassahun and Walker, 1997; Kassahun, 1996) studied the biology of *D. fuscivora*. The result indicated that the life cycle was completed in 26 days at 24 ±1 °C. Adult longevity was affected by the availability of feed and water. Mating and oviposition reduced the life span of males and females, respectively. From the eggs laid by a female, 65–76 larvae were hatched. The female to male sex ratio varied from 1:1 to 7:1, the average being 5:1.

Nematodes

Emana (2002) and Emana et al. (Emana et al., 2001b) reported nematodes on *B. fusca* from their surveys of 1999 and 2000 in major maize and sorghum growing areas of Ethiopia. Nematodes were also observed attacking *B. fusca* during the wet months in the cool wet western Amhara Region, which might have contributed to the low *B. fusca* infestation in the cool-wet western Amhara (Melaku and Gashawbeza, 1993).

Yield loss assessment studies

Yield loss data are available for stemborers, shoot fly, sorghum chaffer, termites, African bollworm, and sorghum midge (Table 4).

Table 4. Yield losses reported due to insect pests on maize, sorghum, and millet in Ethiopia

Crop	Pests	Damage	Percentage of damage		Reference
			Range	Mean	
Maize	*B. fusca*	-	11-90	-	38, 39, 43, 157
Maize	Stemborers	-	30-40	-	225
Sorghum	stemborers	-	20-25	-	225
Sorghum	*B. fusca*	5-64	2-7	-	19
Maize	*B. fusca*	-	3-9	-	19
Sorghum	*B. fusca*	-	-	32.5	19
Sorghum	Stemborers	-	23.4-64.4	-	104
Sorghum	Stemborers	73.5-83.2	-	23.3%	171
Maize	*B. fusca*	100	10-100	30	77
Maize	*B. fusca*	-	-	58.2	66
Maize	*C. partellus*	-	-	4.5	91
Sorghum	*C. partellus*	-	-	8.6	91
Sorghum	*B. fusca*	-	3.0-32.5	14.5	163
Sorghum	Stemborers	-	-	65.9	151
Sorghum	Shoot fly	-	15-25	-	180, 209, 225
Maize	Shoot fly	1-36	1-33	-	19
Sorghum	Shoot fly	-	5-15	11	180
Sorghum	Sorghum chaffer	-	19-41	-	231, 232
Sorghum	Sorghum chaffer	-	3-28	-	64
Sorghum	Sorghum chaffer	-	20-30	-	225
Sorghum	Sorghum chaffer	-	-	80	117, 118
Maize	Sorghum chaffer	-	-	20	117, 118
Sorghum	Sorghum chaffer	-	-	100	210, 211, 212
Maize	Termites	-	0-6	-	235
Maize	Termites	-	0-8	-	235
Maize	Termites	-	-	40	2
Maize	Termite	30-40	-	-	15
Maize	Termites	-	-	58.2	229
Maize	Termites	-	-	45	14
Maize	Termites	-	-	50	14
Maize	Termites	-	-	18	14
Maize	African bollworm	-	70-80	-	14
Sorghum	Sorghum midge	100	40-70	55	86
Sorghum	Sorghum midge	60	-	-	205

Stemborers

Loss assessment study on stemborers began in 1970/71. Yield losses reported due to stemborers greatly varied (Abdurahman and Terefe, 1993; Assefa, 1989a, Gashawbeza and Melaku, 1996; Girma et al., 2001; Melaku et al., 2006; Tadele, 2004; Tadesse, 1987; Tsedeke and Tesfahun, 2003; Tsedeke, 2004; Yirga, 2006). Tadesse (1989; 1987) indicated that losses due to stemborers ranged from 30 to 40% for maize and from 20 to 25% for sorghum. IAR (1997) reported 11-90% yield losses due to stemborers. Adane and Abraham (1996) and Abraham Abraham et al. (1998) reported losses due to stemborers in Bako as high as 33%. Melaku and Gashawbeza (1992; 1993; 1988) reported losses of 23–64% due to stemborers from Ziway. Losses due to stemborers from some localities of Tigray were reported as 39% (MeArc, 2002; TARI, 2004). Tsedeke and Tesfahun (2003) reported a loss of 58% due to stemborers on late-planted maize. A yield loss ranging from 10–19% due to *B. fusca* was reported from Alemaya (Kassahun, 1996). IAR (1993a; 1993b) reported yield losses of 65% from Ziway by stemborers. Emana and Tsedeke (1999) reported yield losses ranging from 10 to 100% from Arsi-Negele. Emana (2002a; 2002b) reported yield losses of 28% due to stemborers in Ethiopia. Melaku et al. (2006) reported 49% grain yield loss due to stemborers from northenn Ethiopia. Yirga (2006) reported yield losses to sorghum ranging from 40% to 65% due to stemborers in northern Ethiopia. He further noted that chafyness and exit holes were highly correlated to sorghum yield loss. Heavy infestation at booting through flowering stages of sorghum caused 81% chaffyness in the fields studied resulting in losses of 65%.

Assefa et al. (1989) reported that the first generation of *B. fusca* caused 22.5–100% crop loss while it was only 0 to 22.6% due to the first generation at Awassa. The study showed that a delay of planting later than April would result in serious crop loss due to the second generation. Second-generation larvae caused up to 80% crop loss on the late-planted maize, while it was only 5–15% due to the first generation on the early-planted maize (Assefa and Ferdu, 1997).

Shoot fly

Losses due to shoot fly to sorghum were in the range of 15–25% (Tadsse, 1987). Adane and Abraham (1996) reported yield losses ranging from 1 to 33% due to shoot fly from Bako depending on the season and the time of sowing – the highest being on June planted sorghum in all seasons. Melaku (MeARC, 2000) reported yield losses of 5.04%, 13.2% and 14.59% from 76T1#23, Seredo and Gambella-1107 sorghum varieties at Kobo due to shoot fly, respectively.

Sorghum chaffer

A large gregarious batch of sorghum chaffer beetles (100–140 per head) feed on sorghum all at the same time, causing heavy losses. They stay on the sorghum head until the grain is exhausted, unless they are disturbed. The damage symptom is indistinguishable from damage caused by grasshoppers, sorghum midge, birds (Emana unpublished). Extensive loss assessment studies have not been done in Ethiopia, but preliminary data by Plant Health Clinics suggest that yield losses due to this pest range from 19 to 41% (Tsedeke and Tesfahun, 2003; Tsedeke, 2004). In a cage trial, 10 beetles per panicle caused 3–28% yield loss (Delenesaw et al., 2007). Tadesse (1987) reported the loss due to sorghum chaffer in sorghum is in the range of 20–30%. Hiwot et al. (1999; 2004) reported loss of up to 80% in sorghum and 20% in maize due to sorghum chaffer.

Termites

Wood (Wood, 1986a; Wood, 1986) reported losses due to termites as 0–6% on maize seedlings and 0–8% on tasseling plants or plants at the young cob stage. Abdurahman (3) reported 40% stand losses of sorghum due to termites. Abraham (1990) reported 30–40% lodging of maize plants from Wellega due to termites. Abraham (1988) reported 45, 50, and 18% yield losses due to termites at Bako, Didessa, and Asossa, respectively. According to surveys conducted on termites in western, southern, and eastern Ethiopa, 15 new species belonging to five genera were identified (Abdurahman, 1990; 1992). The distribution and pest status of some of these species have also been described. So far, 61 species belonging to 25 genera and 4 families have been recorded in Ethiopia (Assefa, 1990; BARC, 1998; Cowie et al., 1999). *M. subhyalinus* is a dominant termite in several parts of Ethiopia. However, significant damage on field crops caused by this species was recorded only in western Ethiopia. Emana and Gure (1997) and Offgaa (2004) studied the status of termites in Manasibu districts on different vegetation types such as croplands, forest area, grazing land, homestead, etc. He indicated that ecological rehabilitation, restricting the herd size on grazing land, growing resistant indigenous plants in strips of rangeland and crop field significantly reduced losses due to termites and enabled the coexistence of termites with the vegetation without much loss. Moreover, elimination and/or removal of stubbles and dry crop residues from crop field can minimize termite infestation on crops grown on the same plot of land.

African bollworm

Little has been done to estimate yield losses on cereals caused by ABW. At Didessa ABW caused 70–80% yield losses on sorghum (IAR, 1984).

Sorghum midge

Up to 100% infestation of sorghum midge was observed in the sorghum variety, Bakomash 80 (Table 5). In the lowland areas of Merhabete and Humera, severe midge damage was reported (IAR, 1986a; 1986b) as well as in late maturing sorghum fields in Wolenchiti area on the Nazareth–Awash highway (Sharma, 1990). Emana (unpublished data) observed 100% losses due to sorghum midge in Bale lowlands and eastern Ethiopia. In Kuraz district of southern Ethiopia, 100% loss in sorghum due to sorghum midge was recorded (personal communication).

Table 5. Status of sorghum sterility of sorghum at Gambella in 1989 on Bakomash variety

Location	Area planted (ha)		
	Total	Infested	Infestation (%)
Shabbo	619.41	379.90	61.33
Ukuna Kijang	92	92	100
Perbongo	343	311.35	91.77
Ubala	792.03	287.97	36.36
Total	1846.44	1071.22	58.06

Source: Ferede and Girma 1989

Population dynamics study

Population dynamics of stemborers was carried out on sorghum at Ziway and Melkassa in 1990. Three species *C. partellus*, *B. fusca* and *Sesamia* sp. were recorded. *C. partellus* was the dominant species comprising 87% of the population, while *B. fusca* made up only 12% and *Sesamia* sp. was reckoned negligible (1%). Stemborers infestation in general was low (less than 2 larvae per plant). Numbers of *C. partellus* larvae declined with delay in planting and on aging plants, while those of *B. fusca* showed a slight increase (IAR, 1991b; Melaku and Gashawbeza, 1992a; 1992b; 1992c; 1999). Melaku (1999) reported similar composition, i.e., 92% *C. partellus*, 7.7% *B. fusca* and less than 1% *S. calamistis* in the Central Rift Valley of Ethiopia (Nazret area). Population dynamics studies of stemborers at Melkassa compared June 1 and 15, and July 1 and 15 plantings. *C. partellus* constituted 98.2%, while *B. fusca* was 1.8% at Melkssa. Stemborer populations increased with delay in planting (IAR, 1991b). This was especially true for *B. fusca*, but not *C. partellus* in Nazret area (Melaku, 1999). The study carried out in 1990 and 1991 led to conclude that sorghum planting should be practiced in July to prevent stemborers (Melaku, 1999).

Emana (2005) studied the population dynamics of *C. partellus* and its natural enemies under Melkassa conditions on both maize and sorghum. The experiment was conducted between 2000 and 2005. In this study, he found out that *C. partellus* density and infestation peaked between January and June on both crops, the highest density being on sorghum. Though egg, larval and pupal parasitoids were recorded on *C. partellus*, more significant parasitism (48%) were attained by the larval parasitoid mainly *C. flavipes*. Towards the end of the experiment, after augmentation release of *C. flavipes*, almost all larvae collected from Melkassa were parasitised indicating the success of the parasitoid. Tsedeke and Selome (unpublished) also recorded more *C. partellus* infestation and density at Melkassa during dry season of the year.

Field experiments were conducted in 2003 and 2004 in the cool-wet western Amhara, Ethiopia, to study the seasonal abundance of borers and their natural enemies on sorghum. Pest and natural enemy numbers and plant damage were assessed at the seedling stage, knee height, flag leaf, heading, grain filling and at harvest of crops planed at three different dates (early, medium, late). The major pest species was the noctuid *Busseola fusca*. Borer density and damage tended to decrease with delay in planting time. Densities increased with crop growth stage until grain filling and then declined towards harvest (Melaku and Gashawbeza, 1993; Melaku et al., 2006). This is in contrast to what was known as in much of the Rift Valley, especially Awassa, Arsi-Negle, and Ziway areas. In Awassa and Arsi-Negele, borer density and damage increase with delay in planting (Asssefa and Ferdu, 1997; Assefa et al., 1989).

Host range study

Stemborers

No plant family has been more important to man as the Poaceae. For example, cereals constitute the basic diet of people in many countries and grasses are the main feeds for their livestock. Poaceae are the most important group of flowering plants in the number of species of the most important tropical pastures. Fodder grasses have originated in East Africa, mostly in Kenya and Ethiopia. However, due to human population pressure, the land has been cleared for intensive and continuous cultivation, which threatens grass biodiversity through loss or even extinction of some indigenous species. The current crop pests might originally have been pests of wild plants. There is a high probability that some of the arthropods entirely feeding on wild plants might have moved to feed on cultivated crops when their wild hosts become extinct.

In this study, the species of grasses grown near maize and sorghum and the types of arthropods (both pests and beneficials) associated to both the wild grasses and cultivated gramineae were investigated. To collect the information needed, monthly sampling of grasses and associated arthropods were done at four sites (three crop fields and one uncultivated park site) at each location (Bako, Nazret and Arsi-Negele). Furthermore, participatory rural appraisal (PRA) was also conducted at each location to exploit the benefits of indigenous knowledge with this issue. The results obtained indicated that over 62 grass species were recorded in Ethiopia near maize and sorghum. About 10 different species of arthropods were also found on both the crops and wild grasses. Some larval and pupal parasitoids were also reared from borers collected from cultivated and wild grasses (Emana, 2004b). Emana (2003; 2002) recorded 17 plant species as hosts of stemborers in Ethiopia. Assefa (1988a) reported that elephant grass (*Pennisetum purpureum*) and wild sorghum (*Sorghum verticilliflorum*) were identified as potential hosts of stemborers in larval development and survival.

Shoot fly

Wild hosts of sorghum shoot fly included *Sorghum arundinaceum*, *S. aethiopcum* and *S. verticilliflorum* (Sileshi and Lakra, 1994; Sileshi, 1994).

Sorghum chaffer

Pachnoda interrupta has a wide host range. It attacks many crops, trees and wild plants including sorghum, maize, sesame, cotton, velvetleaf (*Abutilon* sp.), and *Acacia* spp. However, sorghum is the most preferred host plant (Tsedeke and Tesfahun, 2003). According to the survey made in the Oromiya Zone of the Amhara Regional State, 42 plant species that consisted of trees, shrubs and crops were hosts of sorghum chaffer (SARC, 1997; SARC, 1998; SARC, 2000).

Source of infestation (overseasoning habits)

Stemborers

Wild hosts, stubbles, and stalks of maize and sorghum were identified as sources of *B. fusca* (Assefa, 1988a; 1988b; Emana et al., 2003; 2004; 2004a; IAR, 1983) and *C. p artellus* infestation (Emana, 2002). Although diapause larvae were found in stalks of various lengths left in farmers' fields, more larvae were found in longer stalks than shorter ones. Maize and sorghum stalks kept in an upright position after grain harvest contained the highest number of larvae and pupae. Therefore, upright stalks whether stored or standing would be important in increasing survival of the diapause generation during the dry period.

Sorghum stubble harbored about one-third of the diapause larvae in the infested plants and appeared to be a potential source of infestation for the subsequent season (Yirga, 2006).

Shoot fly

Sorghum stubbles and wild hosts were found to be the main source of infestation of shoot flies (Sileshi and Lakra, 1994).

Sorghum chaffer

Studies were conducted by a team of entomologists from federal and regional research centers and Bureau of Agriculture to identify the potential breeding and hibernating areas of sorghum chaffer (*P. interrupta*) (Hiwot et al., 1999). Soil samples were taken in August and February 2001 from Afar, Amhara and Oromiya regions where the pest prevalence was frequent. The sample areas included nine ecological niches (under trees in the forest, under trees in crop field, on crop field, border of crop field, grazing land, riverside, manure heaps, termite mound and homestead), which were previously suspected to be the sources of infestation to the pest. Metal boards were installed in three selected locations to determine the beetles' flight direction at the time of an outbreak. 156 and 236 samples were investigated from the aforementioned nine ecological niches for identification of the beetles hiding and breeding sites, respectively.

Fertile, humus rich and moist light soil under shades of various tree species in the forest and riverside were found to be the potential areas for hibernating of the aestivating/diapause beetles. The other suspected niches were unsuitable for hibernation of the beetles. Eggs and larvae collected from under litter and vegetation debris of various tree species in the forest developed to adult sorghum chaffer in the laboratory. Therefore, litter and vegetation debris in the forest were the potential breeding sites for *P. interrupta* in its area of distribution. These niches were found in all surveyed districts and the maximum (322) and minimum (3) numbers of larvae per square meter were counted from Amibara district of Afar and Fentale district of Oromyia regions, respectively. The undisturbed acacia and other forest trees in Afar Region are suitable for the reproduction of beetles (Hiwot et al., 1999).

Field surveys conducted in 22 sites of Afar and Amhara regions from January to May 2001 revealed that the aestivating/diapause beetles can be found in 5 to 43 cm of depth favoring mainly moist fertile under the roots of some common shrubs and trees such as acacia and eucalyptus. In few instances, they were also found in crop fields under the shades. Aestivating/diapause beetles were found in altitudes ranging from 802 to 1459 m. In most of the cases, the aestivating/diapause beetles were found at soil temperatures varying from 28 to 31 ^{0}C. In few locations, the beetles were found at soil temperatures varying from 28 to 31 ^{0}C. In few locations, the beetles were found at soil temperatures of 22 to 25 ^{0}C (EARO, 1998).

Survey results indicated that heaps of animal dung and termite mound were not found to be suitable over seasoning sites for aestivating/diapause adult beetles. Fertile and moist soils under the shade of various trees and shrubs were suitable areas to the overseasoning. The beetles were reported to come from Afar Region, but now farmers reported eggs, larvae and pupae in litters, organic soils, dung and under the root zones of some tree spp. (SARC, 2000).

Flight period, direction, and efficiency of trapping

Stemborers

The flight period of *B. fusca* was studied at Awassa, Arsi-Negele, Ziway, Areka, and Alaba (Assefa, 1989a; 1989b; 1992). Synthetic pheromone in Delta traps that attracts males of *B. fusca* was used throughout the year. The number of male *B. fusca* moths trapped was recorded and removed from traps weekly.

Three peaks of *B. fusca* flight periods were observed at Awassa indicating the presence of three generations in the area. The adults from the diapausing larvae appeared between March and June with a peak in May. However, the first generation adults were observed in the months of July, August, and September, peaking in August. Some of the second-generation larvae pupated and gave rise to adults' flight from September to December. Very few adults emerged in January.

In Aris-Negele, flight of the adults from the diapausing larvae was observed between March and June. Flights of the first and the second-generation non-diapausing adults were observed between June and August. There was an overlap between these generations. The highest numbers of adults were caught in May and November.

In Ziway, few adults were caught in February. There was a continuous flight from March to October. This flight was from adults arising from the diapausing larvae, the first generation adults, and some non-diapausing second-generation adults. The flight during October-December is also from the non-diapausing second-generation larvae. From these data, it can be concluded that *B. fusca* have two generations at Ziway

At Areka, three distinct flight periods were observed indicating the presence of three generations of the insect in the area. Flight from the diapausing generation started in March like the other areas. The peak flight in July–August is from the first generation and the October-November peak is from the second-generation non-diapausing larvae.

At Alaba flight from the diapausing larvae started later than other areas (April). There was an overlap between the flight coming from the diapausing larvae and the first generation adults. Flight of adults from the non-diapausing second-generation larvae was observed in September–October.

To know the effect of trap direction and height on trap catch, synthetic pheromone was used in split plot design in two replications. The main plot was direction of trap opening (facing East–West or North–South), whereas the trap height from the ground formed the subplots (0.5, 1, 1.5 & 2 m) (Assefa, 1992). Relatively high catches were from a height of 1m. Lower traps (0.5 m) were damaged by wild animals or contaminated by dust/dirt. Higher traps (2 m) were not convenient. The insect could locate the pheromone irrespective of the direction.

Sorghum chaffer

In order to locate the breeding sites of *P. interrupta*, understanding of the flight direction was a key step. For this study, 14 sites were selected based on their proximity to the suspected breeding ground (Afar), vegetation cover and accessibility. Before the flight direction study, the traps height from the ground was determined. Eight traps were thus installed at Sefi beret, which is 250 km Northeast of Addis Ababa, at 1, 2, 3 and 4 m height above the ground facing East, West, North and South. Sexually mature beetles that entered the traps were counted in July 2000. A total of 8328 beetles (3994 males and 4334 females) were trapped during this period. Considering all directions, the highest mean catches of beetles (724.3) were recorded on traps hanged at 3 m height followed by 2 m (720.8 catches) and 4 m (362.5 catches). The lowest mean beetle catch (279) was recorded on traps fixed at 1 m height. Based on this finding, 154 traps were installed at a height of 3 m (four traps per location) which is one trap per direction (Hiwot et al., 2004). Monitoring of the flight direction of *P. interrupta* from June to October 2000 indicated that trap direction, location, and season vary in the number of beetles caught. Likewise, dates of first and last catches and peak catches varied among locations. This might be due to variations in biotic and abiotic factors that can influence the distribution and incidence of the beetles.

Outbreaks of the beetles are common in September, but trap catches were surprisingly low in this month. In September, cultivated land in the study area was covered by crops mainly sorghum, which was at the flowering and/or milky stages. This might have prevented the dispersal of the beetles and caused low trap catches. It may as well be speculated that most of the September beetles came from the nearby fields, not invaders from long distance such as Afar.

In 6 out of the 14 locations, East oriented traps facing the Afar Region caught the highest number of beetles both in July and September. In five other sites, the highest catches in July and September took place in opposite directions to each other, which might indicate the presence of migration in opposite direction. Peak catches in the remaining three sites showed that there were different directional flights in July and September, which might suggest certain distinct movements dictated by the ecology of the location.

Throughout the study period (June to October 2000), 790,298 beetles (348114 males and 442,184 females) were caught using the metal boards facing different directions. The sex ratio showed that females dominated the population (0.79:1). This was particularly true during the peak catches where the number of males was often many times lower than females.

During the June 2001 outbreak, 1770 beetles were caught from 36 metal boards. The number of beetles caught from North direction is almost double of the South and four times to the East and West direction each. The vegetation cover and suitability of the place for the beetle’s hibernation at each location and the beetle catch were not consistently correlated. This might be attributed to the complex and swarming flight behavior of the beetles for mating and search of food. Therefore, maximum beetle catch at the time of an outbreak didn’t show the sources of the pest infestation (Yeshitla et al., 2004).

Mound soil effect study

Effect of mound soils on commonly grown crop plants including maize and sorghum was studied at Bako (OADB-ARC, 1998a; 1998b). The results obtained indicated that there was no difference between mound and non-mound soils in yields of maize and sorghum.

Molecular systematics in tracing the origin of *Cotesia flavipes*

Differeent populations of *C. flavipes* from Asia (mother stock) and Africa (introduced) were compared with Ethiopian population using polymerase chain reaction (PCR) based molecular methods in Germany, Hohenheim University in 2006.

The PCR analyses for all replications indicated that all *Cotesia flavipes* populations from Ethiopia had similar bands with *C. flavipes* population from the mother stocks (*C. flavipes* from India, North and South Pakistan) and the introduced populations to Africa (Kenya, Uganda and Tanzania) when 16S genes were used (Figure 2). The Kenya population became different from the other populations of *Cotesia flavipes* including the Ethiopian population when ITS2 gene was used (Figure 3). Molecular methods are the finest method of systematics with very minimum errors at 2% level of significance. The current molecular analysis of different populations of *C. flavipes* confirmed that the earlier identification using morphological characters is correct since all *C. flavipes* collected from Ethiopia are identical with the mother stocks from India, North, and South Pakistan, and introduced populations except Kenyan population.

The source of *C. flavipes* voluntarily established in Ethiopia can be any population that originated from the mother stock. The behavioral differences of *C. flavipes* recorded in Ethiopia could be explained by ecological factors which need to be investigated in depth. Emana (Emana, 2002; 2006b) demonstrated the role of ecological factors in some biological parameters of stemborers and their parasitoids particularly *C. flavipes*. From this experiment, it was concluded that the *Cotesia* recorded in Ethiopia was the same species that was introduced to Africa in the classical biological control of *C. partellus.* The *Cotesia* recorded in Ethiopia by chance got all favorable conditions and fully established. Hence, ecological factors that favored C. flavipes in Ethiopia should be investigated in detail and a model should be developed which can be adopted by other countries.

Managing insect pests of maize, sorghum and millet

Cultural control methods

Stem borers

Manipulating sowing date: Sowing date experiments conducted at Awassa indicated that early-planted maize suffers less from the attack of *B. fusca* (Assefa and Rolad, 1989; Assefa, 1989a; 1989b; 1990; 1991; 1992). Similar results were obtained from investigations carried out at Areka (Assefa and Ferdu, 1996). Planting should not be delayed later than April. The study showed that early planting as soon as the rain starts can offset the damage caused by *B. fusca* and ensures high yield without using insecticides. Sowing date trial conducted at Abobo (Gambela) showed that early planting suffer less from the attack of *C. partellus* (AbARC, 1998; Ferdu et al., 2001). Relatively, lower levels of infestation and higher yields were observed from the second (May 8) and May 23 plantings. June 22 planting at Ziway had lower stemborers infestation than June 8 and 17 (IAR, 1991b). A study on sowing date for the management of maize stemborers on sorghum was conducted at Sirinka in 2003. The results indicated that the number of eggs and larvae per plant at 45 and 60 days after emergence were high in the early sowing dates (27 June, 4 July and 11 July) with the mean of 3 to 6 eggs per plant and 4 to 28 larvae per plant. Sorghum sown on 11 July hosted significantly more eggs and larvae before and after harvest.

Similarly, significantly high proportion of infested plants (16 to 74%), number of chaffy heads (25 to 26), peduncle breakage (6 to 13), infested peduncle (84 to 87%), stalk holes (6 hole per plant) and infested internodes (40 to 52%) were recorded in the three early sowings. The lowest grain yield (34 q ha^{-1}) and the highest yield loss (13 q ha^{-1} or 28%) were obtained on 11 July sown sorghum. In all the sowing dates, 2–13 q ha^{-1}(5-28%) grain yield losses were recorded due to stemborers (Asmare et al., 2004). Ferede (1988) tested five sowing dates for stemborer infestation, found out that among the five sowing dates, infestation in terms of number of larvae and/or pupae, and stem tunneling percentage increases with delay in planting, but the number of holes did not show any significant difference.

The effect of sowing date and insecticide (cypermethrin 1% granule) application on infestation and damage of stemborers *C. partellus* and *B. fusca* and grain yield of sorghum were evaluated at two locations (Melkassa and

Meiso) during 1997 main cropping season (Yoseph, 1999). At Melkassa, no significant difference in dead heart injuries, proportion of tillering plants and number of borers per plant was recorded between insecticide treatments early in the season. However, the effects of cypermethrin 1% granule were significant in all parameters taken at harvest. Application of cypermethrin brought a significant difference in number of predatory arthropods, densities of stemborers, percent of chaffy heads, percent of peduncle damage and number of borer holes per plant. Sowing date had significant effect on most of the parameters measured. Interaction effects of cypermethrin 1% granule and sowing date were observed in some parameters indicating the practical implication of combining sowing date with chemical application for effective control and the possibility of minimizing the amount of insecticide used with adjusting sowing date.

The lowest yield per plot was recorded from the last sowing and the highest yield was from July 1 sown sorghum. Early sowing (July 1) in Melkassa had a yield advantage of 58.5% over late sowing (July 15). Grain yield of sorghum showed no significant difference between treated and untreated plots. One application of cypermethrin 1% granule resulted in a net loss of Birr 187 ha^{-1} and the loss reached Birr 374 ha^{-1} in two applications. It was, therefore, recommended that cypermethrin application at low stemborers density and infestation is not economically justified (Yoseph, 1999). Similar results were obtained by Tsedeke and Elias (1997; 1998). Melaku (1999) also found the lowest infestation on plots planted on July 1 in Melkassa area, but not for earlier or later.

Ten sowing dates (March 20 to June 20 at 10 days interval) on stemborer infestation and two sets (treated and untreated) were compared at Awassa. The result showed that April 10 and May 10 planted maize gave better yield (IAR, 1996a).

Late planted sorghum was reported to suffer greater damage than early-planted ones. However, levels of stemborer damage on sorghum vary with seasons and locations. For instance, neither early (June 1) nor late (July 15) sowing dates resulted in least infestation at Melkassa in 1992 and 1993. Lower level of damage and higher yield were reported from sowings made on June 15 and July 1. On the other hand, progressive increases in the level of infestation and a sharp decline in yield (27.1, 17.3, 4.6 and 0.8 q ha^{-1}) was observed at Ziway on June 1, 15, July 1 and 15 sown sorghums, respectively (Gashawbeza and Melaku, 1996). Delayed planting increased borer infestation – the highest infestation being July 27 planted sorghum (Girma, 1996).

Emana (1998a), Emana, and Tsedeke (1999) reported the effect of sowing dates on the control of *B. fusca* on maize in Arsi-Negele. Ten sowing dates starting from March 20 at 10 days intervals were tested. The trials were laid out in two sets: with and without cypermethrin treatment. The results indicated that early sowing with cypermethrin treatment doubled the yield of maize grain. If maize has to be grown without cypermethrin treatment, it should be sown between 20 April and 10 May. The highest economic return with cypermethrin treatment at the rate of 0.30 kg a.i. ha^{-1} applied at 4 and 6 weeks after crop emergence was obtained with early sowing indicating that early infestation of stemborer is very detrimental for maize production at Arsi-Negele (Table 6)

Table 6. Effect of sowing date versus insecticide on economic return of maize grain at Arsi-Negele (combined over years)

Sowing dates	Mean yield (t/ha)		Yield difference (±)	Cost of cypermethrin and its application	Net benefit or loss in Birr (1 t maize grain = 800 birr)
	Cypermethrin treated	untreated			
20 March	5.75	2.90	+2.85	200	+1680
30 March	5.65	3.50	+2.15	200	+1520
10 Aril	5.75	3.15	+2.60	200	+1880
20 April	5.15	4.10	+1.05	200	+640
30 April	4.40	4.04	+0.36	200	+88
10 May	4.05	3.59	+0.46	200	+168
20 May	2.95	3.88	-0.83	200	-864
30 May	2.50	2.97	-0.47	200	-576
10 June	1.75	2.27	-0.52	200	-610
20 June	1.70	1.12	+0.58	200	+264

Source: Emana and Tsedeke, 1999

Twelve sowing date experiments (April to July) were compared and all dates from April to June 26 gave better yield than maize planted in July (IAR, 1987a). Contrary to what was known in the past in Ethiopia, Melaku (2006) reported decreasing borer population and damage with delay in planting in the Addis Zemen area of the Amhara Region. This proves the fact that in northern Ethiopia where there is one effective rainy season and long dry season, the borer incidence behaves differently than in two season regions in the country including Awassa, Ziway, Nazret, and Sirinka.

In general, quite a large number of experiments were conducted in Ethiopia to see the effects of sowing dates on the infestations of stemborers. However, the results obtained were variable. Most experiments recommend early mass planting, while a few of them recommended late planting which suggests the need of optimising sowing dates based on locations.

Manipulating crop residues: Farmers stored sorghum stalks vertically either in the field or around their homestead. The diapause larvae over-season inside the stalk up to the next rainy season. Hence, designing methods by which stalks are kept safe and diapause larvae killed was essential. To this end, several experiments were conducted (Asmare et al., 2004; Assefa, 1988b; IAR, 1995). Girma (Girma, 1996) reported that removal of volunteer plants, alternate hosts; exposing stalks to the sun are the best methods of stemborers control. The recommendation of spreading the stalks in the field and leaving them throughout the dry season or burning has opposition from farmers as they use the stalks for various purposes such as fuelwood, construction and livestock feed. However, after 4 weeks of horizontal placement, farmers can keep the stalks in upright position, which is acceptable by farmers and use the stalks for the intended purpose (Abraham et al., 1998).

Effect of horizontal placement of sorghum stalks for 2, 4, 6 and 8 weeks under the sun including the control (stacking immediately after harvest) on the survival of *C. partellus* diapause larvae at Melkassa indicated that high number of live and low number of dead larvae were recorded from stalks stacked immediately after harvest. Percent of mortality increased up to horizontal placement for four weeks after which no specific trend was observed although the percentage was high for six and eight weeks compared to two weeks (IAR, 1994). Eighty percent of the larvae were found dead in stalks spread for four weeks compared to only 3% in stalks stacked immediately after harvest (farmers practice) (IAR, 1994 ; 1995).

Assefa (1988b) investigated the effect of horizontal placement of infested maize stalks on population of diapause *B. fusca* larvae. He found out that keeping infested maize stalk in the sun for four weeks effectively reduced the carry-over population of the insect by 95%.

It was found out that sorghum stalks exposed horizontally for six to eight weeks had 86 to 88% mortality of diapausing larvae. On the other hand, 17 to 20% diapausing larval mortality was recorded in farmers' stalk storage practice, vertical placement, at the same exposure weeks. Therefore, storing sorghum stalks horizontally for six to eight weeks substantially reduces the carryover diapausing larvae in the next season (Asmare et al., 2004).

Intercropping: In Ethiopia, about 70% of the farmers grow maize and sorghum as an intercrop and 30% as a monocrop (Emana, 2002). Depending on the region, major companion crops are legumes, cereals, pumpkin, groundnut, sesame, potato, and sweet potato. Intercropping has many advantages over mono cropping including pest control. Many of the published works indicate that intercropping lowers the infestation of pests and increases the abundance of natural enemies that is explained by resource concentration and natural enemy hypothesis. Emana (2002) reported lower stemborer density per plant in intercropping than monocropping in his experiments conducted in Awassa, Melkassa, and Meiso. Moreover, he reported non-significant difference with regard to the parasitoids between monocropping and intercropping. He indicated that his findings supported only the resource concentration hypothesis (Emana, 2006a). Intercropping maize or sorghum with legumes also delays the onset of infestation (Girma, 1996).

Cultural control of stemborers in sorghum at Melkassa and Mieso using intercropping sorghum with legumes (haricot bean and cowpea) resulted in significantly lower damage than sole cropping (Asfaw et al., 2005; IAR, 1994). Maize/bean intercropping experiments conducted at Melkassa and Awassa during the 1992 cropping season showed that sole maize had significantly higher incidence of stemborer and cob worms as compared to intercropped treatments. Higher stemborer incidence occurred when maize and bean were planted in the same row at both locations. On the other hand, an inconsistent trend was observed in cob worm incidence across locations. Although the current results are not conclusive, it seems that planting time of the intercrop has an impact on the incidence of stemborer and cob worm. Higher stalk borer incidence occurred in simultaneously planted maize intercrops, whereas higher cob worm incidence occurred in maize relay cropped with beans at both locations (Nigussie and Reddy, 1996).

The mean number of stemborer larvae per maize stem was found significantly lower under chat–maize intecropping than maize monocrops. The chat–maize intercropping was found to decreasing significantly the ear head damage, but lower number of kernels produced per ear and 100 seed weight. In the laboratory, more number of parasitoid cocoons were recorded on the intercropping plot than monocrop (Daniel, 2002). Hadush (2003) and Hadush et al. (2003) reported that stemborer abundance and damage on sorghum were usually lower in the sorghum–cowpea intercropping than in the sorghum monocropping in Tigray (Tables 7 & 8). Numbers of predators (ants, spiders, & ladybird beetles) were relatively high in the intercrop than in the monocrop. Three species of ladybird beetles (*Cheilomenes sulphurea*, *Cheilomenes propinqua* and *Cheilomenes lunata*) were recorded in association with stemborers. There was no significant difference in ladybird beetles density at 31 and 125 days after emergence (DAE). However, relatively (significantly) higher density of beetles per 20 plants was recorded in the intercropped plots than in the monocropped plots at 46, 62 and 78 DAE. On average, for all sampling dates, beetles count was about 4 ladybird beetles per 20 plants in the various sorghum–cowpea intercrops while in the sorghum monocrop it was not more than 2 ladybird beetles per 20 plants.

Table 7. Effect of cropping systems on total larval and adult moth count of the lepidopterous stemborers and Rhynchaenus niger

Cropping system	Stemborers / 10 plants				Total
	B. f	C. p	S. c	R. n	
Sorghum: Cowpea single rows intercropping	99 b	56 b	22 b	3 a	180 (12.3)
Two rows sorghum: One row Cowpea	98 b	58 b	20 b	3 a	179 (12.2)
50% sorghum: 50% cowpea broadcast intercropping	68 b	51 b	19 b	5 a	143 (9.8)
75% sorghum: 25% cowpea broadcast intercropping	73 b	50 b	15 b	4 a	142 (9.7)
Sorghum monocrop in row planting	240 a	120 a	51 a	5 a	416 (28.4)
Sorghum monocrop in broadcasting	232 a	119 a	50 a	6 a	407 (27.8)
Total Percentage	**810** (55.4)	**454** (31.1)	**177** (12)	**26** (1.8)	**1462** (100)
CV (%)	10.3	8.1	9.7	24.0	

Values in parenthesis are percentages and means followed by the same letter within a column are not significantly different using LSD test at 5% level of probability.
B. f = B. fusca, C. p = C. partellus, S. c = S. calamists and R. n = R. niger
Source: Hadush, 2003

Table 8. Effect of cropping systems on total count of larvae, pupae and pupal cases of lepidopeterous stemborer species (*B. fusca, C. partellus* and *S. calamists*) (± se) at different days after crop emergence (DAE) in sorghum

Cropping system	*Larva and pupae density/ 10 plants*					
	31 DAE	46 DAE	*62 DAE*	*78 DAE*	*125 DAE*	*Mean*
Sorghum: cowpea single row intercropping	-- *	2.12±0.2b **	*13.6±0.1c*	*50.19 ±0.2b*	*114.38±0.4b*	*36.1 b*
Two rows of sorghum: one row cowpea intercropping	--	2.5±0.2b	*14.2±0.1bc*	*79.75±0.4b*	*95.84±0.2b*	38.4 b
50% sorghum: 50% cowpea broadcast intercropping	--	2.7±0.1b	*13.7±0.1c*	*49.00±0.2b*	*76.21±0.1b*	*28.3 b*
75% sorghum: 25% cowpea broadcast intercropping	0.2±0.1a	2.4±0.2b	*14.3±0.2bc*	*58.52±0.3b*	*72.17±4b*	*29.5 b*
Sorghum monocrop in row planting	0.2±0.1a	6±0.1a	*32.2± 0.1ab*	*220.08±0.2a*	*273.90±0.6a*	*106.4 a*
Sorghum monocrop in broadcasting	0.4±0.2a	7±0.1a	*38.19±0.2a*	*197.54±0.2a*	*280.20±0.3a*	*104.6 a*
CV(%)	24.0	17.3	*7.66*	*10.38*	14.5	*6.5*

** No larvae and pupae recorded*
*** Mean ± SE followed by the same letter(s) within a column are not significantly different (LSD, 5%).*
Source: Hadush,2003

Delenasaw (2004) and Delenasaw et al. (2007) studied five wild hosts used as trap plants against *C. partellus* and found variability among the wild hosts.

They tested *Pennisetum purpurum* (Scumach), *Sorghum vulgare* var. Sudanese (Pers.), *Panicum maximum* Jacq., *Sorghum arundinaceum* Stapf and *Hyperrhania rufa* (Nees). The results of the studies showed that maize plots surrounded by all tested wild hosts significantly (P<0.05) lowered mean percent foliar infestation and stemborer density than maize monocrop plots 15 m away from the treatment blocks. Interestingly, mean foliar infestation and stemborer density between maize plots surrounded by wild hosts and maize monocrop plots within the treatment blocks was not significant. Percentage of tunneled stalks was significantly (P<0.05) greater in maize monocrop plots than maize plots surrounded by all tested wild host plant species. The highest mean percent parasitism (67%) of *C. partellus* by *C. flavipes* was recorded in maize plots surrounded by *P. purpurem*. The findings showed that these wild hosts have considerable merit to be used as trap plants in the development of strategies for managing graminous stemborers in maize crops.

With the experiment conducted at Bako, Awassa and Melkassa Napier grass attracted more adult moths of *B. fusca* for greater ovipostion by stemborers than maize, resulting in reduced infestation on maize (BMRC, 1999).

The study conducted at Bako (IAR, 1996a) on the effects of sorghum/haricot bean intercropping on incidence of major insects under weeded and unweeded cultures indicated that there was non-significant difference among treatments for the number of stemborer-damaged plants. Relatively, high yield was obtained from intercropped (weeded) sorghum.

Melaku et al. (SPL, 1977) studied the effect of cropping systems (haricot bean, sesame, and sweet potato in eastern Amhara and faba bean, mustard, cowpea, and potatoes in western Amhara) in the infestation of stemborers. He concluded that cropping system had little effect on the infestation of maize by the stemborer, *C. partellus*, while the plots assigned to mustard significantly reduced borer density and damge caused by *B. fusca* especially at the vegatative stage.

Effect of fertilization on stemborer infestation: Emana (Emana, 2002) reported that stemborer infestation was high in the soil where total nitrogen was high. A field experiment was also conducted to see the effects of NPK fertilizers on the infestation of stemborers and the preliminary result indicated that high level of nitrogen favors stemborer infestation (Emana, unpublished data). Melakau et al. (2006a) reported similar result from northern Ethiopia where they indicated that in the cool-wet western Amhara, increasing levels of N fertilizer also tended to increase pest density, plant growth, and damage variables. In the cool-wet ecozone, sorghum yields increased by up to

74% because of fertilization: losses caused by stemborers decreased lineraly with reduction in N dosage from 49% to 36%. In maize, because of low borer densities, there were no discernable trends for pest infestation and yield losses. In the cool-wet ecozone, sorghum yields were positively related to insecticide application and plant height, and negatively to damage variables such as tunnelling and peduncle damage. In semiarid eastern Amhara, the effects of fertilizer on pest, damage and yield were low on both crops because of the higher soil fertility. The results indicate that the profitability of nitrogen fertilizer as an integrated pest management tactic in the control of cereal stemborers depends on the severity of borer damage and the soil fertility status prevailing in an area among others. It is concluded that N fertilizer helps minimize the impact of borers on grain yields, especially on sorghum in the cool-wet ecozone.

Shoot fly

Spacing

Closer spacing of sorghum reduced shoot fly damage and increased sorghum yield (Sileshi, 1994).

Manipulation of sowing date

Adjusting planting time is reported to help control shoot fly (Adane and Abraham, 1996; Fantahun and Seneshaw, 1996; Firdissa and Abraham, 1998; Sileshi, 1994).

Intercropping. Intercropping sorghum with bean did not give comparative advantage over sole cropping in shootfly control (Sileshi and Lakra, 1994). A study conducted at Bako in 1997/8 on the effects of sorghum/haricot bean intercropping on the incidence of major insects under weeded and unweeded cultures indicated that significantly low number of plants attacked by sorghum shoot fly (*Atherigona soccata*) were recorded in monocropped sorghum. One to one (1 sorghum: 1 bean) row arrangement increased bean and sorghum yield and land use efficiency, but increased shootfly damage. Intercropping did not reduce shootfly damage (Adane and Abraham, 1998).

Sorghum chaffer

Farmers' indigenous methods of control include mechanical destruction of the pest, i.e., by hand collecting and killing; manual removal done in the evening or morning when temperatures drop. This method is effective, but it demands the whole family labour and is time consuming. Baiting with banana peels, fogging with smoke, burning of suspected breeding sites, covering sorghum heads with plastic bags or clothes and bending sorghum plants hoping that the beetles will fly over the bent plants, among others, are the possible cultural control methods recommended for the management of sorghum chaffer. Mechanical destruction and baiting appeared to give a better control than all other methods used by farmers (EIAR, 2005; SARC, 2000; Tsedeke, 2004; Tsedeke and Tesfahun, 2003). Farmers practice various control measures with little success mainly because of lack of integration of different methods listed above (EIAR, 2005).

The results from mass trapping study showed that more beetles were caught when more traps were deployed and less beetles were counted on sorghum heads from the plots with 20–25 traps (Hiwot et al., 2004). Comparison of the three collection methods showed that higher proportion of the beetle was collected using banana bait (58%), local beer residue (41%) and hand picking (0.6%) (Elias, 2003). Adult male beetles were more attracted by baits than female beetles. Among the baits tested in another experiment, guava, mango and banana had good luring efficacy (ARARI, 2001).

Termite

Cultural control practices that result in vigorous plant growth other than fertilizer is recommended for the control of termites (Abraham, 1990).

African bollworm

Use of trap crop in the control of African bollworm on sorghum. A trap crop study was conducted at Bako and Didessa for three years against ABW. Based on eggs and larval count, it was found out that lupin caught more insects than the other crops. On the third year sunflower was included in the trial and caught more number of eggs and larvae than the other trap crops. The three seasons mean number of eggs and larvae per plant were 10.5 and 6.1 on lupin, 1.7 and 2.5 on sorghum; and two seasons average on maize was 0.15 and 0.00, while one season mean on sunflower was 272.17 eggs and 46 larvae at Didessa. At Bako one year result showed that the number of eggs and larvae caught per plant were 14.3 and 2.3 on lupin, 0.4 and 0.1 on maize, 0.7 and 0.1 on sorghum, and 21.6 and 4.3 on sunflower, respectively (Abraham, 1986).

Sunflower attracted more ABW populations than sorghum. Trap crop of lupin caught over three times more ABW eggs and larvae than the sorghum plants (IAR, 1986a; 1986b). Control of ABW developed for other crops such as tomatoes can be used for the control of ABW on maize (Melaku, 1999). Trap crops such as maize, sorghum and lupin were compared and more ABW were recorded on lupin than on maize or sorghum (IAR, 1983).

Host plant resistance

Stemborers

Seven released maize genotypes (Guto, BH-140, BH-660, BH-540, ACV-3, ACV-6, Kuleni) were evaluated for their resistance to maize stemborer, *B. fusca*, at Bako between 1996 and 1998 (Assefa, 1994). None of the varieties showed resistance to the pest. To screen maize varieties to borer in laboratory and field, eight maize varieties from CIMMYT and Bako were tested and difference in resistance was observed at Ambo. The optical density of ether extracts of maize leaves under laboratory conditions correlated with results obtained under field conditions. The higher the optical density the lower the damage by *B. fusca* (SPL, 1988).

Two sorghum varieties**,** Al-70 (tolerant) and Birmash (susceptible) infested at different plant growth stages (4, 6 and 10 WAE) with different levels (0, 1, 3, and 5 per plant) of first instar larvae were laid out in two sets: one treated with cypermethrin 1 G at 2.5 kg ha^{-1} and the other without insecticide treatment. Leaf damage, damage score (1–5 scale), dead heart injuries, holes, stem tunnelling and yield were measured. In most parameters, both main and interaction effects stage of crop and density of pests were significantly different. Damage was higher on younger plants at all densities. Damage increased with pest density, but decreased with plant age. An estimate of 57.4% and 56% yield reductions occurred with infestation densities of 3 and 5 larvae at 4 WAE, respectively. Regardless of pest density mean yield loss of 49.1%, 30.6%, and 6.0% (overall mean 28.6%) were recorded for infestations at 4, 6 and 10 WAE. Regardless of plant growth stages, losses of 17.3%, 33.6% and 28.9% occurred at 1, 3, and 5 larvae per plant. The overall mean loss was 26.6% (IAR, 1996b).

Out of 17 sorghum varieties tested against *C. partellus*, T3-307, IS 127-3-4 and PS-1882-4 exhibited low number of holes and number of larvae and/or pupae (Ferede, 1988). National sorghum germplasm collections and introductions from the International Research Centers for various purposes including varieties were tested to identify sources of resistance against stemborers in sorghum. Out of the 90 genotypes evaluated for 4 years in Ethiopia between 1986 and 1989, IS-1054, IS-2146, IS-4664, and PS 18822-4 were reported to show better resistance to stemborers (IAR, 1989a).

Twenty-five varieties obtained from ICRISAT as multi-location test for stemborers resistance were evaluated for 3 years between 1991 and 1993 using natural infestation at Ziway and Melkassa. ICSV-708, PB-14376-1, PB-15469-

2-1-3 and PB-12747 were reported as good sources of resistance (IAR, 1993a; 1993b).

From the large number of sorghum germplasm tested against stemborers SODF 103, 90 MW 5353, ICSV 680 and ICSV 708 were found to be resistant (19, Emana et al., 2002). Forty-two sorghum genotypes were evaluated for resistance to stem borer and 19 were advanced to further testing as they showed good level of resistance against *C. partellus* (IAR, 1990c).
One hundred and thirty entries of sorghum from PGRC/E were evaluated for resistance to stem borers at Awassa and seven tolerant lines were selected for further testing (IAR, 1983).

Emana (2005b) reported considerable variability among sorghum genotypes with respect to stemborers particularly to *C. partellus.* Some of the released varieties such as Gobeye and T76#23 were found to be relatively resistant to *C. partellus*. Extensive screening works which include a number of lines are underway both at Meiso and Melkassa.

Sefedin (2006) and Zerubabael (2007) screened large number of maize and sorghum genotypes against *C. partellus* at Melkassa, respectively. The results showed variations in infestation among the genotypes of both crops.

Since 1970, about 80 maize genotypes from local and international sources were evaluated at Ambo for resistance to stemborer infestation under field conditions, but no resistant variety was found. In 1986, five relatively resistant varieties were found: PR-85A-2B, PR-85-251, TL-82A-1071, TL-82A-1069, PR-85A-1259. The varieties were later advanced for further test in 1987 using the optical density from ether extracts of maize leaves (SPL, 1986). Results showed that damage caused by second instar larvae of *B. fusca* to susceptible varieties ranged from 50% to 60%. Resistant varieties TL-82A-1069, PR-85A-2B, TL-82A-1071, and PR-85A-251 showed only 7.2% to 8.5% damage (the maximum was 13.2%) which confirmed the field results (SPL, 1988).

Commercial varieties KCB, Bako Composite and A-511 were also relatively resistant; A-511 was more resistant than the other two. These results were consistent for the last 4 to 5 years at Ambo. However, further tests in more hot spot areas was recommended in the presence of a standard borer resistant variety (SPL, 1988).

Thirty varieties from Nazareth for one year and 24 ICRISAT materials for two years were tested against *B. fusca* at Ambo. IS-1054, IS-2446, IS-18369, IS-14434, PS-18601-2-2, PS-18822-4, PS-2113-1, PS-21318, PS-27618-5 (all from ICRISAT) and 85MW5672, 85MW5325 (from Nazareth) were relatively resistant (SPL, 1988).

Ninety-five sorghum accessions were evaluated at Melkassa and Meiso and showed high degree of variability in infestation and damage among the accessions. Only few (10 accessions) showed resistance to the pest at both locations. Damage was higher at Meiso than at Melkassa.

Screening of 25 sorghum varieties to stemborers at Ziway and Melkassa indicated differences among genotypes. Damage was higher at Ziway than at Melkassa. Leaf and panicle damage were the criteria for evaluation. Four of the genotypes selected in 1992 were among the top nine genotypes tested in the 1993 season. These genotypes were ICSV-708, PB-14376-1, PB-15469-2-1-3 and PB-12747 (IAR, 1987a; 1991b).

Two sets of experiments using 10 early varieties each with and without 5% karate EC were conducted at Kobo, Sirinka and Cheffa. Infestations differed with locations. It was lower at Kobo than the other two locations. There were differences between treated and untreated plots. Variations among genotypes were not significant, except for some parameters. In yield Seredo, 91MK7001, 90MW5353 and 3443-3-op were reported to have better potential for resistance to borers in all locations (SPL, 1980a).

Yield responses of two sorghum varieties (85MW5552 and Al-70) infested at three different crop growth stages (4, 6 and 10 WAE) with four different levels (0, 1, 3, and 5 first instar larvae per plant) were evaluated and differences between the varieties were observed with respect to stemborer infestation (IAR, 1987a).

Among 40 varieties tested against *B. fusca*, 85Bk6158, 84MW5325, 85Bk6296, 85Bk6274, 84MW4138, and entries PS-2113-1, PS-18822-4, PS-18601-2-2, PS-14454 were relatively resistant. The damage was 17.4–32.9%, while damage to susceptible varieties was up to 77% (Sileshi and Lakra, 1994).

Few attempts were made locally to select sorghum cultivars resistant to the spotted stemborer. Among varieties screened in East Africa, materials from Ethiopia were reported to have high level of resistance to *Chilo* (Tessema Megnassa cited by Abraham et al. (1998).

Nineteen varieties from Bako and Alemaya were tested under artificial infestation (five first instar larvae/plant) under open-air cage conditions. No significant differences among the varieties in borer damage were observed (IAR, 1986d).

Response of sorghum cultivars to yield and yield components to different levels and time of infestation was evaluated in split plots. The varieties were Al-70 (tolerant) and Birmash (susceptible); stages of plants were 4, 6 and 10 DAE; and infestation levels were 0, 1, 3 and 5 first instar larvae per plant. The control plots were treated with cypermethrin 1 g at 2.5 kg ha^{-1}. Results indicated that for most parameters the main effects and interactions of stage and level showed significant differences. Effects of plant growth stage and infestation levels were also significant. Losses of 11–90% were recorded in some of the treatments (Daniel, 2003).

Ten early maturing sorghum lines each in two sets (with and without insecticide treatment) were tested for stemborer resistance at Sirinka and Chefa. The insecticide treatments were cyhalothrin (16 g a. i. ha^{-1}) and karate 5% E.C (20 ml ha^{-1}). Genotypes differed in resistance to stemborers. SODF 013, 90MW5353, KAT369/1 and ICSV680 had lower borer damage at 75 DAE at both locations (SPL, 1979).

Shoot fly

In search of resistant sorghum genotypes, 18 lines obtained from Nazareth sorghum breeding program were evaluated at Bako Research Centre. A susceptible line CK60B was planted at plot borders. However, shoot fly infestation in the season was low and the differences in dead heart counts among genotypes were not significant (IAR, 1990a).

Although efforts were made as much as possible to attract the fly populations, there was no severe shoot fly infestation in the season. However, lines 2,3,6,7,8,9,11,17 and 18 had more dead heart injuries than the rest. The susceptible lines were attacked more severely than others. High yields were recorded from lines 6 (5087 kg ha^{-1}), 5 (5002 kg ha^{-1}), 16 (4787 kg ha^{-1}), 15 (4145 kg ha^{-1}), 9 (1559 kg ha^{-1}), 7 (2319 kg ha^{-1}) and 17 (2523 kg ha^{-1}). In almost all cases, lower yields were recorded from lines with more deadheart injuries (Abraham 1986a; 1986b).

Antixenosis, antibiosis and tolerance were identified in the local sorghum as the modalities of resistance are useful in management of the fly. Out of 99 entries tested, 15 showed antixenosis, 14 antibiotsis and 14 showed tolerances (Sileshi and Lakra, 1994).

Twenty sorghum entries received from ICRISAT, four intermediate maturity and two checks (Asfaw White and Didessa 1057) were evaluated for resistance to shoot fly at Bako. However, the infestation was too low to show varietal differences (IAR, 1986c).

Eighteen sorghum genotypes were evaluated for resistance to sorghum shoofly in 1986/87 and 1988/89 at Bako, and there were differences among the different genotypes (Adane and Abraham, 1991).

For screening sorghum varieties and lines for resistance to sorghum shoot fly (*Atherigona soccata*) and *Diopsis* sp., 30 varieties from Nazareth were tested for one year and 24 ICRISAT materials for two years. IS-1054, IS-2446, IS-18369, IS-14434, PS-18601-2-2, PS-18822-4, PS-2113-1, PS-21318, PS-27618-5 (all from ICRISAT) and 85MW5672, 85MW5325 (from Nazareth) were resistant. Varieties 85JM-6299, 85PGRC/E accession No. 73 and 85PGRC/E accession 105 were more resistant to *A. soccata*, while PS-21113-1, PS-27618-5 were more resistant to *Diopsis* sp. All of the above 10 genotypes from ICRISAT were 4 to 5 times more resistant to shoot fly compared to the Nazareth varieties. These varieties may be used as resistant sources in the breeding program (SPL, 1988).

Sorghum chaffer

Farmers use the sorghum varieties, which could escape the high beetle population or the varieties that had compact heads and thorn as part of sorghum chaffer control. To meet these criteria, 11 sorghum varieties were evaluated by farmers for their reaction to the chaffer and they reported that varieties which were early planted or head compactness, bitterness (*wofaybelash*) or hairy varieties escaped the attack of sorghum chaffer (SARC, 2000). Damage was more severe on loose head than compact headed varieties (SARC, 2000). Compact headed, high tannin sorghum and short varieties were found to be less damaged by sorghum chaffer (SARC, 2000).

Termites

Use of lodging resistant and early maturing maize varieties are more or less tolerant to termite attack (Abraham and Adane, 1998).

Botanical control

Stemborers

Neem, *Azadirachta indica* and Persian lilac, *Melia azedarach* with different formulations were tested against stemborers on sorghum at Sirinka and Chefa in 2000/01 and 2001/02 cropping seasons. Sorghum variety Gambella 1107 was used in both locations. Water extract of neem seeds, neem seeds powder and Persian lilac leaves were used. For comparison, cymbush 1G and Karate 5% E.C. were included in the treatments. Two lepidopterous stemborer species, *B. fusca* and *C. partellus* were important in Sirinka and Cheffa, respectively. There was no significant difference among the treatments in the number of dead heart and infested plants at 4 WAE and 6 WAE, respectively. But, significantly lower number of chaffy heads was recorded using each botanical and insecticides in each location and cropping season. Moreover, there was a significant difference among treatments in grain yield, and better yield advantages over untreated check was obtained using each botanical in 2000/01 at Sirinka and in each year at Cheffa (ARARI, 2001). Yield advantage obtained over untreated check ranged from 5–16, 7–11 and 8–15% using water extract of neem seeds, neem seeds powder and Persian lilac leaves powder, respectively. Moreover, significant yield advantage was recorded in all plots treated with cymbush 1G and Karate 5% E.C. that ranged from 13–40 and 7–27%, respectively (Asmare et al., 2004). Chat leaf extracts inhibited the larval feeding activity and caused larval mortality in stemborers (Daniel, 2002).

A study was conducted to evaluate different botanicals for the control of maize stemborer *B. fusca* using water and oil extraction methods. In the water extraction method, *Azadirachta indica*, *Chrysanthemem* sp., *Allium sativaum*, *Capsicum annuum* var. pubescens, *Phytolacca dodecandra*, *Hagenia abyssinica*, *Croton macrostachyus*, *Milletia ferruginea*, *Girardinia diversifolia* and *Culpurinia* sp. were tested for their potential in controlling maize stemborer. Significant differences were noted among plant types, plant parts and concentration levels. Extracts of *A. indica* seeds and Chrysanthemem flowers caused the highest borer mortality (85–100%), garlic bulb caused 49.88% to 55% mortality at 6% concentration, 54.98–55% mortality at 8% concentration. Extracts of *M. ferruginea* seeds gave 59.9 % mortality. Extracts of endod and all other remaining plant materials caused 50% mortality of stemborers (SPL, 1988).

Effect of endod on *B. fusca* larvae showed 96.3% and 94.4% mortality after 72 hours exposure on second instar larvae treated with 10^5 and 10^4 ppm concentarations, respectively. No variations among concentrations were observed (IAR, 1995).

Oil extracts of *indica*, *Chrysanthemem* sp., *A. sativum*, *C. annum* var. pubescens, *P. dodecandra*, *H. abyssinica*, *C. macrostachyus*, *M. ferruginea*, *G. diversifolia* and *Culpurinia* sp. were tested for their effect against maize stemborers. Oils from *A. indica*, *H. abyssinica* and *M. ferruginea* gave 100% mortality at 5% concentration (EARO, 2004).

A preliminary field test in 1993/94 showed that application of extracts of fruits of Persian lilac (*M. azedarach*), endod (*P. dodecandra*) and pepper tree (*S. molle*) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of the maize stemborer *B. fusca*, and resulted in increases in crop yield at Awassa (Assefa and Rolad, 1989). Extracts of both leaves and fruits of

Persian lilac (either fresh or dried) were effective in reducing the number of larvae. All the rates (2, 10 and 20 kg ha^{-1} for fresh leaves; 1, 2 and 10 kg ha^{-1} for dried leaves; 10, 20 and 30 kg ha^{-1} for fresh fruits, and 2, 10 and 20 kg ha^{-1} for dried leaves) used significantly reduced the number of larvae compared to the untreated control. Fresh leaves and fruits of endod were also effective against *B. fusca*. Fruits of pepper tree were superior to leaves. Fresh leaves of pepper tree did not reduce the number of larvae. Two applications of any of the three botanicals were not sufficient to provide complete protection of maize against the second generation larvae. This suggests that these botanicals have only brief persistence, and more than two applications of the extracts would be necessary to reduce pest numbers (Assefa, 1999).

Neem berries (*A. indica*), pyrethrum flowers (*Chrysanthemem* spp.), garlic bulbs and abasoyo-hot-pepper pods were tested against 2nd and 3rd instars of maize stemborer larvae under laboratory conditions. Applications of extracts of neem berries (seed) and pyrethrum flowers at 8% concentration resulted in 90% and 100% mortality to the first and second instars of *B. fusca* within three days, respectively (EARO, 1998).

Habte (1999) studied the effect of seed powder and aqueous suspension of neem against *C. partellus*. In his study, he demonstrated that neem seed powder and the extract markedly reduced primarily crop damage including foliar damage, dead heart and stem tunneling. The efficacy of neem was found to be comparable with the standard insecticide.

Nembecidine, oil extract of neem, was tested at Melkassa, Meiso and Welenchti and compared with karate 5% and neem seed powder. The results indicated that nembecidine effectively controlled the stemborer (Emana, 2005) (Table 9).

Table 9. Mean percent infestation of *C. partellus*

Treatments	Locations		
	Melkassa	Meiso	Welenchti
Neem oil	26.33	87.01	90.34
Neem powder	36.77	96.30	99.37
Karate	36.99	97.51	99.45
Untreated check	43.31	98.91	100

Source: Emana 2006

Possibilities of using different botanicals to control *B. fusca i*ncluding *Melia azedarach*, *Capsicum annum*, *Datura stramonium*, *Lycopersicum esculentum*, *Eucalyptus* spp., *Allium cepa* and *A. sativum*, showed insecticidal properties against *B. fusca* and aphids. About 66.7 to 100% mortality was observed in second or third instar when treated with extracts of these botanicals. Older instars (4th or 5th) were 2 to 5 times less vulnerable to the botanicals. However, in the field, no differences were observed in grain yield among the botanical treatments (SPL, 1988).

Girma and Fantahun (1991) indicated that botanicals such as *Melia azedarach*, *Datura stramonium*, *Capsicum annuum*, *Lycopersicum esculentum*, *Allium sativum*, *Allium cepa*, *Eucalyptus* spp., etc. were effective against the larvae of the maize stemborer under laboratory condition. However, in the field the results were not satisfactory, although *Datura* and *Lycopersicum* showed repellent effects to adults.

In another study, crude extracts of botanicals were tested for the control of stemborers on sorghum. Neem and pyrethrum at 6, 8 and 10% concentrations, cymbush 25% EC and tap water as control were evaluated. Mortality counted 3, 5, 7 and 10 DAT (days after treatment) indicated that 8% concentration of neem seed and pyrethrum flower extracts killed 88.9% and they 100% mortality on 1st and 2nd instars of *B. fusca* larvae 3 DAT, respectively (EARO, 1998).

Neem seed powder, 500 g in 400 l water, persian lilac one pinch per plant and untreated check were compared on-farm against borers at three locations around Kobo. The trial was superimposed on farmers' fields and no good data were recorded (SARC, 2000).

In 1993 cropping season, single concentration levels of three botanicals (*M. azedrach*, *P. dodecandra* and *S. molle*) were evaluated for the control of maize stemborer (*B. fusca*) in the field at Awassa (Assefa and Ferdu, 1994). Separate experiments were done for the three botanicals in 1994 cropping season using RCBD in three replications. Maize variety A511 was used and each plot had a size of 5.25 X 7.255 m with spacing between and within rows of 0.75 and 0.25 m, respectively. Leaves (fresh and dried) and berries (fresh and dried) in three aqueous concentration levels were evaluated with a standard insecticide lamdacyalohaterin at the rate of 16 g a.i ha^{-1}, and unprotected plots. Leaves and green berries of *S. molle*, leaves and matured *M. azedrach* berries and berries of *P. dodecandra* variety 44 were collected and air-dried in the laboratory. The dried leaves and berries were grounded and repeatedly sieved to obtain fine powders. The fresh leaves and fresh green berries were well crushed with pestle and mortar. All the preparations were water soaked for 24–36 hours. The mixtures were filtered with cheese cloth and the filtrates were sprayed into whorls of maize with a knapsack sprayer. Spraying was done at mid whorl stage (5 weeks after germination) when one or two of the leaves started to show damage by *B. fusca*. Second application was done after ten days. The plots were deliberately late planted to attain high infestation from the second-generation borers. Data were collected on levels of infestation (leaf infestation, stalk tunnelling, dead heart and cob tunnelling). In addition, numbers of surviving larvae were recorded by destructive sampling of five infested plants from the border rows of each plot 3 days after each application. We were unable to count dead larvae because some moved out of whorl and fell off or may be taken by predators or washed away by rain. At harvest the severity of cob damage was visually rated using one to five index (1 = clean cobs, 2 = slight damage, 3 = moderate, 4 = high, 5 = very high). In addition, 20 stalks were randomly dissected from each plot to count the number of surviving larvae. Data were subjected to analysis of variance using MSTATC computer package.

Dried leaves of *S. molle* appeared to be better than fresh leaves in reducing rates of stalk tunnelling and dead heart injury. Dried and fresh berries did not seem to be different in that respect. In general, Lamdacyalohaterin appeared to be more effective than *S. molle*. Leaves and berries of *M. azedarach* produced a significant reduction in the larval population. The effect of *M. azedarach* was comparable to the recommended standard insecticide when the number of live insects was considered 72 hours after treatment. However, due to low persistence, Melia treated plants did not escape from stemborer larval infestation following the application. This was revealed by high number of matured larvae at harvest. Pest damage in terms of stalk and cob tunnelling and deadheart injury were reduced due to *M. azedrach* application. Unlike *S. molle*, the fresh berries of *M. azedrach* produced higher yields of maize than dried ones. On the other hand, no significant differences were detected between dried and fresh berries in yield and plant growth. Yields of maize obtained from *Melia* treated plots were inferior to the synthetic insecticide.

Sorghum chaffer

Some botanical pesticides were tested at both field and laboratory conditions. Among these bio-pesticides, sisal juice caused 62% mortality under laboratory condition. Moreover, other bio-pesticides like *Lantana camara*, *Croton* and Persian lilac caused 33–57%, 43–60% and 45–58% mortality of beetles, under laboratory condition, respectively. At field condition sisal, Jatropha curcas, *Lantana camara*, *C. macrostachyus* and *S. mollie* caused 20–56%, 16–52%, 17–55%, 13–56% and 26–58% beetle mortality, respectively (ARARI, 2001).

Termites

Daniel (2003), Daniel and Bekele (2006) reported that extracts of seed powder of *M. ferruginea* and *A. indica*, fresh stem bark of *C.* m*acrostachyus* showed higher toxic effects on different termite castes.

Biological control

Stemborers

Biological control studies were conducted with isolates of entomopathogenic fungi *Beauveria bassiana* and *Metarrhizium anisopliae* from Ethiopia against *C. partellus* (Tadele and Pringle, 2003a; 2003b; 2003; 2004a; 2004; Tadele, 2004a; 2004b). Four isolates of *B. bassiana* and six isolates of *M. anisopliae* were tested against second instar larvae. Of these isolates, *B. bassiana* (BB-01) and *M. anisopliae* (PPRC-4, PPRC-19, PPRC-61 and EE-01) were found to be highly pathogenic to the larvae inducing 90 to 100% mortality seven days after treatment. Second and sixth instar larvae were more vulnerable to these isolates than third, fourth and fifth instar larvae.

A suitable temperature range for the isolates was from 20 to 30 ^{0}C. At 25 ^{0}C and 30 ^{0}C, the isolates induced 100% mortality to second instar larvae within four to six days. In greenhouse trial, a conidial suspension of foliar $2X10^{8}$ conidia/ml of the pathogenic isolates was sprayed on 3 to 4 week-old maize plants infested with 20 second instar larvae per plant. This prevented foliar damage. Treatments with the fungi also reduced stem tunneling and deadheart formation. In addition, fungal treatments increased mean plant fresh and dry biomass compared to untreated control plants. In general, results from laboratory and green house studies indicated the potential of these fungal isolates against *C. partellus* larvae (Tadele, 2004b). Tadele (2005) studied food consumption by second and third instar larvae of the spotted stemborer infected with four concentrations of ($1x10^8$, $1x10^7$, $1x10^6$,$1x10^5$ conidia ml $^{-1}$) *Beauveria bassiana* and *Metarhizium anisopliae*. After inoculation, the larvae were allowed to feed on maize leaves and on artificial diet. Results showed that the two higher concentrations markedly reduced the daily food consumption. Mortality was lower on larvae fed on artificial diet and had fewer cadavers than larvae fed on maize leaves. The use of *Bacillus thuringiensis* Berliner in the control of stemborer was reported by Abraham et al. (Abraham et al., 1998).

A nuclear polyhedrosis virus (NPV) isolate was tested for its pathogencity against armyworm (*Spodoptera exempta*), maize stemborer (*B. fusca*) and African bollworm (*H. armigera*). The virus suspension was applied by contaminating the respective food substrates of the above three pests. It took 3-4 days to kill the first two larval instars of armyworm, while instars 3-5 took 5 to 6 days. Some of the later stage instars managed to pupate. However, they failed to develop to adults. Nevertheless, the virus isolate was found to be avirulent to both *H. armigera* and *B. fusca* indicating the host specificity of the strain (Adane et al., 1997). Two bacterial preparations *Bitoxi bacillin* and *Dendero bacillin* 10% were applied on the third instar larvae of maize stemborer and caused 80–90% mortality following 10 days after application in the laboratory (SPL, 1988).

Four bacteria and one fungi collected from the maize stemborer larvae during a survey at Ambo area were purified and tested on first instar larvae and the bacteria were found pathogenic to *B. fusca* (IAR, 1996b).

A number of egg, larval and pupal parasitoids of different species of stemborers were recoreded in Ethiopia under natural condition which can be utilized in the biological control of stemborers (Abiy, 2005; Amanuel, 2005; Assefa, 1989a; Assefa, 1992; EARO, 1998; Emana, 2002; IAR, 1997; Tadele and Pringle, 2004a) (Table 10). Of these naturally occurring bioagents, *Cotesia flavipes* is the most abundantly and widely spread species and the first candidate for biological control.

Table 10. Species composition of parasitoids recorded in Ethiopia on maize, sorghum and millet insect pests

Parasitoids	Host species	Host stage	Reference*
HYMENOPTERA			
Braconidae			
Cotesia flavipes (Cameron)	Bf, Cp, Sc	Larva	4, 24, 86
Dolichogenidea fuscivora Walker	Bf, Cp	Larva	4, 24, 86, 162
Dolichogenidea polaszeki	Bf	Larva	4, 86
Cotesia sesamiae (Cameron)	Bf, Cp, Sc	Larva	4, 23, 24, 68, 72, 76, 86, 114
Chelonus curvimaculatus Cameron	Cp	Egg/larva	76, 86
Cotesia ruficrus	Cp	Larva	76, 86
Stenobracon rufus Szepligèti	Bf, Cp	Larva	68, 76, 86
Bassus sublevis	Bf	Larva	76, 86
Glyptapanteles maculitarsis	Bf	Larva	86, 183
Ichneumonidae			
Dentichasmias busseolae Heinrich	Bf, Cp	Pupa	4,21, 23, 24, 76
Procerochasmias nigromaculatus (Cameron)	Bf, Cp	Pupa	86
Eulophidae			
Pediobius furvus (Gahan)	Bf, Cp	Pupa	4, 68, 76, 86
Neotrichophoroides sp	*A. soccata*	Larva	206, 209
Eurytomidae			
Eurytoma oryzivora Delvare	Bf	Larva	68, 76, 86
Scelionidae			
Telenomus busseolae Gahan	Bf	Egg	4, 76, 86
Telenomus thestor	Bf	Egg	4

Table 10. Continued

Parasitoids	Host species	Host stage	Reference
Trichogrammatidae			
Trichogramma lutea Girault	Cp, Bf	Egg	68, 76, 86
HYMENOPTERA			
Chalcididae			
Psilochalcis soudanensis (Stefan)	Bf	Pupa	76, 86
Sphecidae			
Oxybelus sp	*A. soccata*	Larva	206, 209
DIPTERA			
Tachinidae			
Sturmiopsis parasitica (Curran)	Bf, Cp	Larva	72, 76, 86, 114
Eutrixopsis sp.	*P. interrupta*	-	164
Sarcophagidae			
Sarcophaga sp.	Bf	Larva	68, 76, 86
Pyrgotidae			
Adapsilia latipennis (walker)	*P. interrupta*	-	164

Bf = *Busseola fusca*
Cp = *Chilo partellus* Sc = *Sesamia calamistis*

Cotesia flavipes was mass reared in the laboratory and released at Wolenchiti, Meiso and Melkassa in 2004. The recovery/establishment survey was conducted in 2005 and parasitism in all the three areas ranged from 75 to 87%, which is over 50% increment when compared to the pre-release of 2003 parasitism (Emana, 2005). This parasitoid was not released in Ethiopia, but for the first time recorded in Ethiopia in 1999 (Emana et al., 2003; 2001; Emana, 2002). This parasitoid was under classical biological control of *C. partellus* being imported from Pakistan and India into other East African countries since 1974 (IAR, 1975).

In Ethiopia, *C. flavipes* created a new association with certain populations of *B. fusca* under field condition. Parasitism under field condition could be due to multiple parasitisms as *Cotesia sesamiae* and *C. flavipes* can occur together in the field. Hence, suitability study under laboratory condition was conducted to confirm the suitability. Ten populations of *B. fusca* were collected from major *B. fusca* endemic areas of Ethiopia and reared for one generation in the laboratory on natural diet. Cultures of one population of *C. partellus* and *S. calamistis* were also established by rearing them for one generation. Fourth instar of these stemborers were stung to four populations of *C. flavipes* collected from different localities in Ethiopia and kept under ambient laboratory conditions (8 ^{0}C ±2 mean daily minimum temperature; 27±3 ^{0}C mean daily maximum temperature; relative humidity 45–55%) and 12:12hours (L:D). None of the parasitised fourth instar larvae of each stemborers were kept under similar condition to correct for natural mortality using Abbot’s formula. Data on the number of hosts parasitised, number of hosts not parasitised, number of parasitoid larvae not develop to cocoons and number of parasitoid larvae dead inside the host were recorded.

The results indicated that only two populations of *B. fusca* were found to be suitable hosts to all populations of *C. flavipes*. After the data were corrected for natural mortality, significant difference was observed between *C. partellus* and *S. calamistis*, but both populations of *B. fusca* were less suitable than *C. partellus* and *S. calamistis*. It is evident from this study that two populations of *B. fusca* exist (one that is suitable to *C. flavipes* and the other which is not suitable host) in Ethiopia (Emana, 2002; Emana, 2005b).

A pupal parasitoid of stemborers, *Xanthopimpla stemator*, was released in Ethiopia in some parts where stemborers are important in maize and sorghum production. With the 2006 season surveys there was evidences of establishment of the parasitoid as few recoveries were made (Emana, pers. obs.).

Kassahun (1997) and Kassahun (1996) studied on the stemborer *B. fusca* and its major larval parasitoid *D. fuscivora* under field and laboratory conditions in eastern Ethiopia. The braconid *Bracon sesamiae* and sarcophagid *Sarcophaga* sp. also parasitised *B. fusca* in the field, although in low numbers. Parasitism of the maize stem borer by *Dolichogenidea fuscivora* was 71% during the dry season (November to March) and 18% in the wet season (June to September). *D. fuscivora* was active throughout the year.

A number of predators and pathogens associated to stemborers were recoreded by several scientists in Ethiopia which can be good candidates for the biological control program of the pest (Abiy, 2005; Amanuel, 2005; Assefa, 1988a; Emana, 2002; IAR, 1984) (Tables 10).

Shoot fly

Natural enemies such as *Oxybelus* sp., *Neotrichophoroides* sp. and *Opius* sp. appear to be important in controlling shoot fly under natural condition. This shows their potential as biocontrol agents for the biological control of shoot fly via conservation and/or augmentation (Sileshi, 1994).

Sorghum chaffer

Entomopathogenic fungi (*Beauveria* sp. and *Metarrhizium* sp.) were tested against sorghum chaffer at Ambo and caused a maximum of only 20% infection. Hiwot et al. (2004) recorded some parasitoids on sorghum chaffer.

Chemical control

Stemborers

Effective insecticides (belonging to the pyrethroid group) are available for the control of stemborers, but they are broad spectrum and have negative effect on the natural enemy (Tsedeke and Tesfahun, 2003; Tsedeke, 1986).

Ferede (1988) screened some insecticides against *C. partellus* at Melkassa and Meiso. The tested chemicals were selecron, cypermethrin 1% G, cypermethrin 5% EC, primiphos methyl 50% EC, cyhalothrin 5% EC, sumicomb 30% EC, sumicombi 1.8% D, Fenom 100% EC, Fenitrothion 50% EC and Fenitrothion 5% D. The results for the 1988 season indicated that all the insecticides gave significantly lower number of holes than the check except fenitrothion, which was not different from the untreated check at Melkassa. Number of larvae and/or pupae and stem tunneling percent at Melkassa and number of holes, number of larvae/pupae and stem tunneling percent at Meiso was significantly lower for cyhalothrin EC, fenom EC and sumicombi. Grain yield was higher for cyhalothrin treated plots at both Melkassa and Mieso.

Screening of 13 insecticides against stemborer was carried out at Awassa and Areka (Devendra et al., 1998; EARO, 2004). Compared with the untreated check, the lowest cob infestation by stemborers at both locations was observed on Ethiosulfan 35% EC, Diazinon 60% EC, Ethiosulfan 5% EC, Thionex 25% EC, primiphos-methyl % EC, Decitab and cypermethrin G treated plots. At Awassa the highest yield (98.4 q ha^{-1}) was obtained from the plots treated with cypermethrin G.

Three rates of carbosulfan seed dressing (0.9, 1.8 and 2.7 kg q^{-1} of maize) were compared with cypermethrin 1G (2.5 kg ha^{-1}), chloropyriphos 2G (10 kg ha^{-1}) and untreated check in RCBD with four replications for the control of stemborers. The experiments were conducted at eight locations in the western and southern regions of Ethiopia in the 1996/97 cropping season using the maize hybrid BH-660. The evaluation criteria were stand establishment, percentage of damaged maize plants and cobs by stemborers, percentage of plants with damaged roots, plants with maize streak virus symptoms and grain yield. Results of combined analyses over locations showed that a treatment with carbosulfan did not protect maize from stemborers and leaf-hoppers significantly. The highest rate of carbosulfan resulted in significantly low percentage of plants with root damage. The other rates (including the recommended) did not differ from the untreated check in root damage. Therefore, it is advised that carbosulfan should not be included in the package program for the control of stemborers, and other insects attacking maize in locations where this study was conducted. However, further tests may be required to confirm the results on root damage (Abraham et al., 1997).

Trials on the chemical control of stemborers have been started in 1975 at Awassa, Abella, Werer and Bako. The results indicated that endosulfan, carbofuran, diazinon and trichlorfon granules and DDT dust gave promising results (IAR, 1977d).

Experiments were conducted at Ziway and Melkassa in 1990 to determine the optimum period for the application of insecticides that could minimize the damage inflicted by *C. partellus* on sorghum. Two sorghum varieties, the tall local Karadebya and the improved Gameblla 1107, were planted in a split plot design with four replications. Varieties were assigned to main plots and cypermethrin 1G (Cymbush 3.75 g per 15 m^2) applied in the leaf whorl at 15, 30, 45 days after emergence plus unprotected plots were assigned to sub-plot treatments. Leaf damage and dead heart effect were assessed.

Results indicated that the damage inflicted on Gambella 1107, especially with reference to deadheart effect seemed to be lower than that on Karadebya. Pest population and crop damage were more at Ziway than at Melkassa. All applications of cypermethrin made 15 days after emergence, regardless of the second and third applications, showed less damage by the pest than those made at the later stages of plant growth. Results indicated that the pest was more damaging at about 15 days after emergence of the crop or, conversely, the crop was more susceptible to the pest at that growth stage. Similar results were reported elsewhere (Melaku and Gashawbeza, 1992b).

The effect of different insecticides and botanicals in suppressing the population levels of stemborers, infestation and grain yield of sorghum was studied at Mai-tsebri and Mekoni (Testing sites of Mekelle Agricultural Research Center) during the 1997 cropping season. Ten insecticides were included in the screening program. The results indicated that all the tested insecticides were better than the untreated check in stemborer infestation (MeARC, 1997b) (Table 11). Chemical control of *C. partellus* on sorghum was conducted at Kobo in 1983/84 and the results showed that the highest stemborer kill was obtained by cypermethrin and carbaryl. Furadan 10% granule was also found the most effective on borer attacking sorghum (IAR, 1984).

Different dust and granule formulations of chemicals were tested for the control of stemborers on maize at Awassa in which endosulfan and cypermethrin gave the best results (IAR, 1987a).

Table 11. Effect of insecticides on the control of stemborers at Awassa

Insecticides	Rate g.a.i/ha	Plants with leaf damage		Damage score		Yield q/ha
		4th WAE (%)	*6th WAE (%)	4th WAE	6th WAE	
Selecron 3 G	210	5.8a	10.22a	1a	2a	48.04a-c
Cymbush 1% G	25	9.33ab	13.85ab	2ab	1.33a	46.64a-d
Cymbussh 5%G	25	6.72ab	13.04a	1.67ab	1.33a	40.43b-d
Actellic 50% EC	1000	7.12ab	12.45a	1.33a	1.33a	50.08ab
Cyhalothrin 5% EC	16	7.89ab	9.50a	1a	1.33a	56.09a
Sumicombi 30% EC	300	6.58ab	11.43a	1a	1.33a	42.85a-d
Sumicombi 1.8% D	360	8.57ab	11.87a	1a	1.00a	42.37b-d
Fenom 100 EC	400	8.96ab	12.42a	1.33ab	1.67a	51.38ab
Sumithion 5% EC	1000	7.57ab	14.28ab	1.33ab	1.33a	33.99d
Sumithion 5%D	100	6.50ab	11.62a	1a	1a	35.33c-d
Untreated	-	11.70b	27.19b	2.33b	2.33a	43.41a-d
Mean	-	7.82	13.44	1.36	1.45	44.61
SE	-	1.86	4.08	0.35	0.39	3.93
CV(%)	-	41.10	52.56	44.12	46.77	15.25

Source: IAR 1989
**WAE = Weeks after emergence*
Means with the same letter are not significantly different at 5% (DMRT).

Girma and Fantahun (1991) reported that 17 insecticides were evaluated against maize stemborer at Ambo among which carbofuran 10% (4.4 kg a.i.ha^{-1}), decamethrin (12.5 ml a.i. ha^{-1}) and cypermethrin (16 ml a.i. ha^{-1}) gave promising results. Girma (1991) reported the use of cypermethrin G at 10 g.a. i. ha^{-1} as the most effective method of stemborer control (Girma and Fantahun, 1991**)**. Moreover, cyhalothrin was found effective in the control of stemborers (IAR, 1989a; 1989b).

Insecticide screening consisting of 6 ECs, 2 granules and 2 dusts along with the an untreated check were studied and the result indicated that cyhalothrin EC and semicombi dust reduced leaf damage and stem tunnelling caused by the stemborers (IAR, 1988b; 1988c; 1989a; 1989b).

According to a study conducted by the Institute of Agricultural Research cypermethrin granule followed by endosulfan dust were the best in controlling *B. fusca*. Furadan 10% granule was also recommended to be used on stemborers attacking sorghum (IAR, 1985a; 1985b).

In an attempt to use sterility technique as a means of pest control, Girma and Fantahun (1991) tested a chemical called tio-tef was used at the concentrations of 0.05, 0.1 and 0.3% for adults and 0.05% for the larvae. The result indicated that adult moths fed with the chemical showed reduced fecundity and viability.

Similarly, larvae became less viable, 67% for females and 51.2% for males. Moreover, for the control of stemborers, application of endosulfan at the rate of 2 kg ha^{-1} at 4 and 6 WAE was found to be effcetive (IAR, 1987c).

Fipronil ULV, endosulfan 5%, each at 3 rates, malathion 50% and diazinon 10 G were compared at Sirinka and Kobo for the control of stemborers on sorghum. Endosulfan 5 kg, malathion 50% EC and diazinon 10 G were found to be effective in the control of stemborer. The infestation at Kobo was low due to good rainfall in that season (SARC, 1997). Another trial conducted with four different insecticides at different rates indicated that cypermethrin 1%G (20 kg ha^{-1}) reduced borer infestation by 90%.

In the trial to determine the efficacy of different insecticides for the control of stemborers on sorghum Fipronil SC, endosulfan 5% D, malathion 50% and diazinon 10% G were compared at different rates in northern Ethiopia. Dead heart counts, infested plants, leaf damage score caused by stemborers and grain yield did not differ at two locations, except the number of infested plants and leaf damage score at 6 WAE at Sirinka. Endosulfan 5% dust at 5 kg ha^{-1} and 8 kg ha^{-1} at Kobo and Sirinka, respectively, and malathion 50% EC at 2 l ha^{-1} at both locations resulted in relatively lower infestation (SARC, 1998).

Another test of insecticides consisting of fipronil SC 30, 40, 50 g, diazinon 10%, endosulfan 5%, and cypermethrin 1%, was carried out. The results showed that endosulfan and cypermethrin were effective in all parameters measured (ARARI, 2001).

In a field experiment at Awassa, using maize cultivar Bako-Awassa hybrid-540, the control of *B. fusca* with Fenom 100 EC (cypermethrin) (60 ga.i ha^{-1}), Basudin 10G (diazinon) (15 kg ha^{-1}), cymbush 1G (cypermethrin) (3.8 kg ha^{-1}) and Basudin 600EC (2.5 l ha^{-1}) was evaluated in 1995. In 1996, endosulfan 35% EC (2.5 l ha^{-1}), chlorpyrifos 48% EC (3 l ha^{-1}) or 5G (10 kg ha^{-1}), selecron 720EC (profenofos) (750 g a.i ha^{-1}) and karate 3.7% WDG (lambda-cyhalothrin) (400 g ha^{-1}) were evaluated. Except basudin 600 EC and endosulfan, all insecticides controlled stemborer (Emana, 1996b; 1998a).

Studies on the efficacy of 13 insecticides against shoot fly, stemborer and aphids on sorghum indicated that Karate 5% EC at 25 ml ai ha^{-1}, Decis 2.5% EC at 12.5 ml ai ha^{-1}, primiphos-methyl 50% EC at 1 ℓ a.i ha^{-1}, Baythroid, metasystox 25%, Diptrex 95% (700 g a.i ha^{-1}), salut, Dimecron, Basudin 60% EC, Basudin 10% granule were effective. Insecticide application was recommended to be at 17% plant damage (SPL, 1988).

Shoot fly

Girma and Fantahun (Girma and Fantahun, 1991) and IAR (IAR, 1987c) reported that 14 insecticides were evaluated against *Atherigona soccata*. Effective control was achieved by carbofuran 10% (4.4 kg a.i. ha^{-1}), karate 5% E.C. (16 ml a.i. ha^{-1}) and cypermethrin 50% E. C. (1 ℓ a.i.ha^{-1}).

Chemical treatment and sowing dates were tested in split plots in 1994 against sorghum shoot fly. The main plot was insecticide treated and untreated, while sowing dates (21 April, 5 May, and 24 May) were subplot treatments. Insecticide treated plots were significantly superior from the untreated plots in some parameters. Dead heart counts were not significant, while panicle damage was significant. Early and late May sowings were damaged by the stemborer, not by shoot fly. However, grain yields were higher for early May followed by late April. Chemical–sowing date interactions was not significant (IAR, 1987c).

Carbofuran (furadan) 10 G pre-sowing application at 4.4 kg a. i. ha^{-1} and sumicidin 20% at 0.2 kg a.i. ha^{-1} did not give good control of shoot fly (Firdissa and Abraham, 1998). Carbofuran 1.5 kg ha^{-1} as granule in seed furrow application gave the best results in shoot fly control (Sileshi and Lakra, 1994).

Sorghum chaffer

Chemical control (malathion 50% Ec and carbaryl 85% WP) have been tried with limited success (Tadsse, 1989; Tsedeke and Tesfahun, 2003).

Termites

The evaluation of fipronil on BH-660 maize variety for three years at Bako showed that the optimum rates of fipronil for the control of termites were 2.0, 2.4 and 2.8. These rates resulted in low percent of root and stem damages than others (Table 12) (BARC, 1998a).

Table 12. The effects of different rates of fipronil against termites at Bako

Rates (ml/kg)	Root damage (%)	Stem damage (%)
11.6	2.814	0.735
2.0	0.699	0.260
2.4	0.519	0.312
2.8	1.036	0.233
3.2	1.349	0.547
Untreated	9.091	1.994
LSD	2.15	0.746

A series of seed dressing studies were conducted with aldrin 40% WP from 1977/78 to 1982/83 at Anger Didessa and Bako. Aldrin seed treatment was also compared with the untreated check on large scale and unreplicated plots at Didessa, Assosa and Bako in 1987 and 1988 cropping seasons. Combined analysis over the years showed that seed dressing with aldrin (with or without sticker) did not increase maize yield significantly over the untreated check. Plant damage was significantly reduced by aldrin treatment at Bako, but not at Anger Didessa. The lack of significant difference in yield between treated and untreated check over the years suggest that seed dressing with aldrin did not provide adequate protection to bring differences in yield or the species of termites involved were not harmful and/or termite infestations occurred after crop maturity. Therefore, the species of termites harmful to maize, the growth stage of the crop sensitive to termite infestation and the associated losses in yield should be determined before attempting to apply control measures (Abraham and Adane, 1995). Verification of aldrin on maize against termites indicated that 18, 45 and 50% yield reductions due to termites were recorded at Asossa, Bako and Dedessa, respectively (IAR, 1991a).

Integrated pest management

Stemborers

Integration of sowing date and botanical application for the control of stemborer conducted at Areka using neem seed powder showed that the highest cob damage and the lowest yield (45.1 q ha^{-1}) were obtained on the 4th sowing date (22 June 1998) with the application of neem seed powder 30 and 45 days after emergence. The earliest sown maize (June 1) treated with neem seed powder 30 days after emergence resulted in the lowest cob damage and highest yield (65.5 q ha^{-1}) (EARO, 1998).

The combination of resistant sorghum variety, intercropping beans within the sorghum rows at the ratio of 2:1 (sorghum: bean), use of napier grass as a trap plant and application of neem seed powder gave over 97% of *C. partellus* control (Emana et al., 2002; Emana,1998; 1999; Emana unpublished). Integrated management of stemborer on sorghum using chemicals, sowing date–variety gave good control of stemborers at Meiso, Ziway and Melkassa (IAR, 1988b; 1990c; 1991b).

Chemical treatment and sowing dates were tested in a split plots design in 1994 against stemborer. The main plots were insecticide treated and untreated, while sowing dates (21 April, 5 May, and 24 May) were subplot treatments. Chemical treatments were significantly different from the untreated plots in some parameters. Dead heart counts were not significant, while panicle damage was significant. Early and late May sowings were attacked. However, grain yields were higher for early May followed by late April planting. Chemical–sowing date interactions were not significant (IAR, 1987c).

Integrated pest management of stemborers on sorghum at Ambo was studied in split plots, i.e., early and late sowing dates (April 21 and May 4), two sorghum varieties (IS 9302 and Birmash), and endosulfan 35% EC at 2 ℓ ha^{-1} applied at different times (0, 1 and 2 times). Plants with dead hearts, leaf damage, holed plants and holes per plant, chaffy panicles and grain yield were measured (IAR, 1987c). The main plot effects showed significant differences in some of the parameters. The difference between treated and untreated plots was not significant. Early planting and two applications of endosulfan gave significantly better results. IS-9302 showed better performance in yield when planted early and treated with two applications of endosulfan.

Damage assessment to stemborers and sorghum shoot fly on sorghum in split plots with four replications were conducted at Ambo. IS-9302 was planted in two sets each April 20, May 5, June 6 and 20, and July 5, and one set was treated with cypermethrin 1 G at 2.5 kg ha^{-1} at 4 and 6 WAE for stem borer control. Dead heart counts varied among different treatments. Grain yield did not differ between the treated and untreated plots and between sowing dates of April 20 and May 5. Stemborer infestation was higher for mid April and early May plantings (IAR, 1996b).

Sowing date (recommended and 15 days late), sorghum varieties (IS9302-susceptible and Birmash-tolerant), insecticide 1, 2, 3 applications of endosulfan 35% EC at 2 ℓ ha^{-1} in 1994 and cypermethrin 1G at 2.5 kg ha^{-1} in 1995 were evaluated against stemborer (IAR, 1996b). The interaction of varieties, sowing dates and insecticide were significant indicating the benefits of integrating the methods for the management of stemborer. Early planting and two applications of cypermethrin granules on the resistant variety gave the highest yield.

Various combinations of insecticide applications were made for the control of the 1st and 2nd generation of *B. fusca* on maize planted at two different times (early and late). The chemical used was Lamda Cyalohatherin at the rate of 16 g.a.i. ha^{-1}. The treatment combinations were (Assefa, 1992):

- no control
- Partial control of 1st generation (two applications of insecticide at four weeks and ten days later)
- Complete control of the first generation (appliying at ten days interval)
- Partial control of the 2nd generation (two application)
- partial control of 1st and 2nd generation (two application)

- Complete control for the 2nd generation (applications at ten days interval until harvest)
- Complete control for the two generations (applications at ten days interval until harvest)

Shoot fly

Chemical treatment and sowing dates were tested in split plots in 1994 against sorghum shoot fly. The main plot was insecticide treated and untreated, while sowing dates (21 April, 5 May, and 24 May) were subplot treatments. Chemical treatments were significantly different from the untreated in some parameters. Dead heart counts were not significant. Early and late May sowings were attacked. However, grain yields were higher for early May followed by late April. Chemical Vs sowing date interactions were not significant (IAR, 1996a; 1996b).

Sorghum chaffer

Use of indigenous knowledge such as smoking, burning of breeding site, food baiting with banana, *tella*, Guava, *atella* ,mixed with carbaryl, use of resistant varieties, use of effective botanicals and use of biocontrol agents could be some of the components of integration for effective management of sorghum chaffer (Tsedeke and Tesfahun, 2003).

Termites

Ecological rehabilitation, chemical treatment, use of lodging resistant crops, queen removal aided by flooding and/or chemical poisoning and use of some botanical plants are some of the components to be integrated for effective control of termites (Emana and Gure, 1997).

Conclusion

From the detailed review of two decades research, it was learnt that quite a large number of research findings which substantially contribute to the ongoing food self sufficiency and food security agenda of the country are generated. Some of the technologies could significantly minimize losses caused by insect pests which can reach as high as 100%. There are also some areas which did not get the attention they deserve. For example, the problem of termite is very important in maize, sorghum and millet production particularly in most of western Ethiopia, which displaced thousands of households. However, the research findings on this important pest are very few. Though sorghum midge is an emerging pest problem in Ethiopia, it did not also get research focus. Research information on stemborers is quite ample, but for its utilization awareness should be created.

Recommendations

The following recommendations can be made from two decades research in Ethiopia.

- Entomological research conducted on stemborers can provide strong integrated management of the pests. Based on local conditions and species of stemborers, their control package should be developed and popularized by leaflets (booklets), demonstration, etc. In this regard, cultural practices and biological control options should get the highest priority as the potential of these groups of control methods are very high. Mass rearing of *C. flavipes* and field release and conservation of the same should be regularly done.
- Indigenous knowledge documented on the management of sorghum chaffer should be utilized for the management of the pest.
- Ecological rehabilitation with indigenous trees and grass species in termite prone areas should be done in large scale.

Gaps and Challenges

- Less emphasis was given to egg and pupal parasitoids of stemborers.
- For some cultural control methods such as sowing dates which are location specific, the numbers of research activities done are not representative for the country to make recommendation.
- There was no continuity of research on the host plant resistance of maize and sorghum to stemborers.
- Pests and natural enemies information for millet is limited and there is none for pear millet.
- Research on the status and management of shoot fly is inadequate.
- Research on the biology, ecology and management of termite is inadequate.
- No research findings are available on the biology, ecology and management of sorghum midge.
- Research on some aspects of sorghum chaffer is not available or inadequate such as chemical, ecology, etc.
- Research attempts on potentially important insect pests such as maize aphids, leafhoppers (*Cicadulina* spp), cutworm, African bollworm, etc. are lacking
- Biotechnology research on maize, sorghum and millet is almost non-existence
- Storage methods of available data and any related information is inadequate in the country.

Future Research Direction

- Different aspects of egg and pupal parasitoids of stembporers such as fecundity, fertility, developmental time, life table, longevity, etc. should be studied. This should follow a complete inventory of egg and pupal parasitoids that exist in Ethiopia.
- Some cultural control methods such as sowing dates are location specific. Hence, stemborer prone areas of the country need to have their appropriate sowing date at which stemborer infestation is minimal. The number of weeks required for horizontal lying of stalks varies based on the intensity of sunlight which varies from place to place. Hence, stemborer prone areas need to have their own recommendation.
- Host plant resistance studies need to come up with highly resistant and agronomically acceptable crop varieties. Hence, information available on resistance should be incorporated into breeding programs to get high yielding and stemborer resistant/tolerant variety.
- Pests and natural enemy's survey on millets should be done to exhaustively come up with a check list of pests and natural enemies associated with the crop.
- Research on the status and management of shoot fly should be continued.
- Research on the biology, ecology and management of termites should be continued.
- Research on the biology, ecology and management of sorghum midge should be initiated.
- Research on chemical ecology, etc. of sorghum chaffer should be strengthened.
- Data and information storage methods of entomological research should be improved and computerized. Moreover, use of journals to publish data should be encouraged.
- Research on potentially important insect pests such as maize aphids, leafhoppers (*Cicadulina* spp.), cutworm, African Bollworm, etc. should be re-initiated.
- The insect pest status of pear millet should be known as the crop is a newly introduced crop to the country.
- Biotechnology research on major maize, sorghum and millet insect pests and their natural enemies should be initiated.

Appendices

Table 1. Insect pests recorded on maize in Ethiopia

Insect order, family and species	Common name	Status	Reference*
LEPIDOPTERA			
Noctuidae			
Busseola fusca (Fuller)	Maize stemborer	Major	4, 7, 8, 16, 23, 24, 51, 52, 86, 100, 116, 123, 124,131,132,133,135,137,138, 159, 161, 232
Helicoverpa armigera	African bollworm	Minor	7, 23, 86, 100, 232
Agrotis sp.	Cut worm	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,130,161, 162, 232
Eublemma gayneri Rothschild	-	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131, 138,159, 161, 232
Sesamia calamistis	Pink stemborer	Minor	7, 23, 24, 51, 52, 86, 100, 116, 123, 124,131,138 159, 161, 232
Spodoptera exempta (Walker)	Armyworm	Sporadic	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Spodoptera exigua (Hb.)	Lesser army worm	Sporadic	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Crambidae			
Chilo partellus (Swnhoe)	Spotted stemborer	Major	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Pyralidae			
Marasmia spp.	Maize web worm	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Gelechidae			
Sitotroga cerealella	Angoumois grain moth	Minor under field condition	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
ORTHOPTERA			
Acrididae			
Acanthacris ruficornis Fabricius	Grasshoppers	Minor	7, 23, 86,100, 232
Schistocerca gregaria (Forsk.)	Desert locust	Sporadic	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
HEMIPTERA			
Pentatomidae			
Nezara viridula (L.)	Green stink bug	Minor	7, 23, 87, 101, 233
Mirperus jaculus Thunb.	True bugs	Unknown	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232

Table 1. continued

Insect order, family and species	Common name	Status	Reference
Aphididae			
Aphid spp.	Aphids	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Rhopalsiphum maidis (Fitch)	Maize aphid	Minor//Major	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Cicadellidae			
Cicadulina spp.	Cicadulina leaf hoppers	Minor/Major	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
HEMIPTERA			
Delphacidae			
Peregrinus maidis Ashm.	Maize leaf hopper	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
COLEOPTERA			
-			
Megalognatha aenea Loboissiere	Acacia beetle	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Chrysomelidae			
Sesselia pusilla Gerstaecker	Black leaf beetle	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Oulema sp.	Cereal leaf beetle	Minor	7, 23, 100, 232
Coccinellidae			
Epilachna similes (Thunberg)	Tef epilachna	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Cerambycidae			
Nematocerus brachyderes Marshall	Long horn beetle	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Cetonidae			
Pachnoda stehelini Schawn	Sorghum chaffer	Sporadic	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Pachnoda interrupta (Olivier)			
Cucujidae			
Cryplolestes ferrugineus (Steph.)	Rusty grain beetle	Unknown	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Curculionidae			
Sitophilus oryzae	Rice weevil	Minor under field condition	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
Sitophilus zeamais	Maize weevil	Minor under field condition	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
THYSANOPTERA			
Thripidae			
Anaphothrips sudanensis (Trybom)	Wheat ear thrips	Minor	7, 23, 24, 51, 52, 86 100, 116, 123, 124, 131,138,159, 161, 232
ISOPTERA			
Termitidae			
Microtermes spp.	Termite	Major	7, 67
Macrotermes subhyalinus	Termite	Major	7, 67

Table 2. Insect pests recorded on sorghum in Ethiopia

Insect order, family and species	Common name	Status	Reference
LEPIDOPTERA **Crambidae**			
Chilo partellus	spotted stemborer	major	7, 23, 67, 86, 119, 132, 133,136, 137, 142, 143,144, 145, 148, 167, 168, 169, 188, 204, 226, 232
Noctuidae *Busseola fusca*	maize stemborer	major	7, 8,16, 23, 86,167,168, 226
Sesamia calamistis	pink stemborer	minor	7, 23, 24, 51, 52,67, 86, 100, 116, 123, 124, 131, 138, 159, 161, 232
Agrotis spp	cut worm	unknown	7, 67
Eublemma gayneri	Maize cob worm	Minor	7, 67
Helicoverpa armigera	African bollworm	Minor	7, 67
Spodoptera exempta	African armyworm	Sporadic	7, 67
Agrotis ipslon	Cut worm	Minor	7, 67
Sesamia nonagrioides botanephaga	Pink stemborer	Minor	87, 67
Sesamia cretica	Sorghum stemborers	Minor	23, 232
S. pecki (Tams)	Sorghum stemborers	Minor	23, 232
Plusia transfixa	White-streaked looper	Minor	116
_Pyralidae			
Salebria mesozonella (Bradi)	Phycitid moth	Minor	7, 67
Marasmia sp.	-	Minor	7, 67
_Lymantriidae			
Euproctis sp	Hairy caterpillars	Minor	7, 67
Gelechidae			
Sitotroga cerealella (Olivier)	Angoumois grain moth	Minor (field condition)	7, 23, 67, 100, 232
COLEOPTERA			
Curculionidae			
Nematocerus spp.	Shiny cereal weevil	Unknown	7, 67
Sitophilus oryzae (L.)	Rice weevil	Minor (field condition)	7, 23, 67, 100, 232
Sitophilus zeamais Motsch.	Maize weevil	Minor (field condition)	23, 232

Table 2 continued

Insect order, family and species	Common name	Status	Reference
COLEOPTERA			
Curculionidae			
Tanymecus abyssinicus Mrsh.	-	Minor	23, 232
Systates spp.	Systates weevil	Minor	7, 67
Chrysomelidae			
Haltica pyritosa Erichson	Linseed flea beetle	Minor	7, 67
Sesselia pusilla (Gerstaecker)	Black leaf beetle	Minor	7, 67
Mylabris bifasciata	Blister beetle	Minor	7, 67
Chaetocnema pulla	-	Minor	116
Coccinellidae			
Epilachna similes (Thumberg)	Tef Epilachna	Minor	7, 67
Chnootriba similes Thumb	-	Minor	23, 232
Cerambycidae			
Nematocerus brachyderes Marshall	-	Minor	7, 67
Scarabaeidae			
Schizonycha spp.	Chaffer grubs	Minor	7, 67
Cetonidae			
Pacnoda stehelini Schawn	Sorghum chaffer	Minor	16, 83
Pachnoda interrupta (Olivier)	Sorghum chaffer	Major	7, 67
Pachnoda abyssinica	Sorghum chaffer	Minor	64
P. crassa fairmairei	Sorghum chaffer	Minor	64
P. massajae	Sorghum chaffer	Minor	64
P. peregrine	Sorghum chaffer	Minor	64
P. stehellini Schaum	Sorghum chafer	Minor	23, 233
Rhynchophoridae			
Rhynchaenus niger (Horn)	Borer beetle	Minor	67,86
Pissodes dubius	Borer beetle	Minor	67, 86
ORTHOPTERA			
Acarididae			
Schistocerea gregaria (Forsk)	Desert locust	Unknown	23, 232
Zonocerus variegates	-	Minor	7,67, 86, 232
Anacridium melanorhodon walker	-	Minor	23, 232
Catantops pinguis Burn	-	Minor	23, 232

Table 2 continued

Insect order, family and species	Common name	Status	Reference
ORTHOPTERA			
Acarididae			
Kraussaria angulifera (Krauss)	Dagussa grasshopper	Minor	23, 232
Pyrgomorphidae			
Zonocerus variegates	-	Minor	7,67, 86, 232
Gryllidae			
Gryllus bimaculatus De Geer	Two spotted cricket	Minor	23, 232
DIPTERA			
Chloropidae			
Aprometopis flavofacies	Sorghum shoot fly	Minor	209
Anatrichus pygamaeus	Sorghum midge	Minor	209
Elachiptera simplicipes	Sorghum shoot fly	Minor	209
Melanochaeta vulgaris	Sorghum shoot fly	Minor	209
Oscinella nartshukiana	Sorghum shoot fly	Minor	209
Rhopalopterum sp.	Sorghum shoot fly	Minor	209
Scoliopthalmus micantipennis	Sorghum shoot fly	Minor	209
S. trapezoids	Sorghum shoot fly	Minor	209
Steleocerellus tenellus	Sorghum shoot fly	Minor	209
Muscidae			
Atherigona soccata (Randani)	Sorghum shoot fly	Major	67,86, 191,192,193,194, 195,196,197,198 200,202, 232
Diopsidae			
Diopsis thoracica (Westw)	Stalk eyed fly	Unknown	7, 67
Lampyridae			
Lampyridae	Fire flies	Minor	7, 67
Drosophilidae			
Drosophila sp.	Small fruit fly	Minor	7, 67
Cecidomyiidae			
Contarinia sorghicola (Coquillett	Sorghum midge	Major	7, 67

Table 2. Continued

Insect order, family and species	Common name	Status	Reference
HEMIPTERA			
Aphididae			
Rhopalsiphum maidis (Fitch)	Maize aphid	Minor	7, 23, 24, 51, 52, 67,86, 100, 116, 123, 124, 131, 138, 159, 161, 209, 232
Macrosiphum avenae (F. and M.)	Grain leaf aphid	Minor	7,50, 67
Macrosiphum africanum (H.R.L.)	African aphid	Minor	7, 67
Melanaphis sacchari (zhnt.)	Sorghum aphid	Minor	7, 67
Aphis maidis (Fitch)	Maize aphid	Minor	23, 232
Coreidae			
Anoplocnemis curvipes	-	Minor	7, 23, 67, 232
Lygaeidae			
Graptostethus rufus	-	Minor	7, 67, 232
G. servus	-	Minor	7, 67, 232
Lygaeus negus	-	Minor	7, 67
Lygaeus sp.	-	Minor	7, 67, 232
Spilosttethus pandurus	Lygus bug	Minor	7, 67
Engistus exsanguis Stal.	-	Minor	23, 232
Miridae			
Helopeltis schoutedeni Reuter	Cotton heloppeltis	Minor	7, 67
Taylorilygus ricini (Tayl.)	Lygus bug	Minor	7, 67
Taylorilygus virens (Tayl.)	Lygus bug	Minor	7, 67
Taylorilygus vosseleri (Poppius)	Cotton lygus	Minor	7, 67
Cephalocapsus sp.	-	Minor	23, 232
Cephalocapsus sp.	-	Minor	116
Cephalocapsus sp.	-	Minor	116
Pentatomidae			
Acrosternum pallidoconspersum	Larger green stink bug	Minor	7, 67
Agonoscelis pubscens Thunberg	Cluster bug	Minor	7, 67
Nezara viridula (L.)	Green stink bug	Minor	7, 67
Pyrrocoridae			
Dysdercus spp.	Cotton stainers	Minor	7, 67

Table 2. continued

Insect order, family and species	Common name	Status	Reference
HEMIPTERA			
Cercopidae			
Locris auripennis (Ditasnt)	Red spittle bug	Minor	7, 67
Poophilus castles (Walker)	Spittle bug	Minor	7, 67
Cicadellidae			
Poecilocarda nigrinervis Stal.	Black striped jassid	Minor	7, 67
Peregrinus maidis (Ashmead)	Shoot bug	Minor	23, 232
Oxycarenidae			
Oxycarenus zavattari (Feb.)	-	Unknown	23, 232
Oxycarenus sp.	-	Minor	116
Delphacidae	-	Minor	116
Elangers niger	Sorghum head bugs	Minor	7, 67
THYSANOPTERA			
Thripidae			
-	Head thrips	Minor	7, 67
ISOPTERA			
Termitidae			
Microtermes spp.	Termite	Major	7, 67
Macrotermes subhyalinus	Termite	Major	7, 67

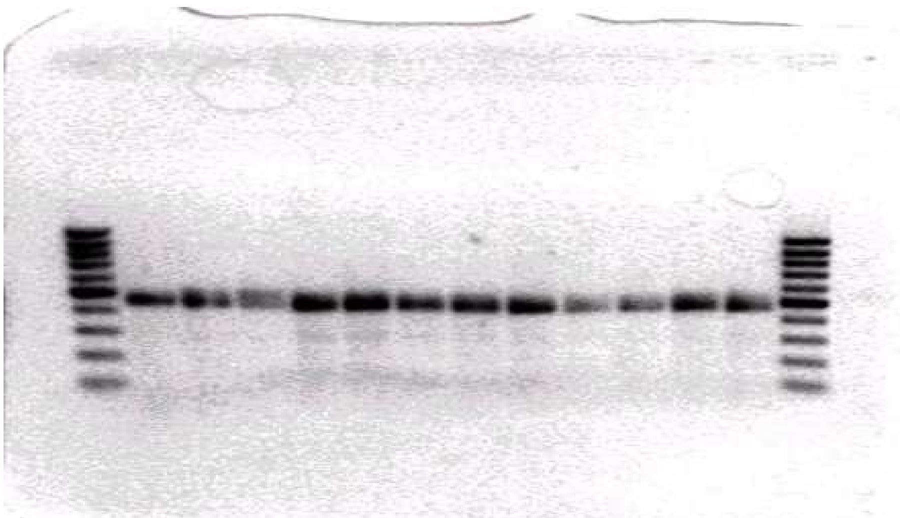


Figure 2. Gel electrophoresis of amplified 16S gene PCR products [Lane 1 & 14 = 100 bp; Lane 2 = Ethiopian Population (voucher specimen); Lane 3 = North Pakistan population; Lane 4 = Kenya population; Lane 5 = Tanzania population; Lane 6 = India population; Lane 7 = South Pakistan population; Lane 8 = Ethiopia population (Central); Lane 9 = Ethiopia population (Eastern); Lane 10 = Ethiopia population (Southern); Lane 11 = Ethiopia population (Northenn); Lane 12 = Ethiopia population (Western); Lane 13 = Ethiopia population (Mixed)].

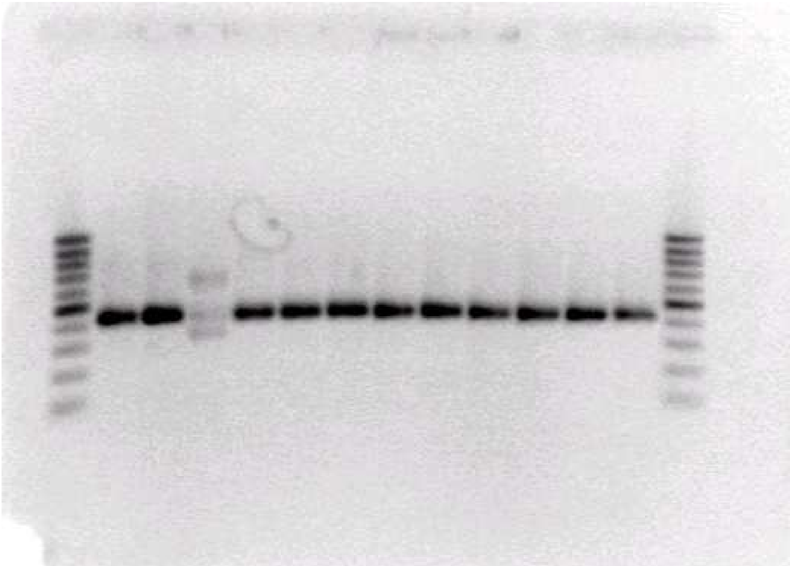


Figure 3. Gel electrophoresis of amplified ITS2 gene PCR products [Lane 1 & 14 = 100 bp; Lane 2 = Ethiopian Population (voucher specimen); Lane 3 = North Pakistan population; Lane 4 = Kenya population; Lane 5 = Tanzania population; Lane 6 = India population; Lane 7 = South Pakistan population; Lane 8 = Ethiopia population (Central); Lane 9 = Ethiopia population (Eastern); Lane 10 = Ethiopia population (Southern); Lane 11 = Ethiopia population (Northenn); Lane 12 = Ethiopia population (Western); Lane 13 = Ethiopia population (Mixed)].
Source for figs. 2 and 3: Emana, 2006.

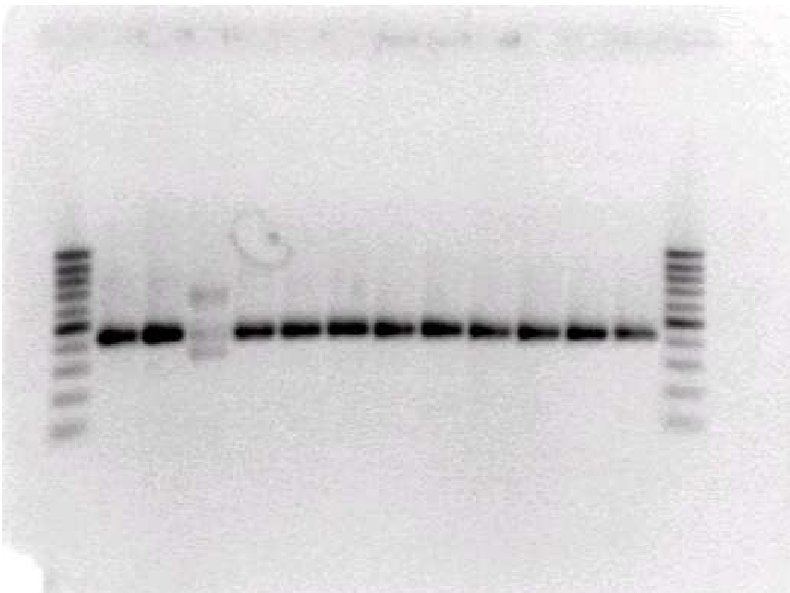


Figure 3. Gel electrophoresis of amplified ITS2 gene PCR products [Lane 1 & 14 = 100 bp; Lane 2 = Ethiopian Population (voucher specimen); Lane 3 = North Pakistan population; Lane 4 = Kenya population; Lane 5 = Tanzania population; Lane 6 = India population; Lane 7 = South Pakistan population; Lane 8 = Ethiopia population (Central); Lane 9 = Ethiopia population (Eastern); Lane 10 = Ethiopia population (Southern); Lane 11 = Ethiopia population (Northenn); Lane 12 = Ethiopia population (Western); Lane 13 = Ethiopia population (Mixed)].
Source for figs. 2 and 3: Emana, 2006.

References

1. Abdurahman Abdulahi and Terefe Gebretsadik. 1993. Simulation of pest damage on maize. P. 23. Proceedings of the First Annual Conference of the Crop Protection Society of Ethiopia (CPSE). 14-15 April 1993, Addis Abeba, Ethiopia.
2. Abdurahman Abdulahi. 1990. Foraging activity and control of termites in western Ethiopia. Ph.D Dissertation, University of London.
3. Abdurahman Abdulahi. 1992. Termites of agricultural importnce in western Ethiopia. *Ethiopian Journal of Agricultural Science* 13:21-29.
4. Abiy Tilahun. 2005. Parasitoid species diversity and rates of parasitism on maize and sorghum stemborers in the Rift Valley of Ethiopia. MSc. Thesis, Alemaya University.
5. AbARC (Abobo Agricultural Research Center). 1998. Abobo research center progress report for the year 1998.
6. Abraham Tadesse and Adane Kassa. 1995. The effect of seed dressing with aldrin on termite control in maize in western Ethiopia. Proceedings of the Second Conference of the Crop Protection Society of Ethiopia (CPSE), 26-27 April 1994, Addis Abeba, Ethiopia.
7. Abraham Tadesse and Adane Kassa. 1998. Some arthropod pests of agricultural importance in westen Ethiopia. A handbook. Institute of Agricultural Research (IAR), Addis Ababa
8. Abraham Tadesse, Ferdu Azerfegn, Assefa Grbre-Amlak and Adhanom Negasi. 1993. Research highlights of maize insect pests and their management in Ethiopia. Pp 34-42. *In:* Benti and Ransom (eds.). Proceedings of the First National Maize Workshop of Ethiopia. 5-7 May 1992. Addis Ababa, Ethiopia. IAR/CIMMYT.
9. Abraham Tadesse, Firdissa Eticha and Emana Getu. 1997. Can marshal (carbosulfan) protect maize from insect pest damage? Paper presented at the 5th Annual Conference of CPSE. 22-23 May 1997, Addis Ababa, Ethiopia
10. Abraham Tadesse, Firdissa Eticha, Selome Tibebu and Legesse Wolde. 1998. Status of cereal stemborers as pests of maize in Ethiopia. Paper presented at the workshop on Habitat Management Strategies for the Supperession of Cereal Stemborers, 19 September 1998, Addis Abeba, Ethiopia.
11. Abraham Tadesse. 1986. Comparison of African bollworm attracted by different crops used as trap crops to control the pest on sorghum at Didessa and Bako. Proceedings of the 18th NCIC. 24-26 April 1986, Nazret, Ethiopia.
12. Abraham Tadesse. 1986. Screening of sorghum lines resistant to sorghum shoot fly, *Atherigona soccata* at Bako. Bako Research Center progress report for 1985/86.
13. Abraham Tadesse. 1987. Major insect problems on sorghum in Ethiopia and strategies for their control. Proceedings of the 5th Regional Workshop on Sorghum and Millet Improvement in Eastern Africa. 5-12 July 1986. Bujumbura, Burundi.
14. Abraham Tadesse. 1988. Verification of the control effectiveness of aldrin on termites in maize. Bako Research Center progress report for 1988.
15. Abraham Tadesse. 1990. Termites: Problems and possible methods of their control in agriculture with reference to the Ethiopian condition. Pp. 50-74. Proceedings of the 10th Annual Conference of the Committee of Ethopian Entomologists (CEE). 7-9 February 1990, Addis Abeba.
16. Abraham Tadesse. 1996. Major insect pests of maize: Their control strategies and future needs for research in western Ethiopia. Paper presented at the Workshop on Technology Generation, Transfer and Gaps in Western Ethiopia. 12-14 November 1996. Nekemte, West Wellega.
17. Abraham Tadesse. 1998. Control strategies and future needs for research on insect pests of maize in Ethiopia. Pp. 291-305. *In:* Beyene S. and Aberra D. (eds.) Agricultural Reserach and Technology Transfer Attempts and Achievements in Northern Ethiopia. Proceedings of 4th

Technology Generation, Transfer and Gap Analysis Workshop. 18-21 March 1997. Bahir Dar, Ethiopia.

18. Adane Kassa and Abraham Tadesse. 1991. Evaluation of sorghum genotypes for their resistance to sorghum shoot fly *Atherigona voria soccata* at Bako. *CEE Newsletter* 12 (1 & 2): 4.
19. Adane Kassa and Abraham Tadesse. 1996. Yield losses in sorghum caused by sorghum shoot fly (*Atherigona soccata* Rond.) and maize stemborers (*Busseola fusca* (Fuller)) in western Ethiopia. *CPSE*. (Abstract) Addis Abeba, Ethiopia.
20. Adane Kassa and Abraham Tadesse. 1998. Yield losses in sorghum caused by sorghum shootfly and maize stalk borer at Bako. *Pest Management Journal of Ethiopia* 2:71-78.
21. Adane Kasssa., Tsehay Azage and Tsedeke Abate. 1997. Experience in biological control of insect pests in Ethiopia: A review. Pp. 12-23. Integrating biological control and host plant resistance. Proceedings of a CTA/IAR/IIBC Seminar held on 9-14 October 1995, Addis Ababa, Ethiopia.
22. AARC (Adet Agricultural Research Center). 2005. Progress report for 2004/05.
23. Adhanom Negasi and Abraham Tadesse. 1985. A review of research on insect pests of maize and sorghum in Ethiopia. Pp 7-9. *In:* Tsedeke A. (ed.). A review of Crop Protection Research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium. IAR, Addis Ababa.
24. Amanauel Tamiru. 2005. Study on the factors affecting altitudinal expansion of *Chilo partellus* (Swinhoe) in Ethiopia. MSc thesis, Addis Ababa University.
25. ARARI (Amhara Agricultural Research Insitute). 2001. Amhara Regional Agricultural Research Institute research directory for 2001/2. Biometric and Information Technology Unit, Bahir Dar**.**
26. Asfaw Adugna, Tesfaye Tefera and Abera Deresa. 2005. Sorghum production and Research experiences. Production Guideline. Ethiopian Agricultural Research Organization (EARO), Addis Abeba.
27. Asmare Dejene, Adane Tesfaye and Eshetu Belete. 2004. Evaluation of *Azadirachta indica* and *Melia azadarach* for the management of stemborers on sorghum. *CPSE*. 12th Annual Conference, 26-27 Addis Ababa, Ethiopia.
28. Asmare Dejene. 2004. Management of stem borers on sorghum using sowing date and horizontal placement of stems in northeastern Ethopia. MSc. Thesis, Alemaya University.
29. Assefa Gebre Amlak and Ferdu Azerefegne. 1996. Integrated pest management on major crops in southern Ethiopia. Awassa College of Agriculture: Annual Research Report, 1994/95. Pp 93-122.
30. Assefa Gebre-Amlak and Ferdu Azerefegne. 1994. Integrated pest manangement on major crops in southern Ethiopia. Pp. 97-124. Awassa College of Agriculture Annual Report for 1993/94. Awassa, southern Ethiopia.
31. Assefa Gebre-Amlak and Ferdu Azerefegne. 1997. Integrated pest manangement on major crops in southern Ethiopia. Pp. 11-122. Awassa College of Agriculture Annual Report for 1995/96. Awassa, southern Ethiopia.
32. Assefa Gebre-Amlak and Ferdu Azerefegne. 1999. Insecticidal activity of chinaberry, endod and pepper tree against the maize stemborer, *Busseola fusca* (Lepidoptera: Noctuidae) in southern Ethiopia. *International Journal of Pest Management* 45: 9-13.
33. Assefa Gebre-Amlak, Roland, S. and Jan, P. 1989. The relationship between sowing date, infestation and damage by the maize stemborers, *Busseola fusca* (Noctuidae), on maize in Awassa, Ethiopia. *Tropical Pest Management* 35: 143-145.
34. Assefa Gebre-Amlak. 1985. Survey of lepidoptrous stemborers attacking maize and sorghum in Ethiopia. *Ethiopian Journal of Agricultural Science* 7: 15
35. Assefa Gebre-Amlak. 1988. Development of maize stemborer, *Busseola fusca* (Fuller) in wild host plants in Ethiopia. *Journal of Applied Entomology* 106: 390-395.

36. Assefa Gebre-Amlak. 1988. Ecology and management of maize stemborer *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) in southern Ethiopia. PhD Disertation, Swedish University of Agricultural Science, Uppsala, Sweden.
37. Assefa Gebre-Amlak. 1988. Survival of maize stemborer, *Busseola fusca* (Fuller) in crop residues in Ethiopia. *Crop Protection* 7: 183-185.
38. Assefa Gebre-Amlak. 1989. Phenology and fecundity of maize stemborer, *Busseola fusca* (Fuller) in Awassa, southern Ethiopia. *Insect Science and its Application* 10: 131-137.
39. Assefa Gebre-Amlak. 1989. Termination of diapause in the maize stemborer *Busseola fusca* (Fuller) in Awassa, southern Ethiopia. *Journal of Applied Entomology*. 107:160-165.
40. Assefa Gebre-Amlak. 1990. Maize stalkborer research in Ethiopia. PP. 22-42. Proceedings of the 10th CEE Annual Meeting. February 7- 9, 1990. Addis Abeba, Ethiopia.
41. Assefa Gebre-Amlak. 1990. Maize stalkborer research in Ethiopia. Pp. 239 - 252. *In:* Gebrekidan Birhane. (ed.). Maize improvement, production and protection in Eastern and Southern Africa Regional maize workshop Proceedings of the 3rd eastern and southern Africa Regional Maize Workshop. 18-22 1989, Nairobi, Kenya.
42. Assefa Gebre-Amlak. 1991. Maize entomology in Ethiopia: research status. Pp 27-29. *In:* Tsedeke Abate, Teferi Gemechu and Abdurahman Abdulahi. (eds). CEE Proceedings. Addis Ababa, Ethiopia.
43. Assefa Gebre-Amlak. 1992. Biology and ecology of the maize stemborer, *B. fusca* in southern Ethiopia. Annual Research Report 1990/1991. Awassa College of Agriclture, Awassa, Ethiopia.
44. Assefa Gebre-Amlak. 1994. Biology and ecology of the maize stemborer, *B. fusca* (Fuller), in southern Ethiopia. Annual Research Report 1992/3. Awassa College of Agriclture, Awassa, Ethiopia.
45. Assefa Teferi. 1990. Termites: Their damage and control on maize, tef and hot pepper in Assosa area. Pp. 43-49. Proceedings of the 10th CEE Annual Meeting. February 7-9, 1990, CEE, Addis Abeba.
46. BARC (Bako Agricultural Research Center). 1998. Chemical control of termite. Bako Research Center progress report for 1997/8.
47. BARC. 1998. Progress report for 1996/97.
48. BMRC (Bako Maize Research Center). 1999. Use of napier grass for the control of stemborers. Bako National Maize progress report for 1998/9.
49. Barnett, E. A. Cowie, R. H. Sands, W. A. and Wood T. G. 1987. Identification of termites collected in Ethiopia in January-February and July 1986. Report prepared on behalf of the World Bank for the MoA, Government of Ethiopia. Tropical Development Research Institute (TDRI). Contract No. C0696.
50. Brihane Gebre-Kidan. 1977. Ethiopian Sorghum Improvement Project Annual Report No. 5, Addis Ababa University.
51. CADU (Chilallo Agricultural Development Unit). 1969. Results of trials and observations 1968/9 Crop Production Department. Addis Abeba. CADU Publication No. 28.
52. CADU. 1969. Report on surveys and experiments Crop Production Department. CADU Publication No. 46.
53. Cowie, R. H., T. G. Wood, E. A. Barnnett, W. A. Sands and Balck, H. I. J. 1990. A checklist of the termites of Ethiopia with a review of their biology, distribution and pest status. African Journal of Ecology 28: 21-23.
54. CSA (Central Statistical Authority). 2000. Agricultural sample survey 1999/2000. Report on area and production for major crops (private peasant holdings, main season). Statistical Bulletin No. 227. CSA: Addis Ababa.
55. Daniel Getahun and Bekle Jembere. 2006. Evaluation of crude extracts of some botanicals on different castes of Macrotermes Termites. *Pest Management Journal of Ethiopia* 10:15-23.

56. Daniel Getahun. 2003. Evalaution of the toxicity of crude extracts of some plants and a synthetic insecticide on different castes of Macrotermes termite. M.Sc thesis, Addis Ababa University.
57. Daniel Tekle. 2002. Effect of chat-maize intercropping and chat leaf extract on the incidence and development of lepidopterous stemborers of maize in Alemaya, eastern Ethiopia. M. Sc Thesis. Alemya University.
58. Delinasaw Yewhalaw. 2004. Study on the potential of wild host grasses as trap plants in the management of cereal stemborers at Melkassa Agricultural Research Center, Ethiopia. M.Sc. Thesis, Addis Ababa University.
59. Delnesaw Yewhalaw, Emana Getu and Emiru Seyoum. 2007. Evaluation on the potential of wild hosts for the management of gramineous stemborers in maize-based agroecosystem. *Journal of Economic Entomology* 100: 000-000.
60. Devendra, G., Julius, A. O., Kit V., Lemma G., and Mullugetta N. 1998. A Participatory systems analysis of the termite situation in West Wollega, Ethiopia. Working Document Series 68: ICRAF/EARO/OADB (Oromya Agricultural Bureau).
61. EARO (Ethiopian Agricultural Research Organizaion). 1998. Plant Protection Research Center progress report for 1997/8. EARO, Addis Abeba.
62. EARO. 2004. Annual Report for 2002/3.
63. EIAR (Ethiopian Insitute of Agricultural research). 2005. Plant Protection Research Center (PPRC) progress report for 2004/5. PPRC, Ambo.
64. Elias Saheldengel. 2003. Species composition and host plants of the genus Pachnoda (Coleoptera: Scarabaeidae) and the damage potential of Pachnoda. M. Sc. thesis. Alemaya University, Ethiopia.
65. Emana Getu and Gure Kumissa. 1997. A strategy for a sustainable control of termite in Manasibu Wereda (West Wellega): A document prerpared by B & M Development consultants PLC for The Ethiopian Evangelical Church Mekane Yesus-Western Synod.
66. Emana Getu and Tsedeke Abate. 1999. Management of maize stemborer using sowing date at Arsi Negele. *Pest Management Journal of Ethiopia*. 3: 47-52.
67. Emana Getu, Fridisa Etecha and Asmare Dejene. 2002. Sorghum entomological research in Ethiopia: A review. Proceedings of the First Sorghum Workshop, Melkassa, Ethiopia, 20-23 September, 2002.
68. Emana Getu, W. A. Overholt and E. Kairu. 2001. Evidence of establishment of Cotesia flavipes Cameron (Hymenoptera: Braconidae) and its host range expansion in Ethiopia. Pests and vector management for food security and public health in Africa: Challenges for the 21st Century. The 14th African Association of Insect Scientists and the 9th CPSE Joint Conference, Addis Ababa, Ethiopia.
69. Emana Getu, W. A. Overholt and E. Kairu. 2003. Analysis of factors affecting the stemborer infestation in Ethiopia. Paper presented on Entomological Society of Australia.
70. Emana Getu, W. A. Overholt and E. Kairu. 2003. Comparative studies on the influence of relative humidity and temperature on the longevity and fecundity of two populations of Cotesia flavipes. *In:* Integrated pest and vector management in the tropics: perspective and future strategies. (Abstract). 15th Biennial Congress of the African Association of Insect Scientists (AAIS) and Silver Jubilee Celebrations jointly organized with the Entomological Society of Kenya (ESK), 9-13 June 2003, Nairobi, Kenya.
71. Emana Getu, W. A. Overholt and E. Kairu. 2003. Comparative studies on the influence of relative humidity and temperature on the developmental time of two populations of Cotesia flavipes. *Ethioipian Journal of Biological Sciences* 2: 49-60.
72. Emana Getu, W. A. Overholt and E. Kairu. 2003. Evidence of establishment of Cotesia flavipes Cameron and its host range expansion in Ethiopia. *Bulletin of Entomological Research* 93: 125-129.

73. Emana Getu, W. A. Overholt and E. Kairu. 2003. Integrated management of cereal stemborers in Ethiopia. Paper presented on Crop Science Society of Africa.
74. Emana Getu, W. A. Overholt and E. Kairu. 2004. Ecological management of cereal stemborers in Ethiopia. *In:* Friesen, D. K and A. E. E. Palmer (eds.). Integrated approaches to higher maize productivity in the New Millennium: Proceedings of the Seventh eastern and southern Africa Regional maize Conference, 5-11 Feb. 2002, Nairobi, Kenya, CIMMYT and KARI.
75. Emana Getu, W. A. Overholt and E.Kairu, M. Leban and J. Zhou. 2002. Predicting the distribution of Chilo partellus and *Cotesia flavipes* using stepwise regression and Geographical Information System. *Insect Science and its Application* 22: 453-489.
76. Emana Getu, W. A. Overholt and E.Kairu. 2001. Distribution of stemborers and their natural enemies in Ethiopia. *Insect Scienc and its Application* 21: 353-359.
77. Emana Getu, W. A. Overholt and E.Kairu. 2002. Effect of cropping system on stemborers and their parasitoids in maize and sorghum based agro- ecosystem in Ethiopia. (abstract). CPSE 10th Annual Conference, 15-16 August 2002, Addis Abeba, Ethiopia.
78. Emana Getu, W. A. Overholt, and E. Kairu. 2004. Comparative studies on influence of relative humidity and temperature on life table parameters of two populations of *Cotesia flavipes* (Hymenoptera: Braconidae). *Biocontrol Science and Technology* 14: 595-605.
79. Emana Getu, W. A. Overholt, E. Kairu, Leban, G. Zhou. 2001. Predicting the distribution of *Chilo partellus* and *Cotesia flavipes* using stepwise regression analysis in Ethiopia. Bulletin for the 5th Africa GIS Conference and Expo. Enhancing socio economic development with geo-spatial knowledge.
80. Emana Getu, W. A. Overholt, E. Kairu and T. Abate. 1999. Determination of temperature and relative humidity thresholds for the development and longevity of *Cotesia flavipes* Cameron. *In:* Denash G. and M. Ali Bob (eds.). Integrated pest and vector management and sustainable development in Africa. Proceedings of Joint Congress of the African Association of Insect Scientists (13th Congress) and the Entomological Society of Burkina Faso 19-23 July 1999.
81. Emana Getu. 1996. Insecticidal control of maize stalkborer. *IAR newsletter* 11: 4-5.
82. Emana Getu. 1998. Effects of sowing dates on the infestation of maize stalkborer, *B. fusca* (Fuller). Sixth Annual Confrence of CPSE. 3-5 June 1998, Addis Abeba.
83. Emana Getu. 1998. Extensive insecticidal screening against stemborers, *Busseola fusca* (Fuller). Awassa National Maize progress report for 1998/9.
84. Emana Getu. 1998. Insecticidal screening against maize stalkborer, *B. fusca* (Fuller). Sixth Annual Confrence of CPSE. 3-5 June 1998, Addis Abeba.
85. Emana Getu. 1999. Integration of sowing date and insecticide for the control of maize stemborer, *B. fusca*, under Awassa condition (abstract). CEE 7th Annual Conference, 5-6 August 1999, Addis Abeba.
86. Emana Getu. 2002. Ecological analyses of cereal stemborers and their natural enemies under maize and sorghum based agro-ecosystems in Ethiopia. Ph. D Dissertation, Kenyatta University.
87. Emana Getu. 2002. Host suitability of *Chilo partellus*, *Sesamia calamistis* and different geographical populations of *B. fusca* for different geographic populations of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) in Ethiopia. 10th Annual Conference CPSE. 15-16 August 2002, Addis Ababa. Pp 14-17.
88. Emana Getu. 2004. Distribution of stemborers and their natural enemies. Pp 41-49. *In:* Frew Kelemu, Betre Alemu and Taye Bekele (eds.). Proceedings of the GIS project winding up workshop, December 18, 2003, Melkassa, Nazareth, Ethiopia.
89. Emana Getu. 2004. Grass species growing in the vicinity of maize and sorghum agro-ecosystem in Ethiopia and their value in terms of stabilizing pest management (abstract). CPSE 12th Annual Conference, 26-27 May 2004 Addis Abeba. Pp 44-45.

90. Emana Getu. 2004. Integrated pest management options for the control of cereal stemborers in Ethiopia: Biological control as a key component. (Abstract). 12th Annual Conference of CPSE. 26-27 May 2004, Addis Ababa, Ethiopia. Pp 21-22.
91. Emana Getu. 2005. Integrated management of cereal stemborers using resistance varieties, biological control, intercropping, fertilizers and botanicals. Progress report of Melkassa Research Center for 2003-2005.
92. Emana Getu. 2005. Suitability of *Chilo partellus*, *Sesamia calamistis* and *Busseola fusca* for the development of *Cotesia flavipes* in Ethiopia: Implication for biological control. *Ethiopian Journal of Biological Sciences* 4: 123-134.
93. Emana Getu. 2006. Effect of maize and sorghum cropping systems on stemborers and their parasitoids in Ethiopia. *Insect Science Journal of China* (In press).
94. Emana Getu. 2006. Molecular comparison of Ethiopian population of *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae) with African and Asian populations: towards tracing the origin of Ethiopian population. BioControl Journal (inpress).
95. Emana Getu. 2006. The influence of relative humidity and temperature on the longevity and fecundity of the parasitic wasp, *Cotesia flavipes*: Towards optimization of biological control of the maize stemborer, *Chilo partellus*, in Ethiopia. *Insect Science* (inpress).
96. Emana Getu. 2007. The effect of temperature and relative humidity on the fecundity and longevity of Ethiopian population of *Cotesia flavipes*. *Journal of Insect Science* 7:1-7.
97. Fentahun Mengistu and Senishaw Aysheshim. 1996. Seasonal occurrence of the sorghum shoot fly (Atherigona soccata) on sorghum at Ambo. Pp 45-47. Proceedings of CPSE Third Annual Conference. May 18-19, 1995. Addis Abeba, Ethiopia, CPSE, Addis Abeba.
98. Ferdu Azerefegne. 1991. Biology and economic importance of maize stemborer, *Busseola fusca* in Awassa, southern Ethiopia. M. Sc. Thesis. Alemaya University of Agriculture, Alemaya, Ethiopia.
99. Ferdu Azerefegne. 1992. Distribution of *Busseola fusca* eggs and larvae in the maize plant. Proceedings of the joint conference Ethiopian Phytopathological Committee (EPC) and Committee of Ethiopian Entomologist (CEE), 5-6 March 1992, Addis Abeba, Ethiopia..
100. Ferdu Azerefegne., Demissew Kitaw and Berhane Amare. 2001. Major insect pests of maize and their management. *In:* Mandefro N., D. Tanner, and S. Twumasi-Afriyie (eds.). Pp 89-96. Enhancing the contribution of maize to food security in Ethiopia: Proceedings of the Second National Maize Workshop of Ethiopia, 12-16 November 2001, Addis Abeba, Ethiopia: EARO and International Maize and Wheat Improvement Center (CIMMYT).
101. Ferede Negasi. 1988. Studies on the integrated management of spotted stemborers of sorghum. Pp. 135-140. Nazret Research Center progress report for 1988.
102. Ferede Negasi and Girma Tegegn. 1989. Survey on the cause of sterility of sorghum seed at Gambella and suggested control measures. IAR Newsletter 4: 5-6.
103. Firdissa Eticha and Abraham Tadesse. 1998. Insect pests, their control recommendations and future needs for research in western Ethiopia. Pp. 151-158. *In:* Beyene Soboka and Aberra Deressa (eds.) Agricultural Research and Technology Transfer Attempts and Achievments in Western Ethiopia. Proceedings of the 3rd Technology Generation, Transfer and Gap Analysis workshop, 12-14 November 1996, Nekemte, Ethiopia.
104. Gashawbeza Ayalew and Melaku Wale 1996. Sowing date against the stemborers, *Chilo partellus* (Swinhoe) and *Busseola fusca* (Fuller) on sorghum in central Ethiopia. Paper presented at the 3rd Annual Conference of the Crop Protection Society of Ethiopia. May 18-19, 1995, Addis Ababa.
105. Gashawbeza Ayalew and Melaku Wale. 1996. Loss caused by the stemborers, *Chilo partellus* (Swinhoe) and *Busseola fusca* (Fuller) on sorghum in central Ethiopia, May 18-19, 1995, Addis Ababa.
106. Gashawbeza Ayalew. 1995. Progress in sorghum insect pests management research. Pp. 174-180. *In:* Habtu Assefa (ed.). Proceedings of 25th Anniversary of Nazareth Research

Center. 25 years of research experience in lowland crops. Pp. 174-180. 22-23 September 1995.

107. Girma Aboma, Mosisa Worku, Dereje Bacha, Abdissa Gemeda, and Demissew Kitaw. 2001. Analysis of off-season maize production in East and West Wellega zones of Oromiya Region. Research report no. 37. Ethiopian Agricultural Research Organization, Addis Ababa.
108. Girma Hailu and Fantahun Mengistu. 1991. Major achievments of entomological research in the Plant Protection Research Center (PPRC). Pp. 37-39. *In:* Tsedeke Abate, Teferi Gemechu and Abdurahman Abdulahi (eds). Proceedings of the 11th CEE Annual Meeting, 21-22 Feb. Addis Abeba.
109. Girma Hailu and Plotnikov, V. 1988. Studies on the distribution, harmfulness and biology of *Diopsis* sp. and *Atherigona indica* on sorghum. Pp. 7-21. Proceedings of the 8th CEE Annual Meeting. 5-6 May 1988. Addis Abeba.
110. Girma Tegegn. 1996. Research recommendations for crop protection with emphasis to chemical technology option. Pp. 101-107. *In:* Aberra D. and Beyene S. (eds.). Research achievements and technology transfer attempts: Vignettes from Shewa: Procedings of the First Technology Generation, Transfer and Gap Analysis Workshop. 25-27 December 1995, Nazareth, Ethiopia.
111. Girma Tegene, Wondmu B and Adane T. 2000. Indigenous crop-pest management techniques in Wollo. *Pest Management Journal of Ethiopia* 4:97-103.
112. Habte Tekie. 1999. Studies on the effect of neem (Azadirachta indica A. Juss) seed powder and aqueous suspension for the maize stem borer, Chilo partellus (Swinhoe) and their potential in pest management. Ph D Dissertation, Addis Ababa University. 78pp.
113. Hadush Tsehaye, Emana Getu and Chemeda Fininsa. 2003. Influence of cropping systems on the occurrence of sorghum stem borers and their natural enemies at Abergelle, Tigray. CPSE 11th Annual Conference, 5-6 June 2003, Addis Abeba.
114. Hadush Tsehaye. 2003. Influence of cropping system on the occurrence of sorghum stemborers and their natural enemies at Aberegelle, Tigray. M.Sc. thesis, Alemaya University.
115. Henock Abraham. 2003. Study on the biology and population variation of *Cotesia flavipes* (Hymenoptera: Braconidae) on *Chilo partellus* (Lepidoptera: Crambidae). M. Sc. Thesis, Addis Ababa University.
116. Hill, B.G. 1965. Insects of cultivated and wild plants, Harar province Ethiopia, 1960-1964. *Bulletin of Entomological Research* 56: 659-670.
117. Hiwot Lemma, Adane Kassa, Yeraswork Yilma, Legesse Zewude, Tsegaye Ejigu, Mohammed Seid, Ararsa Workneh. 1999. The significance, distribution and control of the sorghum chaffer, *Pachnoda interrupta* (Olivier) (Coleoptera: Scarabeidae) in the Amhara and Afar Regions. MoA and EARO, Addis Abeba.
118. Hiwot Lemma, Tessema Meganasa and Yitbarek W/Hawariat. 2004. Possible management methods of sorghum chafer, *Pachnoda interrupta* (Olivier) in sorghum fields. CPSE. 12th Annual Conference, 26-27 May 2004. Addis Abeba.
119. IAR (Insitute of Agricultural Research). 1989. Research Program Directory 1989. IAR, Addis Abeba.
120. IAR. 1975. Holetta Genet Research Station progress report for 1972-1973. IAR, Addis Abeba, Ethiopia.
121. IAR. 1976. Holetta Genet Research Station progress report for 1973-1974. IAR, Addis Abeba.
122. IAR. 1977. Gode Research station progress report for 1973-1977. IAR, Addis Abeba.
123. IAR. 1977. Holetta Genet progress report for 1974-1975. IAR, Addis Abeba.
124. IAR. 1977. Holetta Genet progress report for 1975-1976. IAR, Addis Abeba.

125. IAR. 1977. Summaries on pest research activities (IAR). Proceedings of the National Crop Improvement Committee: Results of the national crop trials and others.
126. IAR. 1985. Department of Crop Protection Progress Report for the period 1983/84. IAR. Addis Abeba.
127. IAR. 1985. Department of Field Crops: Ethiopian Naional Maize Reserach Progress Report for April 1983 to April 1984.
128. IAR. 1986. Crop Protection Department Progress Report for 1986. IAR, Addis Abeba.
129. IAR. 1986. Department of Crop Protection Progress Report for 1984/85. IAR, Addis Abeba.
130. IAR. 1986. Ethiopian Sorghum Improvement Program Progress Report for January 1984 to December 1984. IAR, Addis Abeba.
131. IAR. 1986. Holetta Research Center Progress Report for 1984/85.
132. IAR. 1986. Nazret Research Center Progress Report for 1985/86.
133. IAR. 1986. Nazret Research Center progress report for 1986. Pp 54-56.
134. IAR. 1987. Department of Field Crops Maize Progress Report for 1984/85, IAR, Addis Abeba.
135. IAR. 1987. Nazret Progress report for 1987. IAR, Addis Abeba.
136. IAR. 1987. Nazret Research Center progress report for 1987. IAR. Addis Abeba.
137. IAR. 1987. Progress Report Ethiopia Sorghm Improvenet Program, 1 January to 3 December 1987.IAR. Addis Abeba.
138. IAR. 1987. Research Progress Report for 1986/87. Holetta Research Center. IAR. Addis Abeba.
139. IAR. 1988. Ethiopian Sorghum Improvement Program Progress Report 16. for 1988. IAR. Addis Abeba.
140. IAR. 1988. Sorghum Improvement Program January 1- December 31 1986. Progress Report 14. IAR, Addis Abeba.
141. IAR. 1989. Awassa progress report for 1986. IAR, Addis Abeba.
142. IAR. 1989. Crop Protection Department Progress Report for 1989. IAR, Addis Abeba.
143. IAR. 1989. Ethiopian Sorghum Improvement Program progress report for 1988/89.
144. IAR). 1990. Bako Progress report for 1985/86. IAR, Addis Abeba.
145. IAR. 1990. Ethiopian Sorghum Improvement Program progress report for 1990. IAR, Addis Abeba.
146. IAR. 1990. Kobo progress report for 1989/90, Addis Abeba.
147. IAR. 1990. Nazret progress for 1986. IAR, Addis Abeba.
148. IAR. 1990. Nazret progress report for 1988. IAR. Addis Abeba.
149. IAR. 1991. Bako progress report for 1988. IAR, Addis Abeba.
150. IAR. 1991. Progreess Report 18. Ethiopian Sorghum Improvement, Jan. to Dec.1990. IAR. Addis Abeba.
151. IAR. 1993. Melkassa progress report for January to March 1993. IAR. Addis Abeba.
152. IAR. 1993. Sorghum Improvement Program progress report 21. IAR, Addis Abeba.
153. IAR. 1994. Nazret progress report for 1991/92. IAR, Addis Abeba.
154. IAR. 1995. Plant Protection Research Center (PPRC) progress report for 1994/95. IAR. Addis Abeba.
155. IAR. 1996. National maize progress report for 1995-1996. IAR. Addis Abeba.
156. IAR. 1996. PPRC progress report for 1995/96. IAR. Addis Abeba.
157. IAR. 1997. PPRC progress report for 1996/97. IAR. Addis Abeba.
158. IAR. 1983. Ethiopian Sorghum Improvement Program January 1 to December 31: Progress Report No. 11 for 1981/82.
159. IAR. 1984. Dept. of Field Crops: Ethiopian National Maize Team Progress Report for April 1982 to March 1983.

160.IAR. 1984. Proceedings of the 15th National Crop Improvement Conference. IAR, Addis Abeba.

161.IAR. 1985. Proceedings of the 16th National Crop Improvement Conference. Part II. IAR, Addis Abeba, Ethiopia. (Termination of diapause in the larvae of *B. fusca* at Awassa. Pp. 560-570. Survey of lepidopterous stem borers).

162.Kassahun Yitaferu and Walker, A. K. 1997. Studies on the maize stemborer, *Busseola fusca* (Lepidoptera: Noctuidae) and its major parasitoid, *Dolichogenidae fuscivora*. *Bulletin of Entomological Research* 87: 319-324.

163.Kassahun Yitaferu, Assefa Gebre-Amlak and Mengistu Hulluka. 1995. The importance and phenology of the maize stalkborer, *Busseola fusca* (Fuller) as a sorghum pest at Alemaya. P. 19. Proceedings of the second CPSE Annual Conference, CPSE, 26-27 April 1994, Addis Abeba, Ethiopia.

164.Kassahun Yitaferu, Hiwot Lemma, Tessema Megenassa and Ally Harari. 2004. The field biology of sorghum chafer: Its temporal occurrence and over- seasoning habits. (Abstract). CPSE. 12th Annual Conference, 26-27 May 2004 Addis Abeba.

165.Kassahun Yitaferu. 1993. Phenology and management of the maize stemborers, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), on sorghum in eastern Ethiopia. M. Sc. thesis Alemaya University.

166.Kassahun Yitaferu. 1996. Parasitism of *B. fusca* and the biology of its major parasitoid *Dolichogenidae fuscivora* in eastern Ethiopia. 4th CPSE Annual Conference. 23 - 24 May 1996, Addis Abeba.

167.MeARC (Mekele Agricultural Research Center). 1996. Survey and identification of insect pests of major field crops in Tigray. MeARC progress report for 1996. Mekele, Tigray.

168.MeARC. 1997. Stemborers management program: Insecticidal screening. Mekele progress report for 1997. Mekele, Tigray.

169.MeARC. 1997b. Stemborers management program: Evaluation of botanicals and insecticids. MeARC progress report for 1997. Mekele, Tigray.

170.MeARC. 2000. Yield loss assessment of sorghum due to stemborers in Tigray. MeARC progress report for 1999 and 2000. Mekele, Tigray.

171.Mekele Agricultural Research Center (MeARC). 2002. Effect of sowing date on the management of sorghum stemborers. Mekele progress report for 2002. Mekele, Tigray.

172.Melaku Wale and Gashawbeza Ayalew. 1992. Determination of optimum time of planting for the application of insecticides to minimize damage by Chilo partellus on sorghum. Proceedings of the Joint Conference, CPSE, Addis Abeba, Ethiopia.

173.Melaku Wale and Gashawbeza Ayalew. 1992. Determination of optimum time for the application of insecticide to minimize damage by *Chilo partellus* on sorghum. Proceedings of the Joint Conference EPC/CEE. 5-6 March 1992, Addis Abeba, Ethiopia.

174.Melaku Wale and Gashawbeza Ayalew. 1992. Determination of the relative abundance and dynamics of stalk borer species on sorghum. Proceedings of the Joint Conference, CPSE, Addis Abeba.

175.Melaku Wale and Gashawbeza Ayalew.1993. Determination of the relative abundance and dynamics of stemborers species on sorghum. P. 26. Proceedings of the Joint Conference: EPC/CEE, 5-6 March 1992. Addis Ababa, Ethiopia.

176.Melaku Wale, Fritz Schulthes, E. Kairu and Charles Omwega. 2006. Cereal yield losses caused by lepidopterous stemborers at different nitrogen fertilizer rates in Ethiopia. *Journal of Applied Entomology* 130: 220-229.

177.Melaku Wale, Fritz Schulthess, E. Kairu and Charles Omwega. 2006. Distribution and relative importance of cereal stemborers and thir natural enemies in the semi-arid and cool-wet ecozones of the Amhara State of Ethiopia. *Annales de la Societe Entomologique de France* 42:389-402.

178. Melaku Wale, Fritz Schulthess, E. Kairu and Charles Omwega. 2006. Seasonal abundance of stemborers on sorghum in the cool-wet ecozone of the Amhara state of Ethiopia (submitted paper).
179. Melaku Wale, Fritz Schulthess, E. Kairu and Charles Omwega. 2007. Effect of cropping system on cereal stemborers in the cool-wet and semi-arid ecozones of the Amhara State of Ethiopia. *Agricultural and Forest Entomology* 9:73-84.
180. Melaku Wale. 1988. Loss assessment due to sorghum shoot fly on sorghum. Kobo Research Station progress report for 1988.
181. Melaku Wale. 1999. Population dynamics of the stemborers *Chilo partellus* (Swinhoe), *Busseola fusca* (Fuller) and *Sesamia calamistis* Hampson attacking sorghum in central Ethiopia. *Insect Science and its Application* 19:149-156.
182. Mohammed Dawd, S. Sithanantham and Tadesse Gebremedhin (eds.) 2004. African bollworm management in Ethiopia: Status and needs. Proceedings of the National Workshop held at PPRC, Ambo, during 17-19 April 2002, Ambo, Ethiopia.
183. Mulugeta Negeri. 2001. Survey of parasitoids on lepidopterous stemborers attacking maize and sorghum in some localities of Ethiopia. *Pest management Journal of Ethiopia* 5: 69-75.
184. Nigussie Tesfamichale and Reddy, M. S. 1996. Performance of maize/bean intercropping systems under low and medium rainfall situations: Insect pest incidence. *In:* Eshetu B., Abdurahman A. and Aynekulu Y. (eds.). Proceedings of the Third Annual Conference of CPSE, 18-19 May 1995. CPSE, Addis Ababa.
185. OADB-ARCS (Oromiya Agricultural Development Bureau Agricultural Research Coordination Service). 1998. Bako progress report for 1996/97. OADB-ARCS.
186. OADB-ARCS. 1998. Bako Agricultural Research Center progress report for1997/98. OADB-ARCS.
187. Offgaa Dijrata. 2004. Prevalence of termites and level of their damage on major field crops and rangeland in Manasibue disrtrict, Western Ethiopia. M.Sc thesis, Addis Ababa, University.
188. PARC (Pawe Agricultural Research Center) 1998. Pawe Research Center progress report for 1998.
189. SPL (Scientific Phytopathological Laboratory). 1977. Progress report for 1975/76. SPL, Ambo.
190. SPL. 1979. Progress report for 1977/78. SPL, Ambo.
191. SPL. 1980. Progress report for 1978/79. SPL, Ambo.
192. SPL. 1980. Progress report for 1979/80. SPL, Ambo.
193. SPL. 1981. Progress report for 1980/81. SPL, Ambo.
194. SPL. 1982. Progress report for 1981/82. SPL, Ambo.
195. SPL. 1982. Progress report for 1982/83. SPL, Ambo.
196. SPL. 1983. Progress report for 1983/84. SPL, Ambo.
197. SPL. 1984. Progress report for 1984/85. SPL, Ambo.
198. SPL. 1985. Progress report for 1985/86. SPL, Ambo.
199. SPL. 1986. Progress report for 1986/87. SPL, Ambo.
200. SPL. 1987. Progress report for 1987/88. SPL, Ambo.
201. SPL. 1988. Progress report for 1987/88. SPL, Ambo.
202. Sefedin Berdin. 2006. Screening of maize genotypes against *Chilo partellus*. M.Sc thesis, Addis Ababa University.
203. Seneshaw Aysheshim and Mulugeta Negeri. 2002. Study on the biology of sorghum chafer, *Pachnoda interrupta* (Coleoptera: Scarabaeidae) under laboratory condition. *Pest Management Journal of Ethiopia* 6: 31-36.
204. Seshu R. K.V. and E. O. Omolo. 1985. Sorghum insect pest situation in eastern Africa . Pp 31-36 *In:* Leuschner and Teetes (eds.). Proceedings of the International Sorghum

Entomology Workshoip. 15-21 July 1984 Texas A and M University, College Station Texas, USA.

205. Sharma H. C. 1990. Insect pest problems and host plant resistance to insects in sorghum in eastern Africa (Ethiopia and Kenya), Tour report 15.11-30.1.90. ICRISAT, India.

206. Sileshi Gudeta and Lakra, R. K. 1994. Off-season surival of the sorghum shoot fly, *Atherigona soccata* Rondani (Muscidae: Diptera) in Alemaya Region of Ethiopia. *Crop Research* 7: 97-104.

207. Sileshi Gudeta, Tsedeke Abate and Lakra, R. K. 1995. Effect of intecropping on the incidence of sorghum shoot fly in eastern Ethiopia. *African Crop Science Journal* (in press).

208. Sileshi Gudeta, Tsedeke Abate and Lakra, R. K. 1996. The biology and management of sorghum shoot fly *Atherigona soccata* in Alemaya area: A review. Pp. 98-112. Proceedings of CPSE Third Annual Conference. May 18-19, 1995. Addis Abeba, Ethiopia, CPSE, Addis Abeba.

209. Sileshi Gudeta. 1994. Management of sorghum shootfly, *Atherigona soccata* Rondani (Diptera: Muscidae), in the eastern Hararghe. MSc thesis, Alemaya University.

210. SARC (Sirinka Agricultural Research Center). 1997. SARC progress report for 1997.

211. SARC. 1998. Sirinka progress report for 1996.

212. SARC. 2000. Sirinka progress report for 1999.

213. Tadele Tefera and Pringle, K. L. 2003. Effect of exposure method to *B. bassiana* on mortality, mycosis and sporulation in cadavers of *C. patellus* (Lepioptera: Pyralidae). *Jouranal of Invertebrate Pathology* 84: 90-95.

214. Tadele Tefera and Pringle, K. L. 2003. Food consumption by *Chilo partellus* (Lepidoptera: Pyralidae) larvae infected by *Beauveria bassiana* and *Metarhizium anisopliae* and their effect on natural versus artificial diet on mortality and mycosis. *Journal of Invertebrate Pathology* 84: 220-225.

215. Tadele Tefera and Pringle, K. L. 2003. Germination, radial growth, and sporulation of *Beauveria bassiana* and *Metarhizium anisopliae* isolates and their virulence to *Chilo partellus* (Lepidoptera: Pyralidae) at different temperatures. *Biocontrol Science and Technology* 13: 699-704.

216. Tadele Tefera and Pringle, K. L. 2004. Evaluatin of *B. bassiana* and *M. anisophilae* for controlling *C. partellus* (Lepidoptera: Pyralidae) in maize. *Biocontrol Science and Technology* 14: 849-853.

217. Tadele Tefera and Pringle, K. L. 2004. Mortality and maize leaf consuption of *Chilo aprtellus* (Lepidoptera: Pyralidae) larvae treated with *B. bassiana* and *M. anisophliae*. *International Journal of Pest Management* 50: 29-34.

218. Tadele Tefera and Pringle, K. L. 2007. Biological control of the spotted stemborer *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) with the entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae*. *Ethiopian Journal of Science* (Accepted).

219. Tadele Tefera. 2004. Biological control of *Chilo partellus* using entomopathogenic fungi. (Abstract) 12th Annual Conference of CPSE. 26-27 May 2004, Addis Ababa, Ethiopia.

220. Tadele Tefera. 2004. Evaluation of the entomopathogenic fungi *B. bassiana* and *M. anisopliae* for biological control of the spotted stemborer *C. partellus* (Lepidoptera: Crambidae) in maize. PhD Dissertation. University of Stellenbosch. South Africa.

221. Tadele Tefera. 2004. Farmers perception of sorghum stemborer and farm managemnet practices in Ethiopia. *International Journal of Pest Management* 50: 35 - 40.

222. Tadele Tefera. 2004. Lepidopterous stemborers and their parasitoids in eastern Ethiopia. *Tropical Science* 44: 128-130.

223. Tadele Tefera. 2005. Food consumption by larvae of the spotted stemborer (*Chilo partellus*) infested with *Beauveria bassiana* and *Metarhizium anisopliae* (abstract). P. 32. 13th Annual Conference of CPSE. Addis Abeba.

224. Tadesse Gebremedhin. 1989. Research approach and monitoring pest management practices in Ethiopia. Pp. 108-113. *In:* Proceedings of the 20th NCIC, 28-30 March 1988, Addis Abeba, Ethiopia.
225. Tadesse Gebremedhine. 1987. A country report presented at the regional study workshop on on-farm and post-harvest losses of cereal crops in Africa due to pests and diseases. ICIPE, Nairobi, Kenya. 11-15 October 1987. Nairobi, Kenya.
226. Tesema Megnassa. 1982. Insect pests of sorghum in Ethiopia. Pp. 54-64. Proceedings of the regional workshop on sorghum improvement in eastern Africa, 17-21 October 1982. Nazret and Debre Zeit, Ethiopia. Ethiopian Sorghum Improvement Project.
227. TARI (Tigary Agricultural Research Insittute). 2004. Research center based problem appraisal (identification) and priority setting in Tigray (Unpublished document).
228. Titov, D., Abdulhafiz Ahmed, and Mulugeta Negeri. 1985. Prelimnary notes on natural predatory enemies of the main maize and sorghum pests.16th National Crop Improvemnent Conference. Part II, Institute of Agricultural Research. Addis Abeba, Ethiopia.
229. Tsedeke Abate and Elias Worku. 1997. Sowing date, varietal and carbofuran seed dressing effects on maize stalkborer. *Pest Management Journal of Ethiopia* 2: 85-89.
230. Tsedeke Abate and Elias Worku. 1998. Yield loss in sorghum caused by sorghum shootfly and stemborers at Bako. *Pest Management Journal of Ethiopia* 2: 85-89
231. Tsedeke Abate and Tesfahun Fanta. 2003. Pesticide Evaluation Report and safer use Action for Ethiopia Crop Protectin and Livestock Protection. USAID Funded PL480 Title II: Food Security Program.
232. Tsedeke Abate. 1986. Proceedings of the First Crop Protection Symposium of Ethiopia, Addis Ababa, Ethiopia.
233. Tsedeke Abate. 2004. Pest problems vis-a-vis food security. Pp 105-116. Modernizing agriculture: A way out of food insecurity? Proceedings of a national workshop. Feb. 19-20. The Biological Society of Ethiopia, Addis Abeba.
234. Wood, T. G. 1986. Assessment of termite damage in Ethiopia and recommendations for short-term control and development of long-term pest management strategies. Report for the World Bank and Ministry of Agriculture, Addis Abeba.
235. Wood, T. G. 1986. Report on a visit to Ethiopia to advise on assessment of termite damage to crops. Report No. R1347 (R). Tropical Development and Research Institute, Overseas Development Administration, 127 Clerkenwell Road, London ECIR 5DB.
236. Yeraswork Yilma. 2003. Biology and distribution of sorghum chafer, *Pachnoda interrupta* Oliver (Coleoptera: Scarabaeidae) in North Shewa, Oromiya and South Wollo zones of the Amhara Region. MSc. Thesis, Alemaya University.
237. Yeshitla Merene, Asmare Dejene, Tadesse G/Medhin, Mulugeta Negari, Sineshaw Aysheshim, Yitbareke W/Hawariat and Berhanu Hunegnaw. 2004. Study on source of infestation of sorghum chafer (*Pachnoda interrupta* Olivier) in Northeastern part of Ethiopia. (Abstract). CPSE 12th Annual Conference, 26-27 May 2004, Addis Abeba.
238. Yirga Negash. 2006. The phenology of maize stem borer, B. fusca Fuller (Lepidoptera: Noctuidae) on sorghum, farmers persption and management of stem borrs in Wollo, North Ethiopia. MSc. Thesis, Debub University, Awassa, Ethiopia. 75 pp.
239. Yoseph Assefa. 1999. Mangemnt of stemborers on sorghum. MSc thesis, Alemaya University.
240. Zerubabel Kibret. 2007. Screening of sorghum genotypes against *Chilo partellus*. MSc thesis, Addis Ababa University.

Review of Maize, Sorghum and Millet Pathology Research

Girma Tegegne[1], Fekede Abebe[2], Temam Hussien[3], Tewabech Tilahun[4], Eshetu Belete[5], Melkamu Ayalew[6], Girma Demese[7] and Kiros Meles [8]

[1] Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center, [2] Bako Agricultural Research Center, [3] Haramaya University, [4]Hawassa Agricultural Research Center, [5] Sirinka Agricultural Research Center, [6]Adet Agricultural Research Center, [7]Bako Agricultural Research Center and [8] Tigrai Agricultural Research Center.

Introduction

Maize is widely grown in Ethiopia in diverse agro-climatic conditions. Currently it is being expanded to the highland environments and moisture prone areas. According to the Central Statistic Authority (CSA, 1996), maize is the second most important cereal crop after tef covering about 1.4 to 1.5 million hectares of land with increasing yield ranging from 19 to 22 q ha^{-1} in between 1995 to 1997. Following maize, sorghum is also the most important cereal crops and the area under cultivation was about 1.3 million hectares in 2003 with a slight growth of 1.5 million hectares in 2005 and 2006. During the latter period of production, the national average yield ranged from 14 to 15 q ha^{-1}, which was lower than the world average yield of 1.48 t ha^{-1} (Bruce and Maunder, 2002). Regarding finger millet, it is grown in many regions of Ethiopia and covers an area of 0.3 to 3.3 million hectares with an estimated yield of 10.4 q ha^{-1} (CSA, 1996).

The relatively low yields obtained in maize, sorghum and finger millet production are due to various factors, of which diseases are the major one. Over the past decades, a number of diseases in maize, sorghum and few diseases in finger millet have been recorded and considered to limit production. Many of the diseases attack the leaves, stems, root systems and the reproductive organ of the crops (Richard and Fredericksen, 1986) and some diseases are reported to contaminate grains during storage (Tesfaye and Dawit, 1998). In this review, we provide information on maize, sorghum and finger millet diseases as well as various management options that have been developed in the past.

There are several reasons, which seem convincing to review the progress made in maize, sorghum and finger millet disease researches. First, a great deal of information has been recorded over the last 22 years that increase knowledge about maize, sorghum and finger millet diseases and their managements. However, this information is widely scattered and is extremely difficult to access. Second, there is an increasing demand for reviewing the achievements to identify major gaps, envisage possible future interventions, set future goal and formulate research hierarchy to ensure relevance. Third, published research results on the management of maize, sorghum and finger millet diseases need critical explanation and interpretation to assess their practical application and provide information on the current advancement in maize, sorghum and finger millet pathological research. Fourth, the private sector involved in maize, sorghum and finger millet production, and the extension and development agents at large need to be informed about the available technologies of disease management in maize, sorghum and finger millet diseases. Finally, there is a need to make relevant research information accessible to agricultural scientists and the public at large. Hence, analyzing the past scientific merits from technical perspective and providing information on the advancement of maize, sorghum and finger millet pathological research seem timely and relevant.

This paper, therefore, is essentially a review of published works to provide significant findings on maize, sorghum and finger millet disease management practices and their impact on agricultural development. Analyses on research challenges and suggestions for future research direction are also included in the paper.

Research findings

Maize diseases

Previous reports (Tewabech et al., 2001) indicated that around 47 maize diseases were recorded in maize and 25 more diseases were recorded in the past few years (Carlos, 1984). Field surveys conducted in the major maize growing regions indicated that distributions, incidences and severities of maize diseases across geographic locations are variable. In a recent review, Tewabech et al. (2001) indicated the occurrence of various maize diseases in different agro-ecologies of Ethiopia (Table 1). According to the report, maize diseases are generally caused by fungi, bacteria, nemathods and viruses. Diseases such as turcicum leaf blight (*Exoserohilum turcicum*), common leaf rust (*Puccinia sorghi*), and gray leaf spot (*Cercospora zea-maydis*) are still important constraints in all maize growing regions (Table 1). Turcicum leaf blight and common leaf rust (although they were also common in the past) prevalence and incidence has increased in recent years in all maize growing regions (MRC,

2002) with severity reaching 100%. The occurrence of maize virus has also been reported (Alemu et al., 1999).

The importance of gray leaf spot disease of maize has been emphasized since it was reported in Ethiopia in 1999 (Dagne et al., 1999; EARO, 2004). Results of various surveys conducted in most maize growing regions indicated that the disease has a wide distribution and significant impact on maize yield reduction on both local and improved varieties (Table 1). According to field visit report (Assefa, 1999) of all released hybrid maize, only BH-660 and PHB-30H83 were found relatively tolerant to gray leaf spot. The disease has also been observed in maize seed multiplication sites at East Shewa and Sidama in most released maize varieties (Table 2). Reportedly, the epidemic of gray leaf spot is severee under monoculture maize with no rotation practices (Stromberg and Donahue, 1967) and minimum tillage practices (Perkins et al., 1995).

Table 1. Distribution, importance, prevalence and status of Maize diseases in Ethiopia

Common name	Causal pathogen	Prevalence*	Importance	Distribution
Gray leaf spot	*Cercospora zeae-maydis*	++++	Major	All areas
Turcicum leaf blight	*Exserohilum turcicum*	++++	Major	,, ,,
Leaf spot	*Phaeosphaeria maydis*	+++	Major	Bk, Dd, Arjo, Jimma, Tigray
				Tigray
Leaf spot	*Pellucid leaf* spot	+++	Major	Most areas
Leaf spot	*Curvularia* spp.	+	Minor	Seka, G.gida, Aw, Sh,
Leaf blight	*Helminthosporium maydis*	+	Minor	Assosa, Pawe
Common leaf rust	*Puccinia sorghi* Schw.	+++	Major	Most areas
Sorghum leaf rust	*Puccinia polysora*	+++	Major	Gambella
Eyespot	*Kabatiella zeae*	+++	Moderate	Most areas
Brown spot	*Physoderma maydis*	+++	Major	Gofa, Dila , Sh., AW. & BSF.
Streak Virus	Maize Streak Virus	+++	Major	Ga, Dd, Bk, BSF., A.N. & SSF
Mosaic Virus	Sugar cane mosaic virus	+	Minor	Gi, G.gida, Ambo, Ze., AW., BLF, SSF
Dwarf stripe	Maize dwarf strip virus	+	Minor	Ambo
Bacterial leaf spot	*Pseudomonas* spp.	++	Moderate	E & W.Wolga, Asossa
Corn stunt	Spiroplasm Kunkel	+	Minor	Bk, G.gida, Pw
Crazy top downy mildew	*Sclerospora macrospora Sacc.*	++	Moderate	Ga, Dd, Bk, AW, A.N., Ze. &Ar.
Sorghum downy mildew	*Sclerospora sorghi* (Wetson)	++	Moderate	Ga, Dd, Gtn, Bk. & AW., A.N., Ze. & Ar.
Late wilt	*Cephalosporium* spp.	+	Minor	Seka, Sokoro, Bk, Holleta, kefa

Table 1. Continued

Common name	Causal pathogen	Prevalence*	Importance	Distribution
Rhizopus kernel rot	*Rhizopus stolonifer* (Ehrenberg)	+	Minor	Bako
Penicillium rot	*Penicillium nigricans*	+	Minor	Awasa
Bacterial stripe	*Pseudomonas/Ropogoni spp.*	+	Minor	Pawe
Corn stunt	*Spiroplasm vunkel*	+	Minor	Awasa
Leaf spot	*Septoria maydis* (Schulz)	+	Minor	Gode, Holleta, Awas & Wellega
Leaf spot	*Leptoshpalria matf dis stout*	+	Minor	Holleta, Kefa
Jonson grass mosaic virus	Mosaic virus	+	Minor	Ambo & Awasa
Leaf spot	Hyalothyridium (Shurtleff)	+	Minor	Kokate, Awasa
Head smut	*Sphacelotheca reilliana* (Kuhn)	++	Moderate	Fogera, Enebse, A.N., Ar. & BSF
Gibberella or Falls smut	*Utilaginoidea uirens*	++	Moderate	Aw., Sh. & BSF
Red ear rot	*Gibberella zeae* (Schw.) Petch	++	Moderate	Dd., Bk., Ji. S.R.
Ear rot	*Fusarium moniliforme* Sheld	+++	Major	Dd, Bk. & S.R
Ear rot	*F. graminarium,*	+++	Major	S. R.
Ear rot	*Diplodia maydis*	+++	Major	Dd., Bk., Ga. & S.R.
Ear rot	*Aspergillus flavus* (LK) exfries	++	Moderate	Ji., Dd. & Bk
Nematodes	*Xipphinema brevicole*	+	Minor	Horo Aleltu (H.A)
	X. americanum	+	Minor	H. A.
	Pratelenchus zeae	+	Minor	H. A.
	P. brachyrus	+	Minor	H. A.
	P. coffee	+	Minor	H. A.
	Aphelencoides indicus	+	Minor	H. A.
	A. rutgersi	+	Minor	H.A.
Bacterial stalk rot	*Erwinia caratovora*	++	Moderate	Gim. & Bk.
Stalk rot	*Fusarium* spp.	+	Minor	Ao, Gmi, Did, Sire,
,,	*Gibberella fujikuroi* (Saw) Wr	++	Moderate	East & WW, W.Shoa, & S.R.
Root rot	*Fusarium* spp.	+	Minor	E & WW & W.Shoa, A. N., Aw, Ar., KK. & Ej.
Storage fungi	*Fusarium spp*	+++	Major	All surveyed areas in Southern region
	Aspergilus flavies	++++	Major	Aw., Ar. & A. N
	Phoma spp	++	Moderate	Aw, Ar. & A. N.
	Acremonium sp	++	Moderate	
	Nigropora sp.	++	Moderate	

Ao - Arjo, Aso. – Asossa, A.N- Arsi Negele, AW-Hawassa, Ar.- Areka, BSF.- Billito State Farm, Bk - Bako, Dd - Dedessa, EW - East Wellega, Ej.-Ejali, Gim. - Gimbi, Ga. – Gambella, H.A-Horo Aletu, Ji.- Jimma, Kk-Kokate, PW-Pawe, Sh.- Shallo, S.R.- Southern Region, SSF-Siraro state farm, WW - West Wellega, Ze.-Zeway,
**The intensity increases with '+' sign: +(0-10%), ++(11-30%), +++(31-50%), ++++(over 51%).*

Sources: Assefa (1999), Dagne et al (2001) Teklemariam (1985) Tewabech (2001); Assefa and Mengistu, 1995; Assefa and Tewabech, 1993; Assefa, 1997; 1999; BRS, 1975; Awgichew, 1982; Dagne et al., 1999; Fekede and Kedir, 2000;Eshetu et al., 2006; EARO, 2004; Kranz, 1969; Mengistu, 1982; Mathur et al., 2000; Mekuz, 2001; Negussie and Reddy, 1995; PPS, 1979; Raya, 1988; Rosenow, 1992; Salvaraj, 1978; Sharma, 1978; Shurtleff, 1980; Solomon and Temam, 1989; Stewar and Dagnachewt, 1969; Teklemariam, 1985; Tewabech et al., 2001;Tewabech, 1999; Williams, 1981; Assefa and Legesse, 1996; Korobko, 1985

Table 2. Gray leaf spot disease severity on maize verities at Shallo basic seed production and Sidama state Farm of Southern Ethiopia, 1998, main season

Zone	Field	Altitude (m.)	Varity	crop stage at Evaluation	Severity %	Description
East Shewa	Shallo Basic Seed Farm	1650 1650 1650 1650	A7033xF-7215 142-1-e Gutto Sc-4	Early Maturity Early Maturity Early Maturity Early Maturity	78 23 20 20	Very high infection Light infection Light infection Light infection
	Billito -Siraro State farm	1700 1700	Phb-3253 BH-660	Milk Milk	63 33	Heavy infection Moderate infection
	Farmers field	1700	Local	Milk	58	Heavy infection
Sidama	Hawassa Wondo tica State farm	1650	Phb-3253 Bh-660	Early Maturity Early Maturity	73 18	Very high infection Light infection
	Farmers field	1650	Local	Early Dough	20	Light infection

Source; Dagne et.al. (1999)

Other maize diseases such as brown spot (*Physoderma maydis*) were reported to be severe at Gofa (Saula), Dilla and Shallo seed multiplication fields, but intermediate at Hawassa Research field and Billito State Farm (Tewabech, 1999). Leaf blight (*Phaeosphaeria maydis*), southern corn rust (*Puccinia polysora*) and leaf spot (*Hyalothyridium spp.* F.M. Lattereell) have been observed at Kokate and Hawassa research sites during 2004 cropping season.

Apart from foliar diseases of maize, ear, kernel and stalk rot diseases, which received little attention in the past, are now getting important (Tewabech et al., 2001). The ear rot pathogens found in the tropics are often associated with seed rots and seedling blights (BRS, 1975). Pink ear rot (*Fusarium moniliforme=Gibberella fujikuroi*), red ear rot (*Fusarium graminearum=Gibberella zeae*) and *Diplodya maydis* were identified from Zeway, Arsi Negele, Hawassa, Areka, Billito/Siraro, Ejaji, Shallo and Wondotika area. Ear rots caused by *Diplodia zeae* (Berk.) Sacc., *Fusarium moniliforme=Gibberella fujikuroi* and *Gibberela zeae* are serious and highly important in humid and high rainfall areas of Ethiopia. In Dedessa valley, 100% incidence and 30% severity was reported (Assefa and Legesse, 1996). Some of the experimental materials at the Bako Research Center were infected by *Fusarium moniliforme*. Though Kernel rot is reported to occur in many areas, its effect on maize yield reduction reported to be minimal (Assefa and Legesse, 1996). However, the disease has been reported to occur at Zeway, Arsi Negele, Hawassa, Areka, Billito/Siraro, Aje, Shallo and Wondotika area with mean incidence ranging from 15–85%. Other diseases like head smut caused by *Sphacelotheca reiliana* and *Ustilaginoidea uirens* have been observed mainly at Arsi Negele, Areka and Billito farms with less incidence.

Similarly, maize stalk rot diseases caused by *Gibberella zeae*, *Fusarium moniliforme*, and *Diplodia maydis* have become important and commonly observed on the research sites and state farms than on farmer fields. The incidence was higher at Hawassa (72%) than at Areka (14%) and Arsi-Negelle (25%) (Tewabech et al, 2001). The increase in the prevalence and importance of stalk and root rot diseases of maize might be attributed to monocropping and the use of uniform and susceptible varieties. All these factors contribute to the build-up of the pathogens inoculum (Assefa, 1999).

Results of a recent survey conducted for two consecutive cropping seasons (2003/2004) in Jimma, Illubabor, West Wellega (Table 5), West Shewa, East Wellega, Sidama, North Omo, Gedeo and other areas revealed that diseases such as leaf spot (GLS), triticum leaf blight (TLB), and common leaf rust (CLR) are widely distributed. Of all the surveyed areas, Lira Guliso had the highest incidence (99%) of turcicum leaf blight followed by Darimu (95% on maize variety PHB-30H83 and Sibu Sire (76%) (Table 5). In addition, Curvularia leaf spot has become an important disease and incidence ranged from 16 to 54%, severity of 1.5 to 2.0. Moreover, *Phaeosphaeria* leaf spot (PLS), and ear rot (*Diplodia maydis* and *Fusarium moniliforme*) have become a potential threat to maize production in the surveyed regions (Table 3).

Table 3. Incidence and severity of major maize leaf diseases in southern Ethiopia, during 2003&2004

Zone	Woredas (district)	TLB		CR		GLS	
		Inc.%	Sev. %	Inc.%	Sev%	Inc.%	Sev. %
Sidama	Hawassa Zuria	96	2.5	100	3.0	86	2.5
	Shebedino	84	3.0	100	3.0	70	2.7
	Boricha	70	2.3	72	2.5	54	2.1
	Dalle	80	2.5	56	2.5	59	2.7
	Aleta Wondo	100	3.0	58	2.6	100	3.6
	Agere Selam	67	2.5	45	2.1	80	3.0
North omo	Sodo Zuria	89	3.2	70	3.2	100	3.5
	Humbo	58	2.1	67	3.0	49	3.0
	OFA/Gesupa	62	2.5	58	2.6	50	2.3
	Damot weide	74	2.5	55	2.5	33	1.7
	Boloso Sore/Areka	86	3.5	90	3.5	100	3.5
Gedeo	Dilla/Wonago	88	2.5	70	3.0	68	2.5
	Yirga chefe	72	3.0	50	2.5	45	2.5
	Kochere.	54	2.2	48	2.0	51	2.2
Gurage	Enemor	100	4.0	42	2.2	-	-
	Ener	82	3.0	38	2.0	-	-
Oromya	Zeway	52	2.3	100	3.2	25	2
	Billito/Siraro	100	3.5	70	2.5	100	3.5
	Arsi Negelle	70	2.5	100	4.0	50	2.5
	Shashemene(shallo seed prodn. Field)	80	3.0	91	3.0	72	2.5
	Aje	52	2.5	100	3.0	71	3.0
Special	Alaba Kulito	50	2.0	52	2.0	50	2.5

Source:(EIAR), Awasa National maize Project. Progress report, 2004

A survey conducted at 280 farmers' fields in 10 districts of different cropping systems including sole maize, maize-bean, maize-bean-sorghum and maize-bean-other at Haramaya has shown influencing the occurrence and distribution of maize rust and leaf blight diseases. Mean rust incidences of 69–75% and severities of 48–57% were measured in all the surveyed cropping systems (Chemeda and Jonathan, 2001). However, intercropping reduced severity by 3–9% compared to sole cropping. Comparatively, less rust incidence and severity were observed in maize-sorghum and maize-bean-sorghum intercrops, respectively. Rust incidence and severity among geographic areas and between years were reported to vary (Chemeda and Jonathan, 2001). Mean incidence ranged from 49% in Wobera fields to 84% in Habro. Similarly, severity was higher in Habro than in Chercher and Wobera areas. Incidence was higher in the 1999 cropping season by 6–9% than in 1998. In contrast, severity in 1999 was lower by 6% and 14% in Habro and Chercher, respectively. According to the survey results (Chemeda and Jonathan, 2001), incidence of leaf blight disease was moderate during 1999 cropping season. The highest mean incidence (19%) was recorded in sole cropping, whereas the lowest was recorded in intercropping, except for maize-bean-other. In intercropping, leaf blight was reduced by 7–10%. Comparing disease incidence across locations, higher incidence (6–8%) was recorded in Habro than in Chercher and Wobera areas.

Apart from pathogens causing foliar diseases, various grain mold fungi including *Fusarium*, *Penicillim*, *Aspergillus*, and *Nigropora* spp. have been detected on maize samples collected from Hawassa, Areka, Billito, Shallo and Arsi-Negele. The populations of all the fungi were higher in samples collected from farmers' stores than in the samples collected from research and seed multiplication stores. *Aspergillus* and *Fusarium* were frequently isolated from damaged seeds and *Penicillim* spp were the second most frequent fungal species. Tesfaye and Dawit (1998) also identified four *Fusarium* species associated with maize grain in Ethiopia. The presence of mycotoxins in grains and other staple foods and feedstuffs (Abera and Admasu, 1987; Dawit and Berhane, 1985; Gilman, 1967) has serious implications for human and animal health and reduce seed quality by discoloration of the seeds.

Other diseases such as head smut and downy mildew were observed as important diseases in specific areas. Head smut caused by *Sphacelotheca reliana* ([Kuchn] Clint) was serious in the highlands of northwestern Ethiopia and the Rift Valley areas around Melkassa. Downy mildew, incited by *Sclerospora macrospora*, has been reported around Anger Gutin and Dedessa state farms.

New diseases such as gray leaf spot (*Cercospora zea-maydis* [Tehon and Daniels]), brown spot (*Physoderma maydis*), sorghum leaf rust (*Puccinia polysora*), sugarcane mosaic virus (SCMV), and Johnson grass mosaic virus (JGMV) and stalk/root rot (*Fusarium* spp.) have been identified in the past few years. Gray leaf spot, which has a very recent history of occurrence in Ethiopia, has become the most important threat to maize production in the country (Tewabech, 1999; Dagne et al., 1999) (Table 1). The brown spot (*Physoderma maydis*) of maize has been observed to cause considerable crop damage in warm humid areas of western and southern regions of Ethiopia at Gofa (Saula), Shallo and Hawassa (Assefa, 1999).

The presence of leaf blight (*Phaeosphaeria maydis*) and sorghum leaf rust (*Puccinia polysora)* in the southern regions are recent developments and their importance is increasing. Leaf spot caused by *Hyalothyridium* sp. (F.M. Lattereell) (Shurtleff, 1980) has been observed at Kokate and Hawassa research sites during 2004 cropping season.

Basic studies

Plant pathogens are extremely heterogeneous, possessing diverse ecological requirements and modes of parasitism, dispersal, reproduction and survival (Burdon, 1992). However, studies conducted in this aspect in maize disease pathosystems are very limited in Ethiopia. A preliminary investigation around Bako suggested that *E. turcicum* initiated from third week of July to second week of September. However, infection was observed on maize planted near the riverbanks and bottomlands during the off-seasons (Assefa and Mengistu, 1995). Additionally, there is a report suggesting the variable nature of *E. turcicum* in maize.

Results of studies conducted to determine variability of infecting maize in Ethiopia showed that there is a range of variability among the different isolates of the pathogens in cultural and morphological characteristics as well as pathogenicity to different maize varieties. It was reported that isolates that were collected from Gedo (western shewa) and Hawassa (Sidama) showed the highest mean virulence rating (MVR) of 256.2 and 253, respectively, whereas the lowest MVR (113) was recorded from Shambu (eastern Wellega) isolate on maize variety Beletech (Assefa and Mengistu, 1995).

In the past, studies of disease resistance emphasized on selection of host plant resistance to individual target pathogen but little research has been addressed in assessing inheritance of the resistance gene. In this regard, Dagne et al. (2003) made an attempt to assess the combining ability of a number of maize lines resistant to gray leaf spot crossed with SC-4, Gutto, LMS5 and CML-202 and evaluated their resistance to gray leaf spot, grain yield and other agronomic traits. In this study, a diallel cross analysis of resistance to gray leaf spot (Table 4) indicated that the inbred line CML-387 was a good general combiner with significant effect for all disease parameters while other parental lines such as A-7016, CML-197 and CML-202 tended to increase susceptibility of the disease. Mean squares, due to general combining ability (GCA) and specific combining ability (SCA), were highly significant for all disease parameters. However, the magnitude of mean squares due to GCA was higher than that of SCA for all the parameters, indicating the prevalence of the additive gene effects. This result shows that the resistance to GLS is highly heritable with differences in the experimental lines.

Table 4. Estimates of the general combining ability (GCA) effect for gray leaf spot disease parameters of eight parental maize inbred lines used in a daillel cross

Parents	Incidence DISA[a]	DSS	PIP	ILP	LT	AUDPC	
						Severity	PIP
143-5-i	5.383**	-0.329**	1.007	-5.689**	-0.367**	-9.3458**	71.687
Gutto LMS5	-0.083	-0.121**	-6.920**	-6.363**	-0.100	-3.542**	-204.560**
A-7016	-6.750**	0.804**	14.509**	-18.375**	0.967**	24.042**	458.797**
Sc-4	-1.650	-0.171**	-0.561	-1.605	-0.233**	-5.458**	-14.328
CML-197	-1.417	0.146**	8.523**	12.345**	0.133*	4.208**	321.811**
CML-202	-6.217**	0.188**	7.998**	11.409**	0.133*	5.458**	293.107**
CML-387	9.383**	-0.333**	-23.291**	-20.192**	-0.367**	-9.708**	-858.890**
CML-395	1.350	0.183**	-1.265	-8.281**	-0.167**	-5.342**	-50.625
SE (g)	1.404	0.035	1.298	1.740	0.057	1.051	45.730
SE (g_1-g_2)	2.123	0.052	1.962	2.631	0.087	1.589	69.137

*[a] DISA=days to initial symptom appearance; DSS=disease severity score; PIP=percentage of infected plants per plot; ILP=percentage of infected leaf per plant; LT=lesion type; AUDPC=area under disease progress curve calculated using DSS and PIP; SE (g) =standard error of GCA effects; SE (g_i -g_j) = standard error of the difference of GCA effects; *, ** Significant at P 0.05 and 0.01, respectively*

Sources: Dagne et.al. (2004)

Assessment of losses

Severities of common rust and turcicum leaf blight and their associated effect on 1000-seed mass and yield under artificial and natural inoculation conditions were reviewed (Tewabech et al., 2001). According to reports, yield losses due to turcicum leaf blight range from 2% for hybrid BH-660 to 34% for variety Abo-Bako under Hawassa conditions. The disease can reduce yield by about 49% and 1000-grain mass by 16% on a susceptible variety OPV pool 32 C_{19} under artificial conditions. Yield losses due to rust under artificial and natural infections were 43% and 23%, respectively. Similarly, 1000-grain mass losses due to the rust were 14% and 8.4%, under artificial inoculations and under natural infections (EARO, 1999).

Another study involving five maize cultivars having variable genetic backgrounds to turcicum leaf blight resulted in no yield reduction under natural inoculation system compared to artificial inoculation (Table 5). Maximum yield reduction was observed in the susceptible variety Pool 32 C_{19} in both seasons (1992-1993). However, differences in AUDPC (Area under the Disease Progress Curve) were observed between the seasons. In 1993, AUDPC was greater than in 1992, but yield reduction was almost the same. In contrast, the AUDPC of Beletech in 1992 was 1623.6%-disease days with yield reduction of 13%, but in 1993, the AUDPC was 1370.4%-disease days with yield reduction of 29%. Then it is possible to conclude that the yield loss was not due to the rust alone. Some other uncontrollable experimental factors might have contributed to the yield loss as well. A good degree of resistance to turcicum leaf blight was observed in MDRST-S with the AUDPC of 12.0 and 342.6%-disease days with yield reduction of 25.7 and 29.8 in 1992 and 1993, respectively.

Table 5. Yield and yield loss due to TLB for five maize cultivars under natural and artificial inoculation

Year	Set	Cultivars	Yield ($q\ ha^{-1}$)	Yield loss (%)	500 KW (g)	KW loss (%)	AUDPC
1992	NI	MDRST-S Pool 32 C_{19} Beletech	51.29 50.90 45.06	- - -	138.5 154.0 145.3	- - -	49.9 1199.3 951.3
	AI	MDRST-S Pool 32 C_{19} Beletech	38.32 25.33 39.27	25.7 50.2 12.9	129.9 142.1 124.9	6.8 7.7 14.1	12.0 1614.4 1623.6
1993	NI	MDRST-S MDRST Pool 32 C_{19} Beletech Pool32 C25	61.05 41.29 56.53 54.75 69.56	- - - - -	150.9 150.9 165.5 176.8 172.2	- - - - -	35.9 59.5 520.3 534.9 203.2
	AI	MDRST-S MDRST Pool 32 C_{19} Beletech Pool32 C25	42.86 43.32 29.47 39.07 58.13	29.8 -4.9 47.8 28.6 16.4	132.9 132.9 124.0 167.0 157.5	11.9 11.9 25.0 5.6 8.6	342.6 509.3 2163.8 1370.4 986.6
CV (%)			19.00		17.9		24.6

NI - Natural infestation; AI - Artificial inoculation; 'MDRST-S' - Resistant variety; 'Pool 32 C_{19}' - susceptible variety; 'Beletech' - tolerant variety; KW - kernel weight; AUDPC - area under disease progress curve

Source: Assefa et al. (1996)

Though sufficient data on the effect of gray leaf spot on yields were not available, the responses of recently recommended maize hybrid for different ecological zones were tested at Bako. Although the severity of the disease was not indicated, all fungicide-protected sprayed hybrids gave less yields as compared to the unsprayed check and inoculated plots. Higher yield reduction was observed in maize hybrid PHB-3253 (from 21 to 37%) followed by BH-140 (from 14 to 18%). In the case of BH-660 maize hybrid, there was no much difference in yield (neither inoculated nor sprayed) rather there was a 5% yield increase compared to control when inoculated (Table 6). However, the yield losses ranged from 0.0 to 14.9 indicating that the hybrid might have some level of tolerance to the pathogen.

Table 6. Response of local sorghum cultivars to loose kernel smuts, at Sirinka, 2001

Genotype	Incidence (%)	Yield (kg ha^{-1})
ETS 1176	1.5	3946.6
IS158X(ETS 3235)[4]	0.0	4636.2
Red Degalit	0.0	2795.9
ALOBS Nur acc.#2002B	1.5	4391.7
Ahyo Coll.#12SW Kedida	2.9	4609.3
Local Degalit	5.9	5619.0

Source: Sirinka Agricultural Research Center progress report SARC (2001)

Although yield losses due to gray leaf spot is undergoing at Areka and Billito, preliminary data suggest that a loss of 16–54% was estimated on non-protected plots compared to the protected plot. Elsewhere (Ward et al., 1997), loss of maize due to gray leaf spot was estimated as much as 60%.

In another study, three popular commercial varieties (BH-660, BH-140 and phb-3253) with different levels of resistance to GLS were compared under three treatments (inoculated, fungicide sprayed and unsprayed control) to estimate yield loss at Bako. Results indicated that varietals effect was significant for thousand-kernel weight and grain yield, while treatment effect was significant for ear diameter and grain yield. Mean kernel and grain yield losses ranged from 1.7 to 10.0% and 7.8 to 29.1%, respectively, on different varieties. Grain yield losses in varieties BH-660, BH-140 and phb-3253 were 0-14.9, 13.7-18.3, and 20.8-36.9%, respectively, during the three years (Table 7) (Dagne et al., 2004). The effect of GLS on ear length and diameter, particularly under natural (unsprayed) condition was not significant. The result indicated that GLS could be severe in some favorable seasons causing significant yield losses even on resistant varieties. However, there was no interaction among year, variety and treatment.

Other aspect of yield loss associated with seedling diseases was studied. It was revealed that seed treated with chemicals has 18% yield advantage over the untreated check (Assefa and Tewabatch, 1993).

Table 7. On-farm evaluation and demonstration of *Maesa lanceolata* leaf extracts against covered smut incidence in different locations at Bako

Treatments	Mean covered smut incidence (%)			
	Gida kiramu	Gobu sayo	Sibu sire	Guto wayu
M. lanceolata	0.15	0.1	0.0	0.1
Fernasan D	0.11	0.1	0.3	0.3
Control	2.9	2.0	2.5	3.0
LSD	1.092	0.189	0.317	0.331
CV%	52	9	14	13

Source: Bako Agricultural Research Center progress report (1998).

Disease management

Results of research on cultural control practices have been comprehensively reviewed (Tewabech et al., 2001). The on-set of certain diseases in maize with respect to planting date varied within and across locations. Planting maize after May 4 at Loko, resulted in a severe infection of maize streak virus, whereas planting maize before May 18 reduced incidence of turcicum leaf blight (Assefa, 1997). However, at Bako, planting maize in early May or late April may result in low incidences of leaf blight and leaf spot. In contrast, different planting dates have no effect on the incidences of turcicum leaf blight and rust on varieties BH660, BH140, Kuleni and local varieties at Adet and Upper Birr. However, variability in disease severity was observed on maize varieties (AARC, 1999). At Billito farm, gray leaf spot was observed on both late and early-planted maize plants. The disease severity was almost 100% on late planted (5–18 May) maize; ultimately caused kernel shriveling. Conversely, though the disease severity was high on early planted (April 18–25) maize, its effect on maize yield was minimal (Eshetu et al., 2006).

Interaction effect of different planting date and different maize varieties on disease severity of Turcicum leaf blight (TLB) and gray leaf spot (GLS) was studied at Bako (BNMR, 2001). Results indicated that there was significant difference among the varieties in response to gray leaf spot (GLS) and Turcicum leaf blight (TLB) and showed significant difference among sowing dates to turcicum leaf blight (TLB). Based on average severity records (1–5 scale) variety Beletech scored the highest, while variety Kuleni scored the least and exhibited relatively low reaction to both diseases. On the other hand, among the five sowing dates, the first one exposed plants to GLS infection more than all the others did. Susceptibility of maize varieties to TLB depends on planting date (BNMR, 2001).

Though the choice of crops in intercropping for disease is difficult due to the compelling socioeconomic reasons than the biological reasons (AU, 2002), diversity of crops in traditional tropical agriculture system (Clawson, 1985) and intercropping have played a significant role in securing crop harvest and influence disease development. Research results indicated that intercropping maize with sweet potato when planted simultaneously reduced both turcicum leaf blight and common rust (Tewabech et al., 2001). Alternatively, intercropping maize with haricot bean (when planted during shilshalo) had been reported to reduce both diseases than growing maize as a sole crop (Assefa, 1997). Depending on haricot bean varieties, intercropping maize with haricot bean had been reported to reduce rust infections in beans, but anthracnose disease incidence was increased as compared to sole bean cropping system (Nigussie and Reddy, 1995).

However, intercropping maize and sorghum with increased sorghum population or vice versa produced variable results. In the former case, the severity of turcicum leaf blight was increased while in the later common rust severity was decreased. However, choosing maize and sorghum intercropping as disease management options needs consideration because of cross inoculation of the same pathogens. Nevertheless, the functional relationship between spatial diversity of tested crops and the climatic conditions that influence diseases development and yield benefit gained due to intercropping need further study.

Despite space limitation, crop rotation is another potential strategy to control maize diseases. It was revealed that Maize rotated with other crops produced variable effect on maize diseases at Bako. As commonly known, maize planted after maize increased turcicum leaf blight, while maize following noug-maize-noug and maize after maize /sesbania decreased severity of turcicum leaf blight. On the other hand, maize planted after the maize/sesbania system showed a relatively higher intensity of common rust, while maize after continuous fallow suffered from common rust. Nevertheless, maize yield was increased in the above-indicated rotation systems compared to sole maize systems.

Application of farmyard manure (FYM), nitrogen, and phosphorus were also reported to reduce the intensity and frequency of turcicum leaf blight (Tewabech et al., 2001). Messele (2004) also indicated the influence of fertilizer application in reducing turcicum leaf blight and common leaf rust incidence compared to non-fertilized plots. Although the combined effect of all cultural practices is yet not known, the above results are encouraging and farmers need to be advised to adopt the proven practices, in the absence of resistant varieties.

Host plant resistance: In maize, sources of resistance to turcicum leaf blight, common rust, gray leaf spot, ear rots and maize streak virus have been reported (Tewabech et al., 2001). Maize varieties such as KCC and Pool 32 were reported to have lower turcicum leaf blight incidence than other varieties. Elite maize such as varieties (A-7033 X G-7462) X 1366-d, (A-7033 XG-7462) X 142-1-e, BH660, Kuleni, a cross 8942, ET Phylls 89 SLWD 6230, ETS PL 28 SEWD 1233-2 and ETSPL 32 SEWD 1233-6 were reported resistant to turcicum leaf blight and common rust (Tewabech et al., 2001).

In collaboration with CIMMYT Zimbabwe, significant progress has been made in identifying resistant maize lines against TLC and GLS at Bako. Although the degree of resistant found among maize entries was variable to the tested pathogens , however, out of 85 maize lines screened, entries number 6, 13, 7, 3, and 4 exhibited relatively resistant to GLS, while entries number 6, 13, 14 and 5 revealed relatively resistant to TLB (Table 8). The results of this study indicated that maize entry numbers 6 and 13 have genetic diversity in response to both tested diseases. Therefore, they could be used in developing improved maize varieties for multiple disease resistance. In addition, various maize varieties resistant to turcicum leaf blight and rust were also identified at Adet Research Center (1999).

Table 8. Anthracnose severity on sorghum differentials and their reactions to disease at Bako, Pawe and Jimma

Differential varieties	Locations/years					
	Bako[a] (1992-1998)	Mean virulence	Jimma[b] 93 and 95	Mean virulence	Pawe (1995)	Mean virulence
IS 8354	R	2	MR	5	MR	5
IS3758	S	7	MR	5	S	9
IS2508	R	3	MR	4	S	9
IS17141	R	3	MR	4	MR	4
IS6958	R	2	R	2	R	3
IS12467	R	2	R	3	S	9
IS18760	R	3	R	3	S	7
IS854	R	2	R	2	S	6
IS3552	S	8	R	3	S	8
IS1006	S	9	R	3	S	9
IS18442	S	7	NA	NA	S	8
IS6928	R	3	R	3	R	3
IRAT204	R	1	MR	5	R	3
ICSV247	R	2	MR	4	MR	4
Local Susceptable	S	8	S	7	S	8
Local resistance	MR	4	MR	4	MR	4

[a] R=resistant, MR=moderately resistant and S=susceptible
[b] NA= data not available.
Source: Ethiopian Sorghum Improvement Program Progress Report (1999)

Moreover, considerable screening efforts have been made for sources of resistance to GLS and TLB at Bako, Jimma, and Hawassa. One hundred and thirty maize genotypes introduced from CIMMYT Zimbabwe were evaluated.

Of these, 20 well-performed lines were re-evaluated in 2002 to confirm their resistance. Over the years, entries number 17, 5, 16, 8, 18, and 11 were found to be resistant to GLS (Table 9). Another study was also carried out to evaluate local materials for resistance to GLS at Bako, Jimma, and Hawassa. The results indicated that materials such as 139-4-1, 143-5-b and 143-7-2 were relatively resistant and 136-a, F7189 and 143-5-I were moderately resistant (Table 10). Additionally, in the recent evaluation of 123 normal and QPM maize materials, 48 materials, which were found to be promising, were tested under artificial inoculation in 2006 (Table 11). Promising materials from this test collection were re-evaluated at Hawassa in 2005 cropping season. Of these, seven genotypes, namely 142-1-e, 144-7-b, CML-339, SZSYNA 99 F2-2-2-1, SZSYNA 99 F2-2-7-3, SZSYNA 99 F2-7-2-1 and Cml-179 were found resistant to common rust, turcicum leaf blight and gray leaf spot. In another study, of 15 widely cultivated maize varieties only H625 was reported to be highly resistant to rust, while Al-composite, BC, KCC, KCB, UCA, UCB, EAH-75, BCc3, Jimma -Bako and A511 were moderately resistant.

Table 9. Evaluation of CIMMYT lines for resistance to GLS and TLB

Entries	Average GLS severity records at three locations		
	Bako	Jimma	Hawassa
136-d	1.393a	1.462abc	1.267b
143-5-i	1.443a	1.288cde	1.354ab
Gutto original	1.427a	1.719a	1.335ab
143-7-b	1.190b	1.213cde	1.153c
139-4-1	1.190b	1.288cde	1.080c
143-5-b	1.190b	1.075e	1.105c
136-a	1.173b	1.288cde	1.268b
132-7-b	1.426a	1.462abc	1.433a
F-7189	1.306ab	1.150de	1.394a
Z13-132 (CML-393	1.338a	1.576ab	1.373a
SC-4	1.428a	1.414bcd	1.413a
LSD	0.132	0.247	0.093
CV (%)	5.66	10.56	4.57

Means followed by the same letter(s) in a column are not significantly different at p<0.05
Source: Bako National Maize Research Project, Progress Report, 2001

Table 10. Evaluation of local lines for resistance to GLS disease

Entries	Average severity GLS	Average severity TLB
[LZ966205/LZ966017]-B-2-1-6-B-B	1.958cde	1.917abc
[LZ955459/LZ955357]-B-1-4-6-B-B	2.083bcd	1.750bcde
[DRB-F2-180-2/DRB-3-4-1]X-6-1-3-B-B-B	1.70efg	2.083a
[LZ955459/LZ955357]-B-1-5-1-B-B	2.002cde	1.458f
[LZ966077/LZ966205]-B-3-2-2-B-B	1.167h	1.542def
[CML-216/CML204//CML-202] X-29-2-B-B-B	2.167bcd	1.750bcde
[INTA-241-2-1-/INTA2-1-3] X 11-3-1-B-B	1.833def	1.750bcde
[LZ955459/LZ955357] 1-5-2-B-B	1.375gh	1.542def
[LZ966205/MSR123X1137TN-9-2-4X3]-B-1-3-1-B-B	1.833def	1.625def
[DRB-F2-23-1/DRB-39-2-2] X-6-1-2-B-B	2.750a	1.458f
[LZ966077/LZ966205]-B-3-2-5-B-B	1.420gh	1.500ef
[INTB-91-1-2/INTB-F2-111-3] X-8-2-1-B-B	2.125bcd	1.792bcd
[LATA-76-1-1/LATA-F2-196-2] X 1-1-2-B-B	2.293bc	1.667cdef
[CML-205/K64R//CML-202] X-8-1-B-B-B	2.417ab	1.667cdef
[DRA-F2-5-2/DRA-F2-20-3] X-7-1-2-B-B	2.417ab	1.958ab
[LZ956348/LZ956003]-B-1-1-2-B-B	1.208h	1.625def
[CML-205/CML-208/CML-202] X-21-2-B-B-B	1.125h	1.708bcdef
[INTA-2-1-3/INTA-43-3-2]-3-6-2-B-B	1.417gh	1.792bcd
[LZ955459/LZ955357]-B-1-4-1-B-B	1.667efg	1.625def
[LZ955459/LZ955357]-B1-5-5-B-B	1.583fg	1.625def
LSD CV (%)	0.370 12.24	0.277 9.91

Source: Bako National Maize Research Project, Progress Report, 2001

Table 11. Evaluation of normal and QPM germplasm for resistance to GLS and TLB

Entries	Average severity record for GLS	Average severity record for TLB
142-1-e	1.278ijkl	1.287jk
144-7-b	1.42jkl	1.333jkl
124-b (109)	2.74bcde	2.111bcdefgh
CML-197	3.444ab	3.167a
101-E	3.444ab	2.167bcdefg
FH-625-251-1	2.42cdefghi	2.000bcdefghij
Z-76-12	2.889bc	1.944bcdefghijk
Z-76-25	1.944cdefghijkl	1.667efghijk
CML-339	2.74bcde	2.111bcdefgh
CML-387	2.778bcde	1.889cdefghijk
F-7189	1.889defghijkl	1.611efghijk
Pool 9A-134-2-3-2-3	2.333cdefgh	1.667efghijk
SZSYNA 99-F_2-2-2-1	1.278ijkl	1.944bcdefghijk
SZSYNA 99-F_2-2-2-2	1.333ijkl	1.444ghijk
SZSYNA 99-F_2-2-2-3	1.278ijkl	1.667efghijk
SZSYNA 99-F_2-2-3-2	1.42jkl	1.556fghijk
SZSYNA 99-F_2-2-7-1	1.889defghijkl	1.833cdefghijk
SZSYNA 99-F_2-2-7-2	1.556hijkl	1.500fghijk
SZSYNA 99-F_2-2-7-3	1.556hijkl	1.500fghijk
SZSYNA 99-F_2-3-6-2	1.42jkl	1.74efghijk
SZSYNA 99-F_2-3-6-3	1.42jkl	1.444ghijk
SZSYNA 99-F_2-3-6-4	1.500hijkl	1.444ghijk
SZSYNA 99-F_2-3-7-2	1.42jkl	2.167bcdefg
SZSYNA 99-F_2-3-7-3	2.778bcde	2.056bcdefghi
SZSYNA 99-F_2-7-2-1	1.111kl	1.500fghijk
SZSYNA 99-F_2- 33-4-1	1.74ghijkl	2.000bcdefghij
SZSYNA 99-F_2- 33-4-2	3.500ab	2.000bcdefghij
SZSYNA 99-F_2-80-3-2	3.74a	1.889cdefghijk
SZSYNA 99-F_2-80-3-4	1.111kl	2.42bcdef
SZSYNA 99-F_2-80-3-6	1.389ijkl	1.778defghijk
SZSYNA 99-F_2-133-2-1	1.74ghijkl	1.611efghijk
SZSYNA 99-F_2-133-2-3	2.167cdefghij	1.389hijk
SZSYNA 99-F_2-81-4-3	1.000l	1.42k
SZSYNA 99-F_2-98-4-3	1.778fghijkl	1.444ghijk
SZSYNA 99-F_2-124-8-1	1.056kl	2.444bcd
CML-141	3.889a	2.167bcdefg
CML-142	2.500cdefg	2.556b
CML-143	1.278ijkl	1.889cdefghijk
CML-144	2.000cdefghijkl	1.778defghijk
CML-160	2.056cdefghijk	1.889cdefghijk
CML-173	2.833bcd	2.333bcde
CML-174	1.833efghijkl	2.333a
CML-179	3.556ab	1.74efghijk
CML-182	2.778bcde	1.74efghijk
CML-183	2.667bcdef	1.667efghijk
CML-191	2.778bcde	1.889cdefghijk
CML-194	1.42jkl	2.000bcdefghij
SC-4	2.500cdefg	2.500bc
CV(%)	15.54	11.72

Note: Means followed by the same letter(s) in a column are not significantly different at $p<0.05$

Source: Girma et al. (unpublished data)

An attempt has also been made to screen for resistance to both ear and stalk rots. Twenty-two maize genotypes collected from Bako national maize Project and CIMMT/Zimbabwe were evaluated for their resistance to stalk rot. Result indicated that none of the varieties tested was found free of stalk rot, except Gutto and BH-660 (Table 12). With regard to ear rot, out of 19 maize varieties tested only Abo Bako, Katumani, Alemaya composite and BH-540 were reported to be relatively resistant to the disease (Tewabech et al., 2001). In another study conducted at BAko, maize lines such as 142-1-e and 144-7-b had shown lower ear rot severity and less number of diseased cobs compared to other maize lines and released maize varieties. Interestingly, among the released maize varieties, BH-660 showed high ear rot disease severity (AU, 2002) at the rate of 1 to 6 scale, but showed less number of (2.033) diseased cobs.

Table 12. Evaluation of maize varieties for resistance to stalk rot diseases (2001-2002) combined over two locations, (Hawassa & Areka)

Treatments Seed source (Bako N.maize)	Diseases sev. (1-5) Scale	Disease length in (cm)	No. of harvested plant	Percent stalk lodged plants	Stalk borer hole number
BH-140	3.2 B-**E**	36.19 **A-D**	29.1 **A**	4.34 **C-E**	6.2 **AB**
BH-540	3.5 **AB**	47.19 **A**	29.0 **A**	31.03 **A-C**	6.0 **A-C**
BH-530	2.8 **F**	30.37 **C-E**	29.08 **A**	25.13 **A-E**	5.1 **A-C**
BH-660	1.8 **G**	13.97 **F**	27.75 **A**	27.75 **A-E**	1.9 **D**
PHB-3253	3.6 **A**	45.40 **AB**	28.92 **A**	30.08 **A-D**	5.8 **A-C**
Gibe	2.9 **EF**	36.94 **A-D**	28.42 **A**	24.98 **B-E**	5.4 **A-C**
Kuleni	3.5 **AB**	47.29 **A**	29.42 **A**	26.51 **A-E**	5.0 **A-C**
Gutto	1.8 **G**	14.70 **F**	28.83 **A**	21.50 **DE**	3.8 **C**
A-511	2.9 **EF**	34.92 **B-D**	28.50 **A**	25.61 **A-E**	6.3 **AB**
Katumani	2.1 **G**	18.87 **F**	28.42 **A**	23.4 **C-E**	5.2 **A-C**
Al-composite	2.1 **G**	18.11 **F**	28.83 **A**	34.34 **A**	5.0 **A-C**
PAPZ-92	3.2 **B-E**	44.28 **AB**	29.17 **A**	25.71 **A-E**	4.9 **A-C**
A-7018	3.3 **A-D**	47.17 **A**	28.50 **A**	26.67 **A-E**	7.2 **A**
A-7036	2.9 **D-F**	38.97 **A-D**	28.0 **A**	26.07 **A-E**	6.3 **A**
NSCM41	3.4 **A-C**	44.47 **AB**	20.17 **A**	48.59 **AB**	6.3 **AB**
SC-4	3.2 **B-E**	40.53 **A-C**	28.33 **A**	28.24 **A-E**	6.0 **A-C**
Seed Source (CIMMYT/					
POP-590 BC_3 F_1MBR/MD R BCo	2.1 **G**	21.27 **EF**	28.33 **A**	4.94 **C-E**	4.3 **BC**
POP-391 C_2 F_2 Bulk BCo	2.7 **F**	29.38 **DE**	28.08 **A**	20.30 **E**	5.1 **A-C**
POP-591 C_2 F_2 Bulk BCo	2.1 **G**	19.53 **F**	28.75 **A**	27.13 **A-E**	5.4 **A-C**
ITS-ST GPO G_2 # Bulk BCo	2.9 **D-F**	40.41 **A-C**	27.58 **A**	35.17 **AB**	5.2 **A-C**
ITS-ST GPO G3 # Bulk BCo	3.3 **A-E**	43.18 **AB**	27.58 **A**	27.56 **A-E**	5.2 **A-C**
ITS-ST GPO G4 # Bulk BCo	3.0 **C-F**	39.29 **A-D**	28.42 **A**	31.32 **A-C**	5.2 **A-C**
Mean	2.83	34.19	28.59	27.83	5.31
CV%	14.94	33. 52	7.26	35.39	43.72
LSD (0.05)	0.34	9.24	NS	20.35	1.87
Years (Y)	NS	NS	SD	SD	SD
Location (L)	SD	SD	NS	SD	NS
Y x L	NS	NS	SD	SD	SD
Replication (LY)	NS	SD	SD	NS	NS
Treatments (Fac.A)	SD	SD	NS	SD	SD
YA	NS	NS	NS	NS	NS
LA	NS	NS	NS	NS	SD
YLA	NS	NS	NS	NS	NS

Note: Means followed by the same letters in a column are not significantly different (DMRT)

Prospects of botanicals: In recent years, there has been increased interest in the application of botanicals in crop protection. The potential effect of 13 botanicals at the rate of 60 kg ha^{-1}, each with the application frequency of six sprays in a single cropping season, was evaluated against common rust and turcicum leaf blight (Table 13). The analysis of variance for two years and three locations showed that there was significant difference in common rust, turcicum leaf blight severities, and yield among the treatments (Table 14). Of 13 botanicals tested, eucalyptus (*Eucalyptus globules*) and papaya (*Carica papaya*) crude leaves provided promising results in reducing diseases and increasing yield compared to the other botanicals and the untreated control plot. High yield (65.8 q ha^{-1}) was obtained from plots treated with Mancozeb 80% WP followed by eucalyptus leaf (58.5 q ha^{-1}) and papaya leaf extract (56.3 q ha^{-1}), while untreated plot gave 41.2 q ha^{-1}. Castor seed (*Ricinus communes*) and neem seed (*Azadrechata indica*) sprayed plots showed better control of TLB and CR compared to the plots sprayed with the other botanicals but their yields were not significant compared to the control. Application of both *E. globules* and *C. papaya* is, therefore, of potential value in maize disease control except the high rate required for application. Therefore, it can serve as a component of integrated management of maize leaf diseases in the future.

Table 13. Influence of botanicals in controlling maize disease combined over three locations (2002-2003).

Treatment	**Disease incidence %***			**Disease severity (1-5 scale)**			Stalk bore hole no. mean of 20 plant	Yield Q ha -1.
	TLB	**CR**	**GLS**	**TLB**	**CR**	**GLS**		
Castor seed (Ricinus communes)	30.9 **B-D**	29.11 **BC**	8.4 **A**	2.5 **BC**	2.4 **B-D**	1.4 **A**	6.9 **BC**	44.08 **C**
Datura Seed (Datura stromonium)	35.8 **A-C**	40.3 **B**	8.2 **A**	2.8 **AB**	2.7 **B**	1.4 **A**	8.2 **BC**	45.25 **C**
Datura leaf (Datura stromonium)	39.7 **AB**	44.3 **B**	8.7 **A**	2.9 **AB**	2.9 **B**	1.5 **A**	8.2 A-C	43.87 **C**
Neem seed (Azadrechata indica)	28.1 **B-D**	33.9 C	10.2 **A**	2.5 **BC**	2.5 **B-D**	1.6 **A**	5.4 **C**	50.01 **BC**
Eucalyptus leaf (Eucalyptus globules)	18.7 **CD**	20.6 **C**	9.6 **A**	2.0 **CD**	2.1**CD**	1.5 **A**	7.3 **BC**	58.51 **AB**
Croton leaf (croton macrostachys)	41.9 **AB**	45.0 **B**	7.7 **A**	2.8 **AB**	2.9 **B**	1.4 **A**	8.4 **BC**	43.98 **C**
Tobacco leaf (Nicotna tabacum)	41.9 **AB**	44.8 **B**	8.8 **A**	2.9 **AB**	2.9 **B**	1.6 **A**	8.4 **BC**	43.88 **C**
Papaya leaf (Carica papaya)	19.6 **CD**	21.9 **C**	9.5 **A**	1.9 **D**	2.0 **D**	1.6 **A**	8.0 **BC**	56.28 **AB**
Lemmon Fruit (Citrus lemion)	39.02 **AB**	42.6 **B**	10.0 **A**	2.8 **AB**	2.9 **B**	1.5 **A**	10.7 **AB**	43.49 **C**
Grawa leaf (Vernonia amigdalina)	42.00 **AB**	40.1 **B**	8.6 **A**	2.8 **AB**	2.7**BC**	1.5 **A**	9.5 **AB**	43.84 **C**
Emboai fruit (Solanum)	40.4 **AB**	44.9 **B**	9.8 **A**	2.9 **AB**	3.0 **B**	1.6 **A**	10.5 **AB**	43.57 **C**
Garlic bulb (Allium sativam)	44.1 **AB**	41.4 **B**	8.9 A	2.9 **AB**	2.7 **BC**	1.6 **A**	9.0 **A-C**	45.29 **C**
Feto seed (Lepidium sativam)	42.4 **AB**	44.4 **B**	9.5 **A**	2.8 **AB**	2.9 **B**	1.6 **A**	10.1 **AB**	45.74 C
Fungicide (Mancozeb 80%WP) control	16.00 **D**	18.8 **C**	8.7 **A**	1.9 **D**	1.91**D**	1.4 **A**	9.8 **AB**	65.84 **A**
Untreated (control)	54.00 **A**	60.4 **A**	11.6 **A**	3.4 **A**	3.8 **A**	1.7 **A**	12.3 **A**	41.20 **C**
LSD (0.05)	15.85	14.21	NS	0.519	0.535	NS	3.13	9.09
CV%	27.59	23.08	32.51	12.9	12.27	15.46	21.8	11.83

*****Means followed by the same letter(s) in a column are not significantly different (DMRT)*

TLB= Turcicum Leaf Blight; CR= Common Rust;GLS= Gray Leaf Spot

Source: Hawassa National Maize Project Progress Report (199 to 2004).

Table 14. Evaluation of Botanicals for the control of Maize disease 2002 and 2003

Description	Between treatments	Between Years	Between Location	Year by Location	Repel. Loc. x year	Year by Treatment	Location by treatment	Year Location treatment
Disease Sev. (1-5)								
Turcicum	SD	NSD	SD	NSD	NSD	NSD	NSD	NSD
Leaf Blight Common	SD	SD	NSD	SD	NSD	SD	NSD	NSD
Rust	NSD	SD	SD	SD	NSD	NSD	NSD	NSD
Leaf Spot								
Disease incidence%								
Turcicum	SD	NSD	SD	SD	SD	NSD	NSD	NSD
Leaf Blight Common	SD	NSD	NSD	SD	SD	SD	NSD	NSD
Rust	NSD	SD	SD	SD	SD	NSD	NSD	NSD
Leaf Spot								
Stalk borer hole No.	SD	NSD	SD	SD	NSD	NSD	NSD	NSD
Yield $Q\ ha^{-1}$.	SD	SD	SD	SD	SD	NSD	NSD	NSD

Note: SD = significant difference; NSD=non significant difference.
Source: Hawassa National Maize Project Progress Report (199 to 2004).

Chemical control: The feasibility and economy of foliage spraying have not yet been worked out; promising fungicides have been reported in controlling turcicum leaf blight and common rust in maize (Assefa, 1997). A combined application of mancozeb and propoconazol at the rate of 2.0 kg a.i ha^{-1} two to three times reported to control turcicum leaf blight and common rust diseases. Similarly, two fungicides, namely triadimefon and mancozeb, at different rates and spraying schedules were compared at Alemaya in controlling common rust (*Puccinia sorghi*) on maize varieties with different genetic background. Both fungicide treatments resulted in different levels of disease severity on maize varieties used. Triadimefon, sprayed twice at higher rates (250 and 300 g ha^{-1}) and mancozeb sprayed five times at the rate of 400 and 600 g ha^{-1} effectively reduced incidence and severity of common leaf rust. Percent leaf area disease (LAD) and area under disease progress curve (AUDPC) were negatively correlated with grain yield and thousand-grain weight. Disease severity of up to 35% and relative yield loss of 29% were recorded in unsprayed plots. The results demonstrate the possible effect of fungicides for the control of both turcicum leaf blight and common rust diseases in maize production. Similarly, two fungicides triadimefon and mancozeb at different rates and spraying schedules were compared at Alemaya in controlling common rust (*Puccinia sorghi*) on maize varieties with different genetic background. Both fungicide treatments resulted in different levels of disease severity on maize varieties used. Triadimefon, sprayed twice at higher rates (250 and 300 g ha^{-1}) and mancozeb sprayed five times at the rate of 400 and 600 g ha^{-1} effectively reduced incidence and severity of common leaf rust. Leaf area disease (LAD) and AUDPC were negatively correlated with grain yield and thousand-grain weight. Disease severity of up to 35% and relative yield loss of 29% were recorded in unsprayed plots. Moreover, the varieties tested in combination with chemical application showed variable reactions to both diseases, and depending on the response to the disease, varieties were categorized in five groups: resistant (two varieties), moderately resistant (three), intermediate (three), moderately susceptible (six) and susceptible (two varieties). The time required for common leaf rust severity to reach 10% (T_{10}) ranged from 14 days for Obatanpa to 81 days for BH-670, and 62 to 65 days for the other 10 varieties tested. BH-670 and BH-660, and Kuleni and Alemaya composite were the best performing varieties among the hybrid and open-pollinated varieties, respectively, in disease resistance and yield. The results demonstrate the possible effect of fungicides for the control of both turcicum leaf blight and common rust diseases in maize production. However, economic analyses are required to fix the treatment(s) that would give the highest net return. Leaf area disease (LAD) and AUDPC were significantly lower in BH-670, BH-660, Kuleni, Alemaya Composite, and Katumani as compared to the susceptible check Bukeri. Moreover, maize seed treatments with Luxan TMTD also resulted in the lowest level of kernel rot damage (9.16%), which causes infection during storage. Chemical seed treatment could be a useful means of controlling both storage and seed born diseases of maize.

Conclusion and recommendations

Gray leaf spot is anticipated to threaten maize production until appropriate control methods are developed. However, promising results have been achieved in screening resistant maize lines against gray leaf spot and variations in compatibility have been established. However, other options for integration to control gray leaf spot should be emphasized.

Appreciable results in controlling specific diseases using a single control option have been achieved. However, to ensure long-term effect and to develop integrated maize disease management other components need to be investigated.

Recommendations

It is evidenced from the above results that there are available disease control options that help promote maize production in the country.

- Proper selection of planting dates is of great importance in the management of many plant diseases. Thus, the practice should be carefully considered in maize disease management, and farmers should be advised and encouraged whenever this practice is feasible;

- It is difficult to generalize with any degree of accuracy about disease management with different systems of intercropping. Nevertheless, experimentally, it is reported that less disease incidence is recorded in some types of crop associations than in monoculture. Similarly, intercropping maize with other crops in the traditional farming systems in Hararghe highlands, apparently demonstrated in managing maize diseases. Hence, site and disease specific recommendation could be generated from the results discussed in the text;
- Incorporating organic or synthetic fertilizer for better maintenance of soil fertility is reported to delay or reduce disease pressure on maize and increased maize productivity. Hence, this practice should be recommended;
- There are some indications that certain botanical plants are useful to control maize foliar diseases; however, this practice should only be considered on plants that are available in abundance;
- The widespread use of a few improved commercial maize varieties with common genes often results in serious gray leaf spot disease epidemics. However, a high degree of maize resistant sources is available to either individual or multiple diseases. Thus, breeding need to focus on the development of stable maize resistant varieties to gray leaf spot disease;
- Chemical availability, appropriateness and practicality, although matters to spray chemicals to control maize diseases, under severe disease conditions the practice need to be considered as the last resort. However, preplant seed treatments with chemicals and during storage should be considered whenever necessary; and
- Parents for hybridization are selected based on their performance per se or their general combing ability, but selection of parent source in response to different target environment should be considered.

Gaps and challenges

- Information on environmental conditions in which important maize diseases can reach an epidemic level causing a serious yield loss needs further investigation;
- Pre- and post-harvest yield losses due to field and storage diseases are not quantified;
- Varieties resistant to the major diseases of maize are lacking; and
- Effective and environmentally safe control measures for major maize diseases are lacking.

Future prospects

- Although substantial information on the occurrence of maize diseases is available in major maize producing regions, variation in disease intensity was observed. However, as maize is expanding in diverse agro-environments, there are possibilities of occurrence of other maize diseases. Furthermore, pathogens change or shift throughout the season is common. Hence, understanding of seasonal fluctuations of individual disease in relation to the cultivation practices and maize cultivars is necessary. Thus, the relative importance of maize disease needs to be prioritized based on the environment factors and production system;

- More extensive studies for assessment of varieties for specific regions and identification of control measures against major diseases need to be emphasized;
- Considering a pertinent environmental factor to establish epidemiological parameters for the major maize diseases is necessary;
- Field sanitation or proper maize residual managements in relation to gray leaf spot need to be investigated;
- Improvement of cultural practices, botanical, chemical and biological disease management techniques or refinement of the available technology to maximize the total effect on major maize diseases is needed;
- Field and storage diseases associated with maize, their distribution, occurrence and importance need to be understood; and
- Reliable screening methods for the development of resistance genotypes are needed.

Sorghum diseases

In most sorghum growing areas regular disease surveys with detailed information were not conducted or have never been at all in some areas in the past. Consequently, a complete picture of geographical distribution of sorghum diseases in all sorghum-growing areas of Ethiopia is lacking. However, relatively better understanding of sorghum disease distribution is currently available than in the previous report (Mengistu and Berhane, 1978; Mengistu, 1982; Tarekegn, 1985). Surveys were carried out in the northwestern, Northeast, Southwest, eastern and Tigray of sorghum growing areas to estimate the prevalence, distribution and the relative importance of sorghum diseases (Table 15).

Although the list is not exhaustive, about 27 diseases caused by more than 39 pathogens, including fungi, bacteria, and virus that attack leaves, root, stalk, and panicles were recorded. Of the listed sorghum diseases, fungi cause the largest number of diseases. Sorghum anthracnose, rust, covered and loose kernel smuts were routinely observed in all surveyed areas and considered as major diseases. However, various sorghum leaf spots and leaf blight root and stalk rot, downy mildew, Pokkah boeng, bacterial and viral diseases occur in some localities, they appear to have limited importance. The severity of specific diseases depends on the cultivars and environment, and hence disease of marginal importance in one region may be significant in another region.

Table 15. Regional sorghum diseases distribution pattern and their current status in Ethiopia

Foliar fungal disease	Causal organism	North western	Northeast	Western Bako	Eastern Alemaya	Tigray
Anthracnose	*Colletotrichum graminicola* (Ces.) G.M Wils	xxx	x	xxx	*xxx*	
Rust	*Puccinia purpurea* Cke.	xxx	x	xxx	*xx*	
Downy mildew	*Sclerospora sorghi & Pernosclerospora sorghi* Weston & Uppal	x	xxx	x	*xx*	*x* *x* *x*
Zonate leaf spot	*Gloeocercospora sorghi* Bain & Edgerton	x	xxx	xx		*x* *x* *x*
Oval leaf spot	*Ramulispora sorghicola* Harris		xx	xxx	*x*	
Sooty stripe	*Ramulispora sorghi* Ellis & Everhart	x		xx		*x* *x* *x*
Leaf spots	*Mycospherella holci*			xx		
Leaf blight	*Helminthosporium turcicum* Pass			x	*xx*	
Leaf spot	*Drechslera sp.*			x		
Leaf spot	*Nigrospora sphaerica* (Sacc.) Mason.	x		x		
Leaf spot	*Phyllosticta sorghiphila* Saac.	x				
Gray leaf spot	*Cercospora sorghi*	x	xxx		*xx*	
Leaf spot	*Aschochyta sp*	x				
leaf spot	*Ramulispora sorgicola* Harris	x		x		
leaf spot	*Phoma sorghina Saac*					
Ladder leaf spot				xx		
Pokkah boeng					x	
Root and Stalk disease						
Charcoal rot	*Macrophomina phaseoli* Maublance & Ashby				x	
Grain and panicle diseases						
Covered kernel smut	*Sphacelotheca sorghi* Clint	xxx	xxx	xxx	xxx	x x
Loose kernel smut	*Sphacelotheca . cruenta*	xx	xxx	xx	xxx	
Head smut	Sphacelotheca . *reiliane* (Kuehn) Clint.	x	x	xx	x	
Long smut	*Tolyposporium chrenbergii* (Kuehn) Pat.		xx		x	
Honey dew/Ergot	*Sphacelia sorghi* Macrae	x	x			
Grain mold	• Alternaria state of *Pleospora infectora,* • *Asppergillus niger,* • *Asppergillus flavus,* • *Cunninghamella elegans,* • *Mycosphaerella spp.,* • *Mucor spp.* • *Penicillium spp.* • *Phoma insidosa,* • *Rhizopus stolonifer* • Stemphylium spp. • Trichoderma koningii, • Rhizopus nigrians			x	xxx	
Bacterial diseases						
Bacterial leaf strip	*Pseudomonas andropogoni*		x	x	x	
Bacterial leaf streak	*Xanthomonas holcicola*	x	x	x	xx	
Viral diseases						
Maize dwarf mosaic	Maize dwarf mosaic virus		x			
Sugar cane mosaic						

+++=high; ++=medium; + = low

Source: A review of research on maize and sorghum disease in Ethiopia (1985); Awgichew, 1982; Kranz, 1969; Mengistu, 1982; PPS (Holetta), 1979; Solomon and Mengistu, 1984; stewart, 1967

In the survey conducted during 1996 cropping season involving 246 farmers' fields of which 77% was sorghum indicated that sorghum leaf anthracnose (*Colletotrichum graminicola)*, oval leaf spot (*Ramulispora sorghicola*), rust (*Puccinia purpurea*), covered (*Sphacelotheca sorghi*) and loose smut (*Sphacelotheca* cruenta) were predominantly prevalent in the northern Ethiopia. Disease severity varied among surveyed regions and farm fields. More fields (40%) showed high level of disease severity (7-9 severity scale) than other regions. An average of 42% fields showed relatively high disease severity (Girma, unpublished results). In addition, downy mildew, zonate leaf spot, gray leaf spot, leaf blight, bacterial leaf strip, streak and maize dwarf mosaic and long smut, head smut and ergot of panicle were recorded. In a survey made in Tigray, high incidences of smut (64%) and downy mildew (17 to 35%) were reported (MRC, 1994; 2002). Previously, downy mildew had been endemic only in East Wellega Zone, and presently its intensity is reported to be low in this zone. However, it is getting a potential threat in Tigray.

Regarding finger millet, of 246 farmers' fields, 23% of them were attacked by blast (*Pyricularia griseas*). Of the total finger millet fields, Finote Selam (53%), Bahir Dar (8%), Tigray (4%), and Gonder (6%) showed high incidence of blast (Girma, unpublished results). Relatively high blast incidence was observed in association with high rainfall, weedy and waterlogged conditions. The severity was comparatively high in waterlogged fields, and the lower portion of the stem is severely attacked and plants were caused to lodge.

An intensive survey conducted in the western region of Ethiopia during 1996–1999 indicated the prevalence of various sorghum diseases that vary in severity in relation to altitude. Both sorghum anthracnose with incidence of 55-85% and oval leaf spot with the incidence of 60–75% were observed in the altitude range of 1350-2150 m. Most of the land race and improved sorghum varieties were susceptible to anthracnose around Bako and eastern Wellega (BARC, 1990/1; Fekede and Kedir, 2000). Exceptionally, ladder leaf spot with incidence ranging from 20 to 100%, rust ranging from 80 to 90% and zonate leaf at the incidence level of 60% were recorded in the altitude range of 1600-2000 m. It was reported that ladder leaf spot caused by *Cercospora fusimaculans* showed extensive geographic distribution compared to other diseases. Covered smut was prevalent in all the surveyed areas within the range of 1350-400 m, but the incidence was rather low (15%) in the range of 1350-1600 m (BARC, 1990/1; Fekede and Kedir, 2000). Turcicum leaf blight, bacterial streak, and bacterial stripe were recorded in the range of 1600-2000 m with incidence ranging from 10 to 15%. Besides leaf infection, turcicum leaf blight was reported to infect sorghum seed and cause seed rot and seedling blight if infected seeds are planted in cool and wet soil. Among improved varieties, IS-18442 had been found susceptible to this disease while Birmash and IS-9302 were found resistant (BARC, 1990/1; Fekede and Kedir, 2000).

In addition, results of disease survey conducted in western Oromiya revealed the prevalence of important finger millet diseases like blast, leaf blotch and anthracnose. The panicle disease of finger millet blast has been reported to cause serious damage in finger millet production, but leaf blotch has low or medium impact (BARC, 1990/1; Fekede and Kedir, 2000). However, in Tigray, diseases such as leaf spot/neck blast (caused by *Pyricularia grisea*), foot rot (*Sceloritium rolfsii*), blight (*Helminthosporium nodulosum* and *Helminthosporium* spp.), leaf blotch (*Helminthosporium* spp), smut (*Tolyposporium* spp.) were recorded on finger millet.

In sorghum-growing areas of eastern Ethiopia, apart from the above-mentioned foliar diseases of sorghum, Pokkah-boeng, (caused by *Fusarium* spp.) was recorded in experimental fields at Alemaya and Babille (AU, 2002; Temam and Amare, 1989). Loose kernel and head smuts were also observed, (incidence were less than 4%). Long smut, in lowlands and covered kernel smut in most sorghum growing areas were observed with incidence of 5 to 20% and 7 to 14%, respectively. In some isolated areas, the incidence of covered smut was reported to reach as high as 80%.

In general, sorghum diseases recorded in the last two decades were more than they were in the previous past. However, it appears to be that there are no major changes or shifts in the sorghum pathosystem except the inclusion of two pathogens. The first one was Pokkah boeng (locally “Harquan”) disease supposed to be caused by *Fusarium* spp. (Solomon and Temam, 1989), which was not recorded and properly identified until recently. The other disease grain mold was recorded on stored sorghum grain at Bako. The absence of new emerging disease in the existing sorghum production system was perhaps due to unchanged production practices and introductions of fewer improved sorghum varieties. Hence, many of the previously reported diseases are still limiting factors to sorghum production.

Basic studies

Pokkah-boeng or twisted top

Pokkah-boeng is a relatively new sorghum disease in Ethiopia (Solomon and Temam, 1989; Temam and Amare, 1989). Previously, the causal agent of this disease has not been known. However, a recent investigation at Alemaya provided sufficient information on the causal agents and their symptoms following artificial inoculation (AU, 2002) Three species of *Fusarium*, i.e., *Fusarium proliferatum, F. moniliforme* and *F. proliferatum* were isolated in that order from infected stems and seeds. However, variations in infectivity among *Fusarium* spp. have been detected. *Fusarium proliferatum* exhibited typical pokkah-boeng symptoms eight weeks after inoculation under greenhouse conditions, while *F. monoliforme* and *F. proliferatum* failed to inflict typical symptoms. It was reported that both infected stalks and seeds are the primary sources of inoculum for the disease, and infected seeds often result poor seed germination and seedling establishment.

According to the report (AU, 2002), a range of visible disease symptoms at different subsequent stages of the crop were observed following artificial inoculation of *Fusarium* spp. At early seedling stage (about six weeks after planting), infected leaves generally produce malformation (wrinkling, sometimes discolored at the top of the plants) and in severe cases; it bends the stalks as early as 10 weeks after planting. At heading, leaves unfold with either uniform transverse cuts in the rind (surface) giving the impression that the plant tissue had been removed with a sharp knife or produce a ladder-like appearance. As the plants mature, infected plants become stunted, thin, deformed, and left with very small or no panicle heads.

Screening techniques for resistance to anthracnose, ergot and bacterial streak

A reliable screening technique is a critical step in the successful identification of resistant sorghum germplasm for the development of improved sorghum varieties. In the past, evaluation for resistance to different diseases was done under natural infection using infector/indicator/spreader rows (Kusum et al., 2002) at selected disease hot spots. Currently, artificial inoculation techniques to anthracnose, ergot, and bacterial diseases are available and have been successfully applied.

To reduce the confounding effect of other diseases that arise in natural infection during screening sorghum genotypes against anthracnose, reliable and effective inoculation technique was established using sorghum green leaf medium (SGLM) (Girma et al., 1995; Girma and Pretorious, 2007). With regard to ergot, effective screening technique involving a single inoculation of non-trimmed panicles with suspension of ergot conidia prepared from diluted honeydew when anthesis began in a panicle, followed by bagging was reported to be effective (Girma et al., 1994).

In another study, application of finely ground-infected leaves in leaf whorls and spraying with bacterial suspension following wounding the leaves with sterile fine sand also demonstrated the best result for successful screening of sorghum against bacterial streak caused by *Xanthomonas campestris* pv *holcicola* (Temam, 2001).

All screening techniques have also increased the probability of success in selecting highly resistant sorghum genotypes. However, the available inoculation techniques are applicable to only limited diseases. Therefore, there is a need to develop more techniques suitable for other sorghum diseases.

Assessment of losses

Virtually there are no evidences to show the extent of yield losses in sorghum due to all major diseases, but considering the panicle damage they cause, several researchers made efforts in the past to assess the economic impacts of covered (*Sphacelotheca sorghi*) and loose kernel smuts (*S. cruenta*) ((Dereje, 1971; Tarekegn, 1985).

Recently, Eshetu, et al. (2006) estimated sorghum yield loss on a variety of sorghum cultivars differing in resistance using artificially inoculated versus protected (Apron plus) options. Results indicated that sorghum yield loss ranged from 1 to 54%, with large variations across test locations, seasons and the type of genotypes tested (Table 16).

Table 16. Estimated percent yield loss in different sorghum cultivars due to covered smut at selected locations in Ethiopia, 2001/ 2

Varieties	2001						2002					
	Kobo			Sirinka			Kobo			Sirinka		
	Potential yield (t/ha)	Actual yield (t/ha)	yield loss%	Potential yield (t/ha)	Actual yield (t/ha)	yield loss (%)	Potential yield (t/ha)	Actual yield (t/ha)	yield loss%	Potential yield (t/ha)	Actual yield (t/ha)	yield loss%
Jigurty	5.2	3.7	30	3.0	2.9	1	4.0	3.8	5	4.6	4.5	3
Gambella-1107	4.5	2.1	54	4.4	3.8	14	3.4	3.2	5	3.8	3.6	4
Meko	5.5	3.4	39	4.3	3.9	10	3.2	2.9	7	2.7	2.5	7
76 T_1#23	5.0	3.0	40	4.4	3.8	13	4.1	2.8	33	3.6	3.0	16
Mean	5.0	3.0	41	4.0	3.6	10	3.7	3.2	13	3.7	3.4	8

Source: Eshetu et.al, 2004

In 2001, overall mean yield losses were 41 and 10% at Kobo and Sirinka, respectively. In 2002, the yield loss estimates were 13 and 8% at the respective locations. The magnitude of yield loss depends upon sorghum varieties. For instance, grain yield reductions were more on improved sorghum varieties, Gambella-1107, 76 T_1#23 and Meko than on the local sorghum variety, Jigurti.

In another study at Bako, grain yield loss of sorghum due to covered smut ranged from 31 to 42% compared to the untreated one (Merkuz, 2001). On-farm study conducted at Harer, based on comparison of diseased and healthy sorghum heads, resulted in yield loss of 13% with an incidence ranging from 5 to 20% and 7 to 14% due to covered and loose smuts, respectively.

A marked reduction was also reported in sorghum grain yield due to sorghum loose smut, exceeding 50% (Girma and Pretorius, 2007). However, no significant correlation was observed between sorghum grain yield and incidence of covered smut. Although yield loss information on covered and loose smuts helps in setting research priorities, the yield loss data generated under research centers' conditions need to be validated under farmers' field conditions. This would help to estimate the economic value of intervention to control both diseases and other diseases.

Leaf anthracnose (*Colletotrichum graminicola*) is also another important disease that causes yield losses in sorghum. In experimental inoculations at Alemaya, sorghum growth stage related to the degree of susceptibility was found to influence anthracnose infection and yield losses. Artificially inoculated susceptible variety (ALOB2002B) (locally known as “Wogere”) with anthracnose disease at different growth stages showed the gradual increase of the disease until anthesis and progressively increased at physiological maturity and eventually cause to defoliate most leaves. Conversely, delayed anthracnose disease development was observed on moderately resistant variety (ETS2752) even after anthesis and only fewer leaves were killed at physiological maturity. Mean disease severity on the susceptible variety (ALOB2002B) at 50% flowering was 80, 79 and 82%, in 2001, 2002 and 2003, respectively. The temporal anthracnose disease development expressed in areas under the disease progress curve (AUDPC) was highly varied between the susceptible and resistant sorghum varieties showing high values of AUDPC for the susceptible variety than on moderately resistant cultivar. The AUDPCs of the susceptible cultivar (ALOB2002B) were 545, 371, and 544. However, on moderately resistant variety (ETS2752), it was 263, 214, and 259 for the 3 consecutive years. The dilatory resistance effects observed in moderately resistant sorghum, characterized by a reduced AUDPC, implies a reduction of the amount of initial inoculums (spores) that induce secondary infection and eventually minimize inoculums density in plant population. This form of dilatory effect on sorghum anthracnose was also reported elsewhere in that infection on the resistant sorghum was very low and did not increase later in the season. This suggests that major genes for resistance may exist (Thomas, 1992).

Differences in sorghum yield losses have been observed between the two varieties. Yield losses attributed to leaf anthracnose depend on the degree of susceptibility of tested varieties. Calculated yield data from fungicide-treated and unsprayed plots indicated that yield loss was as high as 35% in 2001, 26% in 2002, and 31% in 2003 for the susceptible cultivar (ALOB2002B). In contrast, a moderately resistant sorghum cultivar (ETS 2752) with almost less AUDPC (9%), had no apparent loss in sorghum grain yield due to anthracnose disease. The reduction of kernel weight due to anthracnose disease was between 16 and 4% for the susceptible cultivar (ALOB2002B), 6, and 12% for moderately resistant variety (ETS 2752).

The above research results imply that the slow development of anthracnose diseases in moderately resistant sorghum cultivar (ETS 2752) has significant effect on the epidemiology of anthracnose disease. Importantly, this type of resistant mechanism is more desirable in disease management, particularly in sorghum subsistence farming system where no other alternative options exist. However, information is lacking on the effect of the environment related to disease development in both susceptible and resistant sorghum varieties. In addition, as there is variability among sorghum anthracnose population, the observed slow down effect on the moderately resistant need to be tested for other biotypes of sorghum anthracnose. Besides anthracnose disease, mixed infection caused by two or more diseases could happen. Hence, further study should be made to determine the extent of damage due to mixed infection.

Sorghum diseases control measures

Sorghum smuts

Cultural methods

Planting sorghum in late April or early May is commonly practiced in the past and it is believed to reduce covered smut incidence (Girma, personal communication). Undoubtedly, the normal rain's pattern that was experienced in the past contributed to this practice. Currently, this situation rarely occurs in most sorghum growing regions. Nevertheless, the relative importance of this practice is poorly understood and only limited report is available.

Following traditional sowing date, different seed treatments were compared in controlling covered smut on different sorghum varieties (Table 17). As it was exemplified in the untreated plots, sowings of Masungi in early May resulted in reduced smut incidence (10%) as compared to sowing of Seredo in late June (38%). The average soil temperatures calculated at an interval of 5 days at Meisso during early planting (May 8) was 27.9 ^{o}C (with a minimum of 27.7 ^{o}C and a maximum of 35.4 ^{o}C). There was a slight decrease in the average soil temperature (26.4 ^{o}C) during late planting (June 17). The minimum and maximum temperatures were 25.1 ^{o}C and 27.3 ^{o}C, respectively. Average rainfall during May was 8.03 mm, and in June it was extremely low (2.74 mm). Thus, it was difficult to conclude whether or not the high smut incidence observed in late-planted sorghum at Meisso was directly related to decreased soil temperature and high rainfall. However, slight soil temperature decrease in late sowing seems to have more influence on covered smut incidence than have soil moisture suggesting that low soil temperature favors the development of covered smut. Doggett (1970) reported that cool conditions tend to increase the frequency of covered smut. Adlakha and Munjal (1963) also stressed the importance of temperature at planting as a determinant factor at initial infection stage of covered smut. Results of the above researchers confirmed that plants sown in the field when the temperature range is from 34 to 42 ^{o}C did not show infection while seed germinated in the temperature range of 4 to 29 ^{o}C did.

Table 17. Effect of sowing dates on the incidence of covered kernel smut in selected locations in Ethiopia. 1996

Treatment	Location							
	Merhabete				Meisso			
	Early planting (June 21/96) Mamito		Late planting (July 10/96) Gamballa 1170		Early planting (May (8/96) Masungi		Late planting (June 17/96) Seredo	
	Incidence (%)	yield (t ha^{-1})	Incidence (%)	yield (t ha^{-1})	Incidence (%)	yield (t ha^{-1})	Incidence (%)	yield (t ha^{-1})
Control	41.7 a	2.35 ab	66.3a	1.39 b	10 b	0.85 b	21 a	1.63a
Metalaxyl	12.7 b	2.28ab	9.0 b	2.43 a	16 a	1.86a	8 b	2.32a
(Thiamethoxan+Mefenoxam+Difenocunazole) +Metalaxyl	8.7 b	2.60ab	2 b	2.43 a	0.3 c	1.21 b	4 b	1.68 a
Fernasan D	8.7 b	2.70ab	1 b	2.68 a	0 c	1.13 b	0 b	1.82a
Cow urine	8.3 b	1.90 b	9 b	1.87 ab	4 c	1.18b	3 b	1.68a
Plant extract	7.0 b	2.5 ab	2 b	1.30 b	0.3 c	0.97 b	1 b	1.61a
Thiamethoxan+Mefenoxam+Difenocunazole	4.7 b	2.94a	3 b	2.49 a	0 c	1.25 b	7 b	1.74a
LSD < 0.05	15.7		14.4		5.2	0.53	8.8	0.92
CV %	67		11.3		69	24.7	81	28.9

Source: Ethiopian Sorghum Improvement Program Progress Report (1999).

Although meteorological data were not recorded at Merhabite, early-planted (June 21) Mamito showed similar trend, but comparatively less than late planting (July 10) of Gambella 1170 (66%). Similarly, a study conducted at Bako (Assefa, 1997) showed that late planted (May 20) sorghum had high covered smut incidence than the early planted (April 20 or/and May 5) sorghum. The studies showed that early planting avoids risk of covered smut infection during seedling growth stage while late planting increases the risk of infection. However, early planting is unlikely to have a major impact on the incidence of sorghum-covered smut, as there is uncertainty of rainfall in most sorghum growing regions during late May or early April. Thus, another alternative, which is readily available, sustainable and effective, is needed.

Traditional practices

Since no chemical control is practical fore small-scale farmers, the logical approach to control covered and loose smuts is exploring and adopting local practices. Resource-poor farmers traditionally practice various methods to control sorghum smuts. Recently, effects` of cow and goat urine stored at different days and diluted with water have been evaluated on both covered and loose smuts (EARO, 1998). The study revealed that cow urine stored for seven days significantly reduced covered kernel smut incidence by up to 81% in 1999 and 26 to 70% in 2000 and increased grain yield, respectively, by up to 95% in 1999 and up to 38% in 2000. Irrespective of storage durations, goat urine treatments significantly reduced smut incidence by 50 and 85% in 1999 and 55 to 82% in 2000, respectively. Sorghum grain yield increased, respectively, to 20 and 140% in 1999 and 28 and 67% in 2000 compared to the control (Fig. 1).

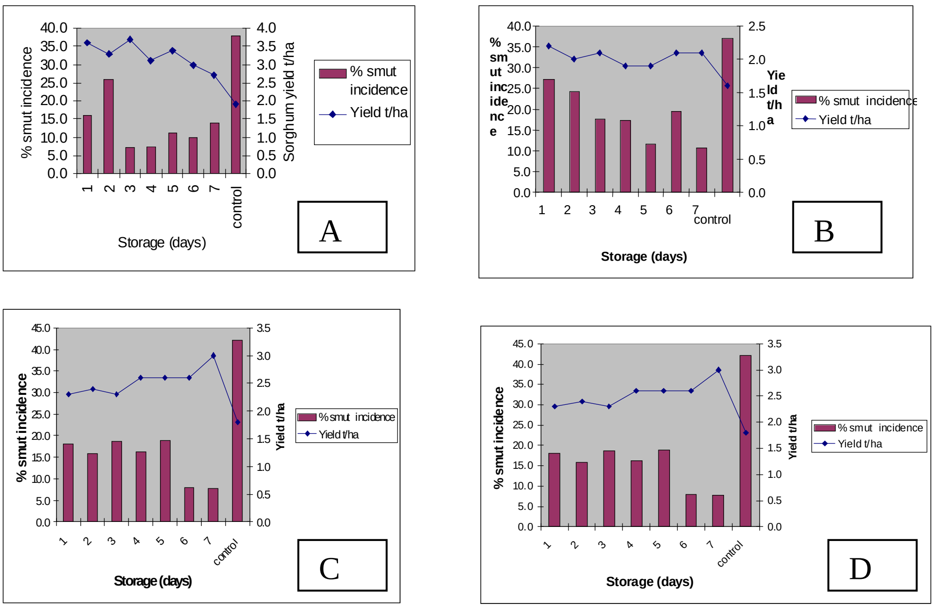


Fig. 1. Effect of cow urine treatments on sorghum covered kernel smut incidence and yield in 1999 (**A**) in 2000 (**B**)**,** and goat urine treatment in 1999 (**C**) in 2000 (**D**).

Additionally, it was also concluded that soaking one kilograms of sorghum seed for 20 minutes in either cow or goat urine diluted with water in a 1:1 (v/v) mixture appeared most effective than 1:2 and 1:3 (v/v) in reducing covered smut. Subsequent tests after soaking sorghum seeds with cow and goat urine and stored for 2–3 weeks also revealed increased seedling height, percent germination and seedling emergence compared to the control treatment (EARO, 1998). Thus, it was concluded that farmer’s practical knowledge has significant role in sorghum smut management. However, this simple practice is not widely adopted.

Biological control

Prospects of botanicals

Though potential benefits derived from plants in crop protections systems is far from the current research priorities, potential anti-fungal natural plants either as crude or extracted form were tested against sorghum covered and loose smuts. Use of antifungal wild plant species to control plant diseases is indeed not widely common compared to insecticide application (Dales, 1996), though farmers in Ethiopia have long been practicing on a small scale to control sorghum smut (Girma, personal communication). Traditionally, farmers use crude extract of *Dolichos kilimandscharicus* L. (Bosha) as a slurry to treat sorghum seed in the control of covered (*Sporisorium sorghi;* Ehrenberg) and loose (*Sphacelotheca cruenta,* Kuhn) kernel smuts (Girma andPretorius, 2007). This local practice has opened up new opportunities for plant disease management. In the last few years, promising plant species showing antifungal effect against sorghum covered and loose smuts were identified at Melkassa, Bako and Sirinka.

Treatment of sorghum seed with *Dolichos kilimandscharicus* (root), *Phytolacacca dodecandra* (berries) and *Maerua subcordata* (root) in a powder form effectively controlled both covered and loose smuts and were as effective as the standard chemical (Table 18), Thiram (Girma and Pretorius, 2007). Fekede and Kedir (2004) indicated the leaf extract effect of *Maesa lanceolata* either applied alone or diluted with water in ratio of 75:25 v/v. The results also indicated that both methods of application completely reduced covered smut incidence and increased yield ranging from 40 to 41% (Table 19). Similar results were also obtained at Sirinka indicating that the leaf extract of *M. lanceolata* have a potential effect in controlling covered smut. Furthermore, the possible application of *M. lanceolata* and its effect under field conditions was demonstrated to the farmers at Bako in a participatory research approach and the practice was appreciated by the farmers.

Table 18. *Maesa lanceolata* leaf extract against covered smut and its effect on yield at Bako (after Fekede and Kedir, 2004.

Treatments	Smut incidence (%)	Yield kg/ha	Yield increase (%)
Leaf extract (100%)	0.0	3757.4	39.5
Leaf extract + water (75: 25 v/v)	0.0	3808.9	41.4
Fernasan D 3 g/kg seed	0.66	3528.9	31.0
Control	28.12	2693.3	-

Table 19. Effect of different seed treatment on covered smut and grain yield in Sirinka

Treatments	Tisabalima		Kobo	
	Incidence (%)	Yield (kg ha^{-1})	Incidence (%)	Yield (kg ha^{-1})
Cow urine	2.8	4695.4	3.6	2426.9
Maesa lanceolata	0.0	4904.7	0.6	3210.8
Control	3.1	4698.6	19.2	2864.1
LSD at 0.05	*	NS	*	NS
CV%	29.7	6.99	76.6	21.3

*Differed significantly (P <0.05) according to the Least Significant Difference (LSD) statistical procedure
Source: Sirinka Agriculatural Research Center progress report (2002),

Additionally, most recently we have identified biologically highly active plant species (*Agaphantus africanus*) collected from South Africa (Girma, 2004) which, when used as seed treatments at lower concentration (0.33, 0.4 and 0.11 g kg^{-1}) provided consistent effect against both covered and loose kernel smuts as opposed to the standard chemical thiram at the rate of 5 g kg^{-1} (Table 20). In general, the plant extracts widely demonstrated their effective in the range of environments. Besides the above-mentioned control options, a number of sources of resistance from the local sorghum cultivars have been found in different regions to covered and loose smut.

Table 20. *In vivo* antifungal activity of crude extracts of plant species collected from Ethiopia against loose and covered kernel smuts (after Girma et al., 2007)

Treatment	Loose smut		Covered smut	
	Incidence (%)	Yield t ha^{-1}	Incidence (%)	Yield (t ha^{-1})
P. dodecandra	4.8c*	3.1 ±a	5.2bc	3.4a
M. subcordata	17.9b	3.0 ±a	9.4b	3.3a
D. kilimandscharicus	13.4b	2.7 ±a	17.2a	2.2b
Fernasan D	0.9c	3.0 ±a	1.5 c	2.1b
Thiamethoxan+Mefenoxam+Difenocunazole	0.7c	3.1 ±a	2.4 bc	1.5bc
Untreated control	35.3a	1.3 ±b	19.1a	0.9c

Values designated with different letters differed significantly (P <0.05) according to the Least Significant Difference (LSD) statistical procedure

Sources of resistance

Growing resistant varieties can also help to control both sorghum covered and loose smuts and some sources of sorghum resistance to covered smut were also reported worldwide Selvaraj,1978). Similarly, a good degree of resistance to covered smut has also been reported from local sorghum collection in Ethiopia. Merkuz (2001), in his recent study, identified "Tetron" local cultivar showing high resistance to covered smut following artificial inoculation under filed conditions. Eshetu (2006) also indicated the superiority of the local sorghum cultivars resistant to sorghum covered and loose smuts with good agronomic performance. Out of 23 land races screened for their resistance to smut, IS158X (ETS 3235) and Red Degalit were highly resistant to loose smut, while ETS 1176 and ALOBS Nur Acc# 2002B showed less susceptible (<2%) (Table 29). However, yield was comparatively lower in the resistant cultivars (Eshetu et al., 2006). Additionally, improved sorghum varieties such as IS-9302, Birmash and Aba-melko reported to show reasonable resistance to covered smut disease than the local varieties at Bako (Fekede and Kedir, 2004). Moreover, from a large number of sorghum accessions tested for panicle diseases, four accessions (690018, 690019, 690044, and 690169) were found to be resistant to sorghum covered and loose smut with high yield potential at Bako. Additionally, out of 38 tested sorghum genotypes, four accessions (Acc#70872, 72838, 74098 and 214845) were found completely resistant to covered smuts (Table 21).

Table 21. Selected sorghum accessions resistant to covered kernel smut under artificial inoculation, Sirinka 2001

Genotype	Incidence (%)
Acc#70990	0.0
Acc# 72838	0.0
Acc#74098	0.0
Acc# 214845	0.0
Acc# 69472 (Check)	16
Acc# 69473 (Check)	19
LSD at 0.05	1.875

Source: Sirinka Agricultural Research Center (2001)

Currently, in collaboration with sorghum national breeding program, resistance breeding in sorghum against covered and loose smuts is being investigated since 2005 at Melkassa following artificial inoculation. F1 generation tested in 2005 resulted in no symptom of both covered and loose smuts compared to the susceptible parent materials. Among the crosses involved Seredo X Tetron, 76T1#23 X Tetron, 76T1#23 X Zengada#2 and Meko X Tetron Zengada#2 showed immunity while crosses between Meko X Zengada#2 and Seredo X Zengada#2 showed high resistance. In loose smut experiment, different proportions of diseased plants were observed, particularly in crosses involving 76T1#23 X Tetron and Seredo X Zengada#2, whereas in the other crosses high resistance was observed. In both cases, the parent materials including 76T1#23, Meko, and Seredo showed susceptibility, while the resistant parent material showed no symptoms of both covered and loose smut infections.

The above result reports evidenced that there are various management options to control sorghum covered and loose smuts. Despite all these available potential control options with significant effect, both smuts are still a limiting factor in many regions in sorghum production systems. Though sorghum resistant cultivars to both covered and loose smuts have been reported, such information needs to be generated for different races of smuts across locations.

Chemical control

As both *S. sorghi* and *S. cruenta* are seed-borne, comparatively more research efforts have been mainly focused on evaluating chemical seed treatments (Tyagi, 1978) worldwide. However, this approach is often not easily adapted by the majority of subsistence farmers in Ethiopia and is not sustainable for a variety of reasons, including inaccessibility of the chemicals and lack of safe application methods. Nevertheless, different seed treatments were compared on local sorghum cultivars Degalit planted on May 19 and Jigurti planted on July 3 at Sirinka. Results indicated that thiram/lindane (Fernasa-D) and Apron plus (Thiamethoxan+Mefenoxam+Difenocunazole) reduced both covered and loose smuts incidence in early-planted sorghum, but trace incidence was observed in late-planted sorghum, particularly in covered smut (Table 20).

Of the alternative seed treatment options, cow and goat urine also reduced covered smut incidence in early-planted sorghum except trace incidences of both covered and loose smuts observed in late-planted sorghum. However, natural plant extract gave no better results in controlling both smuts in early and late-planted sorghum. The incidence of both smuts in the untreated control in early planting was 4 and 8%; in late-planted sorghum, it was 16 and 9%, respectively. Yield increase was also obtained in treated plots with Apron plus in both smut experiments in early planted sorghum but had no difference in late-planted sorghum in covered and loose smut treatments (Table 22 & 23). On-farm demonstration also confirmed the potential effect of both synthetic fungicides and alternative sorghum seed treatments. Both fungicides consistently showed high effect in reducing covered smut incidence in early and late-planted sorghum. Yield increase was observed with Apron Plus treatment in early planted, whereas thiram gave better yield than the control in late-planted sorghum. However, it does not seem that resource poor farmers easily adopt this control option effectively.

Table 22. Effect of various sources of seed treatments on sorghum covered smut incidence and yield at Sirinka

Treatment	Early planting (May 19) Varity, Degalit		Late planting (July 3) Varity, Jigurti	
	% incidence	Yield (t/ha)	% incidence	Yield (t/ha)
Fernasan D	0.0b	1.96ab	0.33c	2.85ab
Thiamethoxan+ Mefenoxam+Difenocunazole	0.0b	1.59a	1.0c	2.27b
Natural plant extract	1.7b	1.74ab	11.7ab	4.18ab
Cow urine	0.0b	1.54b	2.3c	4.75a
Goat urine	0.5b	2.03ab	4.0bc	3.98ab
Hot water	0.3b	1.63ab	0.7c	3.79ab
Cold water	4.0a	1.75ab	5.0bc	3.82ab
Control	4.3a	1.53b	16.0a	3.99ab
LSD (0.05)	1.95	0.523	8.58	2.31
CV%	86	16.35	94	35.6

Source: Ethiopian Sorghum Improvement Program Progress Report (1999).

Table 23. On-farm trial on covered smut incidence in combination to various treatments in Sirinka

Treatments	Early planting (May 19)		Late planting (July 3)	
	Incidence (%)	Yield (t/ha)	Incidence (%)	Yield (t/ha)
Fernasan D	0.3	9.8	2	8.1
Thiamethoxan+Mefenoxam+Difenocunazole	0.0	12.4	0	7.4
Natural plant extract	23	7.9	18	7.0
Cow urine	0.5	10.9	0	6.8
Control	38	7.9	62	7.5

Source: Ethiopian Sorghum Improvement Program Progress Report (1999).

Sorghum anthracnose

Anthracnose, caused by the fungal pathogen *Colletotrichum graminicola*, is a worldwide disease of sorghum (38, 39, (Tar, 1962)). The disease is prevalent whenever sorghum is grown in a warm and humid environment and is commonly observed in farmer's fields at Keffa, Wellega, Illubabor and Gonder in the northern part of Ethiopia and in Hararghe (IAR, 1984). Most of the local land races including improved varieties are susceptible to this disease around Bako and East Wellega.

Previously, limited studies have been made on the economic impact of anthracnose on sorghum yield (Abebe et al., 1986), but emphasis was placed on identification of sorghum resistance lines and developing or adapting inoculation techniques for screening sorghum lines. Additionally, knowledge of the pathotype composition of the pathogen in sorghum has been considered for rational deployment of resistance genes in sorghum breeding programs.

Pathogenic variability of sorghum anthracnose

Variability in *Colletotrichum graminicola* in virulence (disease reaction) and aggressiveness (disease severity) is known worldwide (Ferreira and Casela, 1986). Hence, understanding *C. graminicola* variability in sorghum has been a key factor in the successful management of the disease in Ethiopia. Thus, international sorghum anthracnose virulence nursery (ISAVN) was established in Ethiopia and in nine countries in collaboration with International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Data only from Bako was included for the interpretation of virulence nursery worldwide (Kusum et al., 2002). From international perspective, the variability in disease reaction of several international differentials indicates the existence of different physiological races of sorghum anthracnose. Based on the mean severity score across the entries, the population at Griffin was the most aggressive with a mean severity of 7.1 as compared to Bako population (4.1). The Griffin populations caused susceptible reaction on 11 out of 14 test lines, while those from Bako showed on 4 lines out of 14 tested lines.

With respect to national results, variable reactions were observed on sorghum differentials at Jimma, Bako, and Pawe (Table 24). Based on the mean severity score across the entries, the population of anthracnose at Pawe was the most aggressive with a mean severity of 6.1 as compared to Bako (4.1) and Jimma (4.7) populations. The Pawe population caused an S (susceptible) reaction on 8/14 test lines, while those from Bako and Jimma populations caused S reaction on 4/14, and 0/14, respectively. Nevertheless, sorghum line IS 157, which has been used as a main source of resistance for anthracnose resistant development, consistently showed resistant to anthracnose disease suggesting durability to existing anthracnose population across tested locations in Ethiopia. In summary, results from the pathogenicity test indicated significant differences among the differential sorghum cultivars across tested locations. However, there was no definite conclusive evidence for the existence of anthracnose races within the sorghum infecting pathotype in Ethiopia and isolates were not properly identified. Hence, further research is needed to identify the population structure of sorghum anthracnose across locations.

Table 24. Response of some sorghum genotypes to leaf anthracose at Bako, 1989 and 1994, Ethiopia

Genotypes	Anthracnose severity score (1-9 scale)		
	Before heading	Before harvest	Mean
A-467-2	1.0	2.0	1.5
A-477	1.6	3.1	2.4
ICSV 173	1.7	2.5	2.1
IS-8283	1.8	2.0	1.9
M 36203	1.9	4.4	3.2
PB 8843	1.8	2.5	2.2
PVT_1 #37	3.2	2.4	2.8
PVT_2 #6	2.2	2.0	2.1
ETS-3135	1.9	3.5	2.7
RS/R-20-861 X 2/X IS 9379	2.3	2.0	2.2
IS-10892	2.3	2.5	2.4
IS-1584	2.0	4.5	3.3
IS-2139	5.0	9.0	7.0
PVT_2 F^1	1.8	4.2	3.0

Source: Bako Agricultural Research Center progress report (1993).

Sources of resistance

Of all possible disease control methods for sorghum anthracnose, the use of disease resistant material offers the most satisfactory means of reducing losses (Rosenow, 1992). Sources of resistance to various sorghum foliar diseases are also known worldwide (Sharma, 1978). There has also been considerable evidence that show a number of sorghum genotypes resistant to anthracnose, grain mold, ergot and other foliar diseases in Ethiopia.

A total of 150–200 sorghum genotypes accessions obtained from the Ethiopian Sorghum Improvement Program and ICRISAT were evaluated against sorghum anthracnose. Although disease incidence and severity varied across the region, fairly a number of resistant sorghum genotypes were identified in all tested sites. Out of tested sorghum accessions, eight entries were selected with the highest degree of resistance to anthracnose. The apparent infection rate of the resistant entries was lower –r=0.02 as compared to the susceptible entry with the rate ranging from r=0.04 to 0.14 (Girma et al., 1995).

Additionally, a number of sorghum germplasm were evaluated at heading and before harvesting to see their reaction at different sorghum growth stages (Table 32). As it was shown anthracnose disease pressure increases as the crop grows but severity varies among tested sorghum germplasm. However, disease severity was comparatively less in sorghum genotypes A-467-2, IS-8283, PVT_2 F^1.

Moreover, intensive screening for the search of resistance for various diseases has been conducted in various research centers and in other Institutions. In the evaluation of multiple disease resistance that was conducted in 1989–1993, 85 MW-549, a highly resistant to major diseases at Bako and Dedissa, was identified. Other sorghum genotypes including 85 K MW 6217, 86 JM 4189, Dedessa 1057 and 85 BK F_6 #6296-2 were also found relatively resistant to tested diseases. Two other sorghum genotypes 86 BK 4174 and 86 JM 4176 were also found to be immune to most diseases, except to leaf rust. Moreover, the multiple resistance screening trial at Bako resulted in the identification of 85 K 6217, 86 MW 5259, 85 BK F_6 #6296-2, 86 JM 4189 and Dedessa 1057, which are resistant to anthracnose, leaf rust, cercospora leaf spot, leaf blight and other leaf spots. On the other hand, 85 MW 5363, 86 JM 4157, 86 BK 4174 86 JM 4176, 86 BK 4177 were found to be relatively susceptible to rust, but resistant to other diseases.

In another screening experiment that include early, intermediate and late maturing group of sorghum genotypes indicated that among the early maturing cultivars Acc. No. 690276 and 69035, from intermediate group Acc. No. 690058, 690136 and IS 25555 and from late maturing IS 9308 were identified resistant to anthracnose, rust and oval leaf spot diseases. However, grain yield and 1000 seed weight varied greatly among the groups and high yield was obtained from the late maturing variety IS 9308, but high 1000 seed weight was obtained from early maturing group. In addition, in another experiment eleven genotypes were found resistant to anthracnose of which six were found tolerant to bird damage with good agronomic performance.

Although significant number of resistant sorghum germplasm has been identified for various diseases, the role of these resistant sorghum germplasm in sorghum improvement is yet to be seen. In addition, sources of resistance to foliar anthracnose are known but resistance for grain and stalk anthracnose and their significant role in the build up of the disease (Fredericksen et al., 1984) have to be considered under Ethiopia conditions. Furthermore, a positive correlation between grain and foliar anthracnose has been reported elsewhere (Harris and Johnson, 1967), while other studies reported that lines resistant to foliar anthracnose are susceptible to grain anthracnose (Hazra, 1998; Mathur et al., 2000). However, this relationship has not yet been confirmed in Ethiopia. Thus, there is a research gap in understanding the foliar anthracnose resistant sorghum in relation to grain mold.

Grain mold

Currently, over 20 causing agents of grain mold have been isolated from either matured sorghum grain under field condition or in stored grain sorghum (Bandyopadhayay, 2002). Grain mold complex is more serious particularly where sorghum is growing in warm and wet weather conditions and increases in severity if harvesting is delayed after grain maturity (Tar, 1962; William et al., 2002; William et al., 1981). Apparently, the disease is more pronounced in improved early maturing than late maturing sorghum varieties as the late maturing varieties mature at the end of the rainy season and escape grain mold infection (William et al., 1981). Although various improved sorghum varieties have been released in Ethiopia in the past, none of them showed good grain mold resistance in the wet and humid environments.

Sources of resistance

Major research efforts to manage grain molds still rely on host plant resistance. Hence, diverse sorghum genotypes collected from various sources have been evaluated. Thirty-eight advanced elite materials collected from the Ethiopian National Sorghum Improvement Program and 40 germplasm accessions collected from ICRISAT were planted and visually assessed after harvest at Pawe, Bako and Jimma. After subsequent evaluations eight genotypes, which showed a moderate to high degree of grain mold resistance, were identified (Girma et al., 1995). In another grain mold screening trial at Bako, three sorghum genotypes (IS-25576, 9326 and 25555) were found resistant to grain mold and showed good agronomic performance with high percent of seed germination.

In the past, most screening techniques used to identify grain mold resistance relied on the extent of glum cover on the grain, panicle compactness, and pericarp color. Presently, a biochemical factor in screening for grain mold is gaining importance (Hagerman and Butler, 1994) and a considerable knowledge base exists on bio-chemical factors that regulate grain mold resistance in sorghum (Bandyopadhayay, 2002). Level of grain mold resistance is considered to be dictated by the presence of various levels of phenolic compounds and low level of ergostrol in the resistant sorghum materials. In this regard, Tarekegn et al. (2006) has studied the biochemical response of resistant and susceptible sorghum cultivars collected from Ethiopia and South Africa. According to authors' investigation, the resistant sorghum cultivars have shown high level of glum proanthocyanidins, seed Falvan-4-ols and low level of ergostrol than the susceptible sorghum cultivars.

Fungal infection in seed components

In the past, the mycoflora associated with the grain sorghum in pits was established (Solomon and Mengistu, 1984). However, a preliminary study on the mycoflora of sorghum grain, conducted at the laboratory of Danish Institute of Seed Pathology, indicated the presence of different genera of fungi causing grain mold on sorghum grain collected from Nazreth, Mieso, Bako, Pawe and Jimma (Mohamed, personal communication). The fungi most frequently isolated from the collected samples were *Phoma sorghina, Colletotrichum* and *Fusarium moniliforme,* with mean of 57, 29 and 4%, respectively. However, the frequency of isolated pathogens varied with geographic locations. For example, *Colletotrichum* spp. was isolated only from grains collected from Bako and Jimma, while *Phoma sorghina* was isolated from sorghum grains from all locations. Other fungi were found specific and varied with locations collected. Relatively few pathogens were isolated from sorghum samples collected from Nazreth and Miesso, while more population of fungi were isolated in sorghum samples collected from Bako and Pawe.

In addition, the following fungi, which cause grain mold in stored sorghum grain, have also been isolated from sorghum seed collected from local farmers around Bako: *Colletotrichum, Fusarium, Aspergillus, Penicilium, Phoma, Rhizopus, Alternaria, Helminthosporium,* and including new fungi, which was not yet identified. Of all detected fungi, *Colletotrichum* spp. was commonly observed in all sampled sorghum grains. Results of percentage infection varied with year. Sorghum grain infected with *Fusarium moniliforme* and *Aspergillus* spp. were 6.9, 6.1%, in 1996, 6.4, 8.6% in 1997, respectively. The highest mean infection percent (10.6%) was recorded for *Penicillium* spp. in 1997. Contaminated sorghum seed with grain mold showed low percent of seed germination and low seedling establishment ranging from 8 to 16% in 1996 and 1997 with the average of 12%.

Similar study was conducted at Alemaya. A number of fungal pathogens such as *Phoma insidiosum, Stemphylium* spp., and *Mycospharella* spp. *Alternaria* state of *Pleospora infectoria* Fuckal, *Rhizopus stolonifer, Penicillium* spp., *Fusarium moniliforme* Sheld, *Aspergillus niger, Trichoderma koningii, Cunninghamella elegans, Helminthosporum* spp., and *Mucor* spp were identified. Moreover, the predominant species of Phoma *sorghina* and *Colletotrichum graminicola* were isolated from different sorghum varieties collected from different locations in eastern Ethiopia. However, the frequency of P*homa sorghina* was much higher in early maturing varieties than in the late maturing sorghum variety (ETS 2572).

Although the above information has increased our knowledge of pathogen population of the causal agent of grain mold in under field and stored sorghum grain conditions, the association of incidence of storage fungi and the relative humidity of the storage environment and the type of storage structures is not yet clear. Additionally, the relative risk of mycotoxins in infected sorghum grain to human or domesticated animals is not yet explained.

With regard to selection method for grain mold resistance, it appears that there is a possibilities to apply both visual and biochemical analysis to identify the most durable grain mold resistant varieties. It was also proved that grain mold resistant was not only associated with morphological character of the resistant genotypes but also related to important chemical components that indicate the possible resistant mechanism of sorghum varieties resistant to grain mold

Sorghum ergot

Sorghum ergot is a potential threat to hybrid sorghum, where male sterile is used in developing hybrid. In view of developing sorghum hybrid, an attempt was made to select sorghum local land races against ergot disease at Arsi Negele following an artificial inoculation in 1988, and six sorghum land races with reduced ergot incidence were selected (Girma et al., 1990). These promising sorghum land races were evaluated elsewhere of which sorghum genotype ETS 1446 was found to be highly resistant to ergot disease (Frederickson et al., 1994).

Finger blast diseases

Virtually there is no control practice to manage blast disease in finger millet production systems at present. However, few lines with low level of blast incidence have been identified at Bako. Among 18 finger millet accessions tested Acc. # 49442, comparatively showed low level of blast incidence (6.78%), while others showed variable degree of disease incidence. However, they are better than Acc # 203405, which showed high level of blast incidence. Some of the resistant or tolerant accessions showed better agronomic performance and may be used by direct cultivation or for breeding program.

Conclusions and recommendations

Evidently, adequate research information has been accumulated in the last 20 years that provides a good understanding of major diseases that could be applied for the control of sorghum and millet diseases.

Survey results revealed the importance of sorghum diseases across sorghum growing regions and indicated the emerging of new disease, Pokkah boeng, and unknown grain mold pathogen. An alarming expansion of ladder leaf spot across sorghum growing regions has also been emphasized. Improved screening techniques for ergot, anthracnose and bacterial streak diseases have increased the probability of success in selecting highly resistant sorghum germplasms. In addition, biochemical-based selection of sorghum germplasm for grain mold resistance has proven the success of the selection method, which previously has been based on visual assessments.

In the absence of cheap fungicide for sorghum seed treatment for resource poor farmers, application of readily available cow and goat urine as sorghum seed treatments reflects the demand of small-scale farmers. The practice seems simple, economical and practical. In addition, in light of the current *Endod* production both in homestead and large-scale in Ethiopia and the natural abundances of *Maesa lanceolata* in most regions could permit production of formulated products derived from plants in the future. When available, applications of Thiram and/or Apron star are also important for seed industries due to the impact of the disease on seed production.

Recommendations

- Removing and destroying infected plants with sorghum smuts immediately after noticing them in the field need to be practiced. If feasible, early planting sorghum is advisable, particularly to control sorghum covered smut;
- Promote the application techniques of seven days fermented cow and goat urine that diluted with water proportionally (1:1) to control sorghum covered and loose smuts under small-scale farming system. If feasible, treating sorghum seed with thiram and/or with Apron star is essential to control both covered and loose smuts;
- Some local sorghum cultivars have been demonstrated to be resistant to covered smut. Hence, adoption and dissemination of these cultivars should be encouraged. Genetic enhancement for agronomic traits is highly desirable to transfer disease resistance into cultivars with adaptation to different agro-ecosystems;
- Use of intercropping or tolerant cultivars is needed to minimize the development of sorghum anthracnose disease;
- Natural plants for control of sorghum covered and loose smuts are found effective and need to utilize whenever feasible as some wild plants are found in abundance in some regions;
- In addition to grain color, glume color and panicle compactness, bio-chemical analysis of sorghum grain as selection criteria should be emphasized for grain mold resistance; and

- Although information in finger millet disease management is very little, it was reported that some finger millet varieties are found resistant to blast diseases. Thus, direct use of these varieties has advantage to manage the disease.

Gaps and challenges

- Although there is reasonable understanding of sorghum diseases on their distribution and some aspect of their management, there is little information on the dynamic nature of sorghum diseases in relation to crop growth, cultural practices and the environment. This needs further investigation;
- Finger millet is one of the important traditional cereals that are adapted to some selected localities; however, the relative importance of diseases are not adequately understood;
- The available inoculation techniques seem applicable to only limited diseases, and more techniques suitable for other sorghum diseases need to be developed;
- Study of variability in *C. graminicola* in Ethiopia, although not exhaustive, indicate the occurrence of variation in the pathogens aggressiveness across locations. Hence, identification of new sorghum resistance sources should be done in areas where *C. graminicola* intensity is high, particularly at Pawe;
- Most resistant screening against sorghum anthracnose disease has been concentrated mainly on foliar anthracnose but the possible relationships between grain and stalk anthracnose infection need to be included in the future;
- The effect of plant extract on sorghum smut teliospore development and the shelf life of botanical extracts need further investigation;
- Numerous sources of resistance have been identified among accessions or landrace of sorghum and finger millet germplasm to one or more foliar diseases. However, there seems to have been relatively little direct use of accessions selected for targeted diseases. The contribution of those identified resistant sorghum or finger millet genotypes in the breeding process or the continuation of studies following breeding is also a critical gap; and
- Furthermore, understanding the resistance mechanisms is the most critical limitation in improving durable sorghum varieties. This is particularly important in grain mold screening when malting is envisaged in the future program. This is because for grain mold resistant tannin is the major important component while in malting it is not required. In general, there is a need to assemble all the reported sources of resistance and evaluate them together under common conditions to confirm the reported resistance.

Future prospects

- Conduct regular and systematic survey to identify and describe sorghum and finger millet diseases causal agents, and determine their distribution and population structure in field and storage conditions. Thus, establishment of interregional sorghum disease survey and setting of research priorities is needed;
- Continue selection of sorghum and finger millet germplasm for disease resistance and organize multilocational testing for the identified resistant sorghum and millet germplasm is needed to understand stability across locations;
- Determining genetic variability of germplasm depends primarily on the availability of reliable methods for detection resistant germplasm to targeted pathogens. Hence, adoption of the already existing screening techniques is necessary to identify resistant sources of sorghum germplasm and need to understand the mechanisms and genetics of the resistant germplasm;
- Strengthen collaboration with breeders in order to utilize resistant source of sorghum and finger millet and devise follow up actions is essentially important;
- Assess the influence of pre harvest disease conditions in relation to grain mold development, such as studies on inoculums sources and the infection process; and post harvest environment such as humidity and grain storage structure is necessary;
- Demonstrate and promote the already existing traditional practices to manage sorghum smuts as seed treatment and evaluate more other relevant traditional practices is required;
- The virulence test of sorghum for anthracnose has been attempted but not conclusive and further collaborative research is needed;
- Devising technology transfer mechanisms to demonstrate and disseminate available and proven sorghum disease management practices has to be emphasized;
- Need to systematically investigate finger millet diseases and search management solutions; and
- Investigating the interaction of sorghum growth stage, pathogens, and environment to establish epidemiological parameters is essential to understand the disease epidemics.

Appendices

Table 1 . Gray leaf spot disease severity in some areas of Ethiopia, 1997 and 1998

Zone	District	Site	Altitude	Variety	Severity	
					Rating*	% severity
Western Wellega	Nole Kabba	Alage Jarso	Mid	Local BH660	5 5	 -
	Haru	Kombolcha	Mid	Local BH660	4 3	-
	Dale Lalo	Jarso Damara	Mid	Local Phb-3253 BH660	5 5 3	-
	Seyo	Yangi	Mid	Local BH140	5 5	- -
		Dale Tabor	Mid	BH660 Phb-3253 BH540	2 5 5	- - -
	Ayira Guliso	Degaga Ayira	Mid	Local Phb-3253 BH140	5 5 3	- - -
Illubabor	Aledidu	Gumero Abo	Mid	Local BH660	4.5 3.5	- -
	Halue Bure	Megersa Adare	Mid	Local BH660	4 4	- -
	Darimu	Jarso Tulama Boto	Mid	Local Phb-3253 BH660 BH660 BH140	4 5 4 4 4.5	- - - - -
	Algesachi	Mogu Chomosso	Mid	Local BH660 BH140	4.5 3.5 3.5	- - -
	Yayu	Achebo Wagegne	Mid	BH140 Local Phb-3253 BH660	- - - -	17 45 65 13
Jimma	Seka Chekorsa	Alo-Sebeka Alo-Sebeka Kofee	Mid	BH660 Local BH660	- - -	35 40 20
	Limmu Kosa	Arengama	Lowland	Phb-3253 BH140	- -	ns 25

'-' Data not recorded; Mid - medium altitude (1600-1850 m.a.s.l.) ; Lowland > 1600 m.a.s.l

* Disease rating score 1= resistant, 5=susceptible

Source: Dagne *et al.*, 2001

Table 2. Incidence and severity of major maize leaf diseases in southern Ethiopia, during 2003 and 2004 crop season. (Mean of 5 Locations per Woreda)

Zone	Woredas	TLB[a]		CR[b]		GLS[c]	
		Incidence ((%)	Severity (%)	Incidence (%)	Severity (%)	Incidence (%)	Severity (%)
Sidama	Hawassa Zuria	96	2.5	100	3.0	86	2.5
	Shebedino	84	3.0	100	3.0	70	2.7
	Boricha	70	2.3	72	2.5	54	2.1
	Dalle	80	2.5	56	2.5	59	2.7
	Aleta Wondo	100	3.0	58	2.6	100	3.6
	Agere Selam	67	2.5	45	2.1	80	3.0
North omo	Sodo Zuria	89	3.2	70	3.2	100	3.5
	Humbo	58	2.1	67	3.0	49	3.0
	OFA/Gesupa	62	2.5	58	2.6	50	2.3
	Damot weide	74	2.5	55	2.5	33	1.7
	Boloso Sore/Areka	86	3.5	90	3.5	100	3.5
Gedeo	Dilla/Wonago	88	2.5	70	3.0	68	2.5
	Yirga chefe	72	3.0	50	2.5	45	2.5
	Kochere.	54	2.2	48	2.0	51	2.2
Gurage	Enemor	100	4.0	42	2.2	-	-
	Ener	82	3.0	38	2.0	-	-
Oromya	Zeway	52	2.3	100	3.2	25	2
	Billito/Siraro	100	3.5	70	2.5	100	3.5
	Arsi Negelle	70	2.5	100	4.0	50	2.5
	Shashemene(s hallo seed prodn. Field)	80	3.0	91	3.0	72	2.5
	Aje	52	2.5	100	3.0	71	3.0
Special woreda.	Alaba Kulito	50	2.0	52	2.0	50	2.5

[a] *TLB= Turcicum Leaf Blight,*
[b] *CR= Common Leaf rust*
[c] *GLS= Gray Leaf Spot*
Source:(EIAR), Awasa National maize Project. Progress report, 2004

Table 3a. Incidence and severity of major maize diseases in western Ethiopia, 2003

Zone	Woredas	Locality[a]	Variety	PLS		GLS		TLB		CR		CLS	
				Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)
Jimma	Omonada	Eldashne	BH-660	65.83	1.88	81.25	2.38	63.333	2.13	53.75	1.50	45.40	1.50
		Coticha	BH-660	38.33	2.13	88.75	3.13	64.58	2.25	58.33	1.50	48.33	1.75
	Sokoru	Algae	BH-660	85.85	2.38	86.65	2.38	81.25	2.00	62.90	1.50	25.40	1.63
		Bidiru	BH-660	82.93	2.50	86.65	2.13	59.18	1.63	67.50	1.63	38.35	1.63
	Sigmo saxama	Ambu	Local	100	5	56.65	2.63	67.08	2.13	77.50	2.50	34.58	1.63
		Jimmate	Local	96.65	4.5	85.80	2.63	81.65	2.63	69.15	1.63	36..68	1.75
Illubabor	Bedele	Cherise	BH-660	99.15	4	87.90	1.75	57.48	1.88	72.53	1.75	25.83	1.63
		Qumbo	BH-660	100	4.5	82.90	2.38	70.85	2.38	79.15	1.75	23.33	1.63
	metu	Sore	Local	87.90	2.75	88.35	2.25	70.85	2.00	67.90	1.50	16.25	1.63
		Mendido	Local	82.56	1.88	84.58	1.63	81.25	1.75	80.43	1.50	16.65	1.63
	Darimu	Kulu	Phb-30h83	82.93	1.88	60.83	1.50	95.00	2.38	77.05	1.50	38.75	1.50
		Haro	Local	72.05	1.88	75.85	1.63	71.68	1.88	60.85	1.63	37.50	1.63
		Gutiye	Local	83.36	2.50	86.25	2.50	77.50	2.13	62.95	1.63	24.18	1.63
West Wellega	Sayo	Amdo	BH-660	88.73	2	91.65	2.00	98.33	2.75	65.80	1.50	4.08	1.63
		Gobaya Kamissa	BH-660	86.25	1.63	91.68	2.13	90.83	2.13	51.25	1.50	29.18	1.75
	Iiraguliso	Kurfe	Local	81.28	1.63	60.40	1.63	85.43	2.25	41.65	1.50	50.40	1.75
		Kurfesa Birbir	Phb- 30h83	62.93	2	30.40	1.50	98.75	4.13	45.00	1.50	32.53	1.75
		Gemeda	BH 140	86.65	2.38	65.00	1.63	97.50	2.88	56.25	1.50	34.18	2.00
	Gimbi	Nuri	BH-660	100	5	73.33	1.75	94.60	2.88	61.25	1.63	31.65	1.50
		catolic	BH-660	96.65	4	75.00	1.75	85.00	1.88	55.83	1.50	53.73	1.75

Table 3b. A mean of four samples at each locality

Zone	Weredas	Locality	Variety	PLS		GLS		TLB		CR		CLS	
				Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev. (1-5)	Inc. %	Sev (1-5)
West Showa	Bako Tibe	laga Qala	BH-660	44.19	1.10	90.7	1.90	81.4	1.8	27.13	1.10	27.13	1.00
		Olda oda	BH -660	14.88	1.0	86	1.50	30.58	1.17	7.44	1.00	9.09	1.00
			Gutto	13.18	1.00	76.92	1.75	70.77	2.25	67.69	2.25	00	00
			Local	12.07	1.00	72.41	1.5	65.52	1.75	74.14	2.25	17.24	1.5
	Cheliya	Siba	BH-660	27.27	1.00	94.21	2.63	48.76	1.5	19.01	1.00	49.59	1.00
		Qarsa	BH-660	24.18	1.13	98.9	2.63	68.13	1.25	23.08	1.00	70.33	1.00
		Biche	BH-660	35.24	1.00	83.81	1.63	87.71	1.25	16.19	1.00	40.95	1.00
East Wellega	Sibu Sire	Moto chekorsa	Pioneer hb	17.28	1.00	44.44	1.00	77.78	3.00	67.90	2.25	00.00	00.00
		Aroch	BH-660	59.31	1.63	86.9	1.38	82.76	2.00	20.00	1.00	18.62	1.00
		Abulu	Local	52.99	1.5	76.92	1.38	81.2	2.13	19.66	1.00	11.11	1.00
	Gobu Sayo	Anno	BH-660	43.35	1.25	83.82	2.13	35.84	1.38	38.73	1.13	26.01	1.13
		Baffano	BH-540	14.86	1.00	74.32	1.00	100.00	3.25	97.3	4.00	14.86	1.00
		Qejo	BH--660	31.25	1.00	78.69	1.66	52.11	1.25	32.4	1.00	00.00	00.00

Source: Assefa, 1999

Table 4. Maize yield due to gray leaf spot at Bako 2001

Varieties	Treatments	Yield	1000 seed weight	% yield loss
BH-660	Inoculated	10.9	369.7	
	Sprayed	10.4	355.7	0.0-14.9
	Control	9.1	377.2	
BH-140	Inoculated	8.0	309.1	
	Sprayed	9.2	362.1	13.7-18.3
	Control	8.8	354.5	
PHB-3253	Inoculated	7.1	332.2	
	Sprayed	9.0	353.8	20.8-36.9
	Control	7.9	331.9	
Mean		8.9	349.6	
CV %		13.1	9.1	
SE		0.7	18.4	

Source: Bako National Maize Research Project, Progress Report, 2001

Table 5. Effect of sowing date on disease severity of four varieties

Treatments	**Average severity (1-5 scale)**	
	TLB	GLS
Varieties		
-BH-140	1.156bc	1.373b
-Beletech	1.196a	1.526a
-Gutto	1.166b	1.430b
-Kuleni	1.14c	1.369b
LSD	0.023	0.062
CV (%)	3.15	5.77
Sowing Dates		
-First sowing	1.188	1.504a
-Second sowing	1.153	1.423b
-Third sowing	1.169	1.475ab
-Forth sowing	1.155	1.414b
-Fifth sowing	1.160	1.305c
LSD	NS	0.069
CV (%)		5.77
Variety x Sowing date		
-Var. 1 x 1st Sowing	1.143defg	
-Var. 2 x 1st,	1.121g	
-Var. 3 x 1st,,	1.164cdefg	
-Var. 4 x 1st,,	1.180bcdefg	
-Var. 1 x 2nd,,	1.175cdefg	
-Var. 2 x 2nd,,	1.247a	
-Var. 3 x 2nd,,	1.23ab	
-Var. 4 x 2nd,	1.185bcdef	
-Var. 1 x 3rd,,	1.156cdefg	
-Var. 2 x 3rd,,	1.157cdefg	
-Var. 3 x 3rd,,	1.156cdefg	
-Var. 4 x 3rd,	1.129efg	
-Var. 1 x 4th,,	1.201abcd	
-Var. 2 x 4th,,	1.157cdefg	
-Var. 3 x 4th,,	1.189abcde	
-Var. 4 x 4th,,	1.205abc	
-Var. 1 x 5th,,	1.125fg	
-Var. 2 x 5th,,	1.126fg	
-Var. 3 x 5th,,	1.127efg	
-Var. 4 x 5th,,	1.120g	
lsd	0.052	NS
CV (%)	3.15	

Means followed by the same letter(s) are not significantly different (DMRT).
Source: Bako National Maize Research Project, Progress Report, 2001

Table 6. Evaluation of CIMMYT lines for resistance to Turcicum leaf blight and Gray leaf spot

Entries	Average Severity TLB	Average severity GLS
[INTB-F2-111-3/INTB-277-1-2]-X-2-1-4-B-B	1.778ab	2.056bcde
Sc (PHAM)-3/[[CML-205/Sc//CML-202]-X]-4-B-B	1.74ab	1.74defg
DRB-F2-60-1-2-B-1-B-B-B	1.74ab	1.444fg
LATA-26-1-1-1-1-6-B-B	2.000a	1.667efg
[[NAW5867/P30-SR]-40-1/[NAW5867/P30-SR]-25-1-2-2-B-1	1.667bc	2.278abc
DRA-F2-141-2-1-1-B-4-B-B	1.389c	1.333g
DAB-F2-60-1-2-B-1-1-B-B	1.778ab	1.444fg
[DRA-F2-5-2/ DRA-F2-70-3]-X-7-2-4-B-B	1.778ab	1.944bcde
[SNSYN-F2 (N3) TUX-A-90]-102-1-2-2-2-BSR-B-2-B-B	1.778ab	2.111bcde
DRA-F2-141-3-2-1-1-B-B	1.778ab	2.611a
[INTB-277-1-2/ INTB-197-2-1]-x-9-2-1-B-B	1.778ab	1.889cdef
ZM-605-C2-F2-428-3-B-B-B-B-B	1.778ab	1.778defg
DRA-F2-141-2-1-1-10-B-B	1.611bc	1.444fg
Sc (PHAM)-3/[[CML-205/Sc//Sc]-X]-1-1-B-B	1.611bc	2.389ab
LATA-26-1-1-2-1-1-B-B	1.74ab	2.167abcd
LSD	0.259	0.413
CV (%)	8.96	13.09

Means followed by the same letter(s) in a column are not significantly different (DMRT).
Source: Bako National Maize Research Project, Progress Report, 2001

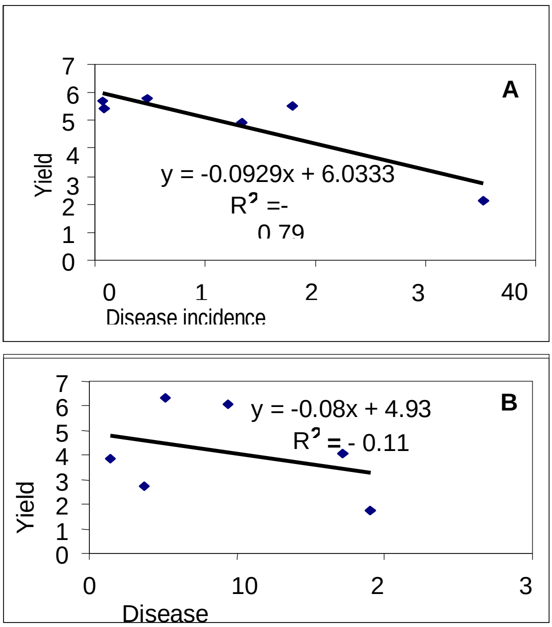


Figure 1. Relationship between sorghum loose (A) and covered (B) kernel smuts incidence and sorghum yield at Melkassa Research Center
Source: Girma Tegegne and Johan C. Pretorius., 2007

Table 7. Evaluation of sorghum seed treatments on sorghum loose smut incidence and yield at Sirinka

Treatment	Early planting (May 19)		Late planting (July 3)	
	Incidence (%)	Yield (t/ha)	Incidence (%)	Yield (t/ha)
Fernasan D	0.0b	1.86ab	0.0c	2.96b
Thiamethoxan+Mefenoxan+Difenocunazole	0.0b	2.13a	1.7bc	2.98b
Natural plant extract	5.0a	1.77abc	4.0bc	4.17ab
Cow urine	0.0b	2.04ab	0.0c	4.98a
Goat urine	0.0b	1.63bc	0.0c	4.17ab
Hot water	0.0b	1.39c	0.7bc	2.72b
Cold water	3.7ab	1.73abc	5.3ab	3.77ab
Control	7.7a	1.63bc	9.3a	3.83ab
LSD (0.05)	4.3	0.41	5.06	1.66
CV%	4	13	25	25.7

Source: Ethiopian Sorghum Improvement Program Progress Report (1999).

References

Abebe Menkir, Yilma Kebede, and Berhane Gebrekidan. 1986. Incorporating anthracnose resistance into indigenous sorghums. *Ethiop. J. Agric. Sci*. 8: 73-84.

Abera Geyed and Admasu Maru. 1987. A survey of Aflatoxin content in Maize, sorghum and tef samples. *Ethiopian Journal of health Dev*. 2:59-70.

AARC (Adet Agricultural Research Center). 1999. Progress report.

Adlakha, K. L., and Munjal, R. L. 1963. Reaction of some varieties of *Sorghum vulgare* to *Sphacelotheca sorghi* (Link) Clint. *Indian Journal of Agricultural Science* 33: 8-10.

AU (Alemaya University). 2002. Proceedings of the 19th Annual Research and Extension Review Meeting.

Alemu Lencho, Adane Abraham, Berhanu Bekele, Mesfin Tessera. 1999. Identification of virus in maize and grass hosts. *Pest Management Journal of Ethiopia*. 1:73-76. Pp.

Assefa Tefferi and Legesse Wolde. 1996. Report on assessment of ear rot situation and recommendation of seed production field of Horro Alleltu/Didessa valley. A field trip report submitted to Bako National Maize Research Program. EARO, Addis Ababa, Ethiopia.

Assefa Tefferi and Mengistu Hulluka. 1995. Pathogenic variation of *Exserohilum turcicum* isolates on maize (Zea mays) variety Beletech. Pp. 157-164. *In:* Proceedings of the third annual conference of the crop protection society of Ethiopia. 18-19 May 1995, Addis Ababa.

Assefa Tefferi and Tewabatch Tilahun, 1993. .Review of maize diseases. research in Ethiopia. Pp.43-51. Benti Tollesa and Joel .K. Ransom (eds.).1993. Proceedings of the First National Maize Workshop. 5-7 May 1992. IAR/CIMMYT, Addis Ababa, Ethiopia.

Assefa Tefferi. 1997. Management of two major diseases of maize in Ethiopia. *African Crop Science Conference Proceedings*. 3:913-920.

Assefa Tefferi. 1999. Survey of maize diseases in western and northwestern Ethiopia. Pp. 121-124. *In:* Maize Production Technology for the Future: Challenges and Opportunities. Proceedings of the 6th Eastern and Southern Africa Regional Maize Conference. CIMMYT/EARO.

Awgechew Kidane. 1982. Additional index of plant diseases in Ethiopia. IAR, Addis Ababa. pp.17.

BARC (Bako Agricultural Research Center). 1990/91. Progress report,

BNMR (Bako National Maize Research). 2001. progress report.

BRS (Bako Research Station). 1975. progress report for April 1974 – March 1975. Addis Ababa. pp. 136-139.

Bandyopadhyay, R., Christopher R. L., Ralph, D. W. and David R. B. 2002. Sorghum Grain Mold: Through the 1999$_s$ into the New Millennium. Pp. 173-190. *In:* Sorghum and Millet Diseases: A Second World Review. John F. Lwaliw (Ed.). World Agriculture Series, Iowa State Press.

Bruce, A. Maunder. 2002. Sorghum Worldwide. Pp. 11-17. *In:* Sorghum and Millets Diseases. John F. Lwaliw (Ed.). Iowa State Press.

Burdon, J. J. 1992. The growth and regulation of pathogenic fungal populations, p. 173-181. *In:* G. C. Carroll and D. T. Wicklow (eds.), The fungal community: Its Organization and Role in the Ecosystem. Marcel Dekker, New York City, New York.

Carlos De Leon. 1984. Maize disease. A guide for field identification CIMMYT, 1984.

Chemeda Fininsa and Jonathan Yuen. 2001. Association of maize rust and leaf blight epidemics with cropping systems in Hararghe highlands, eastern Ethiopia. *Crop Protection* 20: 669-678.

Clawson, D. L. 1985. Harvest security and intraspecific diversity in traditional tropical agriculture. *Econ. Bot.* 39:56-67.

CSA (Central Statistic Authority). 1996. Agricultural sample survey 1995/96 (1988 E.C.): report on area and production for major crops (Private peasant holdings). Addis Abeba, June 1996. Statistical bulletin, 152.

Dagne W., Demisew A., Girma D. 2004. Assessments of losses in yield and yield components of maize varieties due to gray leaf spot. *Pest Management Journal of Ethiopia.* 8: 59-69.

Dagne W., Habtamu Z. Singh and Hussien T. 2003. Inheritance of gray leaf spot (GLS) resistance in selected maize inbred lines. *African Plant Protection* 9 (1): 53-59

Dagne Wegary, Fekede Abebe, Legesse Wolde and Gemechu Keneni. 1999. Gray leaf spot disease: A potential treat to maize Production in Ethiopia. Pp. 147-157. *In:* Proceeding of the Ninth Annual Conference of the Crop Science Society of Ethiopia (CSSE). 4-23 June 1999, Sebil. Vol. 9. Addis Ababa Ethiopia.

Dales, M. J. 1996. Sustainable practices for plant disease management in traditional farming systems. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi: Wewtview Press

Dawit Abate and Berhane Abegaz Gasje. 1985. Prevalence of aflatoxin in Ethiopia on cereal grain. A preliminary Survey in Ethiopia. *Medical Journal* 23:143-148.

Dereje Ashagari. 1971. Importance of sorghum smuts and their control in the Alemaya area. *Plant Science Annual Progress Research Report.* 1:45-50.

Dogget, H. 1970. Sorghum. London, UK: Longmans, Green and Co. 403 pp.

EARO Progress Report. Ethiopian sorghum improvement program, progress report no.26.1998. pp. 44-47.

EARO. 1999. Annual progress report for 1997/98. EARO, Addis Ababa, Ethiopia.

EARO (Ethiopian Agricultural Research Organization). Hawassa national maize project progress report for 1999 and 2004. Hawassa.

Eshetu Belete, Temam Hussein and PK Sakhuja. 2006. Yield losses in sorghum due to covered kernel smut in Northeast Ethiopia. *Pest Management Journal of Ethiopia.* 10: 61-67

Fekede Abebe and Kedir Wako.2000. Paper presented in Crop Protection Society of Ethiopia in Eight Annual Conference. Pp. 10-11. (unpublished).

Fekede Abebe and Kedir Wako.2004. The potential of some botanicals in controlling covered smut of sorghum at Bako. (*in press*).

Ferreira, A. S., and C. R.Casela. 1986. Races pathogenices *de Colletotrichum graminicola*, agent causal de anthracnose em sorgho [*Sorghum bicolor* (L.) Moench]. *Phytopatol. Brazil*. 11:833-837.

FVR (Field Visit Report). 2003. Evaluation of the response of hybrides under production against maize diseases. At Wondo Tica Siraro and Billito. On 20 September and 3 October 2003. Hawassa, Ethiopia.

Frederickson, D. E., Mantle, P. G and Milliano, W. A. J. DE. 1994. Susceptibility to ergot in Zimbabwe of sorghums that remained uninfected in their native climates in Ethiopia and Rwanda. *Plant Pathology* 43: 27-32.

Frederiksen, and G. D Bengston (eds.), Sorghum and millet diseases: Pp. 319-328. *In:* Sorghum and millets miseases: a second world review. W.A.J. de Milliano, R.A. Frederiksen and G.D. Bengston (Eds.). Iternational Crops Research Institute for the Semi-Arid Tropics Patancheru, Andhra Pradesh 502 324, India.

Frederiksen, R. A. 1984. Anthracnose stalk rot. Pp.37-42. *In:* Sorghum root stalk rots, critical review. Proceeding of the consultative group discussion on research needs and strategies for control of sorghum root and stalk rot diseases, 27 Nov-2 December, Bellagio, Italy. ICRISAT. Patancheru, A. P. India.

Gilman, G.A . 1967. Storage problem in Ethiopia with special reference to determination by fungi. Nov. 1967-Feb.1968. Tropical produ. Institute report. 48. Pp.

Girma Tegegne and Johan C. Pretorius. 2007. *In vitro* and *in vivo* antifungal activity of crude extracts and powdered dry material from Ethiopian wild plants against economically important plant pathogens. BioControl. Available: http://www.springerlink.com/content/96r 100717857r 724/fulltext.html. Pp. 1-14

Girma Tegegne, Bandyopadhyay, R., Mulatu, T., and Kebede.1994. Screening for ergot resistance in sorghum. *Plant Disease* 78: 873-876.

Girma Tegegne, Erenso Degu and Aberra Debelo. 1995. Breeding for disease resistance with emphasis on durability. Proceedings of a regional workshop for Eastern Central and Southern Africa, Njoro, Kenya, october 2-6, 1994. Pp. 98-103.

Girma Tegegne, R. Badyopadhyay, T. Mulatu and Y. Kebede. 1990. Development of ergot resistance screening technique and screening of sorghum lines for resistance to ergot and anthracnose in Ethiopia. Pp. 197-206. *In:* Proceeding of 7th EARSAM Regional workshop on sorghum and millet improvement in Eastern Africa. Nairobi, Kenya 25-28 June, 1990.

Girma Tegegne. 2004. Isolation, purification and identification of antimicrobial active substances from *Agapanthus africanus* L. Ph.D. Dissertation, University of Free State, Bloemfontein, South Africa.

Hagerman, A. E., and L. G. Butler. 1994. Assay of condensed tannins or flavonid oligomers and related flavonoids in plants. *Method Enzymol.* 234: 429-437.

48. Harris, H. B., and B. J. Johnson. 1967. Sorghum anthracnose , symptoms, importance and resistance. *Proc. bien. sorg. Improve. Conf. N. Amer.* 5:48-52.

Hazra, S. 1998. Pathogenic Variability in sorghum Anthracnose Incited by Colletotrichum graminicola (Ces.) wils. M. Sc. Thesis, Acharya N. G. Ranga Agric. Univ., Rajendranagar, Hyderabad (A.P.), INDIA.

IAR (Institute of Agricultural Research). 1984. Crop Protection Department Progress Report for the Period 1979/80. Addis Ababa, Ethiopia.

Korobko, A.P. 1985. Stalk rot of maize in Ethiopia condition phytoncido, bacterial plant disease part II UZH Gorf, Nau kova Dumko USSR 1-52.

Kranz, J. 1969. Plant disease situation around Bako Station. IAR Ethio-German Experimental station. Addis Ababa. PP.4.

Kusum Mathur, Ram P. Thakur, Adama Neya, Paul S. Marley, and Carlos R. Casela. 2002. Sorghum anthracnose-problem and management strategy. Pp.211-217. *In:* Sorghum and milles disease. John F. Leslie (ed.), World Agriculture Series, Iowa State Press.

Mathur, K., R. P. Thakur, and V. P. Rao. 2000. Pathogenic variability and vegetative compatibility among isolates of *Colletotrichum graminicola* and *C. gloeosporioides* causing foliar and grain anthracnose of sorghum. *Ind. Phytopathol.* 53: 407-414.

MRC (Mekele Research Center). 2002. Crop protection division progress report, 1995–2002.

MRC. 1994. Progress report

MRC. 2002. Progress report for 1995–2002

Mengistu Hulluka and Berhane Gebrekidan. 1978. Diseases of sorghum in Ethiopia. Pp. 36-39. *In:* proceedings of the International Workshop of Sorghum Diseases, Hyderabad, India, 11-15,International Crops Research Institute for the Semi-Arid Tropics ICRISAT Patancheru, Andhra Pradesh, India 502 324.

Mengistu Hulluka. 1982. Diseases of sorghum at some locations in Ethiopia. *Eth. J. Agric. Sci.* 4(1): 45-53.

Merkuz Abera. 2001. Incidence, severity and distribution of covered kernel smut of sorghum, varietals reactions, and its impact on yield in northwestern Ethiopia. M.Sc. thesis, Alemaya University.

Mesele Gemu. 2004. Research terminal report. Entomology section Hawassa National Maize Research Project.

Nigussie Tesfamichael and Reddy, M. S. 1995. Performance of maize/Bean inter-cropping systems under low and medium rainfall situations: Disease incidence. Pp. 191-195. *In:* Proceedings of the third annual conference of the crop protection society of Ethiopia. 18-19 May 1995, Addis Ababa.

O' Bahnon, J.H. 1975. Nematod survey. FAO. Rome Eth. 74/002 IAR 1975.

Perkins, J.M., Smith, D.R., Kinsey, J.G. & Dowden, D.L., 1995. Prevalence and control of gray leaf spot. 31st Annual Conference of the Illinosis Corn Breeders' School. Univ. of Illinois, March 6-7, 1995

HRS (Holetta Research Station), Plant pathology section. 1979. CMI. Identification of cereal and grass diseases new for Ethiopia. EPC Newsletter No. 8. Addis Ababa. pp. 19.

Raya Abagodo 1988. Sidama mixed farming Zone diagnostic survey report .Sidama Regional Research report No.3188 IAR A.A.

Richard, A. Frederikson. Ed. 1986. Compendium of sorghum diseases. Published by The *American Phytopathological Society*. Pp.1-4.

Rosenow D. T. 1992. Using germplasm from the world collection in breeding for disease resistance. Pp. 319-328. *In:* Sorghum and millets diseases: A second world review. W.A.J. de Milliano, R.A. Frederiksen and G.D. Bengston (Eds.).

Selvaraj, J. cyril. 1978. Sorghum smuts research and control in Nigeria. Pp. 351-366. *In:* Sorghum and millet diseases: A second world review. International Crops Research Institute for the Semi-Arid Tropics Patancheru, Andhra Pradesh 502 324, India. W.A.J. de Milliano, R.A. Frederiksen and G.D. Bengston (Eds.).

Sharma, H. C. 1978. Screening of sorghum for leaf-disease resistance in India. Pp. 249-264. *In:* proceedings of the International Workshop of Sorghum Diseases. Hyderabad, India, 11-15, International Crops Research Institute for the Semi-Arid Tropics ICRISAT Patancheru, Andhra Pradesh, India 502 324.

Shurtleff M.C. 1980 Compendium of corn disease second edition. American phytopathological society university of Illinois, Urban, USA.

Solomon Berhane and Temam Hussien. 1989. A preliminary study on pokkah-boeng: a new sorghum disease in Ethiopia. *In:* proceedings of the 14th Annual Conference of the Ethiopian Phytopathological Committee, March 30-31, 1989. Ambo, Ethiopia.

Solomon Brhane and Mengistu Hulluka. 1984. The mycoflora associated with the grain sorghum in pits and the role of four different types of fungi in the quality of sorghum grains in Alemaya District, Harargie, Ethiopia. Proceedings of the 9th Annual Meeting of EPC. Nazareth, Feb. 2-3. pp.119-121.

Stewart, R.B and Dangatchew Yirgu.1967. Identification of plant disease in Ethiopia. Experimental station bull No. 30 College of Agr. Haile Selassie I Univ. Debre Zeit Pp. 15.

Stewart, R.B. and Dagnatchew Yirgou. 1967. Index of plant diseases in Ethiopia. Experimental Stataion Bull. No.30. College of Agriculture, Haile Selassie I University. Debre Zeit. pp.95.

Stromberg, E.L. & Donahue, P.J. 1986. Hybrid performance of yield losses associated with gray leaf spot disease. Proc. Annual Corn and sorghum Res. Conf. 41:92-105

Tar, S. A. G. 1962. Diseases of sorghum, Sudan grass and broomcorn. Pp. 380. The Common Wealth Mycological Institute, Kew, Surrey (England).

Tarekegn Geleta, N.W. McLaren and W.J. Swart. 2006. Reaction of sorghum to grain mould in relation to its biochemical and morphological traits. *Pest Management Journal of Ethiopia.* 10: 25-32.

Teklemariam Woldekidan. 1985. A review of research on maize and sorghum disease in Ethiopiain. Pp 21-34. *In:* A Review of Crop Protection Research in Ethiopia. Tsedake Abate (ed.).

Temam Hussien and Amare Ayalew. 1989. New disease outbreak. Annual research report of the crop protection section, Department of Plant Sciences. Alemaya University of Agriculture, Alemaya, Ethiopia.

Temam Hussien. 2001. Evaluation of inoculation methods and resistance of some sorghum genotypes to bacterial leaf streak (*Xanthomonas campestris* pv *holcicola*). *Pest Mgt. J. Eth.* 5:21– 28.

Tesfaye Woubet and Dawit Abate. 1998. Toxigenic fusarium species in maize grain in Ethiopia. Pp. 132-134. *In:* Maize Production Technology for the future: Challenges and Opportunities. Proceedings of the 6th Eastern and Southern Africa Regional Maize Conference. CIMMYT/EARO.

Tewabech Tilahun, Getachew Ayana, Fekede Abebe and Dagne Wegary.2001. Maize pathology research in Ethiopia: A review. *In:* Mandefro Negusie, D.Tanner and S. Twmasi- Afrie. (eds.) Proc. of the 2nd National Maize Work shop of Ethiopia. EARO/CIMMYT.

Tewabech Tilahun .1999 .The distribution and importance of maize disease in southern Ethiopia (Abstract).Crop Protection Society of Ethiopia. Seventh Annual Conference 5-6. August Addis Ababa, Ethiopia.

Thomas, M. D. 1992. Sorghum diseases in western Africa. Pp. 25-29. *In:* Sorghum and millet diseases: A second world review. International Crops Research Institute for the Semi-Arid Tropics Patancheru, Andhra Pradesh 502 324, India. W.A.J. de Milliano, R.A. Frederiksen and G.D. Bengston (Eds.).

Tyagi, P. D. 1978. Sorghum diseases in Nigeria. Pp. 45-66. *In:* proceedings of the International Workshop of Sorghum Diseases, Hyderabad, India, 11-15, International Crops Research Institute for the Semi-Arid Tropics ICRISAT Patancheru, Andhra Pradesh, India 502 324.

Ward, J.M.J., M.D. Laining and A.L.P. Cairns. 1997. Management practices to reduce gray leaf spot of maize. *J. Crop Sci*. 37(4): 1257-1262.

William, L. Rooney, S. Delroy Collins, R. R. Klein, P. J. Mehta, Richard A. Frederiksen, and R Rodriguez-Herrera. 2002. Breeding sorghum for resistance to anthracnose, grain mold, downy mildew, and head smuts, Pp. 273-279. *In:* Sorghum and millets diseases. A second world review. John F. Leslie (ed.), World Agriculture Series, Iowa State Press.

Williams, R. J. & Rao, K. N. 1981. A review of sorghum grain moulds. *Tropical Pest Management* 27: 200-211.

Weed Research in Sorghum and Maize

Fasil Reda[1], *Matias Mekuria*[2], *Kiros Meles*[3], *Kassahun Zewdie*[4], *Rezene Fessehaie*[4] *and Tamado Tana*[5]

[1] *Melkassa Research Center, EIAR, P.O. Box 436, Nazreth.* [2]*Awasa Research Center, P.O. Box 61Awasa.* [3]*Mekelle Research Center, P.O. Box – 231, Mekelle.* [4] *Holeta Research Center, EIAR, P.O. Box 2003, Addis Abeba.* [5] *Alemaya University of Agriculture,* P.O. Box 138, Dire Dawa

Introduction

Sorghum and maize are staple food crops in Ethiopia. The crops are grown under a wide range of environmental conditions. Over 8 million hectares of land is allocated for food crops from which over 9 million t of harvest is produced annually (Table 1). Cereals account for over 80% of the cultivated area and 90% of total production in the country (CSA, 2002). Tef, maize, sorghum, wheat and barley are the five major cereal crops. Sorghum occupies 1.3 million ha and maize 1.7 million ha, representing 17% and 22% of the area devoted to cereal production, respectively (CSA, 2001). Among the cereals, maize is ranked first in production and productivity (Table 2).

Table 1. Area and production of major crops in peasant holdings in Ethiopia (2001/2)

Crop	Area (‘000000 ha)	%	Production (‘000000 t)	%	Yield (t/ha)
Cereals	6.72	82.45	8.30	91.75	1.24
Pulses	0.92	11.29	0.71	7.87	0.78
Others	0.51	6.26	0.03	0.38	0.07
All crops	8.15	100	9.05	100	-

Source: Central Statistical Authority, 2002

Table 2. Area under cultivation, yield and production of major cereal crops in 2000/1

Cereals	Area (‘000 ha)	Yield (t/ha)	Production (‘000 t)
Tef	2182.53	0.79	1736.92
Maize	1719.13	1.82	3138.45
Sorghum	1332.89	1.15	1538.28
Wheat	1139.72	1.37	1571.17
Barley	874.01	1.08	945.42
Millet	346.78	0.91	316.17
Oats	40.98	1.21	49.62
Total	7636.65	1.22	9296.03

Source: Central Statistical Authority, 2001

Nearly all of the grain from sorghum and maize is used for human consumption, and the crops are major sources of energy and protein for millions of people in Ethiopia. For instance, about 80% of sorghum grain is used for making *injera* (sorghum is second to tef as the preferred cereal for making *injera, [*a fermented pancake like bread]), 10% home brewed beverages (*Areke*, *Bordie* and *Tella*) and the rest goes into making different food products (*nifro*, *genfo, kitta, kollo* and weaning foods). The leaves and stalks of sorghum and maize are preferred feed sources for animals. The stalk is used for construction and fuel wood.

Weeds have a more direct influence on humans more than any other pest in developing countries like Ethiopia. Weeds not only cause severe crop losses but also compel farmers and their families to spend a considerable amount of their time weeding. Unfortunately, this is a common feature observed in sorghum and maize growing areas of Ethiopia. Loss assessment studies revealed that the crops are highly sensitive to weed competition, especially during their early growth stage. It is documented that uncontrolled weed growth leads to at least 44% and 30% yield loss in maize and sorghum, respectively (Stroud, 1989). The parasitic weed *Striga* on average causes 50–60% loss and often the damage is greater on maize.

The continuing losses due to weeds inequitably distributed across agro-ecosystems. Shifts in weed flora in response to weed management and environmental degradation attest to the need to develop systems of weed management that are sustainable. Although, considerable effort has been made to study weeds and develop strategies to reduce their impact, lack of capacity allowed only limited range of research areas to be addressed. To promote a more holistic view on weeds and develop consolidated weed management research programs, past work has to be thoroughly reviewed and appropriate strategies designed and executed.

This paper reviews weed management research experiences on maize and sorghum in the past 20 years, with the aim of highlighting the current status and future prospects for the relatively young discipline.

Research findings

Weed problem appraisal and weed surveys

The weed flora of maize and sorghum is highly diverse and is composed of a wide range of grass and broadleaf weeds and sedges including parasitic and invasive species (Table 3.)

Table 3. Major weeds of sorghum and maize in Ethiopia

Family	Species	Life cycle	Importance
Amaranthaceae	*Amaranthus hybridus*	A	*
	Amaranthus angustifolius	A	*
	Celosia trigina	A	*
Asteraceae	*Ageratum conyzoides*	A	*
	Bidens pachyloma	A	**
	Bidens pilosa	A	*
	Flaveria trinervea	A	**
	Galinsoga parviflora	A	**
	Guizotia scabra	A	**
	Launea cornuta	P	*
	Tagetes minuta	A	**
	Xanthium spinosum	P	**
	Xanthium strumarium	P	**
Brassiceae	*Erucastrum arabicum*	A	*
Capparidaceae	*Gynandropsis gynandra*	A	**
Commelinaceae	*Commelina benghalensis*	A/P	**
	Commelina latifolia	A/P	**
Convolvulaceae	*Convolvulus arvensis*	P	*
Cyperaceae	*Cyperus rotundus*	P	**
	Cyperus esculentus	P	**
Euphorbiaceae	*Euphorbia hirta*	A	*
Leguminosae	*Medicago polymorpha*	A	*
	Trifolium sp.	A/P	*
Nyctaginaceae	*Boerhavia spp.*	A	*
Oxalidaceae	*Oxalis spp.*	P	*
Papaveraceae	*Argemone mexicana*	A	*
Plantaginaceae	*Plantago lanceolata*	B	*
Poacceae	*Brachiaria spp.*	A	*
	Cenchurus ciliaris	A	*
	Cynodon dactylon	P	**
	Cynodon nlemfuencis	P	*
	Digitaria abyssinica	P	**
	Echinochloa colona	A	*
	Eleusine indica	A	**
	Panicum spp.	A/P	*
	Rottboellia cochinchinensis	A	**
	Setaria spp.	A	**
	Snowdenia polystachia	A	*
	Sorghum arundinacium	A	**
Polygonaceae	*Oxygonum sinuatum*	A	**
	Polygonum nepalense	A	**
Portulacaceae	*Portulaca oleracea*	A	*
Resedaceae	*Caylusea abyssinica*	A	*
Scrophulariaceae	*Striga asiatica*	A	**
	Striga aspera	A	*
	Striga hermonthica	A	**
Solanaceae	*Datura stramonium*	A	**
	Nicandra physalodes	A	**
Tiliaceae	*Corchorus olitorius*	A	**
	Corchorus trilocularis	A	**

Note: A – Annual, A/P – Species capable of showing perennial lifecycle, P – Perennial
*** - Very important, ** - Moderately important, * - Less important

Inappropriate cropping practices and deteriorating environmental conditions have contributed to the occurrence of complex weed problems. The maize and sorghum belt of the country is infested with hard-to-control sedge and grass weeds (e.g., *Rottboellia cochinchinensis*) and parasitic weeds such as *Striga*. The lowlands are invaded by alien invasive species–*Parthenium hystrophorous*, *Prosopis juliflora* and *Lantana camara*. The troublesome perennial grasses – *Digitaria abyssinica*, *Cynodon* spp. and *Pennisetum* spp. represent serious challenge in degraded environments.

In Tigray, complex weed problem represents serious threat to subsistence crop production (IAR, 1994; Ibrahim, 1996). A wide range of weed flora was recorded from 34 peasant associations in 17 weredas (districts) representing highland, mid-altitude and lowland ecologies. However, only 12 were widely distributed, and among these, *Striga hermonthica*, *Cynodon dactylon*, *Acanthospermum hispidum and Brachiaria eruciformis* were found to be the most problematic weeds. A follow up survey specifically on *Striga* showed that the parasitic weed problem increases in magnitude as one moves from South through the eastern part to the West in the Region (G/Medhin et al., 1998).

A diagnostic survey was conducted in the Region to identify and prioritize crop and resource management problems (Esilaba et al., 1998). Ninety percent of the farmers interviewed identified *Striga* as the major constraint to cereal production, 87% expressed the feeling that infestation is increasing, and 52% of them associated the *Striga* problem with declining soil fertility. The farmers indicated seed, farm implements, water erosion and animals as agents of weed seed dispersal. A separate survey conducted in 1997 established *Striga hermonthica* as the widest spread parasitic weed species in Ethiopia. The overall *Striga* incidence rate in the 310 maize fields surveyed was 41%. Pawe and Dhera were registered as the highest (95%) and least (1%) infested districts, respectively (Wondimu et al., 2001).

Weed biology and yield loss assessment studies

Sorghum is susceptible to weed competition at its early stage of growth because the seedlings start weak and frail. Sorghum has also lower water requirement than most weeds. This means that weeds with higher water requirements tend to take up more water per unit of dry mater produced. Thus, they interfere with the growth of crop. It is well established that weeds cause yield loss during certain crop growth stages and controlling weed during such a period is essential. Knowledge of critical weed densities and the critical period of competition can help the farmer make the most efficient use of labor, resulting in an overall saving of time and cost of weed control.

Two sets of field experiments were conducted at two sites representing lowland and intermediate altitude for two years in eastern Ethiopia to determine the influence of *Parthenium* weed density and duration of competition on grain yield of sorghum. In the first set of experiments, weed densities of 0, 3, 7, 13, 27, 53 and 100 plants per square meter were considered. Yield loss was severely affected as *Parthenium* weed density increased. It was observed that even very low density of 3 plants per square meter resulted in a high yield loss (69%). Due to differences between sites and years, however, it was not possible to specify meaningful threshold densities for weeding. The critical period for weed control (the period over which weeding had the greatest benefit on yield) were 19–69 and 40–57 days after emergence of sorghum in 1999 and 2000, respectively at intermediate altitude location (assuming an acceptable loss of 10%). In the lowland, however, it ranged from emergence to 61 and 66 days, indicating more severe competition at this site. The substantial variation in yield, and yield loss between sites and years illustrates the problems of establishing accurate recommendations for threshold densities of *Parthenium* and critical periods in small scale, rain-fed agriculture (Tamado et al., 2002).

Keeping maize weed free for the cropping season was essential to attain the highest possible yield. The cost of weeding increased and grain yield declined as the time of weed removal was delayed. Yield loss due to the presence of weeds during the first 6, 9 and 12 weeks after emergence (DAE), and for the entire growing season were 36, 61, 80 and 85%, respectively (Assefa, 1999). However, it was found that early weeding at 20–25 DAE could be sufficient to bring about significant increase in yield compared to the control at two locations: Melkassa and Wolenchiti (Tilahun et al., 1990). On the un-weeded control plots, up to 69% yield loss was recorded. At Asossa, competition was severe during the first six weeks (IAR, 1988). At Awassa, the critical period of weed competition was between 31 and 49 DAE (Mengistu et al., 2005). The authors recommended two weedings at the start and end of the period to reduce significantly the competitive effect of weeds significantly.

In a host range experiment, nine *S. hermonthica* populations collected from different hosts, locations, and one each of *S. asiatica, S. aspera* and *S. forbesii* were tested on selected crop and weedy species (Fasil and parker, 1990). Sorghum was generally more sensitive than the other test entries to most of the *S. hermonthica* populations and *S. asiatica*. Among the weedy entries, the wild relatives of sorghum (*Sorghum arundinaceum* and *Rottboellia cochinchinensis)* supported greater number of *Striga* shoots, suggesting that these probably were among the primary alternative hosts from which infestation spread to new crops and locations.

In a virulence study, conducted using an *in vitro* system, nineteen *Striga* population samples collected from different host crops and areas of Tigray Region were evaluated against two resistant sorghum varieties (SRN-39 and P 9401). Results showed that significant variability exists in virulence among populations occurring in the Region (Fasil, 2002). Nine populations were able to establish and develop on the resistant sorghum varieties at significantly higher numbers. Most of the virulent populations originated from the southeastern parts of the region where there was a long history of crop culture and thus selection pressure on both the host and the parasite.

Control studies

Hand weeding

Low input agriculture is a common feature of food production in the country. Because of the limited resource base, the subsistence farming community relies on hand weeding for the control of weeds. However, because of overlap of farm operations, farmers either leave their farms un-weeded or perform weeding late in the season. Experience has shown that proper timing of the weeding operation is critical to maximize benefits. According to the findings, crops are particularly sensitive to weed interference in the first four weeks of establishment, and early weeding during this period significantly enhances crop yield performance.

One to two hand weeding is recommended in dry areas where sorghum and maize are important (Stroud, 1989). However, a study conducted on sorghum revealed that three times weeding at monthly interval gave the highest yield of 2700 kg ha^{-1}. Weeding once at 25–30 days after emergence, or when the crop reaches 15 cm height, leads to a comparable yield gain of 2500 kg ha^{-1}. Weeding late, i.e., at grain filling stage, resulted in a heavy crop loss. This was due to loss of moisture from the soil at the time when the crop was badly in need of moisture for grain filling (Stroud, 1989). A study was conducted at Bako on sorghum to compare the recommended twice weeding at 25–30 and 55–60 days after planting with farmers practice for grain yield and labor saving advantages (Gemechu and Legesse, 1989). Results showed that average labor requirement for recommended hand weeding was less compared to farmers' practice (425 vs. 554 hrs/ha). There was no significant difference in grain yield between the recommended (2.7 t ha^{-1}) and the farmer's practice (3.4 t ha^{-1}). However, the second weeding under the recommended practice coincided with the time when labor is in high demand for other farm operations. During that period, the labor requirement for the recommended hand weeding was 226 hours per hectare but only 15 ox hours plus 127 labor hours per hectare for farmer's practice. It was assumed that this could be the reason why farmers preferred their traditional practice rather than the recommended one. Thus, it was suggested that the second weeding is replaced with inter-row cultivation.

On-station and on-farm experiments were conducted by Bako Agricultural Research Center during 1989–1993 cropping seasons using the open-pollinated maize variety Beletech as a test crop (Rezene et al., 1993). Different frequency of ox cultivation, hoeing, and hand pulling were compared. Two times inter-row ox cultivation (at the 4–5 and 7–8 leaf stages) supplemented by one time hoeing at the 4–5 leaf stage and hand pulling at the 7–8 leaf stage gave the most efficient control. The highest maize grain yield of 4.8 t ha^{-1} was obtained from inter-row ox cultivation and hoeing at 4–5 leaf stage, supplemented by ox cultivation and hand pulling at 7–8 leaf stage. In another experiment at Bako, the recommended hand weeding practice, weeding at 25–30 and 55–60 days after planting, was verified on farmer's field for yield, labor requirement and compatibility with current cropping practices. Although the grain yield difference between the recommended practice and the control was not significant, the former was more economical and required 129-man hours per hectare less labor. A single early weeding was sufficient to obtain optimum yield and the highest cost: benefit ratio. Two times weeding was critical on maize in Awassa to maximize yield benefits (IAR, 1989). At Jimma 2 hand-weeding or hoeing at 2 and 4 weeks after emergence was most effective. However, at Metu, 3 hand-weeding or hoeing at 2, 4 and 6 weeks after emergence was necessary to adequately control weeds and improve yield significantly (Tilahun and Tesfa, 1989). At Abobo, timely weed control was more important than frequency of weeding. There was no significant difference between one, two and three times weeding on grain yield (Woldeyesus and Aderajew, 1991).

The only case where early weeding does not seem to have such an obvious effect is on parasitic weeds. The yield gain from early weeding of a s*triga* infested cereal is often insignificant. Although it is difficult to improve yield performance, however, efficiency could be enhanced and economic advantages could be gained from late weeding. It was shown that late weeding of *Striga* (after flowering) requires less than half of the time needed for early pulling (Parker, 1988). Furthermore, late pulling is more manageable as one has to remove only flowering s*triga* plants. Early weeding leads to re-sprouting of more shoots from underground buds – further aggravating the problem. Hand pulling of s*triga* plants is the most feasible control approach for the small-scale subsistence farming community.

Tillage

An experiment was conducted on maize both on-station and on-farm at Bako Research Center during 1989, 1990 and 1993 cropping seasons. Eleven treatments, including weedy check, inter-row ox cultivation, hoeing, and hand pulling were compared (Rezene et al., 1993). Slashing at flowering was uniformly applied for all treatments except the weedy check. The dominant weeds recorded were *Guizotia scabra, Bidense pilosa, Setaria* spp., *Cynodon dactylon* and *Commelina* spp. The results indicated that hoeing and hand pulling offered an efficient control of these weeds. Two times inter-row cultivation (at 4–5 and 7–8 leaf stages of the crop) supplemented by one time hoeing (4–5 leaf stage) and hand pulling (7–8 leaf stage) gave the most efficient control. The combined analysis over three years for grain yield indicated that there was a statistically significant difference ($P<0.0001$) among treatments. The year by treatment interaction was not statistically significant, indicating the consistency of results across years. The location by treatment interaction within years was highly significant, indicating a differential effect of treatments across locations. The weed biomass and maize grain yield were negatively correlated ($r = -0.375$) ($P<0.001$). The highest maize grain yield of 4.8 t ha^{-1} was obtained from one inter-row ox cultivation and one hoeing at 4–5 leaf stage supplemented with one inter-row ox cultivation and one hand pulling at 7–8 leaf stage. The yield level obtained from the treatment was significantly higher compared to farmers practice. The farmers considered one hoeing at 4–5 leaf stage and one ox-cultivation at 7–8 leaf stage supplemented with hand weeding as the best method for controlling weeds in maize. However, mostly, such a practice is never employed due to labor shortage. Inter-row ox cultivation at 4–5 leaf stage combined with one hand pulling at 7–8 leaf stage produced the highest net benefit of Birr 1903 ha^{-1}.

An experiment was conducted at Abobo Research Center, in Gambella Region, to look at the growth and yield response of maize to tillage practices and to compare a pre-emergence herbicide with different hand weeding regimes (Wondimu et al., 2001). Gesaprim combi herbicide at the rate of 3.5 kg a.i. ha^{-1} kept the crop weed free throughout the season. Furthermore, it was less costly. The herbicide treatment was considered particularly appropriate for Gambella Region where labor is in short supply. A non-significant difference was observed between the conventional (disk plough and harrow) and no tillage systems at Bako (Getachew, 1989). Grain yield was not significantly affected by pre-planting spraying of Glyphosate and Paraquate in zero tillage. A preliminary study at Awassa indicated that zero tillage was at least as good as conventional tillage when Glyphosate (3.5 l product ha^{-1}) and Paraquat (4.5 l product ha^{-1}) were applied to control weeds. At Ambo, weed density was lower when tillage was performed with mould board plough than disk plough and disk harrow (Rezene et al., 1993). An experiment was conducted at Melkassa during 1987 and 1989 to examine the right time to perform *shilshalo* (mid-season cultivation) for sorghum. Generally, growth and yield were enhanced when *shilshalo* was performed at 6–8 leaf stage of the crop (Birhane et al., 1991).

The labor and oxen power requirement, weed control efficiency and level of possible crop damage of a wheel hoe weeder implement were assessed at Bako Research Center. The wheel hoe weeder saved 75 hours of manual labor per hectare and 13 oxen-pair hours per hectare compared to farmers' weeding practice. The experiment revealed that the wheel hoe weeder could control 85% of the weed species. The implement was particularly effective on properly tilled light soils (Asfaw and Abdissa, 1991).

Cultural control

Fertility management

At Ambo, yield differences between hand weeding and herbicide (Primagram at 2 kg a.i. /ha) treatments was higher when nitrogen (N) and phosphorous (P) were applied through broadcasting at high rates of 120/120 and 200/200 N/ P_2O_5 kg ha^{-1}, respectively. This difference was not evident when the N/ P_2O_5 fertilizer was banded. Interestingly, the herbicide controlled weeds better and enabled the maize crop to use fertilizer efficiently under broadcasting. At Bako, application of 75/75 kg ha^{-1} N/P_2O_5 between maize rows resulted in a denser weed population, whereas band application favored early maize growth (SPL, 1988).

Striga is less damaging and often less severe in fertile soils and the critical element among the nutrients is widely believed to be nitrogen. Ammonium sulfate and nitroform were compared to organic sources (chicken manure, peat and organic soil) in a pot experiment (Ahmed and Parker, 1988). Nitrogen from both mineral fertilizers and organic manure delayed the emergence of *Striga*. There was no influence of organic matter on *Striga* in the absence of associated nitrogen. The earlier field experiments at Humera and Kobo were inconclusive, but showed at least some reduction of the parasitic weed infestation from application of N. The more recent investigations indicated that the effect of N could vary across varieties. Although nitrogen significantly reduced *Striga* infestation on Gambella 1107 and N13, its effect was more consistent on ICSV-1006 and ICSV-1007 (Babiker and Fasil, 1991). Results of another experiment, designed to develop integrated nutrient management strategy confirmed that the combined use of 41 kg N ha^{-1} and 30 t ha^{-1} of manure led to significant reduction in infestation and considerable increase in sorghum yield (Esilaba et al., 2000). Further experience showed that the outcome from the use of the nitrogen input depended on weather patterns and inherent fertility of a given location (Fasil, 2002). The beneficial effect of N was consistent in the northwestern lowlands of Tigray where there was adequate rainfall and less impoverished soil. On the other hand, mixed results were obtained and no obvious benefit was gained from the use of the input, especially the higher recommended rates (41/46 N/P_2O_5), in the dry highlands in the northeast.

Competitive crops

At Jimma and Metu, the yield response of two maize composites (UCA and UCB) to hand weeding frequency was similar (Tilahun and Tesfa, 1989). At Bako (Asfaw et al., 1990) and Nazreth (Aleligne et al., 1992), farmers observed variability among varieties in their competitive ability with weeds. An early maturing, short variety Guto was rated as a poor competitor compared to an improved relatively taller varieties: Bako Composite, KCC, and KCB.

Host plant resistance

A sorghum variety screening trial for *Striga asiatica* resistance was conducted at Gumaide (Gamo Gofa) in 1987. Twenty-eight improved and local sorghum varieties and one pearl millet variety (Serere Composite) were compared with CK 60 (susceptible sorghum variety) and Medium Dishkaro (local susceptible sorghum check). Although infestation was not uniform, it was evident that some of the local varieties exhibited resistance. Particularly impressive was the variety Short Kulisha (IAR, 1986). Similar experiment was conducted with 12 sorghum cultivars at Konso Wereda in 2000–2002 cropping seasons.

The most outstanding sorghum varieties from the earlier work on resistance screening were SAR-24, ICSV-1006, ICSV-1007, Framida, and N-13 (Fasil, 1999). These varieties were resistant to *Striga hermonthica* populations occurring in the major sorghum producing areas, and suffered relatively less damage. However, most of these varieties often showed inferior agronomic performance compared to the locals, especially under *Striga* free conditions. Successful attempts were made, later, to improve the agronomic quality of these genotypes through crossing. Subsequently, some progenies that exhibited resistance and quality traits were identified and used by the national sorghum improvement project. In recent years, advances that are more significant have been made in collaboration with Purdue University in the USA. Varieties of tropical origin, combining superior agronomic quality and resistance to *S. hermonthica*, were developed by Purdue University and widely tested in the lowland and mid-altitude areas of Ethiopia. This successful endeavor led to the release of two resistant varieties: P9401 (Gobiye) and P9403 (Abshir). These varieties are productive and combine excellent grain quality and drought tolerance – two essential attributes in the drought affected, *Striga* prone areas of the country. In a separate experiment, Wondimu et al., (2001) reconfirmed the resistance of P9401, P9403, SRN-39 and two other local varieties, *Ayefere-Asfachew* and *Wotere.*

Trap cropping and intercropping

Intercropping is a potentially viable, low-cost technology, which enables us to address the two important and interrelated problems of low sol fertility and *Striga*. Identifying the optimal spatial and temporal arrangements, and selection of effective, compatible and adapted legume crops, depending on the natural endowments of localities and existing populations of *Striga*, is an important prerequisite. At Sirinka, one row of legume (cowpea and haricot bean) with every two rows of sorghum was an optimum arrangement in terms of reduction in *Striga hermonthica* incidence and increase in cereal yield (Fasil et al., 1997). At Adibakel, dry highland location in Tigray, the same planting arrangement of sorghum and cowpea was superior in crop productivity and *Striga* control. Intercropping had rather detrimental effect on yield performance of sorghum and showed no obvious suppressive effect on *Striga*, under non-fertilized conditions at Sheraro, in the northwestern lowlands of Tigray (Fasil, 2002). Fertilizer use was eminent and inorganic fertilizer alone improved crop performance and suppressed *Striga* at the site. In another environment, in Tigray, alternate row planting of sorghum and legumes with staggered planting of the crops (sowing of legume intercrops 3 to 4 weeks after the cereal), was more productive and led to overall reduction in infestation, over two seasons. On the other hand, a trial conducted at Konso during 2001/2 cropping season revealed that sorghum and pigeon pea intercropping led to considerable reduction in *Striga asiatica* infestation (SARI, 2003). Those findings suggest the need for developing site-specific recommendations on intercropping.

At Pawe, an experiment was conducted during the 1998 season with the objective of identifying a trap crop and pattern of intercropping to control *Striga hermonthica* in maize (Kassa et al., 2001). Three trap crops (cowpea, soybean and groundnut) were intercropped with hybrid maize variety BH-140 in three planting patterns: alternate row planting, within row interplanting, and broadcast mixed planting. Sole maize was used as a check. Results showed that there was no difference among the three trap crops on *S. hermonthica* emergence, *Striga* count at harvest and *Striga* count/maize plant. However, highly significant variations were observed for planting patterns on the above three parameters measured. The interaction effect between planting pattern and variety was not significant. The highest *Striga* count was recorded from alternate row planting. Among the three systems of planting, alternate row planting of maize and groundnut registered the highest number of *Striga* emergence followed by maize-cowpea and maize-soybean alternate row planting. The lowest *Striga* emergence was observed from the broadcast planting pattern, which could be attributed to minimum direct contact between component crops and the parasite in this arrangement. Among the three trap crops, groundnut was the best trap crop. Maize (HB-140) and groundnut (Manipintar) within row alternate planting gave the highest maize grain yield 1.5 t ha^{-1} followed by maize soybean broadcast planting (1.3 t ha^{-1}).

Crop rotation

The effect of crop rotation on weed control and grain yield of maize was studied in Awassa (Tenaw, 1991). It was confirmed that crop rotation was effective in suppressing weeds. Crop rotation led to shift in weed composition and substantial reduction of weed density. Maize yield was improved by 41% when the crop followed sunflower, soybean, and tef.

Rotation of infested land into non-susceptible crops or into fallow is theoretically one of the simplest solutions for parasitic weed control, but it is also one that is neither simple nor acceptable (Parker and Riches, 1993). Farmers are usually reluctant to break the cereal production cycle. Cognizant of this fact, a five-year experiment was initiated to explore at least possible benefits of yearly alternate cropping of sorghum and annual legumes over the existing system of cereal monoculture under *striga* infested conditions (Fasil and Wondimu, 2001). The final year results showed that yearly rotation of sorghum with either cowpea or haricot bean resulted in significantly higher cereal yields but failed to lead to concomitant reduction in *striga* infestation. The main lesson from the exercise was that the time interval between cereal cropping has to be sufficiently long for a rotation program to be effective against s*triga*.

Time of planting and catch cropping

In a trial conducted to compare the effect of two planting dates (May and July) and catch cropping with Sudan grass on *Striga* infestation in sorghum at Harbu, it was shown that catch cropping could be useful to reduce parasitic weed infestation (Parker, 1988). The infestation level on the susceptible sorghum variety IS 9302 following Sudan grass was five-fold lower even though this did not result in significant differences in yield.

Chemical control

Two series of experiments were conducted at Bako Research Center between 1982 and 1986 to compare the performance of atrazine and atrazine + metholachlor mixtures at 1:1 and 1.7:3.3 ratio of kg a.i./ha with two hand weeding and no weeding for weed control, crop safety and grain yield in sorghum (Dawit and Rezene, 1990). In the first experiment, terbutryne and EPTC + safener (N, N-dially-2,2-dichloroacetamide) were considered and in the second series linuron, dicamba and alachlor were included. Herbicides in the first experiment were applied without sorghum seeds being protected (dressed) with herbicide safener CGA – 43089 (cynomethoxmino-benza-cet-nitrile). In the second series, sorghum seeds were either protected or unprotected with safener. Predominant weeds were *Eeusine indica*, *Commelina* spp., and *Guizotia scabra*. Atrazine gave good control of broadleaf weeds, caused no visible damage to sorghum, and yielded comparably with atrazine + metolachlor mixture. The weeded check produced two-fold increase in yield compared to the untreated check. Atazine + metolachlor mixture gave effective control of *Eleusine indica*, but in the absence of safener especially, at 2.0 a.i. kg ha^{-1}; there was mild crop damage (reduced germination and population density at early stage). This was largely prevented by seed dressing with CGA-43089. The use of atrazine + metolachlor mixtures is justifiable where grass weeds are inadequately controlled by atrazine but safener need to be applied to ensure crop safety. *E*PTC + safener resulted in severe damage to sorghum and inadequate weed control. Terbutryne, linuron and dicamba + alachlor, though safe to sorghum, were unsatisfactory in terms impact on weeds.

A follow up study was carried out at Melkassa using two atrazine-based herbicides: Primagram 500 FW and Gesaprim 500 FW (± sorghum safener) at different rates of application. Primagram without safener (3, 4 and 4.5 ℓ ha^{-1}) caused severe damage. Seed treatment with safener reduced the level of phytotoxicity caused by the herbicide. Crop yield performance was also improved substantially with the use of safener. On the other hand, Gesaprim was effective with and without safener and damage to the crop was minimal at all rates of application. It was concluded that weeds can be effectively controlled with the use of Primagram with safener and Gesaprim. Recently, a chemical control investigation was carried out against a major weed of sorghum – *Sonchus arvensis* in Derashe special wereda (SPL, 1988). Primagram (5 ℓ ha^{-1}) and 2,4-D (2 ℓ ha^{-1}) were most effective herbicides. Because of superior efficacy and improved crop productivity, however, 2,4-D is recommended for use against the weed.

A range of herbicides was tested for weed control in maize at Awassa during 1984–986 cropping seasons. The highest yield (5.4 t ha^{-1}) and better control of weeds was achieved from Bladex and atrazine mixture (2 kg product per hectare) even though treatment differences were not statistically significant (IAR, 1986). The agronomic and economic benefits of the application of Gesaprim 500 FW (atrazine), Primextra 500 FW (atrazine + metolachlor at 1.7:3.3 ratio) and the standard herbicide Primagram 500 FW (atrazine + metolachlor at 1:1 ratio), all at 2 kg a.i./ha, was studied at Awassa (Yohannes et al., 1999). Gesaprim controlled the major broadleaved weeds more effectively and produced higher maize yield and higher net benefit than the other herbicide and hand weeding treatments. Thus, it was recommended as a cheaper and more effective alternative to replace the standard herbicide in Awassa area where broadleaved weeds are prevalent. Early studies from Bako showed combined application of pendemethalin (1.65 kg a.i./ha) + atrazine (0.75 kg a.i./ha) and atrazine + metolachlor at 1:1 ratio (2.0 kg a.i./ha) was effective. Particularly, the former, unlike other herbicide mixtures, offered adequate control of grass weeds (SARI, 2003).

There are a number of herbicides registered for the control of *Parthenium* elsewhere, and where appropriate, chemical control could be considered as one viable option in Ethiopia. A preliminary investigation was conducted at Werer Research Center to determine the effectiveness of four pre-emergence herbicides: Dyanam 500 FW (350 g/l atrazine + 200 g/l flumetralin), Primextra TZ 500 FW (200 g/l terbutylazine + 300 g/l metolachlor), Gesaprim combi 500 FW (250 g/l atrazine + 250 g/l terbutryne), Stomp 330 EC (330 g/l pendimethalin) and two had weeding (Kassaahun et al., 1999). There was significant difference between the herbicides tested. The lowest weed population was registered from Primextra TZ 500 FW and Gesaprim combi sprayed plots. The herbicides effectively suppressed the emergence of *Parthenium* for more than two months.

Chemicals are one of the most important weed control methods in modern maize production (SARI, 2003). The complementarities of manual and chemical control justify the need for the selection of promising herbicides. An experiment was conducted at Bako during the 1996–1998 cropping seasons to select pre and post emergence herbicides for the control of *Cyperus* spp. and other weeds in maize (Kassa et al., 2001). Maize variety BH-660 was used in the study. The treatments were Laddok (bentazone 200 g.l + atrazine 200 g/l) at 3 l product per hectare, Laddok (bentazone 200 g/l + atrazine 200 g/l) at 4 l product/ha, Alazine 35/20 SE (alachlor 350 g/l + atrazine 200 g/l) at 5 l product per hectare, Basagran (bentazone 480 g/l) at 3 l product per hectare, Basagran (bentazone 480 g/l) at 4 l product per hectare, Primagram Gold 660 SC (alfa metolachlor 290 g/l + atrazine 290 g/l) at 4 l product per hectare and twice hand weeding for three consecutive years. The pre-emergence herbicides offered effective control of all weeds, whereas post emergence herbicides controlled broadleaf weeds only. Laddock effectively controlled the target weed, *Cyperus* spp. It was concluded that Primagram Gold and Alazine could be successfully used to manage weeds in maize in Bako area.

A similar experiment was undertaken at Melkassa Research Center, Wolenchiti, and Ziway during 1997–1998 cropping seasons (Kassa et al., 2001). Katumani was the maize variety used in the experiment. Annual weeds were dominant across all testing sites. Moisture stress and insect problem suppressed yield performance of maize. Nevertheless, it was apparent that the pre-emergence herbicides, alachlor + atrazine at 2.2 and 2.75 kg a.i./ha and alfa-metolachlor at 1.32 and 1.98 kg a.i./ha gave superior control of both broadleaf and grass weeds. However, the post-emergence herbicide bentazone + atrazine at both rates (1.2 and 1.6 kg a.i/ha) was effective only on broadleaf weeds and moderately effective on *Cyperus* spp. Overall, Primagram gave on average 3.4 t/ha followed by Gesaprim with 3.3 t/ha. Primagram was more effective in controlling grass and broadleaf weeds. Gesaprim was not effective in controlling grass weeds. Herbicides showed promising results in terms of saving labor during the farmers' busiest period. It was shown that Primagram and Gesaprim application required 448 and 406 less labor hours hectare compared to farmers practice.

The effectiveness of various combinations and rates of post and pre-emergence herbicides were compared for their effect on weeds and productivity of maize hybrid, BH 140 during 1995–1997 under irrigation at Werer (Kassaahun, 1998). Two hand weeding at 35–40 and 55–60 days after crop emergence and the herbicide, Primextra TZ 500 FW effectively controlled major weeds – *Sorghum arundinaceum, Echinochloa colona, Zelya pentandra, Portulaca oleraceae, Corchorus olitorius* and *Boerhaavia erecta*. The author recommended that depending on the severity of infestation the herbicide could be widely used at the rate of 4 and 5 l ha^{-1} to manage weeds in Awash Valley area.

Integrated control

Integrated crop and weed management methods were compared in a trial at Melkassa. Among the single methods employed, recommended weeding produced 72% higher grain yield (IAR, 1988). Combined use of row planting and recommended weeding produced 108% and 144% higher grain and straw yield, respectively, compared to the control (farmer's practice).

Tamado et al. (2002) reported hand hoeing twice and combined use of smother crop with one hand hoeing significantly reduced *Parthenium* biomass at lowland sites with severe weed infestation. Repeated application of 2,4-D was equally effective in adequately controlling the weed at the same site. Growing cowpea as a smother crop reduced *Parthenium* biomass, but it significantly reduced grain yield, leaf area index, plant height, and biomass of associated sorghum. Under the conditions of moisture stress, cowpea (that was used as smother crop) was too suppressive to sorghum. It was concluded that two times hand-hoeing was effective in providing adequate control of *Parthenium* and substantially improving sorghum yield compared to smother crop or 2,4-D.

Research results demonstrated that integrated use of weed control and crop management practices could enhance productivity of sorghum and suppress *Striga* (Fasil et al., 1997). At Sirinka, a treatment consisting of row planting, mineral fertilizer (42 kg N ha^{-1}) and 2,4-D herbicide (1 ℓ ha^{-1}) led to 40% increase in cereal yield and appreciable reduction in *Striga* infestation, compared to the control (broadcast planting, no fertilizer and early weeding; farmer's practice). Combined use of row planting, fertilizers and hand pulling (during flowering) registered 48% higher grain yield and over 50% reduction in *Striga* shoot counts compared to the farmer's practice at Adibakel, in Tigray Region. While studying indigenous *Striga* management practices, it was observed that farmers traditionally employ a variety of measures including relatively better performing varieties, dry and late planting, inter-row cultivation and hand weeding to cope up with the scourge (G/Medhin et al., 1998b).

Gaps and challenges

Weed science research has been a widely neglected field up until recently. This was especially so with sorghum and maize research, which caters for the two crops of the truly subsistence, low input agriculture of the dry lowlands. Nevertheless, research efforts made so far have produced highly valuable set of technologies, knowledge and information, on which further research work could be based. But the fact is there still remain quite a number of gaps and challenges that need to be addressed to alleviate the complex weed problem in the coarse grain producing areas of the country. Some of the challenges faced at present are

- The growing importance of invasive weeds such as *Parthenium,* is becoming a source of major concern. Although it has been over two decades since the noxious weed was first reported, there is no concerted nation-wide effort targeted at mitigating the problem;

- *Striga* is breaking ecological and host range barriers and spreading to new areas infesting a whole range of new crops. The national research system did not build the necessary capacity needed to cope up with the highly diverse problem of *Striga*. It is very difficult to make headway in the fight against parasitic weeds depending on technologies generated from field research alone. The field research has to be backed with research conducted under controlled conditions;
- The weed problem is getting worse in the country. Invasive, hard to control weed species are spreading at an alarming rate. Intensive effort is required to improve our knowledge on the biology and ecology of these species before considerations could be made of containment strategies;
- Weed science research has so far focused on limited aspects: surveys, loss assessment studies, and chemical control mainly due to lack of trained human power. There is great need to diversify the lines of investigations followed, paying greater attention to less explored areas (biological control, cropping systems etc.) and employing new tools in science (GIS, modeling, bio-technology etc.);
- The surveys carried out so far were often not very focused and general in nature. More targeted survey activities will be needed to establish current and future trends of weed problems, and generate more comprehensive information on agricultural, socio-economic and health impact of particularly the noxious and invasive species; and
- The chemical control studies emphasized screening of products for sole application rather than as part of an integrated weed management approach. Working on rate and time of application of herbicides is something virtually all research centers seem to be encouraging very aggressively. Use of chemicals for weed control should be considered as a last resort especially for the small-scale agriculture system in this country. Therefore, greater emphasis should be given to generating and promoting comprehensive package of technologies that are sustainable and that could effectively address the complex problem of weeds.

Future prospects

Efforts have to be made to boost the productivity of maize and sorghum. One way of achieving this is through effective management of weeds, which are among the major production constraints. It is imperative to adopt a strategy, which integrates research, extension and development for a holistic approach to the problem of weeds. Future work in this regard should therefore emphasize:

- Identification and characterization of most problematic weeds in maize and sorghum;
- Studying the biology and ecology of major weed species;
- Developing integrated management approaches including tillage; cropping systems; mechanical, biological, and manual control. Research has to break away from the long held tradition of conducting research on single component or

factor of production. Developing integrated crop and weed management methods through multi-disciplinary approach should be the central theme in future research undertakings;
- Involving the farming community in weed science research and development using new participatory approaches such as farmer research group (FRG) and farmer field school (FFS) should receive due emphasis;
- Comprehensive assessment and analysis of the prospects and opportunities for the promotion of improved weed management in low input farming systems should be pursued more strongly in the future;
- Efforts need to be made to create better awareness on the weed problem in the country in general and the dry lowland areas where sorghum and maize are important through training and sensitization activities; and
- Ensure that weed science discipline is adequately represented in the university curricula around the country so that young people can take up and build a career in this important area to strengthen national capacity.

Conclusion

Weeds were and still are the most pressing problem to the subsistence farming community more than any other category of pests. The problem is particularly acute in the mid and low altitude areas where sorghum and maize are staple food crops and are exacerbated by the recurrent drought and unabated natural resource degradation. It would be helpful to adopt a much broader view and treat weeds as part of an ecosystem to arrive at a holistic solution(s) for the problem. Well thought out integrated crop, soil and pest management approaches have to be made available to cope with the growing problem of weeds. The desired national goal of addressing production shortfalls to ensure food security demands a holistic approach to minimize the impact of abiotic and major biotic factors such as weeds. Therefore, concerted efforts have to be made to select and integrate compatible and effective technologies into packages that would enable to deal with the dynamic changes in weed flora, which will occur in the future due to changes in cropping and crop management practices.

Greater attention should be rendered to creating the necessary capacity in weed research and extension to effectively deal with the weed problem in sorghum and maize growing areas because, very often, there are hardly any other alternative crops in these areas and the two crops are the source of livelihood for the farming community. Furthermore, the weed problem in the country in general and the sorghum and maize areas in particular is growing from bad to worse. Invasive alien weed species such as *Parthenium* and *Prosopis* are already causing havoc across ecologies due to their eminent threat to agriculture and biodiversity. Establishing strong and well-organized weed science research is of paramount importance to face up to the challenge.

Due emphasis should be given to the wealth of indigenous knowledge and build on those to develop more viable technologies that are within reach to the great majority of resource poor farmers. There are indications that many traditional and low input production systems have ecologically sound basis and built-in risk aversion techniques. In many instances where scientists have had the patience to understand the principles on which smallholder farmers base their practices, these production practices have been seen to provide important conceptual framework for small-scale production systems (Akobundu, 1998).

References

Ahmed Sherif and C Parker. 1988. Effect of nitrogen sources and organic matter on *Sorghum bicolor* L. Moench. and *Striga hermonthica* (Del.) Benth. *Ethiopian Journal of Agricultural Sciences* 8:19-35.

Akobundu O I. 1998. Basic elements for improved weed management in the developing countries. Report on expert consultation on weed ecology and management. FAO. 22–24 September 1997. Rome.

Aleligne Kefyalew, Tilahun Mulatu and Senayit Regassa. 1992. Preference of farmers for maize varieties: A case study in the Nazreth area. Research Report No, 19. IAR, Addis Ababa: IAR.

Asfaw Negassa and Abdissa Gemeda.1991. Verification of the weed control performance of wheel hoe on maize in farmers fields around Bako. *In:* Rezene Fessehaie (ed.). Proceedings of the 9th Annual Conference of EWSC. 9–10 April 1991. Addis Ababa.

Asfaw Negassa, Benti Tolessa, S Franzel, Gemechu Gedeno and Legesse Dadi. 1990. On-farm research and the development of early maturing maize variety. Research Report No. 9, IAR, Addis Ababa, IAR.

Assefa Teferu. 1999. Weed incidence and control in the major crops at Asossa: An overview. Pp. 146-161. *In:* Fasil Reda and D.G. Tanner (eds.). *Arem* 5: 14–26.

Babiker A.G.T. and Fasil Reda. 1991. Recent advances in *Striga* research in Sudan and Ethiopia. *In:* Ransom JK, LJ Musselman, AD Worsham and C Parker (eds.). Proceedings of the fifth symposium on parasitic weeds. CYMMIT, Nairobi, Kenya.

Birhane Biru, Nigussie Tesfa-Michael and Habtamu Admassu. 1991. Appropriate cultural practices for dryland farming areas of Ethiopia. *In:* Reddy, M.S. and Kidane Georgis (eds.). Proceedings of the 1st national workshop on dryland farming research in Ethiopia. 26–28 November 1991. Nazreth, Ethiopia.

CSA (Central Statistical Authority). 2001. Report on forecast of area and production of major crops for 2001/2. Statistical Bulletin No. 257. Addis Ababa, December 2001.

CSA. 2002. Statistical abstract for 2001. Addis Ababa, March, 2002.

Dawit Mulugetta and Rezene Fessehaie. 1990. Chemical control of weeds in maize. *In:* Parker C. and Rezene Fessehaie (eds.). Proceedings of the 6th Annual Meeting of EWSC. March 31–April 1, 1988. Addis Ababa, Ethiopia.

Esilaba, A.O., Fasil Reda, Ransom, JK, Wondimu Bayu, G/Medhin W/Wahid and Beyenesh Zemichael. 2000. Integrated nutrient management strategies for soil fertility improvement and *Striga* control in northern Ethiopia. *African Crop Science Journal* 8(4): 403–410.

Esilaba, A.O., Tilahun Mulatu, Fasil Reda, Ransom, J.K., G/Medhin W/Wahid, Adane Tesfaye, Ibrahim Fitwi and Gobena Abate. 1998. A diagnostic survey on *Striga* in the northern Ethiopian highlands. *Arem* 4: 13-27.

Fasil Reda. 1999. *Striga* research in Ethiopia: achievements and future prospects. *In:* Habtu Assefa (ed.). Proceedings of the 25th Anniversary Conference of Nazreth Agricultural Research Center. 20–23 September 1995. Nazreth.

Fasil Reda. 2002. *Striga hermonthica* in Tigray (northern Ethiopia) – Prospects for control and improvement of crop productivity through mixed cropping. PhD Thesis. Free University, Amsterdam, The Netherlands.

Fasil Reda and C. Parker. 1990. A host range study of different *Striga* samples and Alectra vogelli. Pp. 75–81. *In:* Parker C. and Rezene Fessehaie (eds.). Proceedings of EWSC 6th Annual Meeting. 31 March – 1 April 1988. Addis Ababa: EWSC.

Fasil Reda, G/Medhin W/Wahid, Beyenesh Zemichael and Wondimu Bayou. 1997. An integrated approach to the control of *Striga* in sorghum. *Pest management Journal of Ethiopia* 1: 43-49.

Fasil Reda and Wondimu Bayou. 2001. Striga hermonthica control through long-term crop rotation in sorghum-based cropping system in northern Ethiopia. *In:* Fer AP Thalouarn, DM Joel, LJ Musselman, C Parker and JAC Verkleij (eds). Pp. 304. Proceedings of the 7th International Parasitic Weed Symposium. Nantes, France.

G/Medhin W/Wahid, Beyenesh Zemichael and Ibrahim Fitiwi. 1998a. The status of Striga problem in Tigray. *Arem* 4: 28–36.

G/Medhin W/Wahid, Fasil Reda and Beyenesh Zemichael 1998b. Indigenous Striga management systems of farmers in Tigray: An overview. *Arem* 4: 37–45.

Gemechu Gedeno and Legesse Dadi. 1989. Verification of hand weeding recommendation for maize under farmers' conditions in Bako. *In:* Rezene Fessehaie (ed.). Proceedings of the 7th EWSC Annual Conference. 13–14 April 1989. Addis Abeba, Ethiopia.

Getachew Alem. 1989. A review of minimum tillage research in Ethiopia. Pp. 57-73. *In:* Ahmed Sherif, C Parker, A Stroud and Rezene Fessehaie (eds.). Problems and priorities for weed science in Ethiopia. Addis Ababa, Ethiopia. EWSC.

IAR. 1988. Asossa Research Center progress report for 1986–1988. Addis Ababa: IAR.

IAR. 1986. Awasa Research Center progress report for 1986. Addis Ababa: IAR.

IAR. 1989. Awasa Research Center progress report for 1989. Addis Ababa: IAR.

IAR. 1994. Mekelle Research Center progress report for 1986–1987. Addis Ababa: IAR.

IAR. 1987. Nazreth Research Center progress report for 1987. Addis Ababa: IAR.

IAR. 1988. Nazreth Research Center progress report for 1988. Addis Ababa: IAR.

Kassa Yihun, Tolessa Debele, Tolera Abera and Giref Sahile. 2001. Review of weed research in maize in Ethiopia. *In:* Mandefro Nigussie, D.G. Tanner and S. Twumasi-Afriye (eds.). Proceedings of the 2nd National Maize Workshop of Ethiopia. 12–16 November, 2001.

Kassahun Zewdie. 1998. Pre- and post-emergence herbicides for irrigated maize in Ethiopia. Pp 331–333. Maize Production Technology for the Future: Challenges and Opportunities. Proc. of the 6th Eastern and Southern Africa Regional Maize Conference, 21–25 September 1998, Addis Ababa, Ethiopia. CIMMYT and EARO.

Kasahun, Zewdie, Olani Nikus and Tefera Asamenew. 1999. Evaluation of pre-emergence herbicides for the control of *Parthenium hysterophorus* in sorghum. *Arem* 5: 130-137.

Mengistu H/Georgis, Mengistu Hulluka and Matias Mekuria. 2005. Determination of the critical period of weed control and the effect of mixed weed population on maize (*Zea mays*) yield and yield components. *Arem* 6: 57-68.

Parker, C. 1988. Review of *Striga* studies in Ethiopia up to 1986. *In:* Rezene Fessehaie and C Parker (eds.). Proceedings (*Problems and control of parasitic weeds in Ethiopia*) of the Second Ethiopian Weed Science Workshop. 29–30 September 1988, Addis Abeba, Ethiopia.

Parker C, and CR Riches, 1993. Parasitic weeds of the world: Biology and control. CAB International. Wallingford.

Rezene Fessehaie, Woldeyesus Sinebo, Aliye Hussien and Asfaw Negassa. 1993. Weed control research on maize in Ethiopia: A review. Pp. 42–73. *In:* Proceedings of the 1st National Maize Workshop of Ethiopia, 5–7 May 1992, Addis Ababa, Ethiopia. IAR/CIMMYT, Addis Ababa.

SARI, 2003. Awassa Research Center Progress Report for 2003. SARI.

SPL (Scientific Phyto-pathological Laboratory). 1988. Progress report for 1987/88. Ambo, Ethiopia.

Stroud, A. 1989. Weed management in Ethiopia: An extension and training manual. FAO, Rome.

Tenaw Workayehu. 1991. Effect of crop rotation on weed control and grain yield of maize. *In:* Rezene Fessehaie (ed.). Proceedings of the 9th Annual Conference of EWSC. 9–10 April 1991. Addis Ababa.

Tilahun Mulatu, Teshome Regassa and Franzel, S. 1990. On-farm research in Nazreth area: Experiences in developing technologies for smallholders. Rsearch report No. 8. IAR: Addis Ababa.

Tilahun Tadious and Tesfa Bogale. 1989. Optimum number of hand weeding for maize production. *Sebil* 2: 18–19.

Woldeyesus Sinebo and Aderajew Hadis.1991. Tillage and weed control effects on weed growth and yield of maize at Abobo. *In:* Rezene Fessehaie (ed.). Proceedings of the 9th Annual Conference of EWSC. 9–10 April 1991. Addis Ababa.

Wondimu Bayu, Selomon Binor and L. Admasu. 2001. Tolerance of sorghum landraces and varieties to *Striga* (*Striga hermonthica*) infestation in Ethiopia. *Acta Agronomica Hungarica* 49(4): 343–349.

Yohannes Lemma, Taye Tessema, J.K. Ransom and Belayneh Admasu. 1999. Incidence and distribution of *Striga* in Ethiopia. *In:* Fasil Reda and D.G. Tanner (eds.). *Arem* 5: 66–74.

Review of Research Outcomes on Insect Pests of Economic Importance to Major Small Cereals

Bayeh Mulatu[1], Mekasha Chichaybelu[1], Tafa Jobe[2], Tesfaye Belay[3], Yeshitela Merine[4], Asmare Dejen[4], Bayuh Belay[4] and Biruk Wubshet[1]

[1]Ethiopian Institute of Agricultural Research; [2]Oromia Agricultural Research Institute; [3]Mekele University; [4]Amhara Agricultural Research Institute

Introduction

The small cereals that are grown in Ethiopia include tef, wheat, barley, finger millet and rice. Among these, the major ones are tef, wheat and barley. The production areas of these crops overlap in many parts of the country.

Barley is an important cereal crop grown in most parts of Ethiopia mainly for subsistence. It is an important cereal crop and is ranked fifth after tef, maize, sorghum and wheat in the area under production. Over 1 million hectare is covered with barley every year. It covers a little more than 14% of the total area under cereals and contributes 12.80% to the total cereal grain produced. The productivity of the crop, at the national level, was estimated at 13.26 q ha^{-1} (CSA, 2005). In the upper altitude cool highlands of Ethiopia, it is the only cereal crop grown for multiple purposes (food, beverage and feed).

Tef, *Eragrostis tef* is a staple food crop of Ethiopia where it is originated and diversified. It is the most preferred national diet and accounts for about two-thirds of the daily protein intake in the diet of the population (Cited in (Tesfaye and Zenebe, 1998). Over 2.2 million hectares of land is covered with tef every year, which is about 27.80% of the total area allocated to cereal crops and made up 19.57% of the grain production. Its mean productivity at the national level was predicted at 10.34 q ha^{-1} (CSA, 2005).

Wheat encompasses bread, durum and emmer types. Close to 1.5 million hectare is covered with wheat every year. It covers a little more than 18.1% of the total area of cereals and contributes 20.60% to cereal grain produced. Wheat productivity at national level was estimated 16.73 q ha^{-1} (CSA, 2005).

Among the three crops, wheat entomology received little attention. The work carried out on the insect pests of wheat is very much limited and is restricted to the identification of its insect pests and yield loss assessment due to shootfly. On the other hand the work that have been carried out on insect pests of barley and tef are relatively more in number and detailed by considering the major pests in the two crops. The presentation in this review is based on the volume of work that has been done on the insect pests of the respective crops by starting with barley and ending with wheat.

Research findings

Pests recorded on small cereals

There were, before 1985, 64 recorded species of insects that attack barley, wheat and/or tef. Out of this 6, 22 and 6 species were recorded only on barley, wheat and tef, respectively, and 9 more species only on barley and wheat and another 21 species were common on barley, wheat and tef (Adugna, 1981). Between 1985 and 2005, which this review covers, 60 species of insects were recorded on barley, wheat and tef, but most of the species recorded during this period are similar to those reported in the 1985 proceedings (Table 1). What needs particular attention is the shootfly species composition in barley and wheat. The shootfly species causing seedling damage on barley and wheat was taken commonly as *Delia arambourgi* Seguy, since it was first identified on barley in the country in the 1960's. But lately two more species were recorded in Bale highlands: *D. steiniella* and *D. flavibasis*, as major seedling pest of wheat and barley, respectively (ABPHC, 1991; Tafa and Tadesse, 2005). The shootfly species composition in wheat at Alemaya was found to include six different species. Out of these, the two major species are *Atherigona angiustibola* and *Delia aramborgi* (Sileshi, 1994) (Table 2).

Table 1 Insect pests of the major small cereals identified through surveys

Crop species	Number of insect pest species recorded	
	Before 1985	After 1985
Barley	6	15
Tef	6	13
Wheat	22	13
Barley & Tef	---	2
Barley & Wheat	9	8
Tef & Wheat	---	2
The three crops	21	7

Table 2 Field insect pests recorded on different small cereal crops in Ethiopia by name and pest status

Scientific name	Common name	Host Crops	Pest status	References
Acrotylus spp	Grasshopper	IV	Major	76,133
A. patruelis Her.	Grasshopper	IV	Major	133
*Agrotis segetum (*D and S)	Cutworm	I, II, III, etc.	Major	112,114, 73
Aiolopus longicornis (Sjostedt)	Tef grasshopper	I,II,III,IV	Major	112,114,76,133
A. thalassinus (Fab)	Grasshopper	IV	Major	133
Altica pyritosa		II		73
Atherigona angustiloba van Embden	Shootfly	II	Major	126
Carbula recurva	Carbula bug	IV	Minor	76
Chrotonomus senegalensis abyssinicus Bolivar	Grasshopper	IV	Minor	133
Coptoghnatus curtupennis	Chafer grub	I,II	Locally major	54, 73
Decticoides brevipenni	Wello bush cricket	I	Sporadic	8,14,88
Delia arambourgi	Barley fly	I,II	Minor	8,14, 51,88,128
Delia flavibasis Stein	Barley shootfly	I, II ,III	Major	113,124
Delia steinella Emden	-	II	Major	125
Diuraphis noxia	Russian wheat aphid	I	Major	8,9,14,51,88,106,112,128, 73
Epilachna sp	Leaf Epilachna	I	Sporadic	8,14,88,112,73, 128
*Erlangerius niger (*Weise*)*	Black tef beetle	I,II,IV	Major	73,88,128
Eyprepocnemis noxia Dirsh	Grasshopper	IV	Major	76, 133
Eysarcoris inconspicus (HS)	---	IV	Uncertain	14
Haplodiplosis equestris	Gall midge	I, II	Minor	112
Helicoverpa armigera	African bollworm	I,IV	Minor	8,14,112,76
Hysteroneura setariae (Thom.)		I	Minor	10,14
Macrosiphum avenae (F.)	English Grain Aphid	I.IV	Minor	106
Macrotermes spp	Termites	IV	Uncertain	17
*Macrotermes spp.(*Rambur*)*	Termites	I,II,IV	Common	73,88
Marasima spp.	Leaf Webber	I	Minor	88
Marasmia trapezalis	Webworm	I	Minor	8,14,73
Medicogryllus spp.	Crickets	II,IV	Major*	14,73
Melanocaheta vulgaris (Adams)	Shootfly	II	Minor	126
Meloe monticola		II	Minor	73

Table 2 Continued

Scientific name	Common name	Host Crops	Pest status	References
Metapalopium dirhodium (Walker)	Wheat Aphid	I	Minor	9,10,14, 106
Mesoleurus sp	Weevil grubs	I,II	sporadic	76
Monolepta spp.		II		73
Nematocerus brachyridus	Shiny cereal weevil	I	Minor	8,14
Nezara virdula	Green stink bug	II		73
Odontotermes spp	Termites	IV	Major	17
Oscinella acuticornis Beschovski	Shootfly	II	Minor	126
O. nartschukiana Beschovski	Shootfly	II	Minor	126
Phyllotreta spp.	Flea beetles	II		73
Plusia spp.	Plusia worms	IV	--	73
Plusia acuta	Plusia worms	IV		25
Poophilius castles (wlk)	Spittle bug	I	Major	88,128
Rhopalosiphum maidis (Fitch)	Maize Aphid	I	Minor	88,106,112
Rhopalosiphum padi (L.)	Oat Aphid	I	Minor	88,106,112
Rhopoalosiphum maidis (Fitch)	Maize aphid	I	Minor	9,Adugna, 13,88
Rhopoalosiphum padi (L.)	Oat aphid	I	Minor	13,88
Rhopalpterum sp	Shootfly	II	Minor	126
Schistocerca gregaria	Desert locust	I	Minor	8,14
Schizaphis graminum (Rond.)	Greenbug	I	Minor	73,88,106,112
Scoliophthalmus micatipennis Duda	Shootfly	II	Minor	126
Sitobion fragariae (H.)	Cereal Aphid	I	Minor	9,10,14106
Sitotroga cerealella (Oliver)	Augoumois grain moth	I, II	Minor	88
Spodoptera exempta (Walk)	Armyworm	I,II,III,IV	Sporadic	8,14,16,88,128
Spodoptera exigua (Walk)	Army worm	I, II	Sporadic	88,128,76
Spodoptera litura (Fab)	Common cutworm	I, II, III, ETC…	Major	16
Thaumatomyia secunda	Fly	IV	Minor	76
Trilophidia conturbata	Brown Grasshopper	II,IV		73,133
Unidentified	Loop worm	I, II	Major	73,112
Unidentified	Common crickets	I,II,III,IV	Major	73,114
Unidentified	Shootfly	II	Major	73
Unidentified Thrips sp	Florate thrips	IV	Minor	30

I=barley, II=wheat, III=Emerwheat, IV=Tef; *in vertisols

Barley Entomology

Russian Wheat Aphid

Basic studies

Population dynamics

The population dynamics of the Russian wheat aphid (RWA) (*Diuraphis noxia* [Mord.]) was studied at Chacha, the most important place where RWA is an endemic problem. It was found that the aphid population increases during the period when there is moisture stress. Starting at the time when sufficient rainfall is received, its population declines through time and reach to a very low number and cause no significant damage when the rainfall becomes more frequent (Adugna, 1984). Similar results were obtained in North (at Estayesh) and South Wello (at Gimba) (SiARC, 1996).

Biotypic variation of RWA in Ethiopia

The RWA problem covers areas from Tigray in Atsbi to Bale highlands such as Agarfa area. To know whether there are biotypes to the RWA populations in Ethiopia, aphid clones were collected from barley fields in Shewa, Wello, Gonder, Adigrat and Maichew during the Belg season of 2002. The collected colonies were clonally reproduced and maintained in Mekelle. The aphid clones were tested on both susceptible (cv. Kesele and cv. Tsaeda Shewa) and resistant entries (3296-15 and 848-1) of barley and Oat, *Avena sativa* (Webster et al., 1987). The tests were conducted in a greenhouse in Mekelle under natural light conditions. Plants were examined for aphid damage 14 days after being infested. Each plant was evaluated for chlorosis on a rating scale of 1-9 (159), leaf rolling on a rating scale of 1-3 (159) and plant stunting on a scale of 1 to 5 (Burd et al. 1993 cited in Webster et al., 1987). Besides, the aphid biomass was measured. No significant differences in causing leaf chlorosis and rolling were found among the RWA clones on the four barley varieties and oat. The RWA clones, however, differed significantly in causing plant stunting and the biomasses they attained after fed on the different varieties and crops (Tesfaye, 2003). Conversely, the barley entries showed a significant difference on the degree of chlorosis, leaf rolling, and plant stunting they sustained and the biomasses of RWA that developed on them (Tesfaye, 2003). Further, the barley entries did not react differently to RWA clones except 848-1, which was found resistant and susceptible to the Shewa and the Gonder clones, respectively. In general, no significant differences among the Ethiopian RWA clones (Shewa, Gonder and Adigrat) were found with respect to biotypic variation. This indicates that they belong to the same biotype. On the other hand, the results were different for the American biotype, which poorly performed on the RWA resistant wheat lines from the USA on which all the Ethiopian clones performed well (Tesfaye, 2003) (Tables 3 & 4). Nevertheless, there was no genetic variation found among RWA populations from the USA, Syria, Canada, South Africa, Ethiopia (Tigray), Czech, Turkey, Hungry and Moldova. None of the markers revealed variation except for a single substitution obtained on the pseudogene *ptrpE* (Strasser, 1999; Stretch-Lilja., 1977). This might be due to the recent spread of RWA from its area of origin to the Southern and Western Hemispheres, which occurred in the 1970's.

Table 3 F-statistics for the three plant damage measuring parameters taken on the four barley lines and oat, and the RWA biomass

Source of variation	*df*	Chlorosis	leaf rolling	plant stunting	RWA biomass
Replication	3	1.92	1.41	1.14	7.71
Barley X Oat	4	20.62**	18.54**	9.28**	8.67**
RWA	4	1.51	0.34	2.60*	3.16*
Barley x RWA	14	0.63	1.15	1.54	0.76

** and ** significant at 0.05 and 0.01 levels, respectively; df, degrees of freedom.*

Table 4 Mean values ±S.E* of chlorosis on the barley entries and oat caused by he five RWA clones.

Entries	Shewa	Wello	Gonder	Adigrat	Maichew	Mean*
3296-15	4.75	5.25	5.75	5.00	5.75	5.3 ± 0.4 a
Kesele	5.25	4.75	5.27	4.75	4.50	4.9 ± 0.3 a
848-1	3.75	4.75	6.75	5.50	4.50	5.1 ± 0.4 a
T. Shewa	4.50	5.75	5.50	5.50	6.25	5.5 ± 0.4 a
Oat	2.00	2.00	2.25	2.00	2.00	2.0 ± 0.1 b
Mean*	4±0.4 c	4.5±0.4 cd	5.1±0.5d	4.6±0.4 cd	4.6±0.4cd	

*Mean values followed by the same letter are not significantly different (*P*=0.05, DMRT)

Host range

Host range survey conducted in some part of Amhara Region identified 16 cultivated and wild grass species that host the RWA (Amare, 1993). Result of host preference studies conducted in field and pot experiment, on six grass species, showed that broom grass, wheat and barley as the most preferred and oat (cultivated and wild) and tef less preferred hosts, respectively (Unpublished ShARC). Similar results were obtained earlier at Holetta ((Adugna, 1984; Adugna and Taddesse, 1989).

Yield loss assessment

Barley yield loss assessment due to the RWA was conducted by superimposing in farmers fields in South Gonder (Melaku et al., 1998), North Shewa at Chacha (Amare and Addisu, 1996), in North Shewa around Degem (HARC, 1996k; HARC, 1998), at Gimba in South Wello and Estaysh, Debresina, Hamisit and Kon in North Wello (SiARC, 1996). The assessments were made in 1995 and 1996 growing seasons. Similarly, loss assessment studies were conducted in the 1999 and 2000 cropping season in Tigray around Mai-Chew and Alaje (MARC, 1999; 2000). From these assessments, the yield losses estimated are described in Table 5.

Table 5 Barley grain yield losses caused by the RWA in different parts of Ethiopia

Area	Location	Year of assessment	Recorded grain losses (%)
South Gonder	Lay Gayint	1995 and 1996	38.3
North Shewa	Chacha	1995 & 1996	86-100
North Shewa	Degem	1995 & 1996	9.6 & 68
North Wello	Estaysh	1995 & 1996	35
	Debresina	1995 & 1996	26
	Hamisit	1995 & 1996	14
	Kon	1995 & 1996	21
South Wello	Gimba	1995 & 1996	62
Tigray	May Chew and Alajie	1999 & 2000	9.6 & 40.30*

**For the two locations, respectively over the two years*

Study on botanicals

Evaluation of some selected village available botanicals for the control of RWA conducted by Sirinka Research Center in 1998 showed that spray of tobacco and fermented cow urine gave good control of the pest and more than 50% grain yield advantage of barley over the untreated check (SiARC, 1998a).

Control measures

Cultural control

Sowing date trial

Sowing date experiment was conducted at Gimba and Gashena, in North Wello during the *belg* season of 1996. Delayed planting of barley increased aphid infestation and decreased grain and biomass yield indicating the importance of early planting as a cultural control of RWA (Adane, 1998).

Host plant resistance in barley

From 1987 to 1994, 1600 pure lines, breeders' selections, had been evaluated for their resistance against the RWA at Holetta. The screening had been done using irrigation water in off-seasons. Each accession was planted on either sides of a ridge of 1.5 m unreplicated. Prior to the conduct of the screening in each season, RWA Holetta population had been collected and mass reared in greenhouse and under field conditions. RWA carrying seedlings were cut into pieces and used to infest the lines planted in each season by spreading the cuts along either sides of each ridge. After two weeks to the infestation, scoring of the degree of damage incurred on each line had been done three times using the defined scales of 0-9 to measure the degree of chlorosis and leaf rolling caused by the RWA by visually assessing whole plot. In the 1991 and 1992 screening, 19 lines and in the 1993 and 1994, 14 lines were identified as better in their reaction against the RWA damage. None of the lines were free from aphid infestation or killed by the pest attack. For most of the materials, the scoring results range from four to eight for both symptoms of RWA damage. The scored results for the leaf chlorosis, which is the primary criterion for selection, were generally higher. Even among the 33 lines selected, some had mean scores of 40% for leaf chlorosis and mean scores of 10% leaf rolling. The selected lines had mean scores ranging from 3.17 to 4.0 for leaf chlorosis and from 1.0 to 3.83 for leaf rolling. Besides, the accession 3296-15 from the 1993-94 selection had better stand despite the 4.33 mean leaf chlorosis and 3.17 mean rolling scored on it. This is an indication for the presence of tolerance to the RWA damage in the Ethiopian barley germplasm pool (Addissu et al., 1999; Bayeh and Tadsse, 1996; HARC, 1987b; 1988b; 1991b; 1992c; 1996d; 1996f; 1996g). To determine that 3296-15 is indeed a tolerant line, feeding behavior of RWA was studied using electrical penetration graphics technique (Tjallingii, 1987) in comparison with 9301B from USA and 3284-11, RWA susceptible line, from Ethiopia. Total phloem feeding time was significantly shorter on 3296-15 indicating that it has more suitable phloem sap than the others. Although the aphids did not show preference between the lines, live weight of aphids reared on 9301B was significantly lower than on the other two lines (Fig 1). Therefore, it may be stated that 3296-15 is indeed a tolerant line (Bayeh, 1997).

Screening of barley accessions for their resistance against Russian wheat aphid was carried out during the 1995, 1996 and continued until 2000 at Mekele Agricultural Research Center (at Mai-Chew, Alaje and Adigrat locations). About 175 barley accessions collected from PGRC/E were included in the screening program. From 24 accessions that possess some level of resistance/tolerance were selected and tested further in the 1997/1998 cropping season. Furthermore, eight accessions were selected and tested on advanced bases. Results indicated that accessions 465, 2987, 848, 3833, 487, 3583 and 3949 showed better level of resistance/tolerance to the insect pest and better yield. During the study period, it was observed that some accessions showed high level of early growth resistance/tolerance to the insect attack (MARC, 2000).

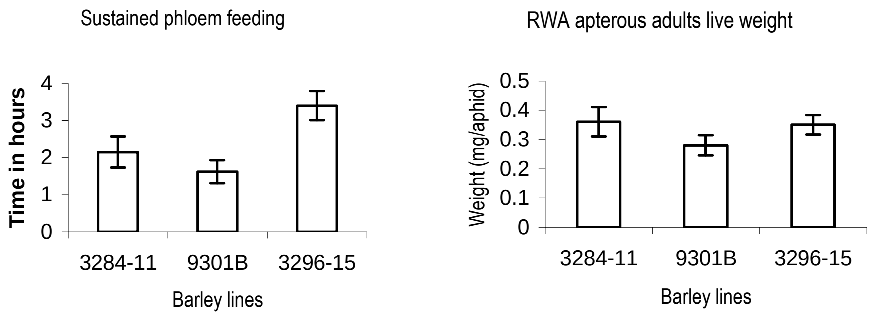


Fig 1. Mean ± SE total time lapsed in sustained phloem feeding and live weight of RWA apterous adults after reared on the three barley lines.

Although screening of landrace of barley for resistance of RWA was not totally terminated. Most of the studies since 1998 at Sheno were focused on the evaluation of advanced barley lines developed at ICARDA by crossing of selected Ethiopian landraces with known RWA resistant parent materials developed in countries where the pest has longer history and introduced through the national barley program. Out of 29 barley lines screened during the 1999 and 2000 belg seasons at Chacha, only seven materials have shown good level of resistance (Table 6), although they were not comparable with respect to their agronomic merits to the local and standard checks (DBARC, 2003).

Table 6. Barley lines with good level of resistance against RWA (D. noxia Mord.) with the local and susceptible checks in1999 and 2000 belg seasons at Chacha

Barley lines	1999 Belg Season				
	I (%)	LC	LR	DH (%)	DH
ROO2	10	1	1	3	111
ROO4	8	1	0	2	104
RO31	26.5	1	1	2	114
RO22	16.5	1	0	1	113
RO26	21	1	0	2.5	119
RO23	12	0	0	1	111
RO18	14	1.5	1	3	120
Local check (Kessele)	49	5	5	13	90
Suscep. check (3284-9)	52	6	5	24	90

% I= Percentage infestation, LC= Leaf Chlorosis using 0-9 scale scoring, LR= Leaf Rolling using 0-9 scale scoring, %DH= Percentage deformed head, DH= Days to heading

Chemical control

Seed dressing insecticides

Carbofuran 35% ST at five concentrations between 1 and 5%, Carbosulfan 75% and Diazinon 50% were compared as seed treaters. All controlled the aphid significantly and gave yield advantages over the untreated control (Adugna and Tadesse, 1989).

The Holetta local barley cultivar Baleme was treated with imidacloprid 70% WS, furathiocarb 400 CS, diazinon-TMTD (15% a.i. for diazinon the active insecticide component), lindane-TMTD (20% a.i. for lindane the active insecticide component) and carbofuran 25% ST at the rates of 88.2, 74, 65, and 74 g a.i./ha. The seed dressing procedure followed was similar to what is described earlier for shootfly.

All the treatments including the standard and untreated checks were planted on plots of 3 x 2 m in four replications. The plots were laid down in a randomized complete block design. When the seedlings reached four leaves stage, all the plots were artificially infested with apterous forms of the RWA. This was done by spreading RWA infested small leaf pieces of the barley cultivar Baleme. The infested leaves were taken from the aphid culture maintained at the time under field condition at Holetta. Since two weeks after infestation, data on number of infested tillers and aphids per tiller were taken at random from six, 50 cm long, rows per plot and degree of leaf chlorosis and rolling and also phytotoxicity were visually scored on whole plot base. The leaf chlorosis and rolling were scored on weekly interval three times. Additional data collected were days to heading, maturity and grain yield. Analysis of variance was done on the collected data and the means are reported.

The results showed that among the five seed dressing insecticides, on imidacloprid 70% WS treated plots, the mean percentage infested tillers was lower over the subsequent scoring days. But the mean aphid count per tiller was not statistically significantly different. However, on the second scoring day, statistically higher number of aphids was recorded on the untreated plots. In general, for both parameters considered in the analysis, the mean infestation level and number of aphids counted per tiller were consistently lower on imidacloprid 70% WS treated plots (Table 7a). Though, the yield obtained in general was low, the yield gap between the untreated check plots and imidacloprid 70% WS treated plots was 3.6 q ha^{-1} (Table 7b) (HARC, 1996i).

Table 7a Mean infested tillers percent and aphids counted on synthetic insecticides dressed barley

Treatments	Rate a.i. (g/ha)	Mean infested tillers (%)			Mean aphid (No/tiller)		
		D-I	D-II	D-III	D-I	D-II	D-III
Carbosulfan 25% ST	162.5	21b	20c	28c	15a	14a	13b
Furathiocarb 400 CS	74	24b	20c	25bc	16b	17a	11a
Imidacloprid 70% WS	88.2	10a	12a	16a	6a	11a	8a
Diazinin-TMTD	55	21b	16b	20ab	8a	9a	6a
Lindane-TMTD	74	24b	16b	19ab	7a	11a	12a
Local check		25b	21c	18ab	10a	18b	8a

Table 7b Mean days to heading, plant height and grain yield of synthetic insecticides dressed barley

Treatments	Rate a.i. (g/ha)	Days to heading	Plant height (cm)	Grain yield (q ha^{-1})
Carbosulfan 25% ST	162.5	89a	87a	14.46bc
Furathiocarb 400 CS	74	89a	87a	14.46bc
Imidacloprid 70% WS	88.2	90a	96b	14.60c
Diazinin-TMTD	55	92ab	85a	10.63a
Lindane-TMTD	74	92ab	86a	14.26b
Local check		94b	88b	11.00a

Rate determination of the seed dressing insecticide, Imidacloprid 70 WS, the most promising among the seed dressing insecticides tested at Holetta, was carried out at Chacha and Kotu in North Shewa in 1995 and 1996 b*elg* seasons. Five rates (0.5, 1, 1.5, 2 and 2.5 g a.i/kg of seed) were compared. The highest rate better controlled the crop from aphid damage and increased grain yield (Addisu and Tadesse, 1999). This study however did not include economic analysis. Thus, another study was conducted in 1998 *belg* season at Chach and kotu (ShARC, 1999) to evaluate the effect of five seed dressing insecticides with Imidacloprid 70% WS and also to determine the economic significance. All were tested at three rates except Imidacloprid 70%WS, which was tested at fixed rate, 0.75 gm ai /kg of seed. The minimum aphid damage and highest grain yield were obtained from the (Imidacloprid 70 WS), Cruiser 70 WS at a rate 0.75 gm ai /kg and Apron star 42 WP at a rate 5 gm ai /kg treated plot (Table 8a). These three seed treatment insecticides were further verified on farmers' fields at Sembo under *belg* rainfall and at Cheki and Chacha with supplementary irrigation on a plot size of 10 x 10 m to see their profitability (ShARC, 2000). It was found that among the insecticides, Cruiser 70WP was the most profitable and use of Cruiser 70WP at a rate of 0.75 gm ai/kg seed can give net benefit of Birr 3065 ha^{-1} and marginal rate of return of 915% over the untreated barley. The other two insecticides Apron star 42Ds and Imidacloprid 70% WS were found effective in controlling the RWA, but they were not profitable because they were too expensive on market and the recommended rates were relatively high compared to cruiser

70WP. The sensitivity analysis showed that a 25% increase of price of Cruiser 70 WP is more profitable (MRR = 736) than a 50% reduced price for both Guacho 70 WP and Apron star 42 DS (Table 2). In other words, the price of these two insecticides must be reduced by more than 80% (Table 8b) for farmers to get an acceptable MRR. In areas like Chacha where RWA is serious and constant problem for barley production during the belg and under irrigation, it was recommended to use this seed dressing insecticides. Similar results were obtained at Gimba (SiARC, 1997).

Table 8a Results of combined analysis over location on the effect of seed dressing insecticides on RWA (Russian Wheat Aphid) infestation and yield of barley at Kotu and Chacha, 1998 belg

Insecticides	Rates (g/kg seed)	Damage score (0-9 score) at three growth stages				Yield (q ha^{-1})	
		Tillering	Booting	Heading	Mean	Straw	Grain
Imidacloprid 70 ws	2.5	1.2	1.3	1.8	1.5	27.2	10.2
Promet 400 cc	5	4.7	5.0	5.2	5.0	30.6	10.1
Promet 400 cc	10	4.7	5.3	5.7	5.2	24.6	7.5
Promet 400 cc	20	4.7	5.3	6.0	5.4	23.7	7.5
Cruiser 70 ws	0.5	2.2	2.7	3.5	2.8	32.3	7.5
Cruiser 70 ws	0.75	1.9	2.7	3.5	2.6	32.0	11.5
Cruiser 70 ws	1	1.7	2.5	3.2	2.4	30.7	10.8
Cruiser 35 Fs	1	2.0	2.8	3.3	2.7	22.8	8.5
Cruiser 35 Fs	1.5	2.0	2.2	2.8	2.3	26.1	10.6
Cruiser 35 Fs	2	1.7	2.2	2.7	2.2	30.2	8.9
Apron star 42 WP	2.5	3.0	4.0	4.7	3.9	29.6	8.0
Apron star 42 WP	3.5	3.2	3.8	4.0	3.7	34.1	8.0
Apron star 42 WP	5	1.2	1.7	2.2	1.7	37.6	11.3
Gaucho raxil	1.5	1.5	2.0	2.7	2.1	28.5	9
Gaucho raxil	2	1.5	2.3	3.0	2.3	26.8	8.8
Gaucho raxil	2.5	1.5	2.0	2.7	2.1	23.6	9.6
Untreated Check		5.5	6.0	7.0	6.2	16.6	5
CV(%)		26.3	25.8	17.3	12.4	23.6	33.7
LSD(5%)		1.1	1.3	1.04	0.9	10.8	5

Table 8b. Partial budget analysis for the three insecticides and untreated local barley seed at Cheki and Chacha under irrigation, 1999

Item description	Cruiser 70WP	Apron Star 42DS	Gaucho 70WP	Untreated barley
Average Grain yield in kg/ha	1124	1008	1188	926
Average Straw yield in kg/ha	2777	1828	1609	1870
Gross Benefit in birr/ha	3359	2747	3020	2600
Total Costs that vary at 10%pm	292	705	1187	219
Total Costs that vary at 15%pm	294	721	1218	219
Cost of labor birr/ha	12	12	12	-
Price of barley seed in birr/ha	219	219	219	219
Price of insecticide at 10% pm	61	474	959	0
Price of insecticide at 15% pm	63	490	990	0
Net Benefit in birr/ha at 10% pm	3067	2042	1833	2379
Net Benefit in birr/ha at 15% pm	3065	2026	1802	2379
Marginal Cost birr/ha at 15% pm	75	502	999	-
Marginal Net Benefit birr/ha at 15% pm	686	(353)	(577)	-
MRR (%) over untreated barley	915			
Sensitivity analysis				
+ 25% price of insecticide (TC, NB, MRR)	310,3049, 736			
- 25% price of insecticide (TC, NB, MRR)	278,3081, 1189			
- 50% price of insecticide (TC, NB, MRR)	263,3096, 1629			
- 85% price of insecticide (TC, NB, MRR)		305,2442,7 3	380,264 0,162	

MNB= Marginal Net Benefit, MRR= Marginal Rate of Return, NB= Net Benefit, pm= allowed profit margin for insecticide importers at Addis Ababa

Note

- *Price of the insecticides is estimated after 10 and 15% allowed profit margin of the importers is included at Addis Ababa*
- *Price of Cruiser 70WP, Apron Star and Gaucho is 672, 759 and Birr 3170 kg^{-1} respectively.*
- *Labor used to treat the seed is the local wage rate of Birr 6 per man-day.*
- *Estimate price of local barley seed at planting is taken to be Birr 1.75 kg^{-1}*
- *Estimate price of local barley out put after harvest Birr 2.0 kg^{-1}*
- *Estimate price of barley straw is Birr 0.4 kg^{-1}.*

Spray insecticide

Verification of the spray insecticide Dimethoate (Ethiothoate) 40% EC for the control of RWA (*D. noxia*) on barley conducted at Chacha and Cheki with supplemental irrigation during *belg* season of 2003. Two spray of this insecticides at a rate of 1.5 l ha^{-1} effectively controlled RWA on barley and gave marginal net benefit of Birr 437.95 and 446.95 ha^{-1} when the price of the chemical is taken at market and company prices, respectively (DBARC, 2003).

Integrated control of the RWA

Integration of different sowing date with one time spray with Pirimiphos-methyl 50% EC (1 l ha^{-1}) was studied at Gimba in 1996 and 1997 to see their combined effect in controlling the RWA on barley. It was found that there is significant interaction between sowing date and insecticide treatment. Early sown barley, after sprayed with insecticide, suffered significantly lower damage than all the other treatment combinations. Moreover, although the difference was not statistically significant, the early sown after treated with insecticide gave the highest yield (SiARC, 1997b) (Tables 9a & b).

Table 9a. Effect of sowing dates and insecticidal treatment on RWA, yield and yield component of barley at Gimba

Treatments	Infestation (%)			Plant height (cm)	Productive tiller (%)	Yield qt/ha	
	Tillering	Booting	Flowering			Biomass	Grain
Treated (A)	6b	26b	35	84A	80	21A	44A
Untreated (B)	9a	33a	40	81B	74	09B	37B
12 January (1)	5	5D	5D	89A	94A	154B	60A
22 January (2)	6	9C	13C	89A	91AB	160A	56B
01 February (3)	7	25B	38B	85B	88B	115C	37C
11 February (4)	11	78A	94A	67C	35C	32D	9D
a x 1	8C	5	4	88	93	158	61
a x 2	6C	9	16	90	92	160	57
a x 3	3D	15	31	88	88	127	44
a x 4	8C	76	88	69	47	40	13
b x 1	3D	5	6	90	96	151	58
b x 2	7C	10	9	88	90	59	55
b x 3	11B	35	45	82	88	102	31
b x 4	14A	80	99	63	23	23	5
CV %	60.21	47.43	7.85	5.60	14.79	18.31	19.52

Table 9b. Effect of sowing date and insecticide treatment on incidence of RWA on Barley at Gimba

Treatments	Chlorosis (1-9)	Rolling (1-6) & stunting (1-9)	Infestation at (%)		
			Tillering	Booting	Flowering
Treated (A)	2.3b	1.7b	1.7a	2.4b	1.7b
Untreated(B)	3. 63a	2.6a	2.7a	4.1a	2.8a
Jan.24 (1)	4.25A	3.25A	3.63A	1.84C	2.76B
Feb.3 (2)	4.63A	3.25A	1.58A	2.77B	3.80A
Feb.13 (3)	1.38B	1.13B	1.22B	4.17A	1.22C
Feb.22 (4)	1.50B	1.00B	1.22B	4.25A	1.22C
A x 1	3.25B	2.50B	4.40	1.70C	2.03C
A x 2	3.00BC	2.00BC	1.72	2.27BC	2.22C
A x 3	1.50D	1.25C	1.22	2.92BC	1.22C
A x 4	1.25D	1.00C	1.22	2.69BC	1.22C
B x 1	5.25A	4.00A	2.86	1.99C	3.49B
B x 2	6.25A	4.50A	1.45	3.27B	5.39A
B x 3	1.25D	1.00C	1.22	5.41A	1.22C
B x 4	1.75CD	1.00C	1.22	5.81A	1.22C
CV (%)	25.05	27.46	45.16	18.65	27.41

In 2000 and 2002, RWA tolerant barley line (3296-15) was integrated with dimethoate and Tobacco or animal urine for the control of the RWA at Gimba. The combination of variety and dimethoate and the two with tobacco or urine gave significantly higher grain yield than the local variety under the farmers' practice (SiARC, 1997; 1998). Besides, the tolerant line was compared with the local cultivar both as dressed and undressed with Gaucho 85% WS as seed treater at Gimba in 2001. The tolerant line in dressed form controlled the aphid significantly better and gave significantly higher yield than all the other treatments (SiARC, 2004) (Table 10).

Table 10. The effect of resistance/tolerant barley variety (3296-15) and seed dressing chemical on aphids at Gimba, 2001

Treatments	Leaf chlorosis (1-9 scale)		Leaf rolling	Aphid counts/5plants		Infestation (%)			Yield kg/ha
	Apr 27	May5	May5	Booting	Flowering	Tillering	Booting	Flowering	
Chemical									
Treated (A)	1.2b	1.0b	1.0b	5.7b	0.0b	0.0b	1.2b	0.0b	1300a
Untreated (B)	2.7a	3.3a	2.3a	50.5a	16.7a	5.2b	7.3a	8.7a	842b
Varieties									
3296-15 (1)	1.8a	2.0a	1.5a	22.8b	5.5b	1.b	2.8b	3.2b	1322a
Ehilzer (2)	2.0a	2.3a	1.8a	33.3a	10.7a	4.2a	5.7b	5.5a	820b
Interaction									
Ax1	1.3a	1.0a	1.0a	2.7b	0.0c	0.0b	0.7b	0.0b	1652a
Ax2	1.0a	1.0a	1.0a	8.7b	0.0c	0.0b	1.7b	0.0b	993a
B2x1	2.3a	3.0a	2.0a	43.0a	11.0b	2.0b	5.00ab	6.3ab	949a
B2x2	3.0a	3.7a	2.7	58.0a	21.3a	8.3a	9.67ab	11.0ab	692b
CV (%)	23.0	13.3	17.3	17.7	62.4	30.5	28.2	25.3	11.9

Barley shootfly

Basic studies

Developmental time

The developmental biology of the new barley shootfly, *D. flavibasis* was studied on six barley genotypes: Arusso, HB-42, PGRCE/E 1799, PGRCE/E 4414, PGRCE/E 4409, PGRCE/E and PGRCE/E 4282. Egg hatching was in the range of 2.5 to 3.13 days. Larval development period was between 4.17 and 5.88 days and the pupal period was between 7.75 and 9 days. The overall developmental period (egg to adult) lasted for 14.88 to 17.67 days. The weight of larvae, pupae and adults were in the ranges of 3.60 to 4.02, 3.00 to 3.63 and 2.13 to 3.11 mg, respectively (Tafa, 2003).

Host plant preference

Five grass species were tested for their preference by the barley shootfly, *Delia aramborgiu* (Seguy) at Holetta. Out of the five host plants barley, tef, wheat, cultivated oat, wild oat and lolium, barley and tef were the most preferred crops

(HARC, 1987a). Emmer wheat, bread wheat, tef, maize and oat were also evaluated for their preference by the new barley shootfly, *D. flavibasis*. The infestation in the susceptible barley variety HB-42 (control) was 100%. Emmer wheat, bread wheat and tef, too, were infested heavily. Thus, they might serve as suitable hosts besides the barley. On the other hand, maize and oats were the least infested. Besides the cultivated crops, a number of wild hosts were recorded to host barley shootfly species in Bale. This include elephant grass (*Penniestum* spp) hosts *D. flavibasis,* whereas *Snowdenia polystachya* hosts *D. steiniella*. Outside the grass family *D. flavibasis,* was also recorded on *Lupinus angustifolius*. It could, therefore, be regarded as an alternative host to *D. flavibasis*. This is a sign that *D. flavibasis* is probably a polyphagous species and might have a wider host range beyond these two families. This, however, needs to be studied further (Unpublished data, Tafa Jobe).

Population dynamics

Ten barley varieties were planted in *Ganna* and *Bona* 2004 to investigate the seasonal variation pattern of barley shootfly population, measured in terms of the degree of infestation they sustained. In *Ganna* 2004, infestation ranged from 7–14%, whereas in *Bona* 2004, infestation ranged from 52 to 100%. This is apparently because there is nearly five months long closed period from *Bona* to *Ganna* than the nearly two months gap between *Ganna* and *Bona* which might have been the source of the higher population buildup observed at the onset of *Bona*. The bulk of barley is produced in *Ganna* than *Bona. T*his is probably to avoid high barley shootfly infestation pressure (SARC, 2005).

Dry season survival

An experiment was conducted at Sinana Agricultural Research Center to test whether barley shootfly infestation on wheat and barley could occur during off-seasons (non-cropping period). Accordingly, five varieties from each of barley and wheat were sown in February of 2004, 2005 and 2006. In 2004 non-cropping period, the infestation level ranged from 7–39% on barley and 12–19% on wheat. In 2005, infestation on barley genotypes ranged from 21 to 54 and that of wheat from 8 to 12. In the three years, it has become apparent that shootflies are active during the dry season, too, and the availability of their host plants during this period helps them increase their number. The implication is that shootflies survive all year round through normal reproduction by infesting its main host, volunteer crops and/or wild hosts (SARC, 2005; SnARC, 2006).

Control measures

Cultural control

Sowing date

The effect of sowing date on infestation of barley shoot fly, *Delia flavibasis* Stein and yield was investigated in 2001, 2002 and 2003 in *Bona* season (August to December) at Sinana Agricultural Research Center. This was done on four sowing dates using two barley genotypes (Arusso and Holker). There was significant response difference between the sowing dates in affecting the infestation levels the varieties sustained but not the grain yields obtained (Table 11). Generally, however, early (late July to early August) than late sowing was found to significantly minimize infestation and increase yield. But, the yield of both varieties was negatively correlated with infestation levels. Hence, early sowing of the local cultivar (Arusso-Bale) could be an alternative way to manage the barley shoot fly in Bale highlands (SnARC, 2001; 2004).

Table 11 Three years Mean ±SE infestation levels of barley shoot fly on barley and grain yields obtained

Sowing dates	Mean Percent infestation		Grain yield (kg/ha)
	Day 1	Day 2	
1st	27.67±3.66b	37.33±6.94b	3268±517
2nd	35.67±8.11b	36.33±12.81b	3139±517
3rd	72.67±13.87a	69.00±13.32ab	2313±498
4th	66±13a	87.00±5.51a	1787±358
P-value (0.05)	0.045	0.02	0.17
F-ratio $_{3,8}$	4.45	5.90	2.16

Means followed by the same letter within a column are not significantly different

Host plant resistance

Resistance to the barley shootfly in barley germplasms

At Holetta from 1986–1995, 2200 lines from land race accessions were evaluated against the barley shootfly, *Delia arambourgi* Seguy. Twenty-two lines from 1986–1991 and 40 from 1991–1995 screenings, which suffered relatively minimum damage from the fly out of the 2200 lines, were further evaluated. The count of dead heart is the primary key for differentiating the barley lines. In general, all the lines suffered from the fly attack (HARC, 1987a; 1998a; 1991a; 1992b; 1996a; 1996c; 1996e; 1996f). Out of the 40 lines, the lowest infestation was on 3284-14 (29.17%) and the highest was on 3520-13 (60.7%). When tested dressed with insecticide, the infestation level on the selected genotypes lowered significantly and on 3520-13 the infestation went down to 7.20%. This indicates the contribution of genetics, in the barley lines, for lowering shootfly infestation is minimal. In general, all the selected genotypes showed early seedling vigour which might have contributed for the lower incidence of barley shootfly damage, viz. the 1938 lines which sustained significant damage. From this, one may state that though all the advanced lines did not escape from attack by the shootfly, the early seedling vigour feature they are having is a good character which enabled them to suffer less damage unlike the bulk of the genotypes tested. However, earliness is very much linked with low yield. For instance, the line, 3284-14, headed too early (in 66 days) than all the other genotypes and yielded very low 7.38 q/ha. Therefore, improving the yield potential of barley germplasms with inherent characteristic of early seedling vigour might probably help to overcome the barley shootfly problem.

A number of improved barley varieties including HB-42, Ardu 10-60B, shegie, Beka, Holker and HB-120 were also tested for their responses to the other barley shootfly *D. flavibasis* attack at Sinana Agricultural Research Center. All cultivars were found highly susceptible, to the fly attack, with 85–100% infestation levels recorded on them (Amare, 1993; Tesfaye et al., 1997). Moreover, 125 malt barley genotypes from exotic sources were screened for resistance to barley shootfly. However, all were found highly susceptible and most were apparently lost without giving any yield (SnARC, 2006). Because of this, the search for shootfly resistance genotypes was focused on indigenous sources, particularly barley landrace collections from Bale. The outcomes from the set of materials screened in 2002 are described below.

Preliminary screening was done on 300 landraces obtained from IBC in a non-replicated nursery. Relatively resistant genotypes were selected for further evaluation based on infestation and crop recovery. The first score of infestation indicated that of the 300 genotypes, 10, 38, 124 and 128 had infestation levels in the ranges of 21–40%, 41–60%, 61–80% and 81–100%, respectively. For the second score, 6, 35, 86 and 173 genotypes had infestation levels below 40%, 41–60%, 61–80% and 81–100%, respectively. Regarding recovery growth, which occurs probably due to the continued availability of rainfall, among the 300 genotypes, 15 were completely wiped out but 50 recovered well. In 2003, 62 genotypes selected from the 2002 trial were re-evaluated. For the first score, two genotypes had infestation level below 60%; nine had in the range of 61–80% and 51 in the range of 81–100%. In the second score, 18, 25 and 19 genotypes had infestation levels in the ranges of 41–60%, 61–80% and 81–100%, respectively. The 18 genotypes were further tested but all sustained significant infestation from *D. flavibasis* attack (between 82–99%), although some genotypes recovered significantly (IBDR-2, Kesele, IBDR-2, IBDR-I, Acc 229999, Acc # 03 and Acc 99). Particularly IBDR-2 was the best in terms of score of recovery growth, which gave the highest yield followed by Kesele.

On the contrary, four accessions were completely lost (yield = 0) to the damage of *D. flavibasis*, whereas the remaining accessions gave very low yield. In general, between 1994 and 2006, 5996 Ethiopian barley landraces were screened at Sinana for their resistance to barely shoot fly (SnARC, 2001). This effort has bear fruits and four *D. flavibasis* resistant barley varieties Harbu and Dinsho in 2003/4 and Dafo and Biftu in 2004/05 were released from the Center.

Mechanisms of resistance *to D. flavibasis*

Ovipositional antixenosis

The presence of ovipositional antixenosis in barley genotypes to barley shootfly was confirmed. This was based on number of eggs a shootfly laid per plant, which was 5.6 for Arusso-Bale (resistant) and 11.3 for HB-42 (susceptible). This confirms that Arusso-Bale is relatively resistant and HB-42 susceptible to the barley shootfly attack. This difference in ovipositional preference response shows that antixenosis is a probable component of resistance in barley against barley shootfly (SARC, 2005; Tafa, 2004).

Tolerance/crop recovery growth

The tolerance in barley genotypes against barley shoot fly was assessed based on seedling infestation level sustained, crop recovery growth and grain yield. There were 170 dead seedlings per plot for HB-42 against 43-62 for the resistant genotypes and this difference was statistically significant ($P<0.05$). Crop recovery growth following infestation, assessed visually, was significantly different between the test genotypes and HB-42. Moreover, in spite of the heavy infestation they sustained, the test genotypes gave significantly higher yield relative to the susceptible check. These results combined make HB-42 a susceptible variety than the test genotypes. The high level of recovery observed in the test genotypes when compared with HB-42 might probably be due to genetic or environment or both. Although the probable internal factors that may contribute to seedling recovery growth and increase number of tillers, after shootfly attack, in a particular genotype are not fully identified, at least it is established that availability of continuous rainfall is a governing environmental factor contributing for the recovery of damaged barley seedlings (Tafa, 2003).

Chemical control

Seed dressing insecticides

Adugna Haile (1986) compared Aldrin with Lindane and Maneb to obtain alternative to the use of Aldrin and found that both chemicals are effective against the barley shootfly on barley. Hence, they could be used as alternatives (Adugna, 1986). The Holetta local cultivar Baleme was taken and treated with imidacloprid 70% WS, furatiocarb 400 CS, diazinon-TMTD (15% a.i. for diazinon the active insecticide component) and aldrin 40% WP (Standard check) at the rates of 88.2, 74, 65, and 200 g a.i. per hectare. In dressing the seeds, enough water was sprinkled over the seeds in polyethylene bags and shook thoroughly to create wet surface on the barley seeds that could allow uniform coating the seed with the insecticides. All the treated seeds were then air-dried under shade. All the treatments including the standard and untreated check were planted on plots of 3 x 2 m in four replications. The plots were laid down in a randomized complete block design. There were 6 rows of 2 m length contained in a plot. Fifteen days after seedling emergence, the number of seedlings live and with dead heart (dead central shoot) were taken at random from six, 50 cm long, rows per plot. The same data were collected for two more weeks. Furthermore, data on the toxicity of the different chemicals on the barley seedlings, days to heading, plant height, and grain yield were recorded. Analysis of variance and group means comparison with LSD (p=0.05) were made.

The untreated check suffered significantly from shootfly attack than the others. Beside, the pest pressure was higher on diazinon-TMTD treated plots. The best control of the fly was attained by the use of aldrin, the standard insecticide. But, the differences in the mean change in percentage damage were not found statistically significant between the standard seed dressing insecticide (aldrin) treated plots and imidacloprid 70% WS and furathiocarb 400 CS treated ones. The grain yield obtained, too, was not statistically significantly different among the plots treated with aldrin and those treated with imidacloprid 70% WS and furathiocarb 400 CS (Table 12). Dazinon-TMTD has caused phytotoxicity on the barley seedlings. The insecticide component in diazinon-TMTD is low (15% by weight) and to get 65 g a.i. to treat 100 kg of seed, 433 g product was needed. This might have been the cause for the observed toxicity on the seedlings (HARC, 1999a).

Table 12 Mean changes over time in percent tillers damaged by the barley shootfly after treated with seed dressing synthetic insecticides

Treatment	Rate a.i. (gm/ha)	Mean change in damaged tillers (%)			Grain Yield (q/ha)
		D-I	D-II	D-III	
Aldrin 40% WP	200	1.00	3.20	13.14	68.31
Imidacloprid 70% WS	88.2	3.60	2.48	21.23	55.87
Furathiocarb 400 CS	74	3.80	8.41	16.20	59.33
Diazinon-TMTD	55	42.41	84.23	78.05	38.92
Check	---	77.15	94.18	88.8	30.15
CV (%)		25.96	5.73	31.64	17.87
LSD(0.05)		10.35	3.397	21.2	13.91

Imidacloprid (Gaucho[R]) and insecticide and fungicide admixtures: tubuconazole (Gaucho[R] and Raxil[R]), thiamethoxam (Apronstar[R]) and heterahabditis (Cruiser[R]) were also evaluated on barley shootfly at Sinana Agricultural Research Center. Heterahabditis (at 50, 75 and 98), thiamethoxam (at 250 and 375) and imidacloprid at 250 g per 100 kg seed were effective as seed dressers against *D. flavibasis* (SnARC, 2001), but imidacloprid was by far the most effective in reducing barley shootfly infestation. It was recommended earlier by Bijlmakers and Selvaraj (1989) that seed treatment should be introduced as a routine crop protection measure in Ethiopia, where and when necessary (Bijlmakers and Selvaraj, 1989). To date, the use of seed dressing insecticides has never received the attention it disserves.

Integrated management of *D. arambourgi*

The search for barley genotypes resistant to the barley shootfly, particularly *D. arambourgi*, was not found promising. However, fertilizer, seed dressing insecticides, seed rate and sowing date were found to be promising (Unpublished data, HARC). The combined effect of these factors was studied for two years at Holetta. The three factors were evaluated at three levels. There was significant difference between the years. Because of this, the analyses were done separately. In the first year (1998), seedling damage was significantly affected by the combined effect of fertilizer and insecticide ($P<0.0001$), whereas in 1999 the combined effect of the two factors was found to be only marginally significant ($P<0.04$). But, as individual factors, both affected seedling damage highly significantly ($P<0.0001$). In 1998, days to heading and grain yield were influenced highly significantly by the combined effect of the three factors (Table 13). The highest rates of insecticide and seed combined with the highest rate of fertilizer gave highly significant yield than without fertilizer application ($P<0.0013$). These results did not repeat themselves in 1999. The main effect insecticide on the level of seedling damage incurred was highly significant. Grain yield was marginally affected by the application of the highest rate of fertilizer (Table 14) (HARC, 1999).

At Sinana, integrated management of the barley shootfly, *D. flavibasis* was studied in three locations (Sinana on-farm, Agarfa and Gasara) from 2004 to 2005 to study the best integration option of seed dressing chemical, variety and sowing date. Combination of early sowing, resistant variety such as Arusso and lower rate of chemical (half of the recommended rate) reduced barley shootfly infestation and increased yield significantly. The study showed that the combination of resistant variety and early sowing also reduced infestation and increased yield (SARC, 2005; SnARC, 2006).

Table 13 Main and interaction effects of different barley shootfly management methods on different parameters measured in 1998

Responses	Sources of variation						
	F	I	SR	F*I	F*S	I*S	F*I*S
Seedling damage on Day 1	NS	NS	**	NS	NS	*	NS
Seedling damage on Day 2	***	***	NS	***	**	NS	NS
Seedling damage on Day 3	NS	NS	NS	NS	NS	NS	NS
Total tillers	NS	*	NS	***	NS	***	**
Productive tillers	**	NS	**	***	NS	NS	NS
Days to heading	***	***	***	***	***	***	***
Days to maturity	NS	NS	NS	NS	NS	NS	NS
Plant height	***	***	***	NS	*	NS	NS
Grain yield	***	***	***	***	***	***	***
1000SW	NS	NS	NS	NS	NS	NS	NS

Table 14 Main and interaction effects of different barley shootfly management methods on different parameters measured in 1999

Responses	Sources of variation						
	F	I	SR	F*I	F*S	I*S	F*I*S
Seedling damage on Day 1	NS	***	NS	NS	NS	NS	NS
Seedling damage on Day 2	***	***	NS	*	**	NS	NS
Seedling damage on Day 3	*	***	NS	**	NS	NS	*
Total tillers	NS	NS	NS	NS	NS	NS	NS
Productive tillers	NS	NS	NS	NS	NS	NS	NS
Days to heading	***	NS	**	*	NS	**	NS
Days to maturity	NS	NS	NS	NS	NS	NS	NS
Plant height	**	NS	NS	NS	NS	NS	NS
Grain yield	*	NS	NS	NS	NS	NS	NS
1000SW	NS	NS	***	NS	*	*	NS

Chafer grubs on barley

Bionomics, host preference and survival of coleopterous seedling pest of barley in Tikur Inchinii and its environs were investigated. The larvae of the root feeding coleopterous species were recorded to be the major pest of barley attacking its seedlings (Unpublished data HARC). Total barley seedlings losses have been recorded in some fields in Tikur Inchinii where barley was planted after barley, linseed or on land fallowed for several years before planted to barley (personal observation). Farmers in the area had been using seed dressing insecticides, which included aldrin, dieldrin, and heptachlor. But in the recent past, Carbosulfan 25% ST has been used for dressing barley and wheat seeds.

Basic studies

Bionomics of the larvae

The chafer grub's different life forms population change showed that the highest population of the larvae was recorded in January followed by February. Eggs were found in March and newly hatched larvae recorded in April-May. The age composition of the larvae varied with time and in the early months, i.e., after crop harvest and until February, the later instars dominated. On the other hand, in April-May, the very young ones dominated (Table 15). During the first two months, there were recovered mated females, which can easily be identified by their distended abdomen. However, from March to May there were very few or no gravid females found. Pupation occurred between April and May (Table 15). All the recovered females were dissected and the number of ready-to-leave eggs were removed and recorded. This was found to be 13–39 eggs/female. The recovered eggs are cream white, have midlongitude and midlatitude size of 1.96 and 1.29mm, respectively (HARC, 1999d).

Table 15 Mean ±SE monthly record of the larvae, pupae and adults of the chafer grub, *Melolontha* sp in the preceding season barley grown field in Tikur Inchinii

Sampling Month	Mean number trapped per 1m^2 quadrate			Range per quadrate for larvae
	Larvae	Pupae	Adults	
January	55	0	14	44-66
February	37	0	10	0-70
March	36	0	0	25-43
April	25	5	2	14-42
May	26	2	1	2-55

During this monitoring, the depth of the digs ranged from under the biomass to a depth of 60 cm. In January and February, when the surface soil was dry and there was no apparent green vegetation cover, the grubs were recovered at depths below 20cm. In March-April, there was some rain shower, which initiated some plant growth and brought wetness in the soil. Hence, the larvae came close to the surface and were recovered underneath the growing plants in up to a depth of 20 cm (HARC, 1999d).

Comparison of the population dynamics of the grub was made in fields wherein barley, wheat, tef or linseed were grown in the previous season or kept fallow for several years. The monitoring was done fortnightly until the end of June 1998. The grub population during the monitoring period in 1998, which extended between January and June, was consistently higher in the fallowed land and linseed grown field, whereas in barley and tef grown fields the recorded larvae from January to mid-February were higher and declined consistently through to the end of the monitoring period (Fig 3). Moreover, the overall mean number of larvae recovered per quadrate was significantly different among the different crops and the fallowed land and the least record was made in tef grown fields ($F_{3,216}=22$, $P<0.0001$) (Fig 2) (HARC, 1999d).

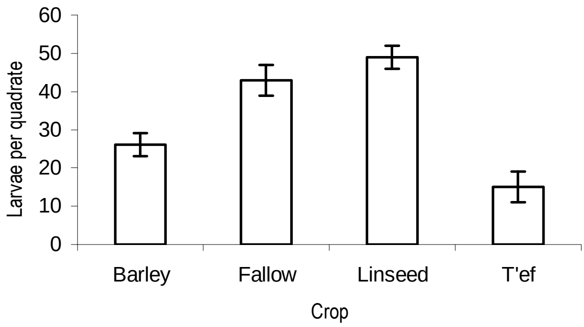


Fig 3 Mean ±SE number of larvae recorded per quadrate taken fortnightly in fields in the previous season barley, linseed and tef grown and in a fallowed field.

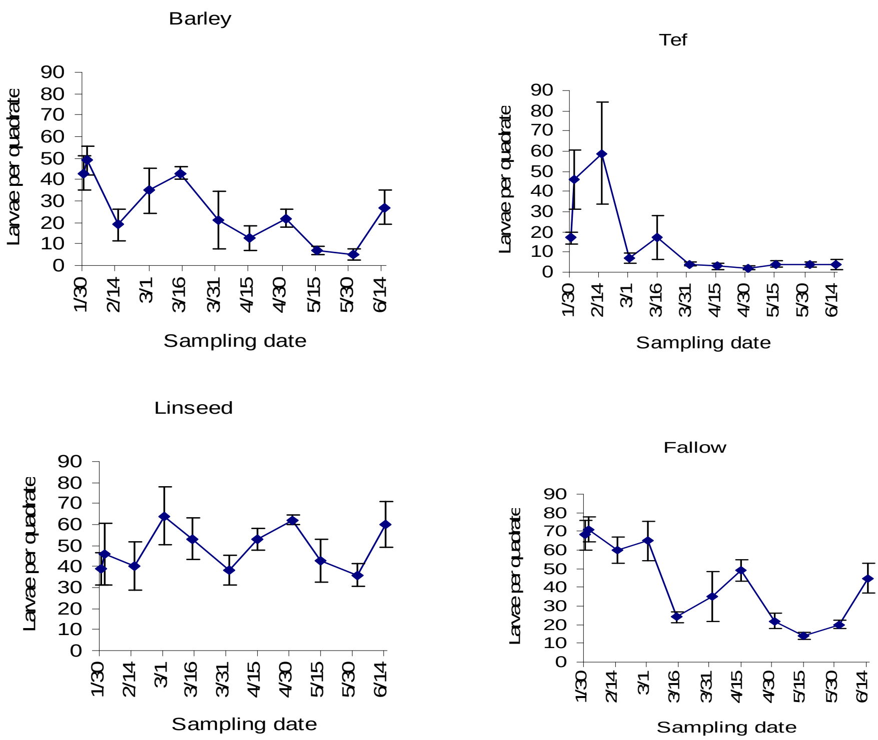


Fig 2 Mean ±SE dry season survival trends in the populations of larvae of the chafer grub, *Melolontha* sp in tef, barley and linseed grown fields and in fallowed field in 1998.

All the larvae recovered in the tef field were by-and-large the first and second instars. This was mainly the case in the first two weeks of the sampling period, implying that the colonization of tef grown fields by ovipositing females of the chafer grub occurred early in the sampling period. However, the population drastically decreased after the second week. As shown in Figs 2, there was no any buildup all through the remaining sampling period. Eggs were found laid in early March only in linseed and barley grown fields and in the fallow land, whereas in the tef grown field, no eggs were laid all through the sampling period. Most of the pupae and adults in the fallowed field were recovered between mid-April and early June. Similar trends were observed in linseed and barley grown fields, although the recorded numbers were much smaller (Fig 4). In tef grown field, only adults were recovered in mid-January, mid-February and early May. These adults might have come to lay eggs, but no eggs were found in the monitored tef field. The large population of early instar larvae recovered in the first two weeks in tef fields have come from eggs laid before the monitoring was initiated (HARC, 1999d). Since tef grown fields had been animal trampled at sowing, the young larvae might have found it hard to survive in the compacted soil. Hence, their number declined continuously all through the sampling period.

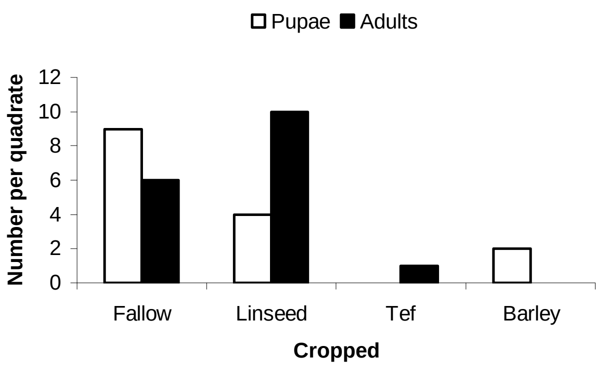


Fig 4. Mean total number of pupae and adults of the chafer grub, recovered between Jan. and Jun, in tef, barley and linseed fields 1998.

Host preference

In a no-choice set, where the crop species were planted in separate compartments, 100% seedling kill was recorded in tef followed by 72% in barley and 64% in wheat. The least damage was recorded in linseed, where only 40% of the seedlings were killed. In a free-choice set, the damage on tef was about 80%, whereas the damage sustained by barley, wheat and linseed seedlings were 30%, 35% and 25%, respectively. Based on this, therefore, it may be said that the most prone to the attack by the larvae of the chafer grub is tef. However, under field condition, the highest damage was sustained by barley and the least by tef. This total reversal was thought to be attributed mainly to the land preparation when the crop to be planted is tef or otherwise (unpublished data, HARC).

Suitability of different soil types

In Tikur Inchinii, in the absence of host plants, the grub survives on soil by feeding on the soil. Different soil types were compared for their suitability as feeding niches to the grub. Avoidance of the Holetta red clay soil by the test grubs was observed at the start of the experiment, but they settled in it after about 48 hours. This might have been because of the no-choice condition they were subjected to. Movement of the test larvae introduced into the Ginchii heavy black clay soil was very much limited. In general, there were observed very high differences in the survival of the grubs in the different soils without growing crop seedlings (Table 16). However, larvae found alive in the Holetta red clay, Ginchi heavy black clay and Denbi silt clay soils were found in poor shape after they elapsed six weeks in the bare soils. Moreover, most of the surviving grubs in these test soils were found infested with mites (Unpublished data, HARC).

Association of soil characteristic and chafer grub survival

Total organic carbon content was determined in all these soil samples in that the Tikur Inchinii loam soil and the Holetta garden soil (the latter received manure) were found to have high organic carbon content. This ensured the survival of greater number of the test larvae (Table 15). These results agree with the reports of Hill (1975) and Richards and Davies (Richards and Davis, 1977), who said that soils with high organic matter content are reputed to be attractive for ovipositing adults of chafer grubs. The improved survival of the larvae in Holetta garden soil implies that the insect has the potential to invade manure receiving crop fields. Thus, in using animal manure to fertilize crop fields, one ought to consider the possibility of colonization of such fields by this chafer grub or other species with similar niche requirement (Unpublished, HARC).

Table 16. Survival of the larvae of the chafer grub in bare soils, brought from different locations, with different textures and organic carbon content

Tested Soil Samples			Survival (%)	Pupation (%)
Source location	Texture	Organic carbon (%)		
Denbi	Silt clay	3.79	32	12
Ginchii	Clay	1.95	36	12
Holetta crop field	Clay	2.43	36	16
Holetta flower garden	Clay	5.17	48	4
Tikur Inchinii	Loom	14.38	68	12

Effect of precursor crops on the Chafer grubs in barley

Barley was sown (undressed or dressed with insecticide) in fields wherein the preceding season different crops were grown or left fallow for several years. Data were collected on the number of larvae before sowing and after harvesting. Moreover, damage to seedlings was recorded twice in the season fortnightly. The reduction in the number of larvae of the grub after barley was harvested from fields in the preceding season planted to different crops or kept fallow was found statistically significant only in barley and wheat fields (Table 17). In barley grown fields after tef, there was reduction in the number of larvae, though it was not statistically significant. In contrast, in fields sown to barley after linseed and fallow, there was either no change in density of larvae or an increase was recorded. When pooled, the mean number of larvae recorded before sowing and after harvesting, in general, showed an increase in the untreated plots, whereas in the treated plots, there was a significant decrease in the number of larvae after harvest (Fig 5). Thus, showing the significance of dressing barley with insecticides in reducing chafer grub larvae caused barley seedling damage (HARC, 1999c).

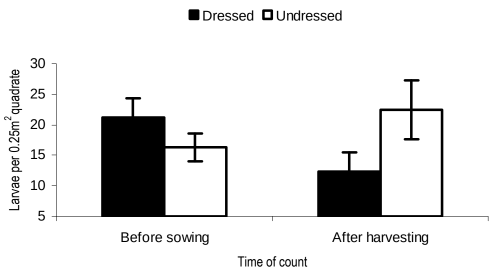


Fig. 5. Mean ±SE larvae of the chafer grub recorded per 0.25 m^2 quadrates before sowing and after harvesting of barley

Table 17a. Mean ±SE number per quadrate of chafer grub larvae before sowing and after harvesting treated and untreated barley, grown in fields with different precursor crops

Precursor crop	Mean ±SE larvae per 0.25m^2 uadrate		P-value
	Before sowing	After harvesting	
Insecticide dressed			
Barley	15±4.47ab	2.83±0.70b	0.02
Wheat	34±8.56a	7.8±3.64ab	0.02
Tef	19±2.34ab	12±3.40ab	0.13
Linseed	28±10.62ab	26±5.60a	0.80
Fallow	11±1.75b	15±5.65a	0.86
P-value	0.025	0.021	
Undressed			
Tef	5.70±1.93	31.50±18.37	0.08
Barley	7.2±2.05	12.40±2.29	0.11
Linseed	27.67±10.33	13.17±3.5	0.42
Fallow	12.60±2.27	31.20±15	0.50
Wheat	22.50±5.75	26.80±11.84	0.98
P-value	0.06	0.77	

Table 17b. Mean ±SE percent barley seedlings damaged by chafer grub larvae in fields with different precursor crops sown to insecticide treated or untreated barley and grain yield per 5m² plot

Precursor crop	Mean ±SE percent barley seedlings damaged			Grain yield g/5m² plot
	Day 1	Day 2	Day 3	
Insecticide dressed				
Barley	4.97±0.90	14.01±2.13	14.70±6.70	524±123
Fallow	4.81±1.94	17.16±1.94	15.66±1.95	-----
Linseed	6.54±2.07	13.33±2.21	16.82±0.80	841±98
Tef	3.87±0.88	12.59±3.43	16.50±1.24	905±96.5
Wheat	8.49±2.42	12.94±2.41	21.39±3.41	1284±230
P-value	0.42	0.70	0.71	0.053
Undressed				
Barley	14±0.59	13.77±2.42b	16.48±4.50	253±60.78c
Fallow	18±2.68	20.47±3.89ab	20.45±3.36	-----
Linseed	10.50±2.63	21.83±2.93ab	22.20±3.05	423.7±22.7bc
Tef	13.25±2.13	27.38±2.12a	27.71±3.07	574±46.00ab
Wheat	13.73±3.80	25.01±0.84ab	25.74±3.91	781±77.68a
P-value	0.43	0.037	0.28	0.002

Chemical control

The Tikurinchinii local barley cultivar was treated with aldrin 40%WS, imidacloprid 70% WS, lindane-TMTD (20% for lindane the active insecticide), diazinon-TMTD (15% for diazinon the active insecticide), furathiocarb 400 CS, and carbosulfan 25% ST at the rates of 200, 88.2, 74, 65, 74, 162.5 g ha^{-1}. The procedure used for seed dressing described earlier was followed. Five farmers' fields were selected in consultation with development agents and farmers based on the history of the field. Fields, which were planted with tef in the previous season, were deliberately avoided. This is because as indicated in the Introduction, the insect pressure is low in such fields. The treatments were planted on plots of size 3 x 5 m and replicated three times and laid in a randomized complete block design. Data were collected one month after sowing on seedling damage and at harvest above ground biomass and grain yield from five randomly taken quadrates of 50 X 50 cm. Moreover, toxicity to the growing plants was visually assessed on whole plot base. In 1998 imidacloprid 70% WS was selected based on the good efficacy it had on the pest and carbosulfan 25% ST was chosen by farmers because of its availability and low price to be re-tested on larger plots of 10 x15 m. Again five farmers were selected at random to host these trials. Analysis of variance was done on the collected data and the means are reported.

In the first two years when six different seed dressing insecticides were compared, imidacloprid 70% WS treated plots gave the highest yield advantage of 4.33 q ha^{-1}

over the untreated check plots (Table 18a). To reconfirm the observed efficacy of imidacloprid 70 WS, it was compared with carbosulfan 25% ST.

The results obtained showed that there was no significant difference on the mean percentage of seedling damage caused by the chafer grub among the treatments in the first three sampling days, whereas on the last sampling day, significantly higher seedling damage was recorded in the untreated checks. However, no significant yield difference was obtained. But, imidacloprid 70% WS treated plots gave yield advantage of 5.24 q ha^{-1} over the untreated check (Table 18b) (HARC, 1996j; 1996l, 1998b)

Table 18a. Mean seedling damage by the chaffer grubs on barley seedlings at Tikur Inchinii and mean dry biomass and grain yields

Treatment	Rate a.i. (gm/ha)	Seedling damage (%)	Dry biomass	Grain yield (q/ha)
Aldrin 40 % WP	200	53.6	45.2	17.13
Carbosulfan 25 ST	162.5	49.8	41	13.23
Diazinon-TMTD	55	58.2	37	16.78
Furathiocarb 400CS	74	53.2	36.7	15.20
Imidacloprid 70 % WS	88.2	51.8	46.9	20.60
Lindane-TMTD	74	52.8	40.2	17.75
Check		50.4	39.8	16.27

Table 18b. The effect of two out standing seed dressing chemical insecticides against the chafer grubs (?Melolontha sp) on barley seedlings at Tikur Inchinii

Treatment	Rate a.i. (gm/ha)	Mean change in seedling damage (%)				Grain yield (q/ha)
		D-I	D-II	D-III	D-IV	
Carbosulfan 25% ST	162.5	6.8	8.2	6.4	6.8	21.74
Imidacloprid 70% WS	88.2	12	10.6	4.0	9.8	26.43
Check		13.6	9.6	6.8	35.2	21.19
P<0.05		NS	NS	NS	0.01	NS

Epilachna beetles in barley

Yield losses

Yield losses assessment experiment was conducted in the 1999 and 2000 cropping season at Machew and Korem where the insect pest is most prevalent. The trial was arranged in RCBD with four replications and farmers' fields were considered as replications. Fenitrothion 50% EC at a rate of 1l ha^{-1} was applied on some of the plots for protection of the crop from the insect pest damage and equal number of plots was left untreated as control plots at each field. Chemical spraying was made fortnightly starting from 1 month after planting.

In the 1999 cropping season, proportion of plants infested in the untreated plots was as high as 68.55 and 32.5 at Korem and Mai-Chew, respectively. Yield losses indicated that a reduction of 18.05% (353.7 kg ha^{-1}) was found at Korem. For the 2000 cropping season, yield losses of nearly 3% was recorded at Korem but there was no yield losses recorded at Maichew. In the field it was observed that plants recover easily from the damage and the duration of high infestation was for a short period of time. This could be the possible reason for the no significant yield losses recorded (MARC, 1999; 2000).

Tef insect pests

Basic studies

Biology of red tefworm

The status of the red tef worm as a major pest of tef was reported in Shewa, Kefa, Gojam and in some places in Tigray and Wellega (Tadesse, 1987). The biology of red tef worm (RTW), *Mentaxya ignicollis* (Walker) (Lepidoptera: Noctuidae), was studied by Taddese and Mathews (Tadesse and Mattews, 1986). Oviposition activity of RTW is mostly nocturnal. Eggs are laid singly or in batches ranging from two to over 300 per batch, sometimes in two or three layers. A few days after oviposition, the eggs turn brown and almost dark before hatching. The well developed head and true legs of RTW larvae are green in color and the upper (dorsal) side is either red, reddish brown or light green. A faint, white line runs right down the middle of the back. Towards the sides are broken brown lines running along each side of the body; a distinct white line also runs the full length of the body (Tadesse and Mattews, 1986). In the laboratory, up to 1031 eggs per female per month were laid (Tadesse, 1987).

RTW has six larval instars and the overall larval developmental period ranges from 25 to 47 days with a mean of 33 days. Between 51 and 65% larval mortality occurs in the first instar followed by the second instar (between 3 to 23%). The depth of the pupation site is 2 to 9 cm deep. Pupation is completed within 2 to 3 days while in the laboratory it ranged from 18 to 78 days with an average of 30.9 ± 3.4 days. Most of the pupae appear to enter diapause in the field at the end of the cropping season and survive to the next one. The pupa is shiny light or dark brown with a mean length of 14 mm and width of 5 mm. The adult is a grayish or brownish night-flying moth with a wingspan of about 3.4 cm for both sexes. The forewing is gray in the female and light brown in the male with three distinct dark brown and black markings on the leading edge. The hind wings are white. The adult longevity under laboratory conditions was similar for both sexes, with a mean of 17.4±2.1 and 17.0±2.7 days, respectively. RTW is estimated to have three to four generations per year (Tadesse and Mattews, 1986; Tadesse, 1987).

Alternate host to the RTW

Only two grass species, *Phalaris paradoxa* and *Digitaria scalarum*, were encountered in Becho and Keffa regions, respectively, to host RTW (Stretch et al., 1979; Tadesse and Mattews, 1986).

Grasshoppers in tef

Species composition and seasonal abundance

Jago (1977) (cited in Tibebu and Landin, 1992) reported the presence of at least two hundred species of grasshopper in Ethiopia. They have been serious threats for the production of cereals particularly tef and wheat (DZARC, 1987). Mostly they are found on natural or semi-natural vegetation and roadsides. The composition and structure of Orthopteran fauna in cereal crops in southeastern Shewa, around Debre Zeit were studied (Tibebu and Landin, 1992). Twenty-nine taxa of short- and long-horned grasshoppers, grouped into four families and nine subfamilies were identified. The fauna mainly consists of members of the family Acrididae, which accounts for about 70% of the total of all species encountered. Many of the species are either pests or potential pests of cultivated crops in different countries including Ethiopia (Stretch-Lilja., 1977). Of these *Aiolopus longicornis* is by far the most numerous species in the samples. It is a serious pest of cereals, tef in particular, at early seedling stage and is highly mobile, suddenly appearing in swarm. Tibebu (1999) reported the seasonal abundance and breeding habits of *A. longicornis* in cereal crops in Ethiopia. *A. longicornis* is more abundant during rainy periods than otherwise. It was also more common on black soils than on light ones. Peak abundance usually declines in the later part of the long rain period of August to September. Its reproduction is also mainly confined to the rainy periods.

Shootfly

Distribution and species composition

A study was made on distribution and species composition of tef shoot fly. The infestation of the pest was low in the central highlands (2-3.69%), intermediate in East Gojam (0.6-15.65%) and high (6.96-37.6) in Tigray (DZARC, 2002). The pest is known as “Mukuta” or “Kubi” in Tigray and farmers in this area attribute the incidence of tef shoot fly to shortage of rainfall and loss of soil compaction. Cultural control practices such as late planting, repeated plowing in May and June when there is sufficient rain and soil compaction by moving cattle on the final seedbed are practiced by farmers in Tigray. The study made on the species composition has not been successful (DZARC, 2002).

Natural enemies to WBC and RTW

Bayeh and Tsedeke (1995) collected specimens of Wello Bush Cricket showing four different disease symptoms. From one of the samples the entomopathogenic fungi were isolated at Ambo Plant Protection Center (Adane Kassa, personal communication). A hymenopterous parasitoid, *Enicospilus rundiensis* Bischoff (Hymenoptera: Ichnumonidae), and generalist predators such as birds, ants and spiders have been recorded on RTW (Tadesse and Mattews, 1986). Moreover, Bacilllus thuringiensis Berl is also an important entomopathogenic bacterium that kills the larvae of RTW (Tadesse, 1987)

Insect pests caused yield losses in tef

Attempts made to estimate yield losses caused by the WBC in Degeza Amba, North Wello, indicated that it could cause 15–35% loss on tef (1999).

Red tef worm could cause up to 24% loss in yield (IAR, 1986). Tesfaye and Zenebe (1998) reported that complete losses of crop in Tigray due to tef shoot fly were common especially when there is rain shortage. Under optimum rain and distribution, the tef crop tillers and compensates for the lost parts or ‘dead hearts’. Further study of yield loss due to tef shootfly was made in Tigray at two locations. In the 1999 cropping season percentage of plants with shootfly damage symptoms (dead hearts) was 24.2 % (Dibdibi) and 28.5 % (Mekoni) on untreated plots. The mean grain yield differences between treated and untreated plots were 174.96 kg ha^{-1} (19.9% loss) at Dibdibo and 947.64 kg ha^{-1} (16% loss) at Mekoni (1999). For the 2000 cropping season, proportion of plants with dead hearts was 28.5% at Mekoni and 26% at Dibdibo on the untreated plots. The average grain yield difference between treated and untreated plots was 720 kg ha^{-1} (24% loss) at Mekoni and 640 kg ha^{-1}, 18.86% loss at Dibdibo (99). In contrast, conclusive result could not be obtained with the studies made to determine economic significance of tef shootfly around Debre Zeit and Alem Tena (DZARC, 2000).

Black tef beetle, *Erlangerius niger* Weise, is a sporadic pest of tef and was found to cause an estimated yield loss of up to 30% (SiARC, 1996). However, around Debre Zeit it was reported that though the population buildup on tef often was significant, the damage it caused has not been found economically significant to warrant control (DZARC, 1984). Further assessment was made at Berfeta, around Holetta and loss due to the black tef beetle was estimated to be 16% (HARC, 1986).

Economic threshold/significance

The impact of four levels of grasshoppers: 0, 5, 10 and 15 adult insects per square meter on tef at different growth stage (early seedling, early tillering and early heading stages) were studied in field cage at DZARC under field condition. This quantitative evaluation of grasshopper damage on tef shows that an increase in grasshopper density per unit area ensues in increased loss and attack of seedlings and eventually a decrease in the biomass at harvest. Thus, a population density of fifteen grasshoppers per square meter is found to be an acceptable density (DZARC, 1988; 1991). Mostly, grasshoppers caused greater plant loss and attack when infestation was made at early seedling stage and the least at early heading stage.

Simulated grasshopper damage to tef was investigated at DZARC, by leaf removal made at early seedling and early tillering stage of the crop. The following levels of leaf removal: 0%, 15%, 50%, 75%, 100% were made using a pair of scissors and compared with 100% grasshopper caused defoliation. In this experiment, it was evident that increase in degree of leaf defoliation resulted in a consistent increase of loss of seedlings and corresponding decrease in tef grain yield. Defoliation made at early seedling stage gave better grain yield than defoliation at early tillering stage. This is perhaps because more tillering and compensatory growth takes place when defoliation is made at early seedling growth (DZARC, 1991).

Control measures

Cultural methods

Wello bush cricket

Stretch et al. (1979) reported different options of controlling WBC. Early sowing of cereal crops including tef would enable them to mature before the natural food sources (weeds and other plants at field boarders) of this pest have dried and hence can escape the attack. As the early instars of WBC are flower feeders, slashing of weeds in the field margins before cereals have headed would deprive this pest of the food and reduce its population near crops. Moreover, although traditional control techniques as a sole method cannot provide satisfactory control, farmers in Wadla Delanta and Enese Sarmidir area drive the pest out of the crop field and kill them using physical means. In addition, they clear out-skirt of a farm and plow it or they spread straw of tef and wheat on the peripheries and set it on fire (Davidson, 1969).

Grasshoppers

Studies were made to determine the effect of planting dates of tef on grasshopper damage and yield (DZARC, 1989; 1990; 1991). The experiment was conducted at Denkaka in 1988/89 and at Akaki in 1989/90 and 1990/91. Five planting dates (Table 18) were compared as insecticide sprayed and unsprayed. Split plot arrangement was used where insecticides allocated in the main plot and planting dates in the subplot. The results indicated that earlier planting exposes tef to a serious damage by grasshopper and gave smaller yield, while the following dates gave higher yield perhaps due to the least loss and attack of seedlings. The last date, similar to the first two dates, gave the least yield, though this low yield could not be attributed to grasshopper attack as there was no difference in yield of sprayed and unsprayed plots of this particular date (Table 19). Rather it could be attributed to the terminal moisture stress. Therefore, in the localities where this trial was carried out, planting tef around end of July to first week of August seems to have relatively lower attack by grasshoppers and gives better yield.

Table 19. The influence of planting date on grasshopper damage to and yield of tef, 1990/91

Sowing date	Percent seedling loss**		Percent attacked seedling**		Grain yield kg/ha	
	USp*	Sp*	USp	Sp	USp	Sp
July 10	32.56	23.46	67.22	28.27	321.04	648.13
July 20	36.96	29.85	62.95	31.82	630.13	880.68
July30	19.76	14.49	30.29	30.49	1267.81	1321.31
Aug. 10	16.88	15.25	27.02	25.61	1023.29	1200.13
Aug. 20	15.11	14.94	25.02	18.71	721.84	739.06
Mean	24.25	19.60	42.62	27.02	792.82	957.86
LSD (0.05)	Insecticide	3.03		4.98		NS
	Date	5.16		8.27		233.79
CV(%)		22.8		23.01		25.88

** USp = Unspayed; Sp = Sprayed; ** Arcsine transformed values were used for analysis; Source: DZARC, 1991*

Red tefworm

Since RTW passes the harsh dry season in the soils as pupae, early plowing of harvested tef fields in an infested area can be employed to reduce the population of diapausing pupae through desiccation and predation. Destruction of *Phalaris paradoxa* and *Digitaria scalarum* from field borders and wastelands particularly during the dry season may help in reducing the possible source of infestation (Tadesse, 1987; 1987b).

Tef shoot fly

Effect of sowing dates (early July, mid-July, late July, early August and mid-August) were studied during the 1995 and 1996 cropping season for the management of shoot fly on tef at Mekele Research Center. Three tef varieties (Dz 01-27, Dz-cr-37 and local check) were used as main plots while the different sowing dates were used as subplots. The general trends showed that early sown tef (early and mid-July) sustained higher percentage of shoot fly infestation than the late sown. Contrary to this, yields of the earlier sowing dates were higher compared to the later sowing dates (MARC, unpublished data). This could be explained in part by the moisture availability so that induced more tillers to be produced and most of which become productive. Hence, in moisture stressed areas (dry land areas), late sowing of tef, though it can escape damage from shoot fly damage, was not found useful. However, it could be put in to practice if it can be supplemented with irrigation or with moisture harvesting practices. It could also integrate with other control practices, host plant resistance of early type of varieties.

Chemical methods

Wello bush cricket

One well timed application of insecticides can effectively control WBC since it has only one generation a year and migration is minimal. Therefore, insecticide application should be after most of the eggs are hatched, before the damage begins to be serious and before weeds flower to take care of nectar foraging bees. This is a time when nymphs are still feeding mostly in the weeds in the margins of the fields and spot treatment of these areas is all that would be required. The most practical formulation is dust. Kemal (Kemal, 1982) has found Lindane dust diluted to 2%, 1%, 0.5% and 2.6% gamma BHC (in the order given) to be most effective in the control of the pest. Moreover, effective control of this pest can be achieved using 7–10 kg ha^{-1} of 2% and 15–20 kg ha^{-1} of 1% Lindane dust diluted with clean wood ash formulated by mixing 20 g and 10 g, respectively, technical Lindane powder per kilogram of wood ash just before application. The author also confirmed the use of Swaine duster or loosely woven Hessian sack as effective means of dusting. Bayeh and Tsedeke (1995) have recorded several insecticides that include Diazinon EC, Endosulfan EC, Carbarly WP, Dimethoate EC, Bendiocarb EC, Dieldrin EC, Ekatin EC, Malathion EC and Phosphamidon 100 SCW supplied by the Ministry of Agriculture for WBC control.

Red tefworm

Taddese (1987a; 1987b) evaluated different formulations of insecticides against RTW. Single spray of Cypermethrin 25 % EC, Fenitrothion 50%EC, Diazinon

60% EC, Trichlorphos 50% EC and Endosulfan 35%EC at the rates of 187.5, 625, 600, 1000 and 700 g ai/ha, respectively, effectively controls the pest. ULV application of Fenitrothion 50%, Endosulfan 25% and Cypermetrin 5% at a rate of 1150, 500, and 110 g ai/ha, respectively, with a swath width of 6 m when the wind velocity drops below 6 km per hour also proved to be effective in controlling the pest. Comparison of different ULV sprayers was made for three years at Becho in farmers' fields using Fenitrothion ULV formulation. However, no single sprayer out performed the others (HARC, 1989; 1990; 1992). In general, all the sprayers dispersed the insecticide very well and could be used to control RTW using effective ULV formulation of insecticides. In an experiment conducted at Bichena, Gojam, Karate Sachet 37.5 g and Profenofos 720 EC at a rate of 20 g a.i. and 750 ml a.i. ha^{-1} were found to control the pest effectively (Fentahun Mengistu, personal communication). It is a known fact that chemical control is more effective on early instars than on the later ones. However, since it is difficult to detect the first instars in the field, control measure should aim at the second instars that could be detected by careful searching of the plants. Therefore, adequate field checks are necessary to optimize the time of spraying. Chemical spraying against RTW should be made when on the average 25 larvae per square meter are counted (Taddese pers. Comm. cited in Seyfu, 1993a; 1993b).

Tef shootfly

Emulsifiable concentrate formulations of malathion, phosphoamidon, dimethoate and metasystox at a rate of 0.12%, 0.05%, 0.06% and 0.05% were recommended to control tef shoot fly (DZARC, 1984). Similarly Dimethoate EC 20, Demeton-O-methyl 50% EC and Trichlorophos 50% WP gave good control of shoot fly (DZARC, 1984; Tareke, 1972). Although the result was not conclusive, the seed dressing insecticide Diazinon 50 SD was also tested at Debre Zeit (DZARC, 1989).

Chemical control trials consisting of seed dressing and spraying (WP and EC) were carried out at Axum and Ilaiia (Mekele) against tef shoot fly for two years during the 2004 and 2005 cropping seasons. Three chemicals (Trichlorophos 50% WP, Fenitrothion 50% EC and Diazinon 60% EC) were compared in 5 x 5 m plots in a randomized complete block design, replicated three times. The results showed that all the chemicals used lowered the level of infestations and gave higher yields than the untreated check. A maximum of 435 kg yield loss (yield difference) was observed between Trichlorphos sprayed and control plots (AxARC, 2004).

Black tef beetle

Chemical control observation trials were made in 1977 and 1979 cropping seasons in Berfeta area in the months of October and November when infestations of black tef beetle were high by superimposing on farmers' fields of tef (Tadesse and kemal, 1984). The four insecticides applied against the pest were Fenitrothion 50% ULV, Trichlorfon 50% ULV, Malathion 96% ULV and Carbaryl 85% WP at a rate of 1.5, 2 l ha^{-1}, 1.5 l ha^{-1} and 1.5 kg ha^{-1} , respectively. In 1977, dead beetles were not counted after spraying. In 1979, however, the pre-and post-spray beetle counts revealed that all the products gave acceptable level of control with Fenitrothion and Malathion being the best followed by Carbaryl (Table 20). In conclusion Carbaryl 85% WP is recommended to be used for small scale farmers against black tef beetle because of its ease of application and cost compared to the ULV products (Tadesse and kemal, 1984).

Table 20. Pre and post spray counts of black tef beetle in 1977 and 1979 at Berfeta

Treatments (insecticides)	Beetle population per m^2					
	Pre spray		Post spray			
			Dead Beetles		Live beetles	
	1977	1979	1977	1979	1977	1979
Fenitrothion 50% ULV	180	171	-	132	0	0
Trichlorofon 50% ULV	250	238	-	88	3	11
Malathion 96%ULV	300	156	-	92	0	0
Carbaryl 85% WP	275	131	-	76	0	6

Source: (SiARC, 1996)

Grasshoppers

About 19 insecticides were evaluated at Denkaka (1988) and at Akaki (1989 and 1990) against grasshoppers by Debre Zeit Agricultural Research Center (DZARC, 1989; 1990; 1991). All insecticides performed better than the unsprayed checks in suppressing the damage to tef seedlings and increased tef yield. In general Carbaryl, Cypermethrin, Sumi-cumbi, Fenitrothion, Propoxur, Delthamethrin, Pirimiphos-methyl and Alphamethrin have got better performance. Carbaryl as a bait is adapted and commonly used by farmers around Debre Zeit to control grasshopper.

Biological control

Red tefworm

Taddese (1987a; 1987b; 1987) reported that application of the biocontrol agents of RTW, *Bacilius thuringiensis,* at the rate of 700mg (WP) reduced larval density and increased grain yield of tef compared to untreated checks.

Grasshoppers

Tibebu et al. (1995) studied the effects of a biological microorganism *Nesoma locustae* on the grasshopper in the laboratory. They found that whereas 55% of the non-inoculated grasshopper reached adulthood, only 19% of the inoculated hoppers survived to adulthood. Overall, treatment with *N. locustae* reduced the intrinsic rate of population growth (r_m) and net reproduction rate (r_o) from 0.255 per week and 38.6 per generation to 0.038 per week and 1.7 per generation, respectively. From their results they concluded that *N. locustae* is a potential control agent worth testing in the field.

Wheat entomology

Biological control

Aphid predators, a serphid, *Sphaerophoria ruppelli* (Wiedman) and three coccinelid species: *Adonia variegate* (Goeze), *A. tredecinsignata* Muls and *Chilomenes lunata* (F.) were found to be the dominant predators in wheat field around Ambo (Mulugeta et al., 1999).

Conclusion

Barley pests

- Barley shootflies and Russian wheat aphid are insect pests of barley with countrywide major importance; and
- The chafer grub, although has limited importance as a major pest of barley, it has the potential to spread wide and become a major pest in many places where manure application is getting attention as a potential replacement for artificial fertilizers.

Tef pests

- The RTW has specific niche requirement; it is a pest of tef in Vertisols;

- WBC is a pest in the mountain ranges with thorny bush covers that could provide this univoltine species with cover; and
- The shootfly and grasshopper problems have country wide importance. The shootfly in tef received little attention, but it is assuming a country wide importance.

Transferable technologies

Russian wheat aphid

The use of resistant/tolerant host plants besides effective, economical and available seed dressing and/or spray formulations of insecticides are possibilities in the management of the RWA.

- Clearing broom grass in and around barley fields is a good cultural practice to use in order to reduce damage by the RWA;
- Early planting of barley in the belg areas of North Wello;
- Promote the use of 3296-15, a proven RWA resistant cultivar;
- Cruiser 70 WP, Furathicarb 400 CS and Imidacloprid 70 WS at the rates of 75, 74, and 88.2 g/100 kg barley seed are effective to use as seed treater against the RWA;
- Dimethoate 40% EC at a rate of 1.5 l ha^{-1} effectively controlled RWA on barley;
- Pirimiphos-methyl 50% EC at 1 l ha^{-1} effectively controlled RWA on barley;
- Early sowing combined with one time spray of Pirimiphos-methyl 50% EC effectively controlled RWA on barley; and
- Combining tolerant line (3296-15) with dimethoate and compliment the spraying with fermented cow urine or tobacco extract effectively controlled the RWA

Barley Shootfly

To manage the barley shootfly, it is possible to use host plants with inherent potential to recover from shootfly damage fast and produce more productive tillers. But, this has a risk in seasons of rainfall shortage. Therefore, the better option for the control of barley shootfly is the use of integrated cultural practices and external inputs.

- Grow barley in Gana to avoid heavy shootfly infestation in Bale highlands;
- Planting barley during the dry season should be avoided unless control measures are used;
- Early sowing of the local cultivar (Arusso-Bale) could be an alternative way to manage the barley shoot fly in Bale highlands;
- Barley cultivars released by Sinana Center could be used to minimize barley shootfly infestations in Harbu and Dinsho in 2003/04 and Dafo and Biftu;

- The seed dressing insecticides Imidacloprid 70% WS, Furatiocarb 400 CS at the rates of 88.2 and 74 g/100kg of barley seed could effectively control barley shootfly in many places except at Sinana where 2.5 kg ha^{-1} of Imidacloprid 70% WS was needed to effectively control the insect on barley; and
- The combination of 41/46 NP_2O_5, 74 g/100 kg seed of Furathiocarb 400 CS and 100 kg ha^{-1} seed rate was effective in controlling the barley shootfly on barley

Chafer Grubs on barley

The chafer grub in Tikur Inchinii can be managed better through crop rotation in an area wide scale, by organizing farmers. That is growing barley/wheat after tef, which receives repeated plowing and trampling by animals at planting could effectively check the grub. Sowing barley in such fields could reduce the potential damage barley might sustain in an otherwise condition.

- Crop rotation following this scheme will reduce chafer grub problem on barley and wheat in Tikur Inchinii (Fallow > Tef > Barley/Wheat > Linseed > Fallow and repeat the cycle);
- Avoid excessive use of organic fertilizer from different organic sources; and
- In places where the problem is endemic like Tikur Inchini and others where organic manure is being used, use Imidacloprid 70% WS at the rate of 88.2 g ha^{-1}.

Tef insect pests

The most effective methods for the control of RTW and WBC are the use of safe insecticides. Besides, for the WBC, field border sanitation and early planting also have significance as control measures. The uses of early sowing and seed dressing and/or spray formulations of insecticides help control shootfly in tef. For the grasshoppers, baiting with Carbaryl is an effective and adapted control method.

Red tefworm

- In places where the red tefworm is a serious problem on tef, remove the alternate hosts: *Phalaris paradoxa* and *Digitaria scalarum*; and
- Fenitrothion 50% EC at the rate of 625 g ha^{-1} active ingredient is a safer insecticide to use against the RTW

Grasshoppers on tef

- When grasshopper population reaches 15 individual per m^2 in tef field, it warrants the use of chemical insecticides;
- Early planting, field border sanitation from grasses and bushes and killing them using physical means could reduce damage by Wello bush cricket;
- Delayed planting of tef help reduce damage by grasshoppers significantly; and
- Carbaryl as a bait is adapted and commonly used by farmers around Debre Zeit to control grasshopper in tef fields

Shootflies on tef

- Although shootfly damage to tef is serious when the crop is planted early, the grain yield is not affected significantly than when sown late. Therefore, early sown probably in integration with effective seed dressing insecticides may reduce damage to tef by shootflies; and
- Trichlorophon 95% WP, Fenitrothion 50% EC and Diazinon 60% EC are promising alternatives for the control of shootfly on tef

Wello Bush Cricket

Diazinon 50% EC, Endosulfan 50% EC, Carbarly 85% WP are safe alternatives to use against the WBC during outbreak years

Black tef beetle

Fenitrothion 50% ULV, Malathion 96% ULV and Carbaryl 85% WP at a rate of 1.5 l ha^{-1}, 1.5 l ha^{-1} and 1.5 kg ha^{-1}, respectively, gave effective control of black tef beetle on tef

Gaps and challenges

- Studies so far made on the major pests of small cereal crops have limited scopes. This has been mainly on screening of insecticide with the aim to pick the most effective ones and manipulation of some cultural practices such as sowing date and seed rates to identify what could best reduce pest incidences and also screening of host plants particularly in barley;
- Insect pests in wheat have received very little attention except the shootfly importance confirmed in Alemaya, Bale and N, W and SW Shewa.;

- Basic knowledge on the biology, behavior and chemical ecology of Wello bush cricket a major pest of tef are very scanty. The same is true for the RTW and black tef beetle;
- The species composition and distribution of shoofly on the three crops has not been given due attention;
- The research system has never given due emphasis to cultural, biological and physical control methods. Due to this, development of integrated control method has never been possible except for the very few;
- The attention paid for indigenous knowledge of farmers in the how of controlling insect pests of crops has never been up to what is expected. Thus, most remained unknown and unrefined;
- There are no central data bases established on insect pests of all sorts of plant species growing in the country. Moreover, there are limited efforts made so far to communicate available plant protection technologies to users in usable ways; and
- It is all common and is serious problem in NARS that no one pursues research works that have been started by one researcher on a certain pest to reach to the end.

Future research directions

- Carry out periodical survey, collection and identification of insect pests of small cereals, to update their spectra and statuses. This is fundamental because insects and host plants interactions are dynamic in nature;
- Collection and identification of natural enemies of the major insect pests of small cereals should be given priority and the utmost attention;
- Developing effective biological control agents that help contain the population buildup of major insect pests of small cereals;
- Acquiring basic knowledge such as on the biology, behavior and chemical ecology of the major pest of small cereals in relation to the host crops and beyond should be considered;
- Identify the species of shootfly on the three crops and establish their importance.
- More efforts should be invested on in developing cultural, physical, biological and chemical control measures that could serve as sound components for the generation of integrated pest management packages for the control of the major pests of small cereals;
- Artificial rearing techniques of the major pests should be developed and implemented to generate pest management technologies faster by undertaking research even at times of low or no infestations;
- Establish central data bases of insect pests of importance and make it available for all users in and outside the country; and
- Create codes of conduct on how research activities planned by predecessors should be handled by their successors both in NARS and higher learning institutions.

References

1. Abraham Taddese. 1976. IAR/EPID Cooperative Program. Nedjo Progress Report 1974-75. Addis Ababa.
2. Abraham Taddese. 1986. Methods and rate of aldrin application on tef to control termite infestation at Bako area. Proceedings of the 18th National Crop Improvement Conference. 24-26 April 1986. Nazret, Ethiopia.
3. Abraham Taddese and Adane Kassa. 1996. The influence of sowing date on the damage by tef fly on tef in the Bako area. pp 87-91 in Eshetu Bekele et al. (eds.): Proceedings of the 3rd annual conference of the crop protection society of Ethiopia. 18-19 May 1995, Addis Ababa, Ethiopia.
4. Adane Kassa and Abraham Taddese. 1996. Yield loss in tef caused by barley fly, Delia arambourgi Seguy) at Bako. Paper presented at the 4th annual conference of the Crop Protection Society of Ethiopia. 23-24 May 1996, Addis Ababa, Ethiopia.
5. Adane Tesfaye. 1998. Effect of sawing date and insecticide treatment on the control of Russian Wheat Aphid (RWA) on barley. ICARDA/NVRSRP Annual report for the period of 1996/97. Cairo, Egypt.
6. Adane Tesfaye, Eshetu Belete and Getaw Tadesse. 2001. Participatory Analysis of Wello Bush Cricket (*Decticoides brevipennis*) problem in Wag-Himra Zone. *Pest management journal of Ethiopia*. Vol.5, pp 81-84.2001.
7. Addisu Birhan and Tadess Gebremedhin. 1999. Imidacloprid as a seed treatment for the control of Russian Wheat Aphid (*Diuraphis noxia*) (Homopetra: Aphididae) on barley. *Pest management journal of Ethiopia.* Vol.3. No.1&2, pp 13-21.1999.
8. Addisu Birhan, Bayeh Mulatu and Tadess Gebremedhin. 1999. Resistance in Ethiopian barley landraces to the Russian Wheat Aphid (*Diuraphis noxia Mordvilko*). *Pest management journal of Ethiopia.* Vol.3. No.1&2, pp 31-38.1999.
9. Adet Agricultural Research Center. Annual report for the period between 1995 and 1996.
10. Adugna Haile. 1981. Cereal aphids: Their distribution, biology and management on highland barley. A thesis, Addis Ababa University.
11. Adugna Haile. 1984. Cereal aphids in Ethiopia. CEE Newsletter II(1): 6-9.
12. Adugna Haile. 1984. Population dynamics of barley aphid. CEE Newsletter, IV(2): 15-17
13. Adugna Haile and Kemal Ali. 1986. A review of research on the control of insect pests of small cereals in Ethiopia. *In*: Tsedeke Abate (ed.). A review of crop protection research in Ethiopia. Proceedings of the first Ethiopian Crop Protection Symposium, February 4-7, 1985. Addis Ababa, Ethiopia. pp 57-75.
14. Adugna Haile.1986. Effects of Maneb, Lindane and Aldrin on barley fly and their phytotoxicity on barley seedlings. CEE Newsletter, V(2): 15-18.
15. Adugna Haile and Tessema Megenasa. 1987. Survey of aphids on barley in parts pf Shewa, Welo and Tigray, Ethiopia. EJAS IX (1): 39-54.
16. Adugna Haile and Tadesse Gebremedhin. 1989. Chemical control of wheat aphid *Diuraphis noxia* on barley at Chacha. CEE Newsletter, VIII(1): 13-16.
17. Amare Andargie. (1993). Infestation and damage level of barley shoot fly (*Delia arambourgi*) at Sinana. *In*: Proceedings of the Joint Conference of the Ethiopian Phytopathological Committee and the Committee of Ethiopian Entomologists. Crop Protection Society of Ethiopia (CPSE), Addis Ababa, Ethiopia. P 28.
18. Amare Andargie and Addisu Berhan. 1996. On farm yield loss Assessment of barley due to RWA. A paper presented in the annual barley coordination meeting, 20-23 may 1996, Addis Ababa Ethiopia.

19. Amare Andargie and Addisu Berhan. 1998. Research on insect pests and diseases in North Shewa. In Beyene Seboka and Abera Deressa (eds.) 1998. Agricultural Research and Technology Transfer Attempts and Achievements in Northern Ethiopia. Proceedings of the Fourth Technology Generation, Transfer and Gap Analysis Workshop. 18-21 March 1997, Bahir Dar, Ethiopia.
20. ARARI (Amhara Region Agricultural Research Institute). 2000. Adet Agricultural Research Center Annual Report for 1997/98, Adet
21. Amhara Region Agricultural Research Institute. 2002. Adet Agricultural Research Center Summary of Research Achievements between 1987 and 2001.
22. ABPHC (Arsi-Bale Plant Health Clinic). 1991. Annual report for the period 1990/1991.
23. Arsi-Bale Plant Health Clinic. 1992. Crop Protection and Regulatory department Annual report for the period 1991/1992.
24. Arsi-Bale Plant Health Clinic. 1993. Crop Protection and Regulatory department Annual report for the period 1992/1993.
25. Arsi-Bale Plant Health Clinic. 1999. Annual report for the period 1999/2000.
26. AxARC. 2004 chemical control of tef shoot fly. Axum agricultural research center progress report for the year 2004.
27. Bandaz, F. 1996. Distribution and population increase of *Melolontha melolontha* in Aoste valley, Italy. Bulletin OILB-SROP 19(2): 5-8.
28. Bayeh Mulatu and Tsedeke Abate. 1995. Survey results on Welo bush cricket, *Decticoides brevipennis* Ragg (Orthoptera: Tettigoniidae). In: Proceedings of the third annual conference of crop protection society of Ethiopia. 18-19 May 1995. Addis Ababa, Ethiopia.
29. Bayeh Mulatu and Tadesse Gebremedhin. 1996. The Russian wheat aphid: major pest of barley in Ethiopia. pp 169-181 inF.B. Pearis, M.K. Kroening and C.L. Simons (eds.): Proceedings of the 6th RWA workshop, Jan 23-25, 1996, Fort Collins, Colorado, USA.
30. Bayeh Mulatu. 1997. Localization of resistance factors in the leaf tissue profile of selected barley lines against the Russian wheat aphid, *Diuraphis noxia* Mordwilko; Homoptera: Aphididae). MSc thesis, Entomology Department, Wageningen Agricultural University. pp 57
31. Bijlmakers, H. and Selvaraj, J.C. 1989. The importance of routine chemical seed treatment in Ethiopia. CEE Newsletter, IX(1): 4-10
32. CSA (Central Statistical Authority). 2002. Ethiopian Agricultural Sample Enumeration. Report on the preliminary results of area, production and yield of temporary crops (Meher season, private peasant holdings), Addis Ababa, Ethiopia. 502 pp.
33. CSA (Central Statistics Authority). 2005. Area and production of crops, private peasant holding, meher season. Agricultural sample survey reports 2004/05. Statistical Bulletin 331. Vol. I. Addis Ababa.
34. Crowe, T. J., and Shitaye G. H. 1972. Crop pest hand book. A guide to the recognition and control of the more important pests of field and plantation crops in Ethiopia. IAR, Addis Ababa.
35. Crowe, T. J., Taddese Gebremedhin and Tsedeke Abate. 1977. An Annotated list of Insect pests of field crops in Ethiopia. Institute of Agricultural Research, Addis Ababa, Ethiopia.
36. Davidson A. 1969. Effect of some systemic insecticides on an infestation of the barley fly *Delia arambourgi* in Ethiopia. East African Agricultural and Forestry Journal 34:422-425.
37. DBARC (Debre Brehan Agricultural Research Center). 2003. Progress report for the period June 2002 to April 2003. Debre Brehan, Ethiopia.
38. DZAES (Debre Zeit Agricultural Experimental Station) . 1972. Annual research report for the period 1971/72.
39. DZARC (Debre Zeit Agricultural Research Center). 1984. Tef Annual Report for the period 1977-1982.
40. DZARC. 1987. Annual research report for the period 1986/87.

41. DZARC. 1988. Annual research report for the period 1987/88.
42. DZARC. 1989. Annual research report for the period 1988/89
43. DZARC. 1990. Annual research report for the period 1989/90
44. DZARC. 1991. Annual research report for the period 1990/91
45. DZARC. 2000. Annual research report for the period 1998/99
46. DZARC. 2002. Annual research report for the period 2000.01
47. Forschle, M. 1996. Occurance of the common cockchafer (*Melolontha melolontha* L.) in the state of Baden Warttemberg, Germany. Bulletin OILB-SROP 19(2): 1-4.
48. Goffan, LJW de. 1996. Population development of Melolontha and other scarabaeidae in the Netherlands during the past ten years. Bulletin OILB-SROP, 19(2): 9-14.
49. Hailu Gebere. 1997. Improved barley varieties for Bale and Arsi zones. *In*: Abera Deressa and Beyene Seboka (eds.). Research achievements and technology transfer attempts in southeastern Ethiopia. Proceedings of the Second Technology Generation Transfer and Gap Analysis Workshop. 9-11 July 1996, Nazret, Ethiopia, V+109 pp.
50. HARC, 1986. Assessment of yield loss in tef due to attack by black tef beetle, Erlangerius niger. HARC Crop protection progress report for 1985/86.
51. HARC. 1987a. Screening of barley cultivars for their resistance to the barley shootfly. HARC Crop protection progress report for 1986/87.
52. HARC. 1987b. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Crop protection progress report for 1986/87.
53. HARC. 1988a. Screening of barley cultivars for their resistance to the barley shootfly. HARC Crop protection progress report for 1987/88.
54. HARC. 1988b. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Crop protection progress report for 1987/88.
55. HARC. 1988c. Host preference studies of the barley shootfly. HARC Crop protection progress report for 1987/88.
56. HARC. 1989. Assessment of different ULV application equipment on the control of red tefworm. HARC Crop protection progress report for 1988/89.
57. HARC. 1990. Assessment of different ULV application equipment on the control of red tefworm. HARC Crop protection progress report for 1989/90.
58. HARC. 1991a. Screening of barley cultivars for their resistance to the barley shootfly. HARC Crop protection progress report for 1990/91.
59. HARC. 1991b. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Crop protection progress report for 1990/91.
60. HARC. 1992a. Assessment of different ULV application equipment on the control of red tefworm. HARC Crop protection progress report for 1991/92.
61. HARC. 1992b. Screening of barley cultivars for their resistance to the barley shootfly. HARC Crop protection progress report for 1991/92.
62. HARC. 1992c. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Crop protection progress report for 1991/92.
63. HARC. 1996a. Screening of barley cultivars for their resistance to the barley shootfly. HARC Progress Report for 1992/93.
64. HARC. 1996b. Screening of barley cultivars for their resistance to the Russian 2Wheat Aphid. HARC Progress Report for 1992/93.
65. HARC. 1996c. Screening of barley cultivars for their resistance to the barley shootfly. HARC Progress Report for 1993/94.
66. HARC. 1996d. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Progress Report for 1993/94.
67. HARC. 1996e. Screening of barley cultivars for their resistance to the barley shootfly. HARC Progress Report for 1994/95.

68. HARC. 1996f. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Progress Report for 1994/95.
69. HARC. 1996g. Screening of barley cultivars for their resistance to the barley shootfly. HARC Progress Report for 1995/96.
70. HARC. 1996h. Screening of barley cultivars for their resistance to the Russian Wheat Aphid. HARC Progress Report for 1995/96.
71. HARC. 1996i. Screening of seed treated insecticides for the management of the RWA. HARC Progress Report for 1995/96.
72. HARC. 1996j. Screening of seed treated insecticides for the management of chafer grubs on barley. HARC Progress Report for 1995/96.
73. HARC. 1996k. On-farm yield loss assessment on barley due to the RWA. HARC Progress Report for 1995/96.
74. HARC. 1996ℓ. Screening of seed treater insecticides for the management of chafer grubs on barley. HARC Progress Report for 1995/96.
75. HARC. 1998a. On-farm yield loss assessment on barley due to the RWA. HARC Progress Report for 1996/97.
76. HARC. 1998b. Evaluation of seed dressing insecticides for the control of chafer grubs on barley. HARC Progress Report for 1996/97.
77. HARC. 1999a. Evaluation of seed dressing insecticides for the management of barley shootfly. HARC Progress Report for 1998/99.
78. HARC. 1999b. On-farm evaluation of seed dressing insecticides for the management of barley shootfly. HARC Progress Report for 1998/99.
79. HARC. 1999c. Study on the comparative effect of cultural practices on precursor crops on the damaging effect of Chaffer grubs on barley in Tikur Inchini. HARC Progress Report for 1998/99.
80. HARC. 1999d. Study on the population of chafer grub in Tikur inchinii. HARC Progress Report for 1998/99.
81. HARC. 1999e. Integrated control of the barley shootfly (*Delia aramborgi* Seg.)**.** HARC Progress Report for 1998/99.
82. HARC. 2004. Survey of insect pests of wheat in N, W, SW Shewa. HARC Progress Report for 1998/99.
83. Hill, DS. 1975. Agricultural insect pests of the tropics and their control. Cambridge University Press, Cambrgdge.
84. Hill, B. G. 1966. Insects of cultivated and wild plants, Harer Province of Ethiopia. 1960 é 1964. Bulletin of Entom. Res. 56: 659-670.
85. Hill, D. S. 1989. Catalogue of Crop pests of Ethiopia (1st edn). Department of Plant Sciences. Alemaya University of Agriculture. Bulletin No. 1.
86. IAR (Institute of Agricultural Research). 1969. Holetta Genet Research Station Progress report for the period March 1968 to March 1969. PP. 101-103, IAR, Addis Ababa.
87. IAR. 1972. Holetta Genet Research Station Progress report for the period April 1971-March 1972. IAR, Addis Ababa.
88. IAR. 1974. Annual report. April 1973 to March 1974.
89. IAR. 1977. Results of the national crop trials and others 1975. National Crop Improvement Committee.
90. IAR. 1981. 13th National Crop Improvement Conference. PP. 185-186. Addis Ababa.
91. IAR. 1983. Crop Protection department progress report for the period 1978/79. Addis Ababa
92. IAR. 1986. Department of crop protection progress report for the period 1984/85. IAR, Addis Ababa, Ethiopia.
93. IAR/EPID. 1976. Cooperative program. Nedjo progress report 1974-1975. Addis Ababa, Ethiopia

94. Keller, S; C. Shweizer, E. Keller; and H. Bremmer. 1997. Control of white grubs (*Melolontha melolontha*) by treating with the fungus *Beauveria brongniartii*. Biocontrol Science and Technology, 7(1): 105-116.
95. Kemal Ali.1982. Chemical control of the Wello bush cricket. Committee of Ethiopian Entomologists news letter Vol. 1(2), p. 19.
96. Malinowski, H. 1998. Protection of forest and agricultural nurseries and plantations against pests of roots in the world and in Poland. Progress in plant protection, 38(1): 211-217.
97. MARC 1996. Survey and identification of insect pests of major field crops in Tigray. Mekele Agricultural Research center progress report for the year 1996.
98. MARC 1999 yield loss assessment of tef due to shoot fly in Tigray. Mekele Agricultural Research Center progress report for the year 1999.
99. MARC 2000 yield loss assessment of tef due to shoot fly in Tigray. Mekele Agricultural Research Center progress report for the year 2000.
100. MARC 1999 yield loss assessment of barley due to Russian wheat Aphid in Tigray. Mekele Agricultural research center progress report for the year 1999.
101. MARC. 2000. yield loss assessment of barley due to Russian wheat aphid in Tigray. Mekele agricultural research center progress report for the year 2000.
102. MARC. 1999 Yield loss assessment of barley due to Epilachna beetles in Tigray. Mekele agricultural research center progress report for the year 1999.
103. MARC. 2000. Yield loss assessment of barley due to Epilachina beetles in Tigray. Mekele agricultural research center progress report for the year 2000.
104. MARC. 1996. Study on effect of sowing date on tef shoot fly infestation and yield. Mekele agricultural research center progress report for the year1996.
105. MARC 1997. Observations on the effect of fertilizations on barley on the population of Russian wheat aphid. Mekele agricultural research center progress report for the year 1997.
106. MARC 2000. Screening of barley accessions for their resistance /tolerance to Russian wheat aphid. Mekele agricultural research center progress report for the year 1995-2000.
107. McFariane, F.A. 1969. Specialist study of stored products problem in Ethiopia. Preliminary report and recommendation.
108. Melaku Wale, Melkamu Ayalew, Fentahun Mengistu, Birhan Assayehegne and Amare Getaneh. 1998. Research on insect pests and diseases of field crops in northwestern Ethiopia. *In:* Beyene Seboka and Abera Deressa (eds.) 1998. Agricultural Research and Technology Transfer Attempts and Achievements in Northern Ethiopia. Proceedings of the Fourth Technology Generation, Transfer and Gap Analysis Workshop. 18-21 March 1997, Bahir Dar, Ethiopia.
109. Mulugeta Negeri, Adane Kassa, Sineshaw Aysheshim and Fantahun Mengistu. 1999. The role of predatory insects in regulating the populations of wheat aphis at Ambo. Pest Mgt J Eth, 3(1&2): 69-76.
110. Nurein, M. O. M. 1989. Desert locust: its threat to agricultural and possible control measure: IN: IAR proceeding: 21th national crop improvement conference, 10-12 April 1989. Addis Ababa, Ethiopia.
111. Onwueme, I.C. and Sinha, T.D. 1999. Field crop production in tropical Africa. Technical Center for Agriculture and Rural cooperation. Michael Heath Ltd. Reigate. Surry, England, 480 pp.
112. Richards, OW and RG Davies. 1977. Imm’s General Textbook of Entomology: Classification and Biology. Chapman and Hill, London, England.
113. Seyfu Ketema. 1993a. Food self sufficiency and the role of tef in Ethiopian agriculture. In: to wards a food and nutrietion strategy for Ethiopia, held at Alemaya University of Agriculture. 8-12 December 1986.

114. Seyfu ketema, 1993b. Tef (Eragrostis tef). Breeding, genetic resource, agronomy, utilization and role in Ethiopian agriculture. Institute of Agricultural Research, Addis Ababa, Ethiopia.
115. Seyfu Ketema. 1997. Tef (*Eragrostis tef (Zucc)Trotter*). Promoting the conservation and use of underutilized and neglected crops. Institute of plant genetic and crop plant research, Getersleben, International plant genetic resources Institute, Rome, Italy.
116. ShARC. 1999. Progress report for the period June 1997 to April 1998. Sheno Agricultural Research Center, Sheno, Ethiopia.
117. ShARC. 2000. Progress report for the period June 1999 to April 2000. Sheno Agricultural Research Center, Sheno, Ethiopia.
118. ShARC. 2002. Progress report for the period June 2001 to April 2002. Sheno Agricultural Research Center, Sheno, Ethiopia.
119. ShARC. 2003. Progress report for the period June 2002 to April 2003. Sheno Agricultural Research Center, Sheno, Ethiopia.
120. SiARC. 1996. Barley diseases and insect pests survey in Wello highlands.. Sirinka Agricultural Research Center, Progress report for the period June 1995 to April 1996.
121. SiARC. 1997. On-farm yield loss assessment on barley due to the RWA, *Diuraphis noxia* Mordwilko. Sirinka Agricultural Research Center, Progress report for the period June 1996 to April 1997.
122. SiARC. 1997. Effect of sowing dates and insecticidal treatment for the control of the RWA. Sirinka Agricultural Research Center, Progress report for the period June 1996 to April 1997.
123. SiARC. 1997. Insecticide screening for the control of RWA, *Diuraphis noxia* Mordwilko on barley. Sirinka Agricultural Research Center, Progress report for the period June 1996 to April 1997.
124. SiARC. 1998. Comparison of some village available insecticides for their effectiveness in controlling the RWA, *Diuraphis noxia* Mordwilko on barley. Sirinka Agricultural Research Center, Progress report for the period June 1997 to April 1998.
125. SiARC. 1998. Progress report for the period June 1997 to April 1998. Sirinka Agricultural Research Center, Woldia, Ethiopia.
126. SiARC. 1999. Progress report for the period June 1998 to April 1999. Sirinka Agricultural Research Center, Woldia, Ethiopia.
127. SiARC. 2002. On-farm evaluation of barley line resistant to the RWA, *Diuraphis noxia* Mordwilko on barley. Sirinka Agricultural Research Center, Progress report for the period June 2001 to April 2002.
128. SiARC. 2004. Integrated management of RWA, *Diuraphis noxia* Mordwilko on barley. Sirinka Agricultural Research Center, Progress report for the period June 2003 to April 2004.
129. Sileshi Gudeta. 1994. Anew record of pests of wheat at Alemaya. p 18. *In:* Eshetu Bekele et al. (eds.): Proceedings of the 1st Annual Conference of the Crop Protection Society of Ethiopia, 26-27 Apr 1994, Addis Ababa, Ethiopia.
130. SnARC. 2001. Sinana Agricultural Research Center. Entomology Progress Report 1993-2001.
131. SnARC. 2004. Sinana Agricultural Research Center. Entomology Progress report for 2003/04.
132. SARC. 2005. Sinana Agricultural Research Center. Entomology Progress report for 2004/05.
133. SnARC. 2006. Sinana Agricultural Research Center. Progress report for 2005/06.
134. Strasser, H. 1999. Evaluation of the efficacy of the biological control agent Melocont R? in fungal infected barley to control cockchafer. Forderungsdrenst, 47(5): 158-159 and 162-164.

135. Strech-Lilja. 1977. Short horned grasshoppers in Ethiopia, their identification and control. IAR. Addis Ababa
136. Stretch, C. Tekleab, K. and Edward, S.B. 1979. The biology and control of Wello bush cricket, *Decticoides brevipennis* Ragg (Orthoptera: Tettigoniidae), A pest of cereals in Ethiopia. *Ethiopian Journal of Science*. Vol. 3 (1). PP. 21-36.
137. Taddese Ebba. 1969. Tef (*Eragrostis tef*). The cultivation, usage and some of the known diseases and insect pests. Part I. Experiment Station Bulletin No. 60. Haile Sellassie I University college of Agriculture.
138. Taddese Gebremedhin and Kemal Ali. 1984. Black tef beetle, *Erlangerius niger* and its control. Committee of the Ethiopian Entomologists Vol. 4 (2). PP. 18-22.
139. Taddese Gebremedhin and Mathews G.A. 1986. The biology of Red tef worm, *Mentaxya ignicollis* (Walker)(Lepidoptera: Noctuidae). Ethiopian Journal of Agricultural Science. Vol. 8(2), PP. 103-115.
140. Taddese Gebremedhin. 1987a. Red Tef worm, *Mentaxya ignicollis* (Walker), a pest of tef. Committee of the Ethiopian Entomologist. Vol. VII (1), PP. 3-8.
141. Taddese Gebremedhin. 1987b. The control of red tef worm, *Mentaxya ignicollis* (Walker)(Lepidoptera: Noctuidae) in Ethiopia. Tropical pest management Vol. 33 (1). PP. 170-172.
142. Tadesse Gebremedhin. 1987. Red tef worm, *Mentaxiya ignicollis* (Walker) a pest of tef. CEE Newsletter VII (1): 3-8.
143. Tafa Jobie 2003. Medchanis(s) of resistance in barley accessions to shoot fly, *Delia flavibasis* Stein (Diptera: Anthomyiidae). M.Sc. Thesis. Alemaya University, Ethiopia. 73 pp.
144. Tafa Jobe and Muluken Goftishu. 2004. Effect of sowing date on infestation and damage caused by barley shootfly, *Delia flavibasis* Stein (Diptera: Anthomyiidae) on barley at Sinana. p 48 *In:* Proceedings of the 12th annual conference of the crop protection society of Ethiopia, 26-27 May 2004, Addis Ababa, Ethiopia.
145. Tafa Jobie and Tadesse Gebremedhin. 2005. *Delia steiniella* Emden: newly recorded pest of wheat (*Triticum aestivum*) and its infestation level at Sinana, Ethiopia. Pest Mgt J Eth 9: 83-85.
146. Tafa Jobie, Tadesse Gebremedhin and P.K.Sakhuja. 2004. *Ovipositional antixenosis* in some barley accessions to barley shoot fly. Pest Mgt J Eth 8: 51-57.
147. Tareke Berhe. 1972. Insecticide trial on tef. *In:* Proceedings annual research seminar, 22 to 24 September 1977. Addis Ababa.
148. TARI 2004. Research center based problem appraisal (identification) and priority setting in Tigray. Unbublished document.
149. Tesfaye Getachew, Mulugeta Amsalu and kassahun Tesfaye. 1997. Varietal improvement on major crops in Bale zone of Oromiya Region. *In*: Abera Deressa and Beyene Seboka (eds.). Research achievements and technology transfer attempts in southeastern Ethiopia. Proceedings of the Second Technology Generation, Transfer and Gap Analysis Workshop. July 9-11, 1996, Nazret, Ethiopia, V+109 pp.
150. Tesfaye Belay and Zenebe Woldu. 1998. Barley fly incidence on tef in Tigray. Proceedings of the fourth technology generation, transfer and gap analysis workshop. 18-21 March 1997. Bahir Dar, Ethiopia.
151. Tesfaye Belay. 2003. Biotypic status of the Russian Wheat Aphid, *Diuraphis noxia* in correlation to resistant barley lines in the highlands of Tigray, Ethiopia. Dissertation an Institut fur Forstentomologie, Forstpathologie and Forstschutz, 134; Wien.
152. Tesfaye Belay, Smith, C.M. and Stauffer, C. 2004. Biotypic status of the Russian Wheat Aphid, *Diuraphis noxia* in Ethiopia. Mitteilungen der Deutschen Gesellschaft fur allgemeine und angewandte Entomologie, 14: 133-136.

153. Tesfaye Belay and Christian Stauffer. Biotypic status of Ethiopian Diuraphis noxia (Mordvilko) and its relation to worldwide populations. p 49 *In:* Anon (edts): Proceedings of the 12th annual conference of the crop protection society of Ethiopia, 26-27 May 2004, Addis Ababa, Ethiopia.
154. Tibebu HabteWold and Landin, J. 1992. Composition and structure of orthopteran faunas in cereal crops in Ethiopia. Bulle. of Entomological research.
155. Tibebu HabteWold, Landin, J., Wennergen, U. and Bergman, K.O. 1995. Life table for the tef grasshopper *Aiolopus longicornis*, under laboratory conditions and demographic effect of the pathogen *Nosema locustae* . Biological Control Vol. Vol. 5, PP. 497-502.
156. Tibebu HabteWold. 1999. Seasonal abundance and breeding habits of *Aiolopus longicornis.*
157. Tjallingii, W.F. 1987. Stylet penetration activities by aphids: new correlations with electrical penetration graphs. pp 301-306 in Labeyrie, V.; Fabres, G. and Lachaise, D. (eds.), Insect-Plants. Junk, Dordrecht.
158. Webster, J.A.; Starks, K.J. and Burton, R.L. 1987. Plant resistance studies with the Russian Wheat Aphid (Homoptera: Aphididae), a new United States wheat pest. J. Econ. Entomol. 80: 944-949.
159. Webster, J.A.; Baker, C.A. and Porter, D.R. 1991. Detection of mechanism of Russian Wheat Aphid (Homoptera: Aphididae) resistance in barley. J. Econ. Entomol. 84: 669-673
160. Yeshitela Merene and Dereje Shiferwaw. Integrated management for the control of Russian Wheat Aphid (*Diuraphis noxia*) on barley. p 48 In Anon (edts): Proceedings of the 11th annual conference of the crop protection society of Ethiopia, 5-6 June 2003, Addis Ababa, Ethiopia.
161. Zimmermann, G. 1998. The Entomopathogenic fungus *Beauveria brongniartii* (Sacc.) Petch and experience in its use for biological control of the European field and forest chafer grubs. Nochrichteblatt-des-Deutschen-Pflanzenschutzdienstes, 50(10): 249-256.

Review of Two Decades of Research on Diseases of Small Cereal Crops

Ayele Badebo[1], Eshetu Bekele[1], Berhanu Bekele[1], Bekele Hundie[2], Melaku Degefu[1], Asnaketch Tekalign[3], Melkamu Ayalew[3] Amare Ayalew[4], Kiros Meles[5] and Fekede *Abebe[2]*

[1]Ethiopian Institute of Agricultural Research at Debre-Zeit, Holetta, Ambo and Kulumsa Research Centers, respectively;
[2]Oromiya Agricultural Research Institute, Sinana and Bako Research Centers, respectively
[3]Amhara Regional Agricultural Research Institute, Debre Birhan and Adet Research Centers, respectively; [4]Alemaya University, [5]Tigray Regional Agricultural Research Institute, Mekele Research Center

Introduction

Cereals in general are the major staple crops in Ethiopia constituting about 79% of the area and 86% of the production devoted to major crops during 2004/05 and 2005/06 main seasons (CSA, 2006)**.** Among the cereals, the major small cereal crops produced in Ethiopia are barley, tef and wheat and they constituted about 22, 46 and 30% of area and 23, 37 and 39% of cereal production, respectively, in the same seasons (Table 1). Oats (presumably including emmer wheat) and rice constitute about 1% of the small cereals area coverage and production and are not currently major cereals in the country. Productivity of small cereal crops in the country is very low compared to most other countries. This is due to inherent genetic limitations in the varieties used so far, nutrition and other soil factors, moisture stresses, low-level cultural practices, other abiotic and biotic factors. Plant diseases are among the major biotic causes that limit productions of these cereal crops worldwide and in Ethiopia. Diseases incur yield and quality loses in Ethiopia, and research results on their identity, the extent of damage they cause, and their managements have been reviewed previously (Eshetu, 1986; Getaneh and Temesgen, 1996; Mengistu and Yeshi, 1992a; Seyefu, 1993; Yitbarek et al., 1997). This paper attempts to review and compile results made available by the research system in the country on small cereal crops in the last two decades (1985–2005).

Table 1. Mean area under cultivation, production and yield of grain crops for 2004/05 and 2005/06 main seasons

Crop Type	Area ('000)		Production ('000)		Yield
	ha	%	q	%	q ha^{-1}
Cereals	7859.5	78.7	108275.5	85.6	13.8
Small cereals	4717.3	60.0	5657.3	52.3	12.0
Barley	1046.7	22.2	12993.7	23.0	12.4
Tef	2190.8	46.4	21005.6	37.1	9.6
Wheat	1428.9	30.3	21978.4	38.8	15.4
Oats/'Aja'	44.8	0.9	484.2	0.9	10.8
Rice	6.2	0.1	112.4	0.4	18..0
Other cereals	3142.1	40.0	51701.2	47.7	16.5
Non-Cereals	2131.5	21.3	18169.2	14.4	8.5

Source: *CSA, 2006*

Research findings

Diseases recorded

Earlier research reviews on cereal disease records, pathogens involved, their distribution and importance and their management showed that 28, 25 and 40 plant pathogens were reported to affect barley, tef and wheat, respectively, at various agro-ecologies and in different farming systems in the country (Eshetu, 1986). The great majority of the pathogens identified were of fungal origin, but a few bacterial, viral and nematode diseases were also reported with limited distribution and effects on the crops (Table 2). Only diseases of fungal origin have been reported on tef so far in the country (Seyfu, 1993). The identifications of the causative agents of the new disease records were based mostly on symptoms, microscopic examinations and comparison with literature.

Table 2. Additional diseases and their causes recorded on small cereals since 1985

Crop	Scientific name	common name	Reference
Barley	Order: Dothideales Family: Pleosporaceae Genus/species: *P. teres* f. sp. *Teres* *P. teres* f. sp. *maculata*	Net form of net blotch Spot form of net blotch	12, 13 12, 13
	Order: : Hypocreales Family: Clavicipitaceae Genus/species:*Claviceps purpurea*	Ergot	*
	Order: Pseudomonadales Family: Pseudomonadaceae Genus/species: *Pseudomonas spp.*	Stem macerating disease	191,192, 224
	Order: Hypocreales Family: Hypocreaceae Genus/species: *Fusarium avenacem*	Root rot	84
	Order: Pythiales Family: Pythiaceae Genus/species: *Pythium* spp	Cereals root rot	84
Oat	Order: Dothideales Family: Pleosporaceae Genus/species: *Helminthosporium avenae* Syn: *Pyrenophora chaetomioides* Speg	leaf stripe/leaf blotch	195
	Order: Uredinales Family: Pucciniaceae *Puccinia coronata* Corda	Leaf rust/crown rust	195
	Order: Uredinales Family: Pucciniaceae Genus/species: *P. graminis* f.sp.*avenae*	Stem rust/oats rust	195
	Order: Ustilaginales Family: Ustilaginaceae Genus/species: *Ustilago avenae (Pers.) Rostr.*	Loose smut of oats	195
	Genus/species: *Claviceps purpurea*	Ergot	160, 206
Rice	Barley yellow dwarf virus	BYDV	42
	Family: Magnaporthaceae Genus/species: *Pyricularia oryzae Cavara [anamorph],* Syn: *Magnaporthe grisea* (Hebert) Barr [teleomorph]	Rice blast disease	5
Tef	Order: Ustilaginales Family: Tilletiaceae Genus/species: *Entyloma oryzae* Syd.	Leaf smut of rice	5
	Class: Hyphomycetes: *Aspergillus flavus* Link. Ex. FR	Aspergillus ear rot	185
	Genus/species: *Coniosporium* sp.	Sooty mold	185
	Order: Phyllachorales Family: Phyllachoraceae Genus/species: *Colletotrichum graminicola* (Ces.) G.W. Wilson [anamorph], *Syn : Glomerella graminicola* Politis [teleomorph]	Anthracnose	185
	Order: Family: Genus/species: *Drechslera miyakei* (Nisik.) Sub. & Jain	Seed rot & seedling blight	75, 185
Wheat	Order: Hypocreales Family: Hypocreaceae Genus/species: *Fusarium spp.*	Scab/ head blight	14, 64, 67, 91
	Class: Hyphomycetes Genus/species: *Alternaria tenuissima* (Kunze) Wiltshire	Black point?	47, 161
	Class: Hyphomycetes Genus/species: *Alternaria tenuis* Nees	Alternaria leaf spot	47, 161
	Order: Pseudomonadales Family: Pseudomonadaceae Genus/species: *Pseudomonas spp.*	basal wheat glume rot ?	154
	BYDV	Barley yellow dwarf virus	154

* Arsi-Bale Plant Health Clinic (unpublished)

Barley

Although many plant pathogens are recorded on barley, scald (*Rhynchsporium secalis*), net blotch (*Pyrenophora teres*), spot blotch (*Cochliobolus sativus)*, leaf rust (*Puccinia hordei*), smuts (*Ustilago hordei* and *U. nuda*) and eyespot (*Pseudocercosporella herpotrichoides*) remain to be the most widely distributed and economically important diseases (Afera, 1997; BARC, 2000; Bekele, 1990; Eshetu, 1986; Getaneh et al., 1999; Kiros, 2004; Lema et al., 1997; Loban,1987; MRC, 2002; Meki and Asnakech, 2004; Yitbarek et al., 1997).

These results of field surveys in major barley growing areas indicated that the distribution and severity levels vary in the different growing regions and/or within a region in different seasons (Table 3). Leaf rust, stem rust and yellow rust all affected barley. A study was undertaken to determine the relative importance of rusts by planting a number of barley accessions at different locations (Getaneh et al., 1999). The results showed that though a few cases of stem rust (at Ambo) and yellow rust (at Sheno) were recorded on some entries, leaf rust was the most widely distributed and severe rust affecting barley.

It was previously reported (Eshetu, 1986) that spot blotch was a widely distributed disease in Bale highlands while surveys made in the later seasons indicated that net blotch, leaf rust, and in some cases, scald were major diseases and spot blotch was intermediate (Loban, 1987; SARC, 1990; 1991). However, among the three helminthosporium leaf diseases, spot blotch remains to be the most widely distributed disease in Arsi, Shewa and East Wellega regions (BARC, 2000; IAR, 1985; ICARDA, 2004; Yitbarek et al., 1997). Disease surveys made in *Bona* (*Meher* or main season) and *Genna* (*Belg* or short seasons), net blotch (94–100%) and leaf rust (25–100%) were again the most widely distributed diseases of barley in both seasons although leaf rust seem to be less severe in *Genna* as compared to Bona season (SARC, 1997; 1999). Scald was more severe in cooler areas like the upper Dinsho. Stem rust affected barley in Bale but with limited distribution and severity. Ergot was previously reported to affect wild oats grown as weed in barley fields, but harvested and consumed together with barley causing human disease known as ergotism in some areas of Welo (Eshetu, 1986; Paul et al., 1994a). Barley seed surveys made recently on market in Bale indicated that ergot sclerotia was found mixed with the seeds at various proportions (Arsi-Bale Plant Health Clinic, unpublished). However, it was not clear whether the sclerotia were present as the result of direct infection of the barley crop or from the wild oats grown as weed in the barley fields.

Table 3. Regularly occurring barley diseases in major producing zones of Ethiopia in the last two decades

Pathogens/diseases	Central (Shewa)	West (E. Wellega)	Eastern (Arsi & Bale)	Northwest (Gjam & Gonder)	North (Tigray & Welo)	East (Jijiga)
Genus/species: *Rhynchosporium secalis* (Oudem.) Davis Common name: Scald	***	***	**	***	***	-
Genus/species: *Pyrenophora teres* Drechsler Common name: Net blotch	***	*** (**)	***	***	***	-
Genus/species: *Puccinia hordei* Otth. Common name: leaf, barley rust	***	**	*** (**)	***	**	***
Genus/species: *Cochliobolus sativus* (S. Ito & Kurib.) Common name: Spot blotch	**	***	**	**	**	-
Genus/species: *Helminthosporium gramineum* Rabenh. ex Schltdl, Syn: *Pyrenophora graminea* S. Ito & Kurib Common name: Leaf stripe	*	-	**	**	*	**
Genus/species: *Ustilago* spp. Common name: loose/covered smuts	*	*	**	***	**	**
Genus/species: *Erysiphe graminis* f.sp. *hordei* Marchal Common name: Powdery mildew	-	*	*	*	*	-

*** Major; ** Intermediate, and * Minor disease problems
Asterisk in parenthesis showed conditions in '*Genna*' (Belg) season in Bale zone

Source: Afera, 1997; Asnakech, 2002; BARC, 2000; 2001; Bekele, 1990, Eshetu, 1986; Getaneh *et al.,* 1999; Kiros, 2004; Lema *et al*., 1997; Loban,1987; MRC, 2002; Meki and Asnakech, 2004; Yitbarek *et al*., 1997).

Incidence of barley scald was high in areas of 2000 m altitude and above where it constituted the major barley growing areas of Tigray (MRC, 2002). Net blotch occurred in relatively lower altitudes but with wider distribution than scald. Leaf rust is also important disease in all barley-growing areas of Tigray.

Disease surveys made 1988–1990 in northwestern Ethiopia showed that scald, spot blotch, net blotch and leaf rust were major diseases of barley with mean incidence of 48, 37, 47 and 22% and 14, 7, 6, 6% severity, respectively (AARC, 1990; Bekele, 1990). Later surveys made in 1992 and 1993 in the region showed that 11 diseases were recorded on early maturing local barley ('Semereta') amongst which scald, leaf rust, net blotch and loose smut were the major diseases and importance of spot blotch was reduced to an intermediate status (AARC, 1992).

In a different study, Melkamu et al (1996) has identified 11 fungal mycoflora associated with black point from seeds of 14 barley varieties. Out of these *Helminthosporium sativum* was the most common. Root rot (*Sclerotium rolfsii*) was also noted as major disease in barley grown under residual moisture in the region (Yitbarek et al., 1997). In a different survey, conducted on major cereal crops grown in western Oromia from 1997 to 2000 showed that scald, leaf rust, spot and net blotches were important diseases of barley in East Wellega (BARC, 1998; 2000). In recent survey around Jijiga and eastern Hararghe, the most prevalent disease of barley was leaf rust, whereas covered smut and leaf stripe occurred in many locations (Sakhuja.and Amare, 2004). Net blotch was not encountered in the two consecutive cropping seasons.

Yitbarek and Bekele (1996) documented that during the 1988 to 1992 growing seasons net blotch, scald, leaf rust and spot blotch were the most widely distributed diseases in central highlands of the country with average incidence of 71, 64, 68 and 53% and severity 33, 31, 22 and 10%, respectively (Yitbarek et al., 1997). However, these levels considerably varied in different seasons and locations in the region. The status of eyespot and root rot diseases of barley in West Shewa was assessed between 1995 and 1997 cropping season (Getaneh et al., 1996). The overall incidence of eyespot and root rot in the zone was 14% and 49%, respectively, which occurred singly or in combination and were more severe on barley grown after barley and linseed. The pathogens that caused root rot diseases were *Cochliobulus sativus*, *Fusarium avenacium* and *Pythium* spp, and the latter two were new records on barley (Getaneh et al., 1996).

Barley yellow dwarf virus (BYDV) is a major virus that affects not only barley but also other small cereals like wheat and oats. Surveys made from 1984 to1986 and 1988 to 1989 seasons showed that BYDV was prevalent in Arsi, Bale, Shewa, Gojam, Gonder, Harerghe and Wellega areas on altitudes ranging from1800 to 3000 m (Yusuf et al., 1992). Five serotypes of BYDV, namely, PAV, MAV, RMV, RPV and SGV were identified from barley samples – PAV being the most dominant serotype. However, a different study conducted in ICARDA on 31 samples collected from Bale highlands during 1997 indicated that serotype RMV was the most distributed followed by PAV and MAV (Abashamo, 2000; Geremew et al., 1998). BYDV survey in barley growing areas of central Ethiopia showed that antigen of the virus was detected in nearly 70% of the barley fields in Arsi, 39% of the fields in North Shewa and 42% of the fields in West Shewa (Berhanu, 1998). Extensive surveys for barley yellow dwarf luteoviruses (BYDVs) and cereal yellow dwarf polerovirus (CYDV) were made from 1997/98 to 2000/01 main and short rainy seasons in barley growing areas of central, northern and western Ethiopia (Berhanu et al., 2003). Using tissue blot immunoassay method, BYDV and CYDV were identified from 72% and 69% of the fields, respectively, in Arsi and West Shewa in 1997/98 seasons, with BYDV-PAV being the most and CYDV-RPV being the least distributed, although there had been great variations between seasons and locations.

Surveys on the incidence and distribution of bacterial diseases of barley were made in 1985/86 and 1986/87 seasons in Arsi, Bale, Gojam, Gonder, Shewa and Wellega areas (SPL, 1987; 1988). Bacterial infection in these areas ranged from 10 to 20% and the causal agent was *Xantomonas campestris pv. translucence*. Another bacterial disease in the genus *Pseudomonas* was identified as causing maceration on pedicle of barley plants at Holetta Research Center during 1986/87 season with infection ranging from 3 to 5% (SPL, 1987; 1988; Yitbarek et al., 1997). The status of this disease is not known since then.

Oats

Oats are grown by farmers mainly in the central highlands (North Shewa) on lands with marginal fertility status where other major crops are not doing well. Wild oats are usually considered as weeds, which seriously affect the production of wheat and barley in most growing areas. Research has not taken up the improvement of this species as a crop, although oat species are major component of livestock feed research in the country. As the result, except the one done by Stewart and Dagnatchew (1967), no formal disease survey and management research has been done on this crop except the recent survey attepmpt by the Debre Birahn Research Center pathology group (DBARC, 2002). In general, leaf rust and helminthosporium leaf diseases are the major diseases of oat (Table 2).

Rice

Rice cultivation in Ethiopia started very recently, mainly in Fogera plainlands in northwestern part of the country. Improvement research on the crop has been going on for some time now but work on management of rice diseases has not been started. A couple of diseases were recorded on the wild relative of the crop (Table 2) by the Adet pathology staff during their survey in 1991 (AARC, 1992).

Tef

It is generally believed that tef suffers less from diseases than most other cereal crops in major production areas of Ethiopia (HARC, 1997; Hailu and Seyfu, 2001; Sewalem et al., 2001; Seyfu, 1993). However, tef rust (*Uromyces eragrostidis*), head smudge (*Helminthosporium miyakei*), damping-off (*Drechslera poae*) and some helminthosporium leaf spots (*Helminthosporium* spp.) cause some concerns in the production of the crop in many areas of the country (AARC, 1992; Eshetu, 1986; Sewalem et al., 2001). Head smudge was found to be prevalent in Wellega region with higher incidence in valley bottoms near rivers and in fields bordering shade trees (Melaku, 1993). Only a few more diseases were reported since the publication of the Review of Crop Protection

Research in 1986 (Table 2), but are generally considered as minor in their distribution and economic importance (Sewalem et al., 2001).

Wheat

Wheat disease surveys have been made annually in more or less regular basis in the last two decades focusing on major production areas. Although disease incidence and severity varied from season to season and from location to location within the regions, the major diseases that occurred regularly and wide spread in the regions are summarized in Table 4. In the central highlands (Shewa), septoria blotches and helminthosporium leaf diseases are the most widely distributed wheat diseases, although the rusts, particularly yellow rust, might have been the most damaging at times in pocket areas (Getinet et al., 1990b). Incidence and severity of septoria blotches were often more in and around Holetta Research Center while *Helminthosporium* leaf diseases (tan spot and spot blotch) were more severe around Ginchi-Ambo areas. Yellow rust was often more severe on high altitudes of Selale, Debre-Birhan and Tikur-Inchini areas.

There have been, however, seasonal variations in diseases severity (HARC Progress Report, 1989/90 to 2000/01; 2001/02 to 2004/05; HARC Wheat Pathology Progress Report, 1998/99 to 1999/00; 2003/04 to 2004/05). Disease surveys conducted in the highlands of North Shewa indicated that tan spot, septoria, stripe rust, alternaria leaf blight and leaf rust were quite common both in *belg* and *meher* seasons. However, stripe rust has recently become a serious problem in all wheat-growing areas of North Shewa on most of improved varieties (DBARC Progress report, 2001/02; SRC Prgress Report, 1998/99). The relative occurrence and frequency of barley yellow dwarf virus (BYDV) isolates was studied on 2220 and 1500 samples collected from wheat growing areas of central and northern Ethiopia during 1997 and 1998, respectively. Out of the serotypes, PAV was the most common (EARO, 2000).

Table 4.Regularly occurring wheat diseases in major producing zones in the last two decades

Major Diseases	Central (Shewa)	Eastern & (Arsi Bale)	Northwest (Gjam & Gonder)	North (Tigray & Welo)	East Hararghe
Genus/species: *Puccinia striiformis* Westend. Common name: Yellow/stripe rust	**(*)	***	***	***	*
Genus/species: *Puccinia graminis* f. sp. *tritici* Common name: Stem/black rust of wheat	***	***	***	*	**
Genus/species: *Puccinia recondita* f.sp. *triticina* (Erikss. & Henn.) Common name: Leaf /brown rust	**	**	**	***	***
Common name: Septoria tritici blotch/glume blotch Genus/species: *Mycosphaerella graminicola* (Fuckel) J. Schröt. [teleomorph]/ *Phaeosphaeria nodorum* (E. Müll.) Hedjar. [teleomorph]	***(**)	***	***	***	-
Genus/species: *Pyrenophora tritici-repentis* (Died.) Drechsler Common name: Tan spot	***	***	**	*	
Genus/species: *Gibberella zeae* (Schwein.) Petch [teleomorph] Common name: Scab/Fusarium head blight	**	*	**	-	-
Genus/species: *Ustilago nuda* f.sp. *tritici* (Schaffnit) Common name: loose: wheat smut	*	-	*	*	***
Genus/species: *Pseudocercosporella herpotrichoides* (Fron) Deighton Common name: eyespot	*	*	-		

***** Major; ** Intermediate; and * Minor disease problems*
Asterisk in parenthesis showed conditions in durum wheat
***Source:** Progress Reports of Adet, Holetta, Debre-Zeit, Kulumsa, Mekele and Sinana Research Centers*

The three wheat rusts (leaf, stem and yellow rusts) caused by *Puccinia recondita, P.graminis and P.striiformis*, respectively, were found to be important in disease surveys conducted in Sidama, North Omo and Borena zones by Awassa Plant Health Clinic before and during 1998 (Fantahun and Girma, 1995). Recent wheat diseases surveys in Arsi indicated that yellow rust, stem rust and steptoria tritici blotch were found to be the most important diseases (KARC Progress Report, 2005). The varieties grown by the farmers in Arsi were Kubsa, Galama, Abola, Katar, Pavon 76, Shinna, Tusie, ET-13 A2, Tura Wetera, Sofomer, Meda-Welabu, K6290-Bulk, K6292-4A and Enkoy. Kubsa and Galama varieties constituted about 25–50% and 18–20% of the total area coverage, respectively. State farms grow most of the aforementioned varieties but often apply fungicides like Tilt-50EC and Bayleton for the control of rusts. Surveys made from 1996 to 2005 in Bale indicated that stem rust was the most damaging to the crop with severity levels of 40% in 'Genna' and 90% in 'Bona' seasons, followed by yellow rust with 40% and 80% severity in these seasons, respectively (SARC Progress Report, 2004). Although stem and yellow rusts occurred in both seasons, studies indicated that stem rust was relatively more severe than yellow rust in 'Genna' season, but both did not cause economical concerns to wheat production in ‘Genna’ season as compared to their destructiveness in ‘Bona’ season in Bale (Bekele et al., 2002; Serbessa, 2003). Septoria blotches and tan spot were also wide spread in these zones.

In the northwestern part of Ethiopia, 17 wheat diseases were noted in surveys carried out in Gojam and Gonder regions during 1992 and 1993. Out of these, yellow rust and septoria leaf blotch were the major ones (AARC, 1992, Melkamu et al., 1996)**.** However, a survey made in 2000 indicated that most other diseases were not severe, except septoria blotches, which had become very severe on all released wheat cultivars (AARC, 2000).

In Tigray Region, wheat diseases survey made in 1994 and 1995 resulted in identifying eight fungal and one nematode disease (MRC Progress Report, 1994; 1995 to 2002). Yellow rust, leaf rust and septoria blotches were the most important diseases affecting wheat production in the region (Table 4). Yellow rust was quite rare and stem rust was less important around Jijiga and East Hararghe in comparison to the reports from Arsi and Bale (Sakhuja.and Amare, 2004). On the other hand, leaf rust was quite prevalent throughout most wheat growing areas of eastern Ethiopia.

A coordinated wheat diseases survey was conducted in major wheat producing areas of Ethiopia during 1988 (Getinet et al., 1990b). In this survey, the three rusts (stem, leaf and stripe) caused by *Puccinia graminis* f.sp. *tritici*, *P.recondita* and *P.striiformis*, respectively, Stagnospora/Septoria blotches, *Helminthosporium* spp., *Fusarium* spp., bacterial (*Xanthomonas transluscens*, *Pseudomonas atrofaciens*) and nematode (*Anguina tritici*) were noted. The high yielding CIMMYT originated bread wheat cultivar Dashen was heavily infected by yellow rust and *Fusraium* head scab in Arsi and Bale highlands. Generally, stem rust, yellow (stripe) rust, Stagnospora/Septoria blotches, tan spot (*H. tritici-repentis*) and spot blotch (*H. sativum*) remained to be the major foliar fungal diseases that affect wheat production in most areas (Eshetu, 1986; Mengistu et al., 1991).

Surveys made in the last two decades indicated that stripe rust has been widely distributed in all bread wheat-growing areas of the country almost in all seasons affecting almost all improved cultivars at various levels. Yellow rust remains to be one of the most destructive diseases of bread wheat particularly in the highlands of Arsi Zone (KARC Progress Report, 1989–2005; Temesgen et al., 1995; 2005). Severe yellow rust development was reported in Bale in which the severity on the susceptible variety Wabe reached 94% at Agarfa and 48% at Sinana (Dereje, 2003). Yellow rust was, however, reported to be less severe on durum wheat varieties at Debre Zeit (Mandefro, 2000).

Studies on the relative importance of leaf blighting or spotting diseases of wheat in major wheat producing regions of the country was initiated at Holetta Research Center in 2002/03. Leaf samples with blighting and/or spotting symptoms were collected from national, pre-national and regional variety trials planted at different locations and analyzed at Holetta Research Center plant pathology laboratory for three seasons (HARC Progress Report, 2002/3–2004/05). The results indicated that among the foliar diseases (except the rusts), septoria leaf blotch was the most widely distributed and severe disease of wheat, particularly at Holetta Research Center (Table 5).

Three species of septoria (*S. tritici*, *S. nodorum* and *S. avenae* Frank f.sp. *triticea* Johns) were identified based on conidiospore measurements and number of septations. *S. tritici* was by far the most dominating species at Holetta (80 to 98%) and the other two species occurred in less proportion. *S. nodorum* was more prevalent at Ambo and Debre-Zeit. The perfect (sexual) state of this fungus (*Mycosphaerella graminicola)* was also identified from samples collected in late in the growing seasons from Ginchi, Ambo and at low proportion from Holetta. The identification of the third septoria species (*Septoria avenae* f.sp. *triticea)* and the role of the perfect state identified from samples collected late in the seasons assisted the survival and possibly sexual recombination of the pathogen which makes the septoria diseases of wheat to be more complex and difficult to develop highly resistant varieties. Nevertheless, the results of this study (HARC Progress Report, 2002/3–2004/05) indicated that Holetta for *S. tritici;* Ambo and Ginchi for *H. tritici-repentis*; Ambo and Debre-Zeit for *S. nodorum* and *H. sativum* could be hot spot locations to screen germplasms for resistance and carryout management studies for the respective diseases.

Table 5. Frequency (%) of fungal species identified from blighted and/or spotted wheat leaves collected from national and regional variety trials

	Locations									
Species	Ho	Gin	Am	TE	Wol	DZ	Ew	AR	AT	Al
Septoria tritici	80-98	11-73	0-58	0-58	0-83	0-19	0-10	0-47	0	0
Septoria avenae f.sp *trticea*	1-10	0-3	0-8	0	0	0-4	0	0	0	0
Septoria nodorum	2-5	0-4	11-68	0	0	7-38	0	0-7	0	0
Mycosphaerella graminicola	0-2	3-42	0-13	0	0	0-4	0	0	0	0
Ascochyta sp.	0-2	0-11	0	0	0	0	0	0	0	0
Helminthsporium tritici-repentis	0	6-67	7-67	0	0	0	0-52	0-42	0	0-6
Helminthsporium sativum	0	0-3	0-13	0	0	0-71	0	0	0-16	0-13
Phoma sp.	0	0-11	0-17	0-2	0-9	0-19	0-6	0-12	0-24	0-19
Fusarium sp	0	0	0-12	0	0-4	0	0	0	0	0
Altenaria sp	0	0	0	0	0	0-8	0-3	0-29	0-22	0-31
Helminthosporium Spp.	0	0	0	0	0	0-21	0	0	0	0
Cladosporium Spp.(?)	0	0	0	0	0	0	0-43	0	0-55	0

Note: *Number of samples varied according to seasons and locations: Ho (Holetta= 73-360), Gin (Ginchi =64-180), Am (Ambo=15-179), TE (Tikur Enchini=15), Wol (Wolisso=15), DZ (Debre Zeitt=23-51), Ew (Enewari=63), AR (Arsi Robe=51), AT (Alem Tena=55), Al (Alemaya=19).*

Source: *HAR Progress reports for the period 2002/3, 2003/4 and 2004/5*

Among the head diseases of barley and wheat, smuts (*Ustilago* spp.) and wheat bunt (*Tilletia* spp.) are widely spread in the country, mostly on land races or farmer's varieties (Eshetu, 1986; Mengistu et al., 1991). Wheat seed nematode caused by *Anguina tritici* was also reported in Arsi (Ayele et al., 1989). Loose smut of wheat was found to be prevalent around Jijiga during 2003 cropping season (Sakhuja and Amare, 2004) and in eastern and central Ethiopia during 2004, being more important in eastern than in central Ethiopia (Endalle, 2005). However, head scab, also known as *Fusarium* head blight (FHB), is often a sporadic disease of small cereal crops, particularly wheat, in cool, wet climate and high altitude areas of Ethiopia (Eshetu, 1986).

Survey made in 1988 cropping season, which happened to be one of the scabby season in Ethiopia, indicated that up to 85% incidence occurred in some state farms with infected spikelets per head (severity) ranged from 5 to 80% (Eshetu, 1990; 1994) (Table 6). The high yielding cultivar of the time Dashen was found very susceptible while the cultivar Enkoy was highly resistant to FHB. Considerably lower level of FHB was recorded at farmer fields than at state farms and research centers. The results might have indicated that FHB is more of a problem to the improved cultivars under improved management conditions than to farmer varieties under their management. Thirteen *Fusarium* spp. were identified from scabby wheat heads in which *F. nivale* and *F. avenaceum* were dominant in cool, moist, high altitude areas, whereas *F. graminearum* was more frequent at lower altitudes and in northwestern regions (Table 7). Most of these species were found to be seed-borne (Awgichew, 1996; Eshetu, 1990; Eshetu and Karr, 1997).

At Debre-Zeit, 15 fungal species were isolated from wheat seed, among which *Alternaria*, *Fusarium* and *Phoma* were the most common genera (DZARC, 1989; Yeshi and Mengistu, 1990)**.** Moreover, 32 fungal species were identified in a study carried out at 7 locations in northwesern Ethiopia on 21 wheat seed samples (Paul et al., 1994b). Of these, *Alternaria tenuis, Drechslera sativus, Epicoccum purpurascens*, *Fusraium graminearum, Mychosphaerella graminicola*, *Septoria nodorum*, *Tilletia foetida and T. caries* were identified *as* potentioal sources of inoculum. Recent surveys conducted on storage and seed borne fungal diseases of wheat in Arsi indicated that *Helimnthosporium sativum, Fusarium graminearum, Penicillium* spp*. Aspergilus* spp were the dominant (KARC Progress Report, 2001/2– 2002/3).

Table 6. Incidence and severity of FHB in different wheat fields, 1988

Location	Incidence (%)	Severity (%)	Remarks**
Experiment Centers	0 - 56	0 - 80	Adt. Hol., Kul.
Seed Production	0 - 57	0 - 60	Hol., Kul.
State Farms	0 - 84	0 - 80	Dix., Gof., Lol.
Farmer Fields	0 - 35	0 -50	Central Shewa and Arsi

Adt=Adet, Dix=Dixis, Gof=Gofer, Hol=Holetta, Kul=Kulumsa, Lol=Lole
Source: Eshetu, 1990; 1994

Table 7. Percentage of *Fusarium s*pecies identified from scab by wheat heads collected from different sources in 1988 season

Species	Research centers	State farms	Farmer fields
F. nivale (Fr.) Ces.	48	52	35
F. avenaceum (Fr.) Sacc.	15	37	31
F. graminearum Schwabe	22	2	29
F. Poae (Peck.) Wollenw.	<1	2	1
F. sambucinum Fuckel	-	2	-
F. lateritium Nees	-	1	1
F. sporotrichioides Sherb.	<1	-	1
F. stilboides Wallnw	<1	-	-
F. heterosporum Nees	<1	-	-
F. tricinctum (Corda) Sacc.	<1	-	-
F. semitectum Berk. Rav.	<1	-	-
F. equiseti (Corda) Sacc	<1	-	-
F. moniliforme Sheldon	-	<!	-
Fusarium spp.[1]	13	8	-

[1] *Species could not be identified due to contamination and/or insufficient structural evidences*
***Source**: (Eshetu, 1990; Eshetu and Karr, 1997)*

Eyespot has been the most encountered root disease on barley and wheat crops. Up to 50% infection was recorded on wheat during the different surveys in pocket areas of farmer fields in northwestern Shewa (HARC Progress Report, 2003/04) and up to 25 and 30% on barley and wheat, respectively, in 'Bona' season in the highlands of Bale (SARC Progress Report, 1996–2004). In a different study, the incidence of root rots on wheat was assessed at Ambo and Diksis (Loban, 1987). The highest incidence was noted at Diksis with the distribution of 85–97% on varieties Dashen and Enkoy. Based on the soil analyses *ca*. 98% of the samples were fungi mainly of *Fusarium culmorum* and *Helminthosporium sativum*.

Another root problem of barley and wheat at farmer's fields, which is currently at low level but seems to be increasing in some wheat producing areas in central Shewa and in northwestern part of the country was the one caused by *Sclerotium rolfsii* (AARC Progress Report, 1992; HARC Progress Report, 2004/05; Yeshi and Mengistu, 1988b). Take all is another persistent root disease, which is usually reported as a problem where monocropping of wheat was practiced. In the 1999–2001 seasons, a root problem, locally known as ‘Gasash’ or ‘Abrik’ occurred in northern Shewa (Menz) affecting both improved (ET-13) and local wheat and barley varieties. Although not confirmed, the disease was most likely to be *Rhizoctonia* root rot caused by *Rhizoctonia solani* since Rhizoctonia, like sterile mycelium, was mostly isolated in culture and the field symptom looks like it (EARO, 2004; Eshetu Bekele and Meki Shehabu., personal communication). This needs, however, a closer look and follows up if the problem still persists and tends to spread to other areas.

Bacterial stripe and black chaff were identified to be common on barley and wheat in Ethiopia (Eshetu and Korobko, 1988). The distribution was estimated on wheat entries from the Ethiopian Wheat Rust Trap Nursery (EWRTN) at 10 locations and on national and international nurseries planted at Ambo during 1985 and 1986 (Eshetu and Korobko, 1987; Korobko et al., 1985). Based on the cultural, morphological and biochemical properties, the pathogen was identified to be *Xanthomonas campestris* pv. *translucens*. It was isolated from leaves and heads of bread and durum wheat. The incidence of bacterial infection varied with wheat species, genotypes and altitude. According to this report, the disease was less conspicuous towards higher altitudes and *Triticum aethiopicum* and Triticale did not show any sign of infection while durum and bread wheat genotypes showed variable reactions against the disease.

Basic studies

Methodology

Methods of drying and preserving stem rust urediospores were studied at Ambo between 1985 and 1987. Preservation of spores was optimal after drying at room temperature for 48 hours, after drying in a dessicator with $CaCl_2$ for 48 hours or after sealing and storing at 4-5 ^oC (Loban et al., 1988b; 1988d; SPL, 1989). A study made for tef rust preservation at Ambo indicated that three months of storage had decreased the viability from 97 to 62.5%, whereas six months storage under +6 ^oC had only 22.5% viability (Sewalem et al., 2001).

Two different media were compared for isolation of *Drechslera* species at Ambo. Tef extract agar (TEA) most effectively permitted growth of *Drechslera* species than potato dextrose agar (PDA). *Drechslera miyakei* sporulated freely on TEA medium on the 5th day, but *D. poae, D. setariae* and *D. sorokiniana* sporulated on the 4th day (Sewalem et al., 2001).

Five inoculation methods of stem rust on wheat at field conditions were compared at Ambo during 1986 and 1987 off-season (Mozgovoy et al., 1988; SPL, 1987). Among the treatments, spraying plants with spore suspension and spore talc mixtures followed by covering plants with plastic sheet for 12–14 hours at night gave good results. In a different study, field and laboratory inoculation techniques of bacterial stripe caused by *Xanthomonas campestris* pv.*translucen*s were evaluated on durum wheat at Debre-Zeit during 1987–90 seasons (Yeshi and Mengistu, 1996). Inoculation by leaf trimming and spraying was found to be more effective than wounding and rubbing technique.

Characterization of pathogens

Variation among pathogen isolates

Attempts have been made to establish whether physiologic races of *Rhynchosporium secalis* (scald) exist in barley production areas of Ethiopia (HARC Progress Report, 1989/90–1990/91; 1993/94). Other more detailed studies on isolates of *R. secalis* demonstrated pathogenic variability among the isolates of the pathogen, and 19 (Kiros, 2004) and 17 (Yitbarek and Fehrmann, 2002) distinct pathotypes were identified based on their reaction to barley differentials. Pathotypes which were most virulent to overcome resistant genes have been identified. Kiros et al (2000; 2004) reported pathogenic and phenotypic diversity in this pathogen isolates collected from different locations in the country. Moreover, amplified fragment length polymorphism (AFLP) study of different isolates showed that there exists genetic diversity in the pathogen population in Ethiopia (Kiros et al., 2000). Yitbarek and Fehrmann (2002) suggested environmental conditions, farming practices and the cultivation of barley largely as land race population could be responsible for generating variability in the pathogen in Ethiopia.

In Ethiopia, net blotch was previously reported to be caused by the fungus *Pyrenophora teres* (*Helminthosporium teres* Sacc). However, recent studies by Asnakech et al (2005) showed that the disease could actually be caused by two forms of the fungus: the net type (caused by *P. teres* f. sp. *teres*) and the spot type (caused by *P. teres* f. sp. *maculata*). The spot type was usually confused with other spot blotch disease of barley caused by *Cochliobolus sativus,* as the symptoms are indistinguishable. Analysis of samples collected from Northwest and central highlands of Ethiopia with spot blotch symptom showed that about 80% of them were associated with *P. teres* f. sp. *maculata* while the rest were *C. sativus* (Asnakech et al., 2005). In view of this finding, it is believed that a large proportion of what was reported previously as spot blotch caused by *C. sativus* could be spot type of the net blotch caused by *P. teres* f. sp. *maculata.* Although there were no significant morphological and cultural variations between the net (*P. teres* f. sp. *teres)* and the spot (*P. teres* f. sp. *maculata*) types of the pathogen, significant variations in virulence was observed among and within these isolates (Asnakech, 2002; Asnakech et al., 2005).

Pathogenic variability of isolates of *D. miyakei*, the fungus that cause head smudge in tef, was also studied and variation in pathogenesity existed among the isolates collected in Wollega area (Melaku, 1993). Serological studies conducted at Ambo on 16 strains of *Drechslera* sp. from different locations in Ethiopia on three test species of *D. miyakei, D. poae* and *D. setariae* strains indicated that *D. miyakei* antisera were similar to the antigens of other *Drechslera s*pecies (Sewalem et al., 2001).

Variation in virulence within the *Septoria tritici* isolates (cause of septoria leaf blotches of wheat) in Ethiopia was also reported (Temesgen, 1999). Pathogenic variation was also demonstrated among isolates of *Pyrenophora tritici-repentis*, (cause of tan spot disease in wheat) with significant cultivars by isolate interactions (Ayele and Fehrmann, 2003). The mycotoxin production potential of *Fusarium* species that cause head scab in wheat was studied and the common *Fusarium* isolates (*F. nivale* and *F. avenaceum*) did not produce any of the mycotoxins under the procedures employed (Eshetu, 1994). However, *F. sporotrichioides*, which was a rare species isolated from Ethiopian wheat, produced a variety of trichothecene mycotoxins two of which (8-n-pentanoylneosolaniol and 8-n-hexanoylneosolaniol) were new and reported for the first time (Eshetu, 1990; Eshetu et al., 1991).

Monitoring of wheat rust races and virulences

Wheat rusts races and virulence studies have been made at various times locally and/or in collaboration with foreign laboratories (Ayele and van Ginkel, 1989; Belayeneh and Emebet, 2005; Mamluk et al., 2000; Temam, 1984; 1985a; 1985b; Temam and Solomatin, 1984; Temam et al., 1985; van Ginkel et al., 1989). For example, the effectiveness of stem and leaf rust resistant genes were monitored among the Nile Valley and Red Sea countries (Ethiopia, Egypt, Sudan and Yemen) since 1993 (ICARDA, 2004; 2005; Mamluk et al., 2000). For example, out of the samples sent to Egypt during 1992/93–1996/97 for analyses, 28 leaf and 19 stem rust races were identified in the region during the study period in which 16 leaf and 16 stem rust races were from Ethiopia. Out of these, 12 and 5 pathotypes, respectively, were common to all the countries. The most effective leaf-rust-resistant gene in the region was *Lr* 17 at both the seedling and adult plant growth stages while *Lrs 2, 2a, 3ka, 11, 21* and *30* were effective at seedling stage. Stem rust resistance gene Gt+ was the most effective in the region at both growth stages while *Srs 7b*, *8a* and *30* were effective only at the seedling stage (Mamluk et al., 2000).

Yellow rust races

Nine different yellow rust races were identified from samples collected from various parts of the country in the Institute for Plant Protection (IPO-DLO), Wageningen, and the Netherlands within 1977–90 (Table 8). The most frequent races during the aforementioned periods were 6E16, 82E0, 82E16, 134(166E) 150 and 166E158 (Ayele and Stubbs, 1995; van Ginkel et al., 1989). Races 82E0 and 82E16 had frequently been detected from the central and northwestern part of the country where durum wheat had been the dominating wheat species. Race 134 (166) E150 was the most frequent one among the race population detected after 1986 in the southeastern Ethiopia where bread wheat was being commonly grown (Ayele and van Ginkel, 1989). It had virulence phenotypes for *Yr*2, *Yr2+*, *Yr6*, *Yr6+*, *Yr7*, *Yr7+*, *Yr8*, *Yr9*, *Yr9+*, *YrSD* (Strubes Dikkopf) and *Yr* A (Anza). Later, similar race identification activities resumed at Kulumsa Research Center and elsewhere (Ayele, 2002). In 1998, a new race 230E158 was detected that overcame the resistance of high yielding bread wheat cultivar, 'Kubsa' and other CIMMYT originated bread wheat cultivars in Arsi and Bale regions.

Table 8. The yellow rut races and virulence identified in Ethiopia during 1986 to 1989

Race	Yellow rust virulence factors	Location	Year
6E16	6,7,8	Gondie, Arsi	1986
		Hararghe	1989
38E18	6,7,8, SD	Kulumsa	1989
82E0	7,10, SU, (v9)	Selalie, Degem, Bichena	1989
82E16	6,7,8, 10, SU (v2, v9)	Holeta	1986, 1987
		Degem	1987
		Wolisso, Sellalie, Deneba	1989
86E0	6,7,10, SU, (v9)	Holetta	1987
		Arsi Robe, Holetta	1989
134 (166) E150	2, 2+,6, 6+,7, 7+, 8,9, 9+ (SD)	Kulumsa	1986, 1987
166E150	2, 2+,6, 6+,7, 7+, 8,9, 9+,SD	Bekoji, Arsi Robe,	1987
		Asasa,Garadella, Serufta, Arsi Robe,Debera, Wolisso, Akaki	1988
166E158	2, 2+,3N, 6, 6+,7, 7+, 8,9, 9+,SD	Ambo	1987
		Bekoji, Kulumsa, Debre Zeit	1989

Source*: Ayele and Stubbs, 1995; van Ginkel et al., 1989*

Stem rust races

One hundred and eighty-seven stem rust samples from Ethiopia were analyzed in Minnesota, USDA Cereal Rust Laboratory. Out of these, 41 different races were detected from 1987 to 1990 (Table 9). The stem rust race JCC/L was the most frequent while RRT/T was the most virulent followed by RRTP and RRKT, respectively (Ayele et al., 2001; van Ginkel et al., 1989). The aforementioned races were identified from samples collected at Arsi-Robe and Debre Zeit. Out of the 16 *Sr* genes used for race analyses, *Sr 8a*, *9e*, and *36* were the most effective but *Sr15* was the least. Recently, 44 different races were identified from the 75 isolates studied based on 12 differential lines (three letter systems) at Ambo during 2001–2004 (Belayneh and Emebet, 2005). Totally, 20 races from Bale, 15 from Arsi, 9 from Shewa, 3 from Gojam and 1 from Gonder were recorded in the 4 cropping seasons (Table 10). Most races identified in these seasons were virulent to most wheat differentials (Table 11). For instance, a race like TTT was virulent to all the differential lines, which might be a threat to wheat production in the country. Similarly, race TTR was virulent to all differentials except *Sr3*0 gene (Belayneh and Emebet, 2005).

Table 9. Stem rust races detected in Ethiopia from 1987 to 1990

Pgt code	No.	Virulence factors	*Pgt* code	No.	Virulence factors
1987			**1988**		
JHC/Q	8	21,9e, 6, 9g, 17, 15, 8b	MKP/F	3	5, 7b, 6, 8a, 9g, 36, 30, 17, 28, 10
KMH/Q	4	21, 9e, 7b, 11, 9g, 9b, 17, 15, 8b	FKK/R	3	9e, 7b, 6, 8a, 9g, 9b, 30, 17,28, 10
JRC/Q	3	21, 9e, 11, 6, 9g, 17, 15, 8b	RKC/F	3	5, 21, 7b, 6, 8a, 9g, 17, 28, 10
QHM/T	3	5, 21, 6, 9g, 36, 17, 15, 8b, 28, 10	HFH/P	14	21, 7b, 8a, 9g, 9b, 17, 15, 28, 10
QHM/P	1	5, 21, 6, 9g, 36, 17, 15, 28, 10	HTJ/F	4	21, 7b, 11, 6, 8a, 9g, 9b, 30, 28, 10
JHR/Q	1	21, 9e, 6, 9g, 36, 9b, 17, 15, 8b	KTC/R	7	21, 9e, 7b, 11, 6, 8a, 9g, 17, 15, 8b, 10
QRR/P	3	5, 21, 11, 6, 9g, 36, 9b, 17, 15, 28, 10	**1989**		
RHM/P	1	5, 21, 7b, 6, 9g, 36, 17, 15, 28, 10	HHK/K	1	21, 7b, 6, 9g, 9b, 30, 17, 8b, 28, 10
QCH/P	1	5, 21, 9g, 9b, 17, 15, 28, 10	JCC/H	1	21, 9e, 9g, 17, 8b, 10
JCC/L	15	21, 9e, 9g, 17, 15	JCC/Q	6	21, 9e, 9g, 17, 15, 8b
KRC/Q	1	21, 9e, 7b, 11, 6, 9g, 17, 15, 8b	JCC/R	1	21, 9e, 9g, 17, 15, 8b, 10
1988			JMC/Q	1	21, 9e, 17, 15, 8b
RRT/P	2	5, 21, 7b, 11, 6, 9g, 36, 9b, 30, 17, 15, 28, 10	KFH/R	1	21, 9e, 7b, 8a, 9g, 9b, 17, 15, 8b, 10
RHF/N	5	5, 21, 7b, 6, 9g, 30, 17, 15, 28	KTH/R	1	21, 9e, 7b, 11, 6, 8a, 9g, 9b, 17, 15, 8b, 10
JCC/L	32	21, 9e, 9g, 17, 15	QRR/T	2	5, 21, 11, 6, 9g, 36, 9b, 17, 15, 8b, 28, 10
KCC/Q	1	21, 9e, 7b, 9g, 17, 15, 8b	RHF/P	3	5, 21, 7b, 6, 9g, 30, 17, 15, 28, 10
KMC/Q	3	21, 9e, 7b, 11, 9g, 17, 15, 8b	RHK/P	6	5, 21, 7b, 6, 9g, 9b, 30, 17, 15, 28, 10
RRT/T	2	5, 21, 7b, 11, 6, 9g, 36, 9b, 30, 17, 15, 8b, 28, 10	RRK/P	1	5, 21, 7b, 11, 6, 9g, 9b, 30, 17, 15, 28, 10
QRM/T	10	5, 21, 11, 6, 9g, 36, 17, 15, 8b, 28, 10	RRK/T	1	5, 21, 7b, 11, 6, 9g, 9b, 30, 17, 15, 8b, 28, 10
JMH/Q	19	21, 9e, 11, 9g, 9b, 17, 15, 8b	RRT/T	1	5, 21, 7b, 11, 6, 9g, 36, 9b, 30, 17, 15, 8b, 28, 10
QHP/T	7	5, 21, 6, 9g, 36, 30, 17, 15, 8b, 28, 10	**1990**		
HFK/P	1	21, 7b, 8a, 9g, 9b, 30, 17, 15, 28, 10	RRH/T	4	5, 21, 7b, 11, 6, 9g, 9b, 17, 15, 8b, 28, 10

Source: *Ayele et al., 2001; Mengistu et al., 1991; van Ginkel et al., 1989*

Remark: *Additional set (fourth set) comprising Sr15, Sr8b, Sr28 and Sr10 were used to differentiate the stem rust races (A. Roelfs, personal communication, USDA, Minnesota)*

Table 10. Types of races in Arsi, Bale, Shewa, Gojam and Gonder regions of Ethiopia in the years 2001- 2004

Year	Region	Types of Races
2001	Arsi	DRR, DTR, HGR, HRR, LPR, RTK, TTT
	Bale	JGH, KKR, KTR,
	Shewa	CPR, GDB, KJR, RRG,RTR, TTR
2002	Arsi	DGG, DPR, JGH, JGQ, KGH, SGH, TRK, TTR
	Bale	DBG, FGG, FGR, FGQ, JGR, KGQ, DGR, KKQ, KQQ, RRT, TPT, TRR, TRT, TTR
	Shewa	KTR
2003	Arsi	TTR
	Bale	MRL,PTR,TTR,TTT
	Gojam	JHG,LQG,QGB
	Gonder	TTT
2004	Arsi	TTR
	Bale	TTR
	Shewa	TTQ,TTR,TTT

Source: Belayneh and Emebet, 2005

Table 11. Avirulence/ virulence formulae on Sr genes, based on seedling reactions, for 44 pathotypes of *Puccinia graminis* f. sp. *tritici* identified in Ethiopia during 2001-2004

Pgt code	Avirulence/ virulence formulae	Pgt code	Avirulence/ virulence formulae
CPR	5, 6, 9E, 21, 30 / 7b, 8a, 9b, 9g, 11, 17, 36	KTR	5, 30/ 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 36
DBG	5, 6, 7b, 8a, 9g, 11, 17, 21, 30, 36 / 9b, 9e	LPR	6, 7b, 9e, 21, 30/ 5, 8a, 9b, 9g, 11, 17, 36
DGG	5, 6, 7b, 9b, 11, 21, 36/ 8a 9e, 9g, 17, 30	RRG	8a, 9e, 17, 30, 36/ 5, 6, 7b, 9b, 9g, 11, 21,
DPR	5, 6, 7b, 21, 30 / 8a, 9b, 9e, 9g 11, 17, 36	RRT	8a, 9e / 5, 6, 7b, 9b, 9g, 11, 17, 21, 30, 36
DRR	5, 7b, 8a, 21, 30 / 6, 9b, 9e, 9g, 11, 17, 36	RTK	9e, 36 / 5, 6, 7b, 8a, 9b, 9g, 11, 17, 21,30
DTR	5, 7b, 21, 30 / 6, 8a, 9b, 9e, 9g, 11, 17, 36	RTR	9e, 30/ 5,6, 7b, 8a, 9b, 9g, 11, 17, 21, 36
FGG	5, 8a, 9g, 11, 17, 21, 30, 36 /6, 7b, 9b, 9e	RTT	9e/ 5, 6, 7b, 8a, 9b, 9g, 11, 17, 21, 30, 36
FGR	5, 8a, 9g, 11, 21, 30 / 6, 7b, 9b, 9e, 17, 36	SGH	7b, 8a, 9g, 11, 30, 36/ 5, 6, 9b, 9e, 17, 21
FGQ	5, 8a, 9g, 11, 17, 21, 30 / 6, 7b ,9b, 9e, 36	TPR	6, 30/ 5, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 36
GDB	5, 6, 7b, 9b, 9e, 9g, 11, 17, 30, 36 / 8a, 21	TPT	6/ 5, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 30, 36
HGR	5, 8a, 9e, 9g, 11, 30/ 6, 7b, 9b, 17, 21, 36	TRK	8a, 36 / 5, 6, 7b, 9b, 9e, 9g, 11, 17, 21, 30
HRR	5, 8a, 9e, 30 /6, 7b, 9b, 9g, 11, 17, 21, 36	TRR	8a, 30 / 5, 6, 7b, 9b, 9e, 9g, 11, 17, 21, 36

Table 11. Continued

JGH	5, 7b, 8a, 9g, 11, 30, 36 / 6, 9b, 9e, 17, 21	TRT	8a / 5, 6, 7b, 9b, 9e, 9g, 11, 17, 21, 30, 36
JGQ	5, 7b, 8a, 9g, 11, 17, 30 / 6, 9b, 9e, 21, 36	TTR	30 / 5, 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 36
JGR	5, 7b, 8a, 9g, 11, 30 / 6, 9b, 9e, 17, 21, 36	TTT	/5, 6, 7b, 8a, 9b, 9e, 9g, 11, 17, 21, 30, 36
KGH	5, 8a, 9g, 11, 30, 36 / 6, 7b, 9b, 9e, 17, 21	JHG	5,7b,8a,11,17,30,36/6,9b,9e,9g,21
KGQ	5, 8a, 9g, 11, 17, 30 / 6, 7b, 9b, 9e, 21, 36	LQG	7b,8a,9e,9g,17,**21**,30,36/5,6,9b,11
KGR	5, 8a, 9g, 11, 30/ 6, 7b, 9b, 9e, 17, 21, 36	MRL	8a,9b,9e,17,21,30/5,6,7b,9g,11,36
KJR	5, 9g, 11, 30/6, 7b, 8a, 9b, 9e, 17, 21, 36	PTR	21,30/5,6,7b,8a,9b,9e,9g,11,17,36
KKQ	5, 11, 17, 30 / 6, 7b, 8a, 9b, 9e, 9g,21,36	PTT	21/5,6,7b,8a,9b,9e,9g,11,17,30,36
KKR	5, 11, 30/ 6, 7b, 8a, 9b, 9e, 9g, 17, 21, 36	QGB	7b,8a,9b,9e,9g,11,17,30,36/5,6,21
KQQ	5, 8a, 9g, 17, 30 / 6, 7b, 9b, 9e, 11, 21, 36,	TTQ	30,17/ 5,6,7b,8a, 9b, 9e, 9g, 11,21,36

***Source**: Belayneh and Emebet, 2005*

Stem rust caused an epidemic on the cultivar Enkoy, a widely adapted disease resistant cultivar in Ethiopia in 1994. Since then, more and more of the wheat cultivars released for production in Ethiopia were becoming susceptible to stem rust. The discovery of a new race known as Ug99 virulent to stem rust resistance gene *Sr*31 in Uganda in 1999 is considered to be a threat to wheat production in the eastern African highlands and possibly beyond (Anonym., 2005; Pretorius et al., 2000). Stem rust has been significantly controlled worldwide and in Ethiopia with the use of *Sr*31 (in Kavkaz) with the 1BL.1RS translocation. According to Belayneh and Emebet (2005), virulence for *Sr*31 was detected in greenhouse tests at Ambo during 2003 in Ethiopia. However, severity up to 30S has been recorded in the field tests in the southeastern and central Ethiopia from a rust trap nursery distributed from Kulumssa Research Center since 1998 (KARC Progress Report, 1998–2005). Thus, race UG99 or similar ones might have occured earlier than 2003 in Ethiopia.

Leaf rust races

During 1988–1990, 282 leaf rust samples were analyzed in Minnesota Cereal Rust Laboratory. Of these, 33 different races were identified (Table 12). Among the leaf rust races, EEE/E was the most frequent. A total of 35 different leaf rust races were identified at Ambo from samples collected from Arsi, Bale, Shewa and Wellega during 2001–2003 growing seasons (Tables 13 and 14). In general, leaf rust races from Ethiopia were less virulent as compared to yellow and stem rusts (Mengistu et al., 1991; PPRC, 2004; van Ginkel et al., 1989).

Table 12. Leaf rust races detected in Ethiopia during 1988 to 1990.

Year	Leaf rust races	Number of isolates	Leaf rust races	Number of isolates
1988	BBB/B	15	FGDT	5
	BBB/L	4	FGDL	4
	BBB/R	4	FCPB	1
	BBB/Q	21	FBDR	1
	CBB/M	12	FGBN	1
	CBB/R	1	MBLQ	6
	CBB/C	6	NBBL	18
	CBB/Q	2	NBLS	12
	CGDR	4	PBBQ	6
	CBD/M	7	SBDD	12
	CHP/Q	4	SBJD	3
	DBB/L	4	SBDJ	7
	DBD/L	5	TCQR	9
	FBB/Q	11	TCBH	18
	FBB/M	1	TCLH	36
	FBD/M	1	TCLT	15
	FBL/Q	25		
1989	CBB/M	19	LBBB	2
	CBD/M	6	LBGR	1
	EEE/E	79	MLMQ	1
	FCM/Q	3	TCBG	1
	KBB/R	1		
1990	CBB/C	5	EEEE	3
	CBB/M	1	FGDM	1
	CBD/M	1		

Source: *(Mengistu et al., 1991; van Ginkel et al., 1989)*
Remark*: Additional set (fourth set) comprising Lr10, Lr18, Lr21 and Lr23 were used to differentiate the leaf rust races (A. Roelfs, 1990. Personal communication, USDA, Minnesota).*

Table 13. Types of leaf rust races in Arsi, Bale, East Shewa, North Shewa and East Wellega regions of Ethiopia in the year 2001-2003

Year	Region	Types of race
2001	Arsi	HHR, MBH, FFG, PKT, KJR, KGR
	Bale	FBR
	Shewa	FKR, CBR, PGT, KCC, KHR, FKK, BGB, CBH, LBC, KKT, PBG, FJB, BBB, PHT
	East Wellega	FBC, KGK
2002	Arsi	FKR,FJR,FHR
	Bale	FJR,FDT,FBK,SHT,TTH
2003	Shewa	PKR,FKT,FJS,NJJ

Source*: PPRC, 2004*

Table 14. Avirulence/ virulence formulae on Lr genes, based on seedling reactions, for 35 pathotypes of *puccinia triticina f. Sp. tritici* identified in Ethiopia in 2001 -2003

Prt code	Avirulence/ virulence formulae	*Prt* code	Avirulence/ virulence formulae
BBB	1,2a,2c,3,9,3ka,16,24,26,11,17,30/	MBH	2a,2c, 3ka, 17, 9,16,24,26/1, 3, 11, 30
BGB	1,2a,2c,3,3ka,9,11, 17,24,26,30/16	PBG	2a, 9,3ka,16,17, 24,26,30/1, 2c,3, 11
CBH	1,2a,2c, 3ka, 9,16, 17, 24,26/3, 11, 30	PGH	2a,9, 3ka, 17,24,26 /1, 2c,3, 16, 11, 30
CBR	1,2a,2c, 9,16,17, 24,26/3, 3ka, 11, 30	PHT	2a, 3,9, 24/1, 2c, 16, 26, 3ka,11,17,30
FBC	1,2a, 9,16,24,26,3ka,11,17/2c,3, 30	PKT	2a, 9/1,2c,3, 16,24,26,3ka,11,17,30
FBR	1,2a, 9,16,24,26, 17, /3ka, 2c,3,11, 30	FBK	1,2a, 9,3ka, 16,24,26/2c,3,11,17,30
FFG	1,2a, 9,16, 3ka, 17,30/2c,3, 24,26, 11	FDT	1,2a, 9,16, 26 /2c,3, 24, 3ka,11,17,30
FJB	1,2a, 9, 26,3ka,11,17,30/2c,3, 16,24	FGR	1,2a, 9, 17, 24,26/2c,3, 16, 3ka,11, 30
FKK	1,2a, 9, 3ka /2c,3, 16,24, 26, 11, 17,30	FHR	1,2a, 9, 17, 24 /2c,3, 16, 26, 3ka,11, 30
FKR	1,2a, 9, 17 /2c,3, 16,24, 26,3ka, 11, 30	FJR	1,2a, 9,17, 26 /2c,3, 16, 24, 3ka,11, 30
HHR	1, 2c, 9, 24, 17, /2a, 3, 16, 26, 3ka, 11, 30	FKR	1,2a, 9, 17 /2c,3, 16, 24,26, 3ka, 11, 30
KKC	1, 9,16,24, 3ka,11,17, /2a,2c,3, 26, 30	SHT	3,9,24/1,2a,2c, 16, 26,3ka,11,17,30
KGK	1, 9, 24,26,3ka /2a,2c,3, 16, 11,17,30	THH	9, 3ka, 17, 24/1,2a,2c,3, 16, 26, 11, 30
KGR	1, ,9, 24,26, 17 /2a,2c,3,16, 3ka,11, 30	PKR	2a,9,17/ 1,3ka,16,11,26,24,3,2C,30
KHR	1, ,9, 24, 17, /2a,2c,3,16, 3ka,11, 26, 30	FKT	1,2a,9,/ 3ka,16,11,2c,24,17,3,26,30
KJR	1, 9, 26, 17/2a,2c,3, 16,24, 3ka,11, 30	FJS	1,2a, 9,26/ 3ka,16,11,2c,24,17,3,30
KKT	1, 9/2a,2c,3, 16,24,26,3ka,11,17,30	NJJ	9,2a,3ka,3,26,30/ 1,16,11,2c,24,17
LBC	2a,2c,3,9,16,24,26,3ka,11,17, /1, 30		

***Source**: PPRC, 2004*

Wheat rust trap nurseries

Monitoring rust virulence under field conditions has been going on for quite a long time by planting the Ethiopian wheat rust trap nursery (EWRTN) comprising internationally known yellow, stem and leaf rust differential lines, commercial cultivars and advanced lines at strategically located multi-location sites (KARC Progress Reports, 1989–2005). Getinet et al (1990a) have reported the status and distribution of rusts virulence across six locations in Ethiopia during 1988. For stripe rust, virulence was detected for *Yr*2^+, *Yr*3N, *Yr*6, *Yr*6^+, *Yr*7, *Yr* 7^+, *Yr*9, *Yr*9^+, *Yr*10 and *Yr*A, and three of the locations (Asassa, Bekoji and Sinana) represented the widest virulence spectra. For stem rust, virulence was found for *Sr*5, *Sr*7a+10, *Sr*7b+, *Sr*8b, *Sr*9a, *Sr*9b, *Sr*9d, *S*r9e, *Sr*9f, *Sr*9g, *Sr*10, *Sr*11, *Sr*12, *Sr*14, *Sr*15, *Sr*16, *Sr*18, *Sr*19, *Sr*27, *Sr*28, *Sr*30, *Sr*34, and *Sr*35, and the widest virulence spectrum was noted at Debre Zeit. For leaf rust, virulence was found for *Lr*2c, *Lr*3, *Lr*3bg, *Lr*10, *Lr14*a, *Lr*20, *Lr*23 and *Lr*33, and Debre-Zeit exhibited the widest virulence spectra. It was concluded that the virulence spectra in Ethiopia for stem and stripe rusts are among the broadest in the world, whereas leaf rust virulence was considered as narrow (Getinet et al., 1990a).

The stability of stem and leaf rust resistance genes in the trap nurseries were evaluated at Debre Zeit during 1998–90, both on main season and off-season

(Mengistu and Yeshi, 1992b). Among 18 *Sr*-genes reported not to have encountered virulence in 1987 and 1988, 10 of them showed susceptibile reaction (30-90S) in the 1989 main and off-seasons. Only *Sr* genes 22, 26+9g and 36 remained stable throughout the seasons with little or no change in reaction to the prevailing races. *Sr*29, *Sr*31, *Sr*32, *Sr*35+5 and *Sr*34 exhibited a wide variation in reaction depending upon the season under test. The reaction of stem rust on *Sr*31 (Line E/KVZ) ranged from 10S to 30S during the 1989 main and off-seasons. Out of the 23 *Lr*-genes claimed not to have virulence in 1988, only 12 had truly expressed stability across the six seasons.

Wheat rust virulences have been monitored in Ethiopia since 1988 after planting rust trap nursery comprising of standard differential lines across locations. Most stem and yellow rust resistance genes were overcome by the prevailing races, especially in hot spot areas of Arsi and Bale zones (KARC Progress Report, 1989–2005; Bekele et al., 2002; ICARDA, 2004; 2005). Out of 25 stem rust resistance genes so far included in the EWRTN, currently, only *Sr*24 showed dependable resistance across seasons and locations, whereas *Sr*26+9g exhibited moderate resistance. The EWRTN data at Kulumsa Research Center in 1998 (KARC, 1998) indicated virulence for *Sr*31, although noticed in Uganda in 1999 (Pretorius et al., 2000). Since 1996, the effectiveness of yellow rust resistance genes has been moitored on selected spring yellow rust wheat differential cultivars obtained from CIMMYT and ICARDA after planting at several locations (KARC Progress Report, 1997–2005). Most of these differential lines were developded via backcrossing the original winter wheat parents with Austrailian spring wheat cultivars. However, the performance of some these of spring wheat backcross differential lines varied when compared with the original winter wheat parents. Due to these facts virulence for some of the yellow rust resistance genes, for example, *Yr1,* has been wrongly reported (Ayele Badebo, Personal communication). In general, virulent races for *Yr1, Yr3V, Yr5, Yr15, Yr17, YrS*P and *YrCV* genes have not been detected so far in Ethiopia (Ayele, 2002). Virulence analysis in the field could be influenced by growth stage, environmental conditions and background of the test cultivars. Therefore, race and virulence analysis should be supported by controlled greenhouse tests**.**

Epidemiology

Sources of inoculum

Comprehensive studies on the sources of initial inoculums for wheat rusts is generally lacking although spores were often trapped on the plant in the dry season (Ayele and Wondimu, 1992; Mengistu et al., 1991). The aerobiology of two wheat fields at Adet Research Center was studied using slide traps from the end of August to mid-October 1992 (Paul et al., 1994b). Ten fungal species, namely, *Puccinia striiformis*, *P.graminis*, *P.recondite*, *P.hordei*, *Drechslera* spp., *Alternaria* spp., *Epicoccum purpuascens*, *Aschochyta* sp., *Oidium* sp., and *Ustilago* spp. were trapped. Urediospores of *P. striiformis* were observed to be dominating throughout the period studied. The highest peaks *P. striiformis* urediospores were recorded at the end of August and after the first week of October.

The atmospheric spore load of *Puccinia graminis*, *P.recondita* and *P.striiformis* were monitored at Ambo during 1990/91 and 1991/92 cropping seasons on which glass slides were mounted in the North, South, East and West directions (Getaneh and Temesgen, 1995). Stem rust and leaf rust urediospores were detected in the air through out the year except in July 1990, and the highest spore load was in January 1991. Yellow rust was trapped in nine of the months in 1990 except in February, March and April. Most spores were trapped on slides placed on North and East directions. Easterly followed by westerly wind directions attributed to the maximum influx spores.

An organized epidemiological study was conducted under the NVRSRP of ICARDA to identify the primary sources of inoculums and their movements, in the Nile Valley (Egypt, Ethiopia and Sudan) and Red Sea (Yemen) region for five consecutive years (Mamluk et al., 2000). Burkard spore trap samplers were installed at seven locations in the region (3 in Ethiopia), and they were running all round the year from 1993 to 1997. The results indicated that the primary source of inoculums in Ethiopia could be endogenic due to the presence of wheat plants during the whole year in the different agro-ecologies, and the inoculum did not seem to come from any of the above three countries, considering the wind direction during the wheat-growing period in Ethiopia (Mamluk *et al*., 2000). Although spores of both rusts were trapped throughout the year, the peak spore loads of both rusts were in October–November in Ethiopia.

Host range

A study to determine the importance of grasses in the epidemiology of wheat stem rust was carried out during 1985–87 (Loban et al., 1988a; 1988c; Mozgovoy et al., 1988; SPL, 1988). Stem rust was collected from 12 species of wild grasses from different wheat growing regions in the country. Wheat seedlings were infected only with stem rust collected from *Lolium multiforum*. However, rust collected from *Agrostis* spp., *Bracharia* spp., *Poa* spp., *Avena* spp., *Cynodon* spp., and *Bromus* spp.caused yellowing of leaves. Urediospores collected from *Hordeum* spp and *Setaria* spp. infected universally stem rust susceptible wheat varieties Ashahan and Morocco giving infection type 1 and 2 (score in a 0–4 scale). In a reciprocal artificial inoculation of stem rust urediospores, the result indicated that a number of grass species could be potential hosts to the stem rust pathogen (Zerihun and Abdalla, 2000). In a different study, yellow rust was noted on an alternative host *Phalaris* spp., during the 1988–90 off-seasons in Arsi (Ayele et al., 1992).

A study was carried out on 18 wild relatives of tef, barley, sorghum, maize, wheat, oat, forage grasses and grass weed species to identify alternative hosts for tef rust (DZARC, 1987; Sewalem, 2004). Except *Eragrostis curvula,* (cv. 07 61-111 [L.e]) all the wild relatives of tef were infected by the tef rust fungus indicating that they are alternative hosts. In the second set, only two grass weed species, *Cynodon dactylon* and Murei were infected by urediospores of *Uromyces eragrostidis* Tracy. *Cynodon dactylon* could be more important for survival of the fungus because it is a perennial grass and it is always there in the field. The fungus did not infect all other test species. In a different study carried out at Ambo for alternate hosts of BYDV-PAV in the central Ethiopia for two consecutive seasons (2001/02), 13 grass species were identified (PPRC, 2002).

Histological studies

Histological characteristics of the wheat stem rust fungus (*Puccinia graminis* f. sp. *tritici)* were studied at Ambo during 1987/88 (SPL, 1988). In tissues of a susceptible variety, infection hypha appeared 24 hours after inoculation of seedlings with stem rust spores. On the second and third days, mycelia spread between parenchyma cells around the vascular bundle and in some cells, haustoria were found. On the 8th day, formation of urediospores was observed under epidermal cells. In resistant varieties, however, development of mycelia was limited and cells around the infection hypha were strongly discolored, which was an indication of hypersensitive reaction.

Influence of altitude

The influence of altitude on rust development was studied on 32 bread and durum wheat varieties for three consecutive seasons (Kuzmichev et al., 1985). The highest levels of stem rust infection was observed at altitudes between 1600 and 2500 m and for leaf rust from 1800 to 2600 m, and for stripe rust 2150–2850 m.

Studies on disease development

Development of net blotch (*Pyrenophora teres)* on barley has been studied and the disease could start as early as three leaf stage on a susceptible variety and infection could establish within 36–52 days after planting on varieties with different resistance levels (Bekele, 2005). The infection process of the pathogen was studied under susceptible and resistant host background

Attempts to study the seasonal carry over of wheat rusts among seasons at Holetta area resulted with no conclusion (HARC Progress Report, 1989/90–1990/91; 1993/94). A study at Debre-Zeit showed that the rate of stem rust infection on the durum wheat variety Arendeto averaged 0.15 units per day for the off-season and 0.13 units per day for the main season of 1998 (Mandefro, 2000). The maximum rates of increase were 0.24 and 0.19 units per day for the off-season and main season, respectively, at flowering stage of the crop. Similar work showed that yellow rust progressed at the rate of 0.244 and 0.173 units per day on a susceptible variety Wabe at Agarfa and Sinana, respectively, and 0.068 units per day on variety Meda Walabu at Agarfa (Dereje, 2003). It was also reported that yellow rust severity at booting growth stage of the crop negatively correlated with yield and developed significantly faster on the flag and penultimate leaves.

Yield loss assessment study

Different yield loss figures were reported previously, due to major diseases of barley, tef and wheat, depending on the varieties used, locations and weather conditions in the seasons (Table 15).

Table 15. Yield losses reported on small cereal crops due to major diseases since 1985

Crop	Varieties	Diseases	Estimated loss (%)	Reference
Barley	Different	Scald	21-67	110, 221
	Different	Scald	10-32	32
	Different	Net blotch	34	61, 221
	Different	Net blotch	12-32	208
	Malt & food	Net blotch	31-41 ('Bona')/27-59 ('Genna')	35
	Local	Leaf rust	26-28	85, 109
	Arusso	Net blotch and leaf rust	28-29	36
	Local	Scald & net blotch	26-46	147
	Improved	BYDV	51-80	41
	Different	Scald & net blotch	5-37	148
Tef	Different	Leaf rust	10-41	53
Wheat	Dashen	Yellow rust	52-58	19, 34
	ET 13	Yellow rust	20	34
	Wabe	Yellow rust	71	46, 180
	Mitike	Yellow rust	28	46, 180
	Madawolabu	Yellow +stem rusts	13	46, 180
	Hollandi	Yellow + stem rusts	47	34
	Different	Yellow + Stem rust	11-44	46, 180
	Ambo local	Stem rust	42-52	82, 154
	Locals	Foliar diseases	24-40	147

Barley

The effect of barley leaf rust in reducing grain yield and yield components depend on the growth stage of the crop and planting dates (Getaneh, 1998;

Getaneh and Fekadu, 2001). Losses in grain yield and kernel weight increased from 7 to 40% and 6 to 28%, respectively, with the delay of sowing dates from June 1 to July 16 at Ambo Plant Protection Research Center (Getaneh, 1998). The onset of the disease was relatively at the later crop growth stage and the disease severity progressed significantly at lower rate during the first sowing dates as compared to the latter. Two-season study in North Shewa indicated that yield losses could range from 5 to 37% due to mixed infection of scald and net blotch at different locations and seasons (Meki and Asnakech, 2004). On-farm studies in Bale highlands indicated that losses in grain and straw yield and in kernel weight due to mixed infection of net blotch and leaf rust on local variety Arusso were significant in 'Meher' and 'Belg' seasons (Bekele et al., 2001).

Differences in disease severity between fungicide protected and unprotected treatments were significant in both seasons with more severities in the 'Meher' season. Yield losses that ranged from 26 to 46% were recorded on local landrace varieties due to a combined infection of scald and net blotch at different locations in Tigray Region (MRC Crop Protection Progress report, 1995–2002). Yield loss assessment was conducted against scald on three barley varieties at Shambu, East Wellega Zone during 2001–2002 (BARC Crop Protection Progress Report, 2004). The two years mean loss for IAR H-485, local check and HB-42 varieties were about 25%, 6 % and 19 % for biomass and 32%, 10% and 13% for grain yield, respectively. In a different study done at Bekoji, Arsi Zone, in 1996 showed that BYDV caused grain yield losses of 80% and 51% in barley varieties AHOR880/61 and HB-42, respectively, under natural infection condition (Berhanu, 1998). Regression models were also developed for the two varieties to predict yield loss when the dependent variable was BYDV severity at late booting stage.

Tef

Tef rust was reported to incur 10 to 25% grain yield loss while head smudge could debilitate tef production in western part of the country where warm and humid weather conditions prevail (Eshetu, 1986). However, recent reports from Debre Zeit indicated 10 to 41% yield loss due to tef rust on experimental plots (DZARC, 1994; Sewalem et al., 2001). Damping-off is a seedling disease of tef caused by a number of species in the genus *Drechslera* and other pathogens. The disease usually occurs in patches in farmer fields with infection levels up to 50% (Evmenenko, 1985a; 1985c; Sewalem et al., 2001). However, due to high tillering capacity of tef, significant yield reduction occurred when the severity was more than 40%.

Wheat

Previous reports showed up to 96, 75, 61 and 82% yield losses due to yellow, leaf, stem rusts, and septoria blotches, respectively, in susceptible wheat varieties at hot-spot areas (Eshetu, 1986; Mengistu et al., 1991). Not many yield loss studies in wheat have been made in recent years. The yield loss incurred by yellow rust could be 58–96% (Ayele and Wondimu, 1992; Eshetu, 1986). The threat of stem rust is increasingly becoming important to wheat production in Ethiopia. For instance, in 1993/94 the yield losses due to stem rust on the bread wheat cv., 'Enkoy' ranged from 67 to 100% in Arsi and Bale zones (Shank, 1994).

During the 1986/87 cropping season, a study done at Ambo with a susceptible local variety (Ambo local) with natural and artificial inoculation of stem rust spores showed that 45% and 52% losses in grain yield and 42% and 47% loss in kernel weight, respectively (Getaneh, 1996; Mengistu *et al.*, 1991). Yield losses due to stem rust in durum wheat cultivars in relation to different heading dates was studied at Debre-Zeit and it was found out that maturity alone was not sufficient to determine yield losses (Yeshi and Mengistu, 1999). Yellow rust alone and in combination with stem rust caused 11 to 71% yield losses in Bale area depending on the level of resistance in the wheat varieties used, seasons and locations where the trials were made (Bekele, 2003; Dereje, 2003). When yellow rust affected the head of the plant, it could reduce kernel and hectoliter weights, kernels per spike and spike numbers per plant.

The susceptible variety Wabe was affected most as compared to the relatively resistant varieties Mitike and Madawalabu. Attempts were made to develop models to predict yield loss from yellow rust severity data (Dereje, 2003). An equation y =5203-40.6x (where x was percentage of yellow rust severity on the flag leaf about 82 days after planting) predicted that each percentage increase in rust severity could result in 41-48 kg ha^{-1} yield reduction. Another model estimated that every 10% increase in disease severity could result in 2 to 3 kernels per spike and 1.5 to 1.9 g in thousand grain weight in susceptible variety Wabe at Agarfa condition. A three-season yield loss study in local varieties at different locations in Tigray did not give conclusive results due to low severity of the foliar diseases. In two locations in the first year, however, the loss reached 24-40% (MRC Progress Report, 1995–2002).

Disease management

Cultural methods

Small grain cereal diseases could be, to some extent, controlled by cultural practices such as optimum planting date, optimum fertilizer application, use of suitable cropping system, use of early warning and proper monitoring systems. However, cultural disease management practices give adequate protection if only combined with other practices.

Barley

Planting dates study at Holetta showed that susceptible barley cultivars sown towards the end of June suffered less from scald and yield increased significantly compared to early planting (HARC Progress Report, 1997/98). Planting date study at Sinana revealed that planting in August for 'Bona' or 'Meher' season and planting in April for 'Genna'or 'Belg' season reduced net blotch and leaf rust and significantly increased grain and biomass yield (SARC, 1998). Leaf stripe and loose smut of barley are seed transmitted diseases and are usually very severe on barley grown in the main season. A study carried out at Adet revealed that when seed harvested from off-season barley was used as a seed source for the main season crop, the incidence of barley stripe and loose smut was reduced by 91 and 99%, respectively, and yield increased by 2.7q ha^{-1} (AARC, 1992; Getaneh et al., 1996).

Tef

A study at Ambo showed that tef was more damaged by damping-off when planted at higher seed rate (35-50 kg ha^{-1}) and rust development was lower in early sown tef fields as compared to the late sown fields (Evmenenko, 1985b). On the other hand, rust development was less in early sown than late sown tef fields but seed rate had no significant effect on rust development. The effect of sowing dates on the severity of tef rust was studied at Debre-Zeit on black soil (DZARC, 2002). Three sowing dates and three varieties of different maturity dates were used. There were significant differences among varieties and sowing dates. The first and second sowing dates decreased rust severity and increased yield. The effects of tef rust on agronomic traits and total protein content was studied at Debre-Zeit for two seasons, 1999–2000 (DZARC, 2002). According to a comparison made between sprayed and non-prayed plots of a susceptible tef variety DZ-01-196, there were no significant differences among agronomic traits. However, total protein content has increased on sprayed plots.

Wheat

The effect of sowing dates on severity of leaf and stem rusts and yield on susceptible durum wheat cultivar was investigated at Debre-Zeit during 1985–88 (Yeshi et al., 1990). The results showed that grain yield was much higher on plots planted early (July 5 and 15) than plots sown later in the season (July 25 and August 5). However, rust severity was the highest on early sown plots and the least on the late one.

The advantage of variety mixtures in the management of wheat rusts has been demonstrated in which rust severity could be reduced by 50% (SARC, 2004; SARC, 2005, unpublished). Disease escape mechanism could be exploited for the control of stem and yellow rust in areas where wheat is grown twice in a year. For example, continuous monitoring of rust diseases in Bale Zone indicated that the incidences of yellow and stem rusts were minimal during the 'Genna' season (Bekele et al., 2002). Effect of planting dates on the development of stem rust on wheat at Ambo was studied for three seasons and planting in the first half of June significantly reduced disease incidence and increased yield as compared to late planting (Mengistu et al., 1991). Long-term rust monitoring in the highlands of Bale revealed that yellow rust and stem rust were not important in 'Genna' season as in 'Bona' season and was suggested that farmers should be encouraged to grow wheat in 'Genna' season provided that appropriate varieties and cultural practices are developed for the season's production (Bekele et al., 2002). Experiments conducted in Arsi Zone on the effect of alternative crop management practices on take-all and eyespot diseases revealed that rotation of wheat with dicot crops in a 2-year cycle significantly reduced both diseases (Asefa et al., 2002; Tezera et al., 1996). Stubble burning controlled eyespot, but had no impact on take-all. On the contrary, minimum tillage has decreased take-all incidence.

Host plant resistance

Review of cereal crop disease researches in the last two decades showed that the emphasis of disease management research was on identifiction of host plant resistance or tolerance to major diseases from different nurseries for use in the breeding programs: on variety evaluation and characterization for their reaction to diseases at different agro-ecologies and farming systems and to some extent on the incorporation of diseases resistant traits into promising cultivars (HARC Progress Report, 1989/90–2004/05). Many international disease nurseries, locally constituted screening nurseries for targeted disease problems, and land races have been evaluated at hot spot multi-locations with or without artificial inoculation (Tables 16 and 17).

Table 16. Barley germplasm screening nurseries for resistance/tolerance to major diseases, at HARC

Year of Test*	Type of nursery	No. of entries tested each year	Lines identified each year (%)
1986-89	Screening for resistance to eye spot	51	2
1987/88-1989/90	International (CIMMYT and ICARDA) nurseries	777	8 (see ref. 98)
1986/87-1997/98	Scald and net blotch screening nursery	32-445	0-42
1989/90-1993/94 & 2001/02	Evaluation of barley land race accessions	300-640	5-12
1995/96-1997/98	Evaluation of early barley accessions	25-159	1-24
1989/90-1993/94	Evaluation of cultivars for field resistance to major diseases	16-26	19-47
1986/87-1993/94	Tolerance of cultivars to scald	10-20	10-30
1989, 1992-1994	Screening landraces, varieties for their resistance to the three rusts	150	12
1996-2004**	Screening & advanced screening barley genotypes to major barley diseases	15-480	4-72

**Reports of some years may not be included; **Genotypes screened at Sinana for resistance to Net blotch, scald and leaf rust*
***Source:** HARC and SARC Progress reports for the respective years*

Table 17. Wheat screening nurseries for resistance/tolerance to major diseases

Year of test*	Types of nursery	No. of entries tested each year	Lines identified each year (%)
1986-87	Screening for bunt resistance	60	25
	Screening for eye spot resistance	60	?
	Screening for septoria resistance	60	5
1986/87-1990/91	Tolerance of cultivars to septoria	7-10	0
1989/90-1992/93	Screening for eye spot resistance	13	23-25
1989/90-1996/97	Screening for field resistance to major diseases	25-26	0-20
1994/95-1995/96	Screening local germplasm for resistance to major diseases	27-232	48-55
1993/94-1994/95	Durum & bread wheat septoria nursery (ICARDA)	113-135	36-38
1997/98	Screening for head scab (FHB) resistance	212	0
1999/2000	Septoria and tan spot nursery (CIMMYT & ICARDA)	252	8
1996/97-2004/05	Durum disease (key location) nursery	140-220	?
1996-2004**	Bread wheat advanced screening; early, medium & late	21-85	19-71
1996-1997**	Crossing block	70	11-73
1999-2001**	Emmer wheat Screening	21-365	6-98
2003-2004**	Evaluation of durum wheat	152-185	45-86

** Reports of some years may not be included*
***Genotypes screened at Sinana for resistance to the three rusts*
***Sources:** HARC & SARC Progress reports for the respective years*

Barley

A large number of barley germplasms with resistance to one or more of the major diseases were identified from the different nurseries (Table 16). Over 770 barley lines from international nurseries of CIMMYT and ICARDA were evaluated for three years (1987–1989) at Ambo for resistance to scald, net and spot blotches (Getaneh,. 1993). Many entries were found to be resistant to two or more diseases and were suggested for multi-location tests. Asnakech et al (2005) reported several barley lines (CI4929, CI5401, CI2750, CI7584 and CI4907) to be resistant to both spot and net form of net blotch. Yitbarek et al. (1997) reported that barley genotypes such as HB42, HB99, HB100, HB114, HB115 and HB116 had good field resistance to scald. Bekele et al. (1995) evaluated 224 barley genotypes to scald at Injibara, Mota and Debre-Tabor during 1990–1992 and 33 showed a scald severity of ≤18% across locations, whereas the cultivar Osiris exhibited complete resistance across locations.

Moreover, Kiros (1993) reported that the majority of the 36 barley lines studied had good levels of resistance to scald and ARDU 12-60B, ARDU 12-9C, HB-118 and HB-129 were among the varieties that combined scald resistance and high yield (Kiros, 2004). The malt and food barley varieties Proctor, Holker, Ardu 12-60B and HB100 and a number of landraces (PGRC/E accessions) were also reported to have good resistance to leaf rust (Getaneh and Temesgen, 1996). In another multi-location study, Getaneh et al. (1999) reported that several barley entries showed different reactions to leaf rust at different locations indicating that there would have been different pathogen populations in these locations. More than 4000 barley accessions have been screened for resistance to major diseases at Sinana during the 1996 to 2004 cropping seasons and a number of genotypes were identified to have good levels of resistance to one or more of the diseases (SARC, 1996; 1998; 2001; 2004).

Two hundred barley genotypes were evaluated for their resistance to leaf diseases at Sheno on-station, Faji and Ankober under natural infection during 2003/04 seasons. Out of these, 10 genotypes exhibited resistance to scald and net blotch diseases across locations, showing average disease severity of < 15%. (Debre Birhan Research Center, Unpublished). In a different experiment, 94 barley genotypes and accessions were evaluated against major diseases (scald, net and spot blotches and rust) at Shambu during 2000 and 2001 seasons (BARC, 1998; 2000). Out of these, acc. 229158-1 showed multiple resistances to scald, net and spot blotches diseases, but gave lower grain yield than the standard check HB42. Acession 208038-15-1 showed resistant to major diseases and gave better yield than the control.

Tef

According to the review made by Sewalem et al. (2001), large numbers of tef accessions from different sources and at different times have been screened for resistances to damping-off and leaf rust at Ambo and Debre Zeit. Among the several tef accessions screened at Debre-Zeit for rust resistance, no accession was reported with complete resistance, although some were found relatively resistant to rust (DZARC, 1991; Yeshi and Mengistu, 1995). In a different experiment, 2322 tef accessions were screened at Debre-Zeit for three seasons against tef rust (DZARC, 1994). Thirty-six accessions, showing lower level of rust infection, were selected and planted on hill plots in three replicates. Most of them exhibited high severity while only four accessions scored less than 30S.

Screenings of some 120 to150 tef genotypes were also made in 1996/97 and 1997/98 seasons at Holetta. Accordingly, 7 to10% of the materials were found relatively resistant to leaf rust (HARC Progress Report, 1996/97; 1997/98). A total of 4039 tef mutant (M3) lines derived from gamma-irradiated (700 gy) DZ-01-196 parent were evaluated for tef rust resistance at Debre-Zeit in 2000/1 seasons (DZARC, 2002). The results showed that mutation did not create rust resistant tef lines. However, some lines had lower severities compared to the non-mutant parent. Thus, re-testing those mutant lines, changing the parent material and applying different doses of gamma rays were recommended. Twenty-seven tef cultivars were screened for resistance to head smudge, and only the cultivar 'Manya' had relatively lower (36%) disease score (Melaku, 1993).

In a different study, 150 tef accessions obtained from Debre-Zeit Research Center were evaluated against head smudge during 2001–2004 at Bako (BARC, 2004). The over all disease severity and incidence was highly variable across years due to environmental conditions. The highest diseases incidence was noted in 2002. During this season, none of the accessions exhibited complete resistance of which a local cultivar called ''Ijaji white'' gave relatively low severity (30%) when compared to the rest.

Wheat

Experiences with wheat production in the last two decades showed that new rust races continually appeared or those occurring in low proportion have become dominant in the rusts' population and become real threats to the breakdown of many high yielding commercial bread wheat cultivars (Ayele et al., 2001; EARO, 2004; Eshetu, 2003; Masresha, 1996; Temesgen et al., 1996). Assessment of commercial bread wheat cultivars in the last two decades at different locations showed that they have become more and more susceptible to stripe and stem rusts (KARC Progress Report, 2002–2005; SARC Progress

Report, 1998–2004). Most released bread wheat cultivars were susceptible to yellow rust in the highlands of Arsi and Bale. Wheat cultivars Enkoy, KBG01, Madawolabu were resistant to moderately resistant to yellow rust. On the other hand, cultivars K6295-4A, ET13, Mitikie, Pavon 76, Simba and Sirbo exhibited moderately resistance to moderately susceptible reactions. However, the later varieties might not give adequate protection in higher altitudes (>2400 m). Currently, bread wheat cultivars which resist to the prevailing races of stem rust races in mid-altitudes of Arsi and Bale zones are hardly available (<2400 m). However, few old bread wheat cultivars such as K6290-B, K66295-4A, Derselign, Mitikie, Pavon-76 and one recently realesed (KBG-01) and some old Kenyan bread wheat cultivars (for example, Kenya Plume and K.Kudu) have exhibited moderate level of resistance to stem rust.

Hence, identifying resistant lines from different local and international sources for the breeding activities and monitoring and evaluations of wheat cultivars against rusts have become the major and continuous task of the wheat pathology research.As the result of such activities, many lines and cultivars have been identified from the different local and international nurseries and screening trials (Table 17). However, most of the commercial durum wheat cultivars exhibited stable resistance to wheat rusts across seasons in hot spot areas of the country (DZARC Progress Report, 1987–1991; 1994; 2002; 2003; EARO, 2004; Efrem et al., 1995; Melkamu et al., 1996; Sewalem et al., 2000).

Moreover, durum wheat genotypes of exotic and local crosses had regularly been evaluated for resistance to major diseases under field conditions in the hot spot areas, and landraces were found to be valuable sources of resistance to stem rust (Mengistu and Yeshi, 1992a). Out of 1948 durum wheat accessions received from the Plant Genetic Resources Center of Ethiopia (PGRC/E), large proportion of the accessions was resistant or moderately resistant to stem rust but susceptible to leaf rust. Another study also confirmed that land races exhibited good levels of stripe rust resistance (Getachew et al., 1992; 1997). Susceptibility to head infection was higher than for leaf infection. For most lines, it seems that there was a positive correlation between head and leaf infection. Among the released cultivars, Boohai exhibited satisfactory resistance, whereas Gerardo was the most susceptible one. There were some morphological differences in head infection of which lax spikes seemed to be infected less. Such types of discrepancies of leaf and spike infections were observed among bread wheat genotypes as well (Ayele and Temesgen, 1996).

In a different experiment, the reaction of 218 commercial bread wheat cultivars and advanced lines were tested for yellow rust resistance at seedling stage in the greenhouse and under field conditions at Kulumsa and Meraro during 1995–96 seasons (Ayele et al., 1998). About 66 and 50% of the entries were resistant at seedling stage and field conditions, respectively. The Kenyan originated bread wheat cultivars such as Enkoy, K6295-4A and ET 13 and a number of CIMMYT crosses such as Lira "S", Chilero "S" and Carpentero "S" showed good resistance to one or more of the rust isolates and were suggested to be included in the crossing program. Moreover, in intensive greenhouse and field evaluations of 200 bread wheat cultivars from CIMMYT, 25 of them exhibited double resistance to yellow rust and stem rust (Ayele et al., 2001). Genotypes with incomplete types of resistance to either of the pathogens were quite common among tested materials.

Naod (2004) reported 18 emmer and 6 durum wheat accessions to have good sources of resistance to stem rust and bread wheat varieties KBG-01, HAR2419 (Bobicho) and Megal as well as the durum variety CD-9524-24 (Ude) were found to be resistant to all 18 stem rust races used in the test (Naod, 2004; Naod et al., 2005). Bread wheat cultivars such as K6295-4A, HAR 1709, ET-13, Kenya plume and Kenya leopard showed good resistance to either or both yellow and/or stem rusts over long time and at many locations in at least Bale Zone. They could be considered as sources of resistance to the wheat breeding program (SARC Progress Report, 1991–1993; 1996–2004). However, this has to be viewed in light of the recent outbreak of the stem rust race, Ug99, in eastern Africa, which may require totally new sources of resistance.

Attempts have been made to identify slow rusting bread and durum wheat lines to stem rust. Despite the fact that the bread wheat genotypes have shown inconsistent responses in slow rusting resistance across locations, a number of them were suggested for use as a source of slow rusting resistance to stem rust (Debebe, 2003). Aida (2005) has identified slow rusting reaction in bread wheat lines/varieties HAR3820, HAR710, Dereselign, HAR3790, and ETBW4274 at one or more locations. Slow rusting was also demonstrated in durum wheat where lines DZ2023, CLGMB91-347-1b and DZ1928 were identified as slow rusters (Fetsum, 2004). In a different experiment, however, Yeshi et al (1997) identified slow rusting type of resistance to leaf rust in the Ethiopian durum wheat landraces. In a controlled environment, the reaction of 42 bread wheat varieties and lines were inoculated with 19 isolates of yellow rust differing in their virulences (Ayele et al., 1990). The yellow rust resistance genes *Yr*2, *Yr*3, *Yr*4, *Yr*6, *Yr*7, *Yr*9 and *Yr*A either singly or in combination were postulated, of which *Yr*9 was present in 67% of the varieties and lines.

Recently, there have been some efforts in searching new sources of disease resistance genes from wild and cultivated relatives of wheat. A collection of 203 accessions from five different *Aegilops* species was evaluated for their resistance to leaf rust, stem rust and septoria tritici blotch under controlled greenhouse conditions (Solomon, 2001). Out of the tested 169 *Aegilops* *tauschii*, 11% were resistant to leaf rust, 8% to stem rust and almost 95% to septoria tritici blotch. Introgression of multiple diseases resistance genes from *Ae .tauschii* into bread wheat cultivars has been accomplished via synthetic hexaploids derived from *Ae.tauschii* and *Triticum durum*. Similarly, Ayele and Fehrmann (2005) exposed 68 *Ae.tauschii*, 41 *Triticum durum* and 120 synthetic hexaploids to the most virulent yellow rust isolates from Ethiopia and Germany. Out of these 51%, 12% and 22% of the materials exhibited high level of resistance. However, transferring resistance from wild or cultivated progenitors into bread wheat via bridge cross is not always promising (Ayele, 2002; Ayele et al., 1997). Sometimes, the resistance donated by one of the genomes could be diluted or suppressed when combined at a high ploidy level and this phenomenon has reported to be genetically inherited.

Limited resistance studies of wheat against other foliar diseases were undertaken compared to that of the rusts. Despite the many host resistance studies of bread wheat to septoria blotches carried out so far, no variety or line with high level resistance to the disease was identified. However, studies indicated that some bread wheat cultivars possessed partial resistance to or tolerated the disease and yielded reasonably well (Eshetu, 1985; Solomon et al., 1994). In a separate study made at Holetta and Bekoji, HAR3638, HAR1698, HAR2096, HAR3641 and cultivar Mitikie were found relatively resistant to septoria blotches (Temesgen and Payne, 2000). The report stated that the type of resistance is quantitative type and most likely confounded by plant height and maturity. This needs to be corrected while comparing different genotypes.

In an effort to develop septoria blotch resistant and high yielding bread wheat cultivars, some selected lines and cultivars were crossed at Kansas State University with a number of highly resistant winter wheat cultivars that had been developed by transferring resistant genes from *Triticum tauschii*. Septoria blotches and rust resistant and spring type plants have been selected from successive segregating generations (HARC Progress Report, 1996/96–1997/98; 2000/01–2001/02). Similarly, in another experiment, alien sources of resistance to septoria blotches were incorporated into some commercial cultivars through embryo rescuing techniques and relatively resistant lines were developed ((HARC Progress Report, 2000/01–2001/02). Seeds from uniform lines (F_6-F_7) of both experiments were handed over to the national and regional wheat-breeding programs to be included in the yield trials. However, there is no information whether or not useful varieties from these lines were released, except the few lines that are now under the verification stage at Holetta for possible regional variety release.

The resistance of durum wheat genotypes to septoria blotch was also studied in field experiments at Holetta during 1987–88 (DZARC, 1991; Yeshi et al., 1990). There was no complete resistance to the disease, although variations among genotypes were observed. Durum wheat genotypes with a pedigree of Reichenbanchi have showed relatively good level of resistance. Tan spot is another important disease of wheat, which has not been adequately covered by the research. Ayele and Fehrmann (2003) attempted to see the level of tan spot resistance in commercial cultivars in Ethiopia. In greenhouse tests, 21 commercial bread wheat cultivars from Ethiopia were exposed to a mixture of three aggressive tan spot isolates at two leaf stages in the greenhouse and only three genotypes exhibited adequate level of resistance. The genetic variations among wheat genotypes for resistance to eyespot (Rebeka and Bainbridge, 1990) and bacterial stripe (Yeshi and Mengistu, 1988a) have been demonstrated, but have not been further utilized in the development of resistant cultivars to the diseases.

Biological methods

Biological control research in the management of small cereal crop diseases has the least emphasis due to less applicability. Antagonistic activity of *Trichoderma lignorum* strain has been studied in a greenhouse experiment at Ambo (Sewalem et al., 2001). Seeds of tef were wetted in a spore suspension of *T. lignorum* and planted in the soil, which was infected by *Drechslera miyakei*. It was found that the application of *T. lignorum* increased microbiological activities in the soil, improved germination of tef seeds by 2.7 times and reduced the seed destruction by controlling the pathogen *D. miyakei*. In the laboratory test, the antagonistic activity of *T. lignorum* had a strong inhibiting action on the development of *D. miyakei*, *Helminthosporium* sp. and *Fusarium* sp.

Chemical methods

Use of pesticides in cereal disease management is not generally emphasized and consequently the research on this aspect of disease management was much limited. Since diseases such as yellow and stem rusts of wheat could not be controlled through host resistance alone, large commercial farms in Bale and Arsi zones usually spray their wheat fields. Previous chemical disease management works had been reviewed before (Eshetu, 1986; Mengistu et al., 1991). In order to provide options in cases where fungicides could safely and economically be used for the control of major diseases, chemical control experiments have been carried out in the last two decades and some recommendations have been made (Tables 18 and 19). Some fungicides such as *Propiconazole* (Tilt 250EC) and *Flutriafol* (Impact) can have enhanced effect against two or more major diseases (the rusts and septoria blotches in wheat), and they can economically be used in complex disease situations (Eshetu, 1992). The use of these fungicides should, however, carefully be thought of since their effectiveness and economical uses usually depend on the level of resistance of the variety used, the growth stage of the crop when the disease begins, disease severity and inoculums build up, and prevailing weather conditions, since frequencies and rate of applications usually depend on these factors. Environmental considerations have always to be taken whenever one decides on the use of chemicals for the control of diseases. Some of these fungicides may not be officially registered in the country for the intended uses reported here.

Barley

Chemical control of barley diseases mainly concentrated on foliar application against net blotch and seed dressings for the control of loose smut and stripe disease (Table 18). The possibility of controlling *H. sativum* by seed treatment was assessed in laboratory at Adet (Melkamu et al., 1995). Vitavax/prochloraz, Vincit, Baytan universal, Prelude universal and Agrosan 'H' all effectively controlled at 3, 2, 1.5, 2 and 2 g per kg seed, respectively. These seed dressing fungicides were also evaluated against loose smut and barley stripe (Bekele et al., 1994). The former four fungicides controlled loose smut by 82–99%, whereas all five controlled barley stripe by 98%. Out of several fungicides evaluated in Ethiopia, Tilt 250EC and Bayleton 25WP (*Triadimefon*) were registered for official use in cereals (Abdurahman, 1997; Anonym., 2004; Abdurahman and Berhanu, 1999) including barley. One time and twice tilt application at 0.5 l ha^{-1} have suppressed leaf rust and net blotch (SARC, 1998). Out of single to three times Tilt applications (at the rate of 0.5 l ha^{-1}) studied at various crop growth stages during 2002–2003 at Sinana, twice applications at GS30 and spray at GS39 improved grain yield by 23% and thousand kernel weight by 4–6% across years (Bekele, 1990).

Table 18. Some recommended fungicides and their rates for the control of barley diseases

Fungicide	Diseases to be controlled	Rate	References
Foliar			
Propiconazole	Net blotch of barley	0.5l/ha	89, 172, 208, 221
Sportak sigma	Net blotch of barley	1.0lha	89, 172, 208, 221
Sportak 45% EC	Net blotch of barley	1.0l/ha	89, 172, 208, 221
Alto 100 SL	Net blotch of barley	0.8l/ha	89, 172, 208, 221
Seed treatment			
Apron star 42WS	Net blotch of barley	250-375g/100kg	175
	Leaf rust of barley	375-500g/100kg	175
Vincit	Loose smut and stripe disease of barley	2g/kg	36, 89
Prelude Universal	Loose smut and stripe disease of barley	2g/kg	36, 89
Vitavax	Loose smut and stripe disease of barley	3g/kg	36, 89
Baytan Universal	Loose smut and stripe disease of barley	1.5g/kg	36, 89

Tef

According to Evmenenko (1985a), seed dressing with Campogram, Brassicol, Rizolex and Pronopol has significantly controlled damping-off diseases. It also increased yield in tef considerably. In addition, spraying with *Triademorph* had decreased *Helminthosporium* leaf spot and rust 25-30% and 80% severity to 1-2% and trace levels, respectively. Fungicide trials undertaken at Holetta and Denbi (Deber-Zeit) in 1996/97 and 1997/98 seasons showed that *Flutriafol, Propiconazole, Diffolatan* and *Chlorothalonil* had good control over *Helminthosporium* leaf diseases of tef (HARC Progress Report, 1996/97–1997/98). More recently, the efficacy of four fungicides was tested for the control of tef rust on the susceptible variety DZ-01-99 at Debre-Zeit (DZARC, 2002). The fungicides were applied every fortnight according to the manufacturer's recommendation. There were significant differences in disease severities but not in yield; although treatment with Bumper and Tilt 250 EC had lowered disease severity and yielded relatively higher than the rest of the treatments.

The efficacy of two fungicides Bumper 25 EC and Noble 25 WP was verified with the respective standard checks, Tilt 250 EC and Bayleton 25 WP on 10 x 10 m plots in two replicates at Debre Zeit, Akaki, and Alem-Tena (DZARC, 2002). At Debre-Zeit and Alem-Tena, the test fungicides, Bumper 25 EC and Noble 25 WP, significantly differed in controlling tef rust and performed as good as the respective standard checks, Tilt 250 EC and Bayleton 25 WP. On the other hand, at Akaki there was no significant difference since the rust pressure was too low to discern between the treatments. Generally, the two fungicides were found to be promising in controlling the disease, but the effect was not reflected in increasing straw or grain yield of tef. This might be due to the fact that the rust pressure during the season was not severe enough to affect straw or grain yield at the three test locations.

Wheat

Most chemical control trials made in wheat were on the management of rusts, particularly yellow and stem rusts. Out of five fungicides tested against leaf and stem rust at Debre-Zeit, a weekly or twice application of Tilt 250 EC and Bayleton at recommended rate had controlled the diseases (DZARC, 1989; Yeshi, 1988). At Ambo, the most effective and profitable control of leaf and stem rusts and septoria tritici blotch was achieved with twice application of Tilt 250 EC at the rate of 0.5 l ha^{-1} (Mozgovoy et al., 1987a; 1987b; SPL, 1987; 1988). In 1986/87, six fungicides were tested for rust control on the three bread wheat cultivars (Dashen, Enkoy and Laketch). Out of these three fungicides Bravo 500 (*Chlorothalonil),* Tilt 250 EC and Brestan 60 (*Fentiuacetate*) performed better (Mengistu et al., 1991). In a different experiment, the efficacy of five fungicides was compared on bread wheat variety Enkoy at Kulumsa during 1994–95.

Nobel and Tilt 250 EC significantly controlled stem rust and increased 1000 kernel weight and yield, respectively (Ayele and Temesgen, 1996). The slurry seed dressing chemicals were evaluated in the laboratory and greenhouse against *Fusarium*, *Septoria*, *Helminthosporium* and *Tilletia* seed-borne pathogens. The most effective products were Vincit 200, Panoctin, Vitaflo 250, Vitavax, *Prochloraz* and Sportak Delta (Mengistu et al., 1991). Some of the recommended fungicides for the control of major wheat diseases are summarized in Table 19.

Table 19. Summary of some recommended fungicides and their rates for the control of wheat diseases.

Fungicide	Diseases to be controlled	Rate	References
Foliar			
*Propiconazole**	Yellow, stem & leaf rusts	0.5-1.0 l/ha	21, 51, 154, 173, 193, 207, 211
	Septoria blotches	0.5-1.0 l/ha	191
Flutriafol	Yellow, stem & leaf rusts	0.5-1.0 l/ha	154, 192
	Septoria blotches	0.5-1.0 l/ha	191
Triadimefon**	Yellow &leaf rusts	0.5-1.0 kg/ha	192
Fenpropimorph	Yellow &leaf rusts	1.0 l/ha	154, 192
Chlorothalonil	Septoria blotches	1.125 kg a.i./ha	154, 192
Alto 100SL	Rusts	0.4l/ha	34
Tebuconazole	Yellow and stem rusts	?	SARC, unpublished
Epoxiconazole	Yellow and stem rusts	?	SARC, unpublished
Sonazole	Stem and leaf rusts	0.5 l/ha	DZARC, un published
Picazole	Stem and leaf rusts	0.4 l/ha	DZARC, unpublished
Seed treatment			
Dividend 3 WS/DS	Take all	1.0 g/kg	175
Carboxin	Loose smut	1.5 g/kg	61, 154
Vitavax	seed borne	-	61, 154

Registered under different trade names: Til and Bumper; **Bayleton and Nobel*

***Source**: (Anonym., 2004)*

Integrated disease management

Integrated disease management is the most preferred option whenever applicable for the management of plant diseases, particularly cereals. However, little work has been undertaken in this regard. Despite the absence of significant effect on grain yield and other yield components, fungicide by planting date interactions affected net blotch and leaf rust development in barley (SARC, 1998). Single and twice application of Tilt 250 EC at the second planting date gave the highest grain yield at Sinana. A study on the integration of fungicides, sowing dates and varieties for effective control of yellow rust in wheat was carried out at Sinana. Although fungicide application had a profound effect on the disease control across all the sowing dates, better disease control and grain yield was obtained from planting dates ranging from 4–13 August for Sinana conditions (Bekele, 2003).

Effect of sowing dates on bread wheat varieties with different levels of resistance and two rates of fungicide on the management of septoria blotches was studied (Eshetu and Zerihun, 2003). Late sowing significantly reduced septoria development and severity, but had no effect on kernel weight and yield. The use of relatively resistant cultivars or fungicide application at appropriate time and rate has a pronounced positive effect on the management of the disease. In another experiment, the influence of rotation, residue management, nitrogen fertilizer levels and varieties on the development and severity of septoria blotches of wheat, kernel weight and yield was studied (Eshetu, 2004). One or two year's rotation of wheat with faba bean and/or 'gomenzer' or burning crop residues delayed the on set of the disease and consequently increased wheat yield. Nitrogen fertilizer had no effect on septoria blotches, but the higher rate increased wheat yield. Combining the use of resistant varieties with either faba bean or 'gomenzer' rotations greatly reduced the threat from the disease and increased yields.

Conclusion and recommendations

- The threatening diseases and races have been monitored especially for wheat through annual diseases surveys, wheat rust trap nurseries and race identification works. There have been attempts to identify and monitor intimidiating races and virulences. Stripe and stem rusts are considered as main threats for bread wheat production in Ethiopia, especially in Arsi and Bale zones. Areas less than 2400 m altitude are considered suitable for leaf and stem rusts, but higher and cooler altitudes suits for yellow rust development;
- There have been loss assessment studies on prioritized diseases. The yield losses incurred by net blotch and scald on barley could be 59 to 67%; and 58 to 71% for yellow and stem rusts, singly or incombination depending on the locations, seasons and varieties, respectively;
- The major contribution of small cereal disease research is in the development of high yielding disease resistant cultivars. Several disease resistant wheat and barley genotypes were identified from different nurseries and collections after exposing them to the prevailing pathogens and races in greenhouse and/or in the field sown at key locations. Some of these materials have either been utilized by breeders to develop new varieties or included in crossing blocks. In general,

there are barley and durum wheat genotypes which exhibit combined resistance to major diseases. However, bread wheat genotypes often succumb to yellow and stem rusts. Only few bread wheat cultivars such as Mitikie, K6295-4A, Pavon-76 and KBG-01 that partially resisted to the prevailing stem and yellow rust races. These varieties might even require one critical fungicide spray to control yellow rust at high altitudes (>2400 m) and stem rust in mid altitudes (1800-2400 m);

- Fungicides are known to control small grain cereal diseases. So far, two products: *Propiconazole* (Tilt and Bumper) and *Triadimefon* (Bayleton and Noble) have been utilized by state and some emergent farms in Arsi and Bale zones. In general, chemical disease control may not be recommended for smallholder peasant agriculture, which constitutes the large majority of cereal production system in the country. However, utilization of relatively cheaper generic chemicals including seed treatments should be investigated for use by farmers' that can afford high-level inputs for economical cereal production. Currently, such types of generic fungicides are available and should be verified under farmers's conditions for economic benefits; and
- Generally, early sowing enhances cereal yields and economically manages rust diseases in most cases and can be followed in problem areas. Even though the rust sometimes become more severe on early sown crops, the advantage of avoiding terminal moisture stress and utilization of the available moisture fully in the season due to early planting enhances the yields. If early sowing, coupled with the use of relatively resistant cultivars, rotation with legumes such as faba bean or *gomenzer* or stubble burning from previous season could reasonably reduce the threat of stubble/soil borne diseases such as septoria and blotches in wheat and eyespot disease of barley and wheat. Stubble burning could be controversial due to its negative effect on soil fertility and structure, but one has to weigh the advantages and disadvantages of stubble burning in relation to these problems.

Gaps and challenges

- Small cereal disease surveys and monitoring, particularly on wheat, have been going on for a long time and more or less regularly during main cropping seasons. However, the results were reported in scattered manner in progress reports of each center, which usually put out to users with considerably long delays. Such surveys and disease monitoring information should be summarized in a way showing the crop diseases situations for the current season at national level and be published immediately after the season is over since they are useful source of information to users;
- Rusts, particularly stem and yellow rusts, remain to be the major diseases of wheat, but the work on race and virulence analysis are not being done continually or routinely in a coordinated and systematic manner to monitor the most frequent and stable races that occurred annually in most places and to monitor the occurrence of new ones in the country. Such a work is important to gear the breeding programs towards developing resistant cultivars to the known

rust races. As a matter of urgency, it is necessary to exert efforts to organize and develop rust race and virulence analysis facilities and expertise in the country;

- Although a number of studies had shown that there were variations in pathogenesis or virulence among isolates of major pathogens of cereals, there has not been follow up studies to establish whether these variations qualify them to belong to known races or designate them as new races. Type cultures have not been maintained for future studies (no information); and the relevance of these variations in the development of race specific resistance breeding has not been pursued so far. Most of these studies were initiated as thesis projects, which could be good areas for academic studies but with little practical values at this moment for developing race-specific resistance in the host;
- Epidemiological studies on wheat rusts are very much limited. The influx of rust spores from neighboring countries is usually presumed but not proven through studies. This requires inter-countries collaboration within a region and sub-regions and most effectively done through the coordination and finance of international agricultural research institutions;
- Generally, the various reports on yield loss greatly vary with varieties, locations, seasons (weather) and inoculum’s build up at critical time of crop growth stages. Yield loss values, therefore, should not be generalized for the whole situations, but could be limited for specific conditions as indicated above. The very few attempts made so far to develop models for predicting yield losses due to rusts in wheat did not consider all major factors and seem to be inadequate. Yield losses studies should be refined further considering the different scenarios that affect yield in specific production conditions;
- The major line of defense in cereal diseases management is the use of resistant varieties. Many resistant lines have been identified from different local and international disease nurseries annually, but their utilizations in the breeding programs or their development as varieties had not been well pursued and documented. It is therefore necessary for the plant pathologists and breeders to work together more closely in the development of resistant and high yielding cultivars;
- Emphasis should be given to integrated disease management (IDM) where two or more of the control measures could be integrated for sustainable disease management in cereals. Although some IDM technologies have been reported so far, the research in this regard should be intensified;
- Post harvest disease problems are not adequately addressed by the research so far. In view of the current emphasis on the production of crops for export markets, research on post harvest disease control and monitoring of level of contamination by pathogens and their undesirable products (toxins) in marketable cereal produces has to be investigated; and
- The major challenges in small cereal crops improvement research in general and in wheat and barley improvement research in particular in the country are those posed by diseases. Several high yielding varieties have been released to farmers since the inception of crop research in the early 1950’s after being evaluated against major diseases of the time. Nevertheless, experiences showed that due to the appearance of new pathogens and races of the pathogens, the resistance of

these varieties has often become ephemeral. Cases in point are the often reports on the break down of resistance in many bread wheat cultivars just after a very short period of production due to the appearance of new or undetected stem and yellow rust races. Recently, a new wheat stem rust race known as UG99, which first been detected in Uganda in 1999, is becoming a global issue of concern. This race attacks most of the CIMMYT materials having *Sr*31 gene and as the majority of Ethiopian commercial cultivars and breeding lines originated from this gene, there is a great challenge for wheat production in the country. Currently, commercial cultivars, which combine high yield, quality and multiple resistances to the prevailing races of pathogens, are hardly available in the country. This is an obvious gap existing for long time in the efforts of developing high yielding disease resistant and stable varieties in wheat and barley.

Future prospects

The challenge of the day, then, should be to review and reorganize the research strategies of small cereal improvement research to give adequate emphasis to resistance breeding. This requires an organization of a very effective and functional national coordination system with adequate resources in trained and experienced human resources, laboratory and greenhouse facilities and financial requirements. Effective coordination, collaboration and share of responsibilities between breeders and plant pathologists, among pathologists and institutions involved in small cereal improvement research should be established.

Well consulted and worked-out variety improvement approaches, techniques, procedures and systems should be in place so that new researchers joining the programs should continue the work without any problems and keep the work sustainable. Technical constraints that are facing the small cereal improvement programs in general and cereal pathology research in particular now can only be avoided if such joint and integrated efforts are applied. The future prospects of small cereal research in the country heavily relay on meeting these challenges and fill research gaps.

References

1. Abashamo Lencho. 2000. Pulse Pathology and Barley Viorology, 1996-1998. Sinana Agricultral Research Center, Sinana. 70 pp.
2. Abdurahman Abdulahi. 1997. The status of pesticide registration in Ethiopia. *Pest Mgt J Eth* 1:57-62
3. Abdurahman Abdulahi and Berhanu G/Medhin. 1999. Additional list of registered pesticides in Ethiopia. *Pest Mgt. J. Eth* 3: 95-97
4. Adet Agricultural Research Center (AARC). Progress report 1990
5. AARC. Progress report 1992.
6. AARC. Progress report 2000.
7. Afera Berhanu. 1997 .Crop pest study and action program in Tigray. Bureau of Agriculture and Rural Development, Tigray, Ethiopia.
8. Aida Zewdu. 2005. Identification of sources of slow rusting resistance to stem rust in bread wheat (*Triticum aestivum*). MSc. Thesis, Alemya University Alemaya, Ethiopia. 78 p.
9. Anonym. 2004. List of registered pesticides as of December 23, 2004. Ministry of Agriculture and Rural Development, Crop Protection Department, Addis Ababa Ethiopia. 15 pp.
10. Anonym. 2005. Sounding the Alarm on Global Stem Rust: An Assessment of race Ug 99 in Kenya and Ethiopia and the potential for impact in neighboring regions and beyond. Report of the expert panel on the stem rust outbreak in Eastern Africa. 29 May 2005. CIMMYT.
11. Asefa Taa, Tanner, DG., Bennie, ATP. 2002. Effect of stubble management, tillage, and cropping sequence on the severity of take all and eye spot diseases of wheat. *African Crop Science Journal* 10: 67-79.
12. Asnakech Tekalign. 2002. Relative importance and pathogenic variability of barley net and spot form of net blotch (*Pyrenophora teres*) in North West and Central Highlands of Ethiopia. MSc. Thesis. Alemaya University, Alemaya, Ethiopia. 103p.
13. Asnakech Tekalign, Yitbarek Semeane and Temam Hussien. 2005. Importance and pathogenic variability of the barley net and spot type net blotch in north and central highlands of Ethiopia. Pest. Mgt J. Eth. 9: 71-81
14. Awgechew Kidane. 1996. Evaluation of bread and durum wheat germplasm for resistance to the major seed-borne diseases in Ethiopia. pp. 490-493. *In*: Tanner, DG, Payne, TS and Abdalla, OS. (eds.). The ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT.
15. Ayele Badebo, A. Bainbridge and Getinet Gebeyehu. 1989. Ear cockle of wheat in Arsi. IAR Newsletter. Vol. 4 number 1. Addis Ababa, Ethiopia. IAR.
16. Ayele Badebo and M. van Ginkel. 1989. The identification of races in stripe rust and its importance in wheat breeding (Abstract). Paper presented during the fourteenth annual meeting. March 30-31 1989. SPL, Ambo, Ethiopia.
17. Ayele Badebo, RW. Stubbs, van Ginkel M. and Getinet Gebeyehu. 1990. Identification of resistance genes to *Puccinia striiformis* in seedlings of Ethiopian and CIMMYT bread wheat varieties and lines. *Neth. J. Pl. Path*. 96: 199-210.
18. Ayele Badebo, Getinet Gebeyehu, Rebeka Desta, Bekele Geleta, Balcha Yai and Temesgen Kebede. 1992. Current status of stripe rust (*Puccinia striiformis* f.sp. *tritici*) in Ethiopia (Abstract). Paper presented during the sixteenth annual meeting of the Ethiopian Phytopathological Committee. March 5-7, 1992. Addis Ababa, Ethiopia.
19. Ayele Badebo and Wondimu Bayu. 1992. The importance of stripe rust in the major wheat producing regions of Ethiopia during 1988-1990. *In*: Tanner DG., and W. Mwangi (eds.). Proceedings of the seventh regional wheat workshop for Eastern, Central and Southern Africa. Nakuru, Kenya: CIMMYT. 196-202. pp.

20. Ayele Badebo and RW Stubbs. 1995. Valuable sources of resistance of wheat to the East African yellow rust isolates. *In*: Danial DL (ed.). Breeding for disease resistance with emphasis on durability. Proceedings of a regional workshop for Eastern, Central and Southern Africa. October 2-6, Njoro, Kenya. 206-214. pp.
21. Ayele Badebo and Temesgen Kebede. 1996. Effects of fungicide and frequency of application on the yield and stem rust severity of bread wheat at Kulumsa. (Abstract.) *In*: Eshetu b., Tibebu H., Yitbarek S., Mengistu K. and Kasahun B. (eds.). Proceedings of the fourth annual conference of the crop protection society of Ethiopia. 23-25, May 1996. Addis Ababa, Ethiopia. CPSE.
22. Ayele Badebo and Temesgen Kebede. 1996. Relative infection of leaves and spikes of bread wheat by stripe rust in southeastern Ethiopia. pp. 500-503. *In*: Tanner DG., Payne, TS., and Abdalla OS. (eds.). Proceedings of the ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT.
23. Ayele Badebo, GHJ. Kema, M. van Ginkel, and CH. van Silfhout. 1997. Genetics of suppressors of resistance to stripe rust in synthetic wheat hexaploids derived from *Triticum turgidum* subsp. *dicoccoides* and *Aegilops squarrosa*. Proceedings of African Crop Science Conference. Uganda. 3: 195-202.
24. Ayele Badebo, Temesgen Kebede, Zewdie Alemayehu, Bedada Girma and Osman Abdalla. 1998. The reaction of bread wheat lines and varieties to stripe rust at seedling and adult plant growth stages. *Pest Mgt. J. Eth*. 2(1&2): 36-42.
25. Ayele Badebo, Alemtaye Andarghe, Bedada Girma, and T. Payne. 2001. Double sources of resistance to *Puccinia striiformis* and *P. graminis* f.sp. *tritici* in CIMMYT bread wheat lines. Sebil 9: 11-19.
26. Ayele Badebo. 2002. Breeding bread wheat with multiple disease resistance and high yield for the Ethiopian highlands: Broadening the genetic basis of yellow rust and tan spot resistance. Ph.D. thesis. Cuvillier Verlag Goettingen, Germany. 115 pp.
27. Ayele Badebo and H. Fehrmann. 2003. Importance and pathogenic variation of wheat tan spot in Ethiopia. *Pest Mgt. J. Eth*.7: 19-27.
28. Ayele Badebo and H. Fehrmann. 2005 Resistance to yellow rust in *Aegilops tauschii (*Coss.), *Triticum durum* and their synthetic amphiploids. *Eth. J. Agric. Sci.* 18 (2): 129-135.
29. BARC (Bako Agricultural Research Center) 1998. Bako Agricultural Research Center Crop protection research division progress report, 1997/1998.
30. BARC.2000. Bako Agricultural Research Center Crop protection research division progress report, 1999/2000.
31. BARC. 2001. Bako Agricultural Research Center Crop protection research division progress report, 2000/2001
32. BARC.2004. Bako Agricultural Research Center Crop protection research division progress report, 2003/2004.
33. Bekele Hunde. 1990. Plant diseases situation in North Western part of Ethiopia pp. 10-13 *In*: Seid Ahmed and Yaynu Hiskias (eds.). Proceedings of the Ethiopian Phytopathological Committee (EPC) fifteenth annual meeting, Addis Ababa Ethiopia, EPC.
34. Bekele Hundie. 2003. Short report on stripe rust and stem rust. Pp. 67-78. *In*: Bedada Girma. (ed.). Proceedings of the agronomy workshop, Bale Agricultural Development Enterprise (BADE). Addis Ababa.
35. Bekele Hundie. 2005. Infection biology: Epidemiology and resistance of barley land race lines to *Pyrenophora teres.* PhD. Thesis, Kasetsart University.156 p.
36. Bekele Hundie, Shambel Kumbi and Abashamo Lencho. 2001. Barley yield loss due to net blotch and leaf rust in Bale highlands. *Pest. Mgt. J. Eth*. 5:45-53.
37. Bekele Hundie, Shambel Kumbi and Dereje Hailu. 2002. Seasonal variation in occurrence of wheat stripe rust in Bale highlands. *Pest Mgt. J. Eth.* 6: 65-72.

38. Bekele Hundie, Melkamu Ayalew and Yibarek Semeane. 1995. Evaluation of barley cultivars to scald in the North West region of Ethiopia. *In*: Daniel L and Danial (eds.). Breeding for Disease resistance with emphasis on durability. Proceedings of a regional workshop for Eastern, Central and Southern Africa, Njoro, Kenya, October2-6,1994. Breeding Dept., Agri., Univ. Wageningen, the Netherlands. PP 197-201.
39. Bekele Hundie, Hailu Tefera, Melkamu Ayalew, Mesele Alemu and Paul, Y.S. 1994. Management of loose smut and leaf stripe of barley using seed dressing fungicides. CPSE. *In*: Eshetu Bekele, Yitbarek Semeane, Tibebu Habtewold, Mengistu Kebede and Kasahun Kebede (eds.). Proceedings of of the first Ann. Conference, 14-15April1993, Addis Ababa, Ethiopia. P 40-41.
40. Belayneh A. and Emebet F. 2005. Physiological races and virulence diversity of *Puccinia graminis* f. sp. *tritici* on wheat in Ethiopia**.** *Phytopathologia Mediterranea 44(3): 313 - 318*
41. Berhanu Bekele. 1998. Distribution of barley yellow dwarf virus (BYDV) isolates in Arsi and Shewa Regions of Ethiopia and their impact on yield losses. MSc. Thesis. Alemaya University, Alemaya, Ethiopia.126 p.
42. Berhanu Bekele, Abdulrazak Yusuf and KM. Makkouk. 2003. Status of barley yellow dwarf and cereal yellow dwarf viruses infecting barley in Ethiopia. *Pest Mgt. J. Eth*. 7:29-40.
43. CSA (Central Statistical Authority) 2006. Agricultural sample survey 2005/2006 (1998 E.C). Volume 1. Report on area production of crops, private peasant holdings, Meher season. Addis Ababa, Ethiopia.
44. Debebe Masresha. 2003. Evaluation of bread wheat genotypes (*Triticum aestivum*) for slow rusting resistance to stem rust and association with yield and yield related traits. MSc. Thesis, Alemaya University. Alemaya, Ethiopia. 113 p.
45. DBARC (Debre Birhan Agricultural research Center). Progress report, 2001/02
46. Dereje Hailu. 2003. Effects of yellow rust (*Puccinia striiformis*) on yield, yield components and quality of improved bread wheat (*Triticum aestivum* L.) varieties. MSc. Thesis. Alemaya University, Alemaya, Ethiopia. 105 p.
47. Dereje Tadesse and Paul, YS, and Berhanu Bekele. 1992. Studies on black point diseases on durum wheat in Ethiopia. *In:* Tanner DG., and W. Mwangi (eds.). Proceedings of the seventh regional wheat workshop for Eastern, Central and Southern Africa. Nakuru, Kenya: CIMMYT. Pp.231-235.
48. DZARC (Debre-Zeit Agricultural Research Center).1987. Annual Research Report. 1986/87
49. DZARC. 1988. Annual Research Report. 1987/88.
50. DZARC. 1989. Annual Research Report 1988/89.
51. DZARC. 1990. Annual Research Report. 1989/90
52. DZARC. 1991. Annual Research Report for the period 1990/91.
53. DZARC. 1994. Annual Research Report for the period 1991/92.
54. DZARC. 2002. Annual Research Report for the period 2000/2001.
55. DZARC. 2003. Annual Research Report. 2002/03
56. EARO (Ethiopian Agricultural Research Organization). 2000. Annual report 1998/99. EARO. Addis Ababa, Ethiopia.
57. EARO . 2004. Annual Report 2002/03. EARO. Addis Ababa, Ethiopia.
58. Efrem Bechere, Tesfaye Tessema, Mengistu Hulluka and Yeshi Andnew. 1995. Breeding durum wheat for resistance to leaf and stem rusts in Ethiopia. *In*: Danial DL (ed.). Breeding for disease resistance with emphasis on durability. Proceedings of a regional workshop for Eastern, Central and Southern Africa. October 2-6, Njoro, Kenya. CIMMYT. Pp.125-132.

59. Endalle Hailu. 2005. Prevalence and management of loose smut (*Ustilago segetum* var. *tritici*) of wheat (*Triticum aestivum* L.) in some selected districts of Central and Eastern Ethiopia. MSc. Thesis. Alemaya University, Alemaya, Ethiopia.
60. Eshetu Bekele. 1985. Tolerance of some bread wheat cultivars to septoria blotch. *Eth. J. Agric. Sci.* 7(2): 89-98.
61. Eshetu Bekele, 1986. Review of research on diseases of barley, tef and wheat in Ethiopia. *In*: Tsedeke Abate (ed). A review of crop protection research in Ethiopia. Proceedings of the first crop protection symposium .IAR, Addis Ababa, Ethiopia. Pp. 79-108.
62. Eshetu Bekele.1990. Identification of *Fusarium* spp. and Mycotoxins Associated with Head Blight of wheat in Ethiopia. A Dissertation Presented to the Graduate School, University of Missouri-Columbia in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy. 186 pp.
63. Eshetu Bekele. 1992. Studies on the fungicidal control of Septoria leaf blotch of wheat. *Eth. J. Agric. Sci*. 13:37-46.
64. Eshetu Bekele. 1994. Mycotoxin production potential of *Fusarium* species identified from Ethiopia wheat. p.47 (Abstract). *In*: Proceedings of the First Annual Conference of Crop Protection Society of Ethiopia. (CPSE). Addis Ababa, Ethiopia.
65. Eshetu Bekele. 2003. Wheat diseases in Ethiopia. *In*: Bedada Girma (ed.). Proceeding of the agronomy workshop. Bale Agricultural Development Enterprise. (BADE). Addis Ababa, Ethiopia. pp. 51-60.
66. Eshetu Bekele. 2004. Integrated management of septoria blotch of wheat: Effects of stubble management, rotation, nitrogen level and variety. *Pest Mgt. J. Eth*. 8: 23-30
67. Eshetu Bekele and A.L. Karr. 1997. Fusarium Head Blight in Ethiopian wheat and the identification of species causing the disease. *Pest. Mgt. J. Eth*. 1 (1&2): 29-36.
68. Eshetu Bekele , AA Rottinghaus, GE. Rottinghaus, HH. Casper, DM. Fort, CL. Barnes and MS. Tempesta. 1991. Two new trichothecenes from *Fusarium sporotrichioides*. Journal of Natural Products. 54:1303-1308
69. Eshetu Bekele and Zerihun Kassaye. 2003. Integrated management of seprotia blotch of wheat: Effects of sowing date, variety and fungicide. Pest. Mgt. J. Eth. 7: 11-18.
70. Eshetu Wondimagegne and AP. Korobko. 1987. Bacterial stripe and black chaff of wheat. Ethiopian Plant Pathology Newsletter. 12 (4): 34-43.
71. Eshetu Wondimagegne and AP. Korobko. 1988. Bacterial disease on wheat and barley in Ethiopia. Sebil 1:30
72. Evmenenko, A. 1985a. Chemical control of damping-off on tef. *In*: Proceedings of the sixteenth National Crop Improvement Conference. Addis Ababa, Ethiopia. IAR. 784-788 pp.
73. Evmenenko, A. 1985b. Study on the development of damping-off in connection with tef cultivation methods. *In*: Proceedings of the sixteenth National Crop Improvement Conference. Addis Ababa, Ethiopia. IAR. 800-804 pp.
74. Evmenenko, A. 1985c. Crop loss assessment study due to damping-off of tef. pp. 794-799. *In*: Proceeding to the sixteenth National Crop Improvement Conference (NCIC). Part II. Addis Ababa, Ethiopia. IAR.
75. Evmenenko, A. 1985d. Identification of pathogens causing damping-off on tef using serological methods. pp. 800-804. *In*: Proceedings of the sixteenth National crop Improvement Conference (NCIC). Addis Ababa, Ethiopia. IAR.
76. Fantahun Asefa and Girma Kebede. 1995. Diseases of important crops in Southern Ethiopia. CPSE. *In:* Eshetu, Abdurhman, Aynekul, Fantahun and Mesresha (eds). Proceedings of the second Ann. Conference 26-27April, 1994, Addis Ababa, Ethiopia. P 28.

77. Fetsum Sahlemariam. 2004. Identification of slow rusting durum wheat (*Triticum durum*) lines to stem rust and association with yield and yield related traits. MSc. Thesis, Alemaya University. Alemaya, Ethiopia. 58 p.
78. Geremew Eticha, Tilahun Geleto and Aliye Husien. 1998. Adecade of research experience, sinana Agricultural Research Center, 1986-1997. Agricultural Research coordination Service, Oromi ya Agricultural Development Bureau. Bulletin No 4. PP.52
79. Getachew Belay, Tesfaye Tesemma, Demissie Mitiku and Ayele Badebo. 1992. Variability in durum wheat genotypes for leaf and head infections of yellow rust in Ethiopia. *In*: Tanner DG., and W. Mwangi (eds.). Proceedings of the seventh regional wheat workshop for Eastern, Central and Southern Africa. Nakuru, Kenya: CIMMYT. Pp. 135-141.
80. Getachew Belay, Tesfaye Tessema, Demissie Mitiku, Ayele Badebo and Efrem Bechere. 1997. Potential sources of resistance to stripe rust (*Puccinia striiformis*) in durum wheat. Rachis 16(1/2): 70-74.
81. Getaneh Woldeab. 1993. Screening of international barley varieties or crosses against major leaf diseases at Ambo (Abstract). *In*: Eshetu Bekele, Tadesse Gebremedhin, Yitbarek Semeane, Mengistu Kebede and Kasahun Bekele (eds.). Proceeding of the joint conference: Ethiopian Phytopathological Committee and Committee of Ethiopian Entomologists. Addis Ababa, Ethiopia. CPSE.
82. Getaneh Woldeab. 1996. Studies on fungal diseases of wheat at the Plant Protection Research Center, 1974-1994. *In*: Eshetu B., Abdurahman A. and Aynekulu Y. (eds.). Proceedings of the third annual conference of the Crop Protection Society of Ethiopia. Addis Ababa, Ethiopia. CPSE. Pp. 171-177.
83. Getaneh Woldeab. 1998. Yield loss due leaf rust on barley at different sowing dates. *Pest Mgt. J. Eth*. 2(1&2): 79-84.
84. Getaneh Woldeab. 2002. Status of eyespot and root diseases of barley in west Shewa. *Pest Mgt. J. Eth*. 6:53-58.
85. Getaneh Woldeab and Fekadu Alemayehu. 2001. On farm yield loss due to leaf rust (*Puccinia hordi* otth) on barley. *Pest Mgt. J. Eth*. 5: 29-35
86. Getaneh Woldeab and Temesgen Belayneh, 1995. Preliminary study on atmospheric spore load of wheat rust at Ambo. CPSE. *In*: Eshetu, Abdurhman, Aynekul, Fantahun and Mesresha (eds). Proceedings of the second Ann. Conference 26-27April, 1994, Addis Ababa, Ethiopia. P 35
87. Getaneh Woldeab and Temesgen Belayneh.1996. Occurrence of rust and reaction of barely varieties, land races. *In*: Eshetu Bekele, Abdurahman Abdulahi and Aynekulu Yemane (eds.). Proceedings of the third annual conference of the Crop Protection Society of Ethiopia. Addis Ababa, Ethiopia. CPSE. Pp. 178-185.
88. Getaneh Woldeab, Fekedu Alemayehu, Bekele Hundie and Melkamu Ayalew. 1999. Evaluation of barley germplasm for resistance to barley leaf rust (*Puccinia hordei* Otth). *Pest Mgt. J. Eth*. 3(1&2): 39-45
89. Getaneh Woldeab, Bekele Hundie, Yitbarek Semeane and Dereje Tadesse. 1996. Barley diseases management research. *In*: Hailu Gebre and Joop van Leur. (eds). Barley Research in Ethiopia: Past work and future prospects. Proceedings of the First Barley Research Review workshop. Addis Ababa, Ethiopia. IAR/ ICARDA. Pp 116-122.
90. Getinet Gebeyehu, M. van Ginkel, Mentwab Haregewoin, Mengistu Hulluka, Yeshi Andnew and Ayele Badebo. 1990a. Wheat rust virulence in Ethiopia. *In*: Tanner, DG., M. van Ginkel, and W. Mwangi (eds). Sixth regional wheat workshop for Eastern, Central and Southern Africa. Mexico, D.F. CIMMYT. pp. 28-38.
91. Getinet Gebeyehu, M. van Ginkel, Temesgen Kebede, Mentwab Haregewoin, Rebeka Desta, A. Bainbridge, Mengistu Hulluka, Yeshi Andnew, Dereje Tadesse, Amanuel Gorfu, and Ayele Badebo. 1990b. Wheat disease survey in Ethiopia in 1988. *In*: Tanner, DG, M.

van Ginkel, and W. Mwangi (eds). Sixth regional wheat workshop for Eastern, Central and Southern Africa. Mexico, D.F. CIMMYT. pp. 153-165.

92. Hailu Tefera and Seyfu Ketema. 2001. Production and importance of tef in Ethiopian agriculture. *In*: Hailu Tefera, Getachew Belay and M. Sorrells (eds). Narrowing the rift: Tef research and development. Proceedings of the international workshop on tef genetics and improvement, 16-19 October 2000, Addis Ababa, Ethiopia. EARO. 3-7 pp.
93. HARC. (Holetta Agricultural Research Center). Progress report for the period 1989/90
94. HARC. Progress report for the period 1990/91.
95. HARC. Progress Report for the period 1993/94.
96. HARC. Progress Report for the period 1994/95.
97. HARC. Progress Report for the period 1995/1996
98. HARC. Progress Report for the period 1996/97.
99. HARC. Progress Report for the period 1997/98.
100. HARC. Progress Report for the period 2000/01.
101. HARC. Progress report for the period 2001/02.
102. HARC. Progress report for the period 2002/03.
103. HARC. Progress report for the period 2003/04.
104. HARC. Progress report for the period 2004/05.
105. HARC. Wheat pathology progress report for the period 1998/99
106. HARC. Wheat pathology progress report for the period 1999/00
107. HARC. Wheat pathology progress report for the period 2003/04
108. HARC. Wheat pathology progress report for the period 2004/05
109. IAR (Institute of Agricultural Research). 1997. Annual Report for the period of 1996/97. IAR. Addis Ababa.
110. IAR. Department of crop protection progress report for the period 1983/84.
111. IAR.1985. Crop protection department progress report for the period 1980/81-1982/83.
112. ICARDA. 2004. Technology generation and dissemination for sustainable production of cereals and cool season legumes, Progress Report first season 2002-2003. pp. 170-171.
113. ICARDA. 2005. Technology generation and dissemination for sustainable production of cereals and cool season legumes, Progress report final season 2005-06. pp. 32-34.
114. Kiros Meles. 1993. Studies on barley scald. (*Rhynchosporium secalis* (Oud.)Davis) and evaluation of barley lines for resistance to the disease in Ethiopia. MSc. Thesis. Alemaya University, Alemaya, Ethiopia. 133 p.
115. Kiros Meles A. 2004. Pathogenic and genetic variability in *Rhynchosporium secalis* (oud) Davis on barley. PhD Thesis. University of Jordan, Amman, Jordan. 116 pp
116. Kiros Meles, Mengistu Hulluka and ML Deadman. 2000. Pathogenic variation in *Rhynchosporium secalis* on barley in Ethiopia. *Agricultural Sciences* 5: 75-78.
117. Kiros Meles, Mengistu Hulluka and MM. Abang. 2004. Phenotypic diversity in *Rhynchosporium secalis* from Ethiopia and host response to barley scald. *Plant Pathology Journal*. 3: 24-26.
118. Korobko, AP., Eshetu Wondimagegne and BV Anisimoff. 1985. Bacterial stripe and black chaff of wheat in Ethiopia. pp. 147-150. *In*: Regional wheat workshop for Eastern, Central, and Southern Africa and Indian Ocean. Njoro, Kenya. CIMMYT.
119. KARC (Kulumsa Agricultural Research Center). 1989. Progress report for 1988/89.
120. KARC. 1990. Progress report for 1989/90.
121. KARC. 1991. Progress report for 1990/91.
122. KARC 1992. Progress report for 1991/92.
123. KARC. 1993. Progress report for 1992/93.
124. KARC. 1994. Progress report for 1993/94.
125. KARC. 1995. Progress report for 1994/95.
126. KARC. 1996. Progress report for 1995/96.

127.KARC. 1997. Progress report for 1996/97.
128.KARC 1998. Progress report for 1997/98.
129.KARC. 1999. Progress report for 1998/99.
130.KARC. 2000. Progress report for 1999/00.
131.KARC. 2001. Progress report for 2000/01.
132.KARC. 2002. Progress report for 2001/02.
133.KARC. 2003. Progress report for 2002/03.
134.KARC. 2004. Progress report for 2003/04.
135.KARC. 2005. Progress report for 2004/05.
136.Kuzmichev B, Anisimoff BV, Masresha Aklilu, and Temam Hussien. 1985. Influence of altitude on rust disease of wheat in different agro-climatic zones. Proceedings of the sixteenth National Crop Improvement Conference. Addis Ababa, Ethiopia. IAR. pp. 816-833.
137.Lema Ebsa, Bekele Hundie and Dereje Tadesse. 1997. Crop protection research and recommendation for southeastern Ethiopia. *In*: Abera Deressa and Beyene Seboka (eds.). Research achievements and technology transfer attempt in southeastern Ethiopia. Proceedings of second technology generation, transfer and gap analysis workshop. Nazaret, Ethiopia. pp. 60-63.
138.Loban VL. 1987. Root rots of wheat in Ethiopia. Ethiopian Plant Pathology Newsletter. 12 (3): 31-35
139.Loban L, Temam Hussein and Zerihun Kassye. 1988a. Wild cereals, reservoirs and transmitters of stem rust on wheat. EPC Newsletter 13(1): 17.
140.Loban L, Zerihun Kassye and Temam Hussein. 1988b. Studies on adoption of appropriate methods of drying and preserving stem rust urediospores. EPC Newsletter 13(1): 20.
141.Loban L, Zerihun Kassye and Temam Hussein, 1988c. Wild grass and reservoirs of wheat stem rust of wheat. EPC Newsletter 13(3): 12-15.
142.Loban L, Temam Hussein, Zerihun Kassye and Guto Dikssissa. 1988d. Studies on the adoption of appropriate methods of drying and preserving stem rust urediospores. EPC Newsletter 13 (4): 4-9.
143.Mamluk, OF, El-Daoudi, YH., Bekele, E., Solh, MB., Ahmed, MS., Mahir, MA., and Bahamish, HS. 2000. Wheat leaf and stem rusts in the Nile Valley and Red Sea Region: Incidence, spore movement, pathotypes and effective resistant genes. ICARDA/NVRSRP. Cairo, Egypt. 75 p.
144.Mandefro Aslake. 2000. Influence of microenvironment in the development of rust epidemics on durum wheat (*Triticum turgidum* L. *var. durum*). MSc. Thesis. Alemaya University, Alemaya, Ethiopia. 74 p.
145.Masresha Aklilu. 1996. Wheat rust races identified in virulence surveys in Ethiopia. *In*: Tanner DG., TS. Payne and OS. Abdala (eds). Proceedings of ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 458-461.
146.MRC (Mekele Research Center). Progress report for the period 1994
147.MRC. Crop Protection Division Progress Report for the period 1995 to 2002.
148.Meki Shehabu and Asnakech Tekalign. 2004. Yield loss due to scald and net blotch on barley in north Shewa. *Pest. Mgt. J. Eth*. 8: 111-118
149.Melaku Jirata. 1993. Distribution of head smudges disease of tef (*Eragrostis tef*) and variability of the pathogen *(Drechslera* species) in Wollega, Ethiopia. MSc. Thesis. Alemaya University, Alemaya, Ethiopia. 130 p.
150.Melkamu Ayalew, Bekele Hundie and Mesele Alemu. 1995. Effects of black point disease on barley seed germination and its chemical control. CPSE. *In:* Eshetu, Abdurhman, Aynekul, Fantahun and Mesresha (eds). Proceedings of the second Ann. Conference 26-27April, 1994, Addis Ababa, Ethiopia. P 38.

151.Melkamu Ayalew, Bekele Hundie and Messele Alemu. 1996. The status of wheat diseases in northwestern Ethiopia. *In*: Tanner DG., Payne, TS., and Abdalla OS. (eds). Proceedings of the ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 479-484.

152.Mengistu Hulluka and Yeshi Andnew. 1992a. Variation within indigenous durum wheat germplasm for response to stem and leaf rust races in Ethiopia. *In*: Tanner DG and W. Mwangi (eds.). Proceedings of the seventh regional wheat workshop for Eastern, Central and Southern Africa. Nakuru, Kenya. CIMMYT. pp. 131-134.

153.Mengistu Hulluka and Yeshi Andnew. 1992b. Stability of the reaction of wheat differential lines to stem and leaf rust at Debre-Zeit, Ethiopia. *In*: Tanner DG and W. Mwangi (eds.). Proceedings of the seventh regional wheat workshop for Eastern, Central and Southern Africa. Nakuru, Kenya. CIMMYT. pp. 190-195.

154.Mengistu Hulluka, Getaneh Woldeab, Yeshi Andnew, Rebka Desta and Ayele Badebo. 1991. Wheat pathology research in Ethiopia. *In*: Hailu Gebre-Mariam, Tanner D.G., and Mengistu Hulluka (eds). Wheat research in Ethiopia: A historical perspective. Addis Ababa. IAR/ CIMMYT. .Pp. 173-217.

155.Mozgovoy A., Getaneh Woldeab and Temam Hussien. 1987a. Effectiveness of chemicals in controlling wheat rusts and other leaf diseases. Ethiopian Plant Pathology Newsletter. 12 (4): 20-28.

156.Mozgovoy A., Getaneh Woldeab and Temam Hussien. 1988. Comparison of artificial methods of inoculation with stem rust in field conditions. Proceedings of the nineteenth National Crop Improvement Conference. Addis Ababa, Ethiopia. IAR

157.Mozgovoy A., Getaneh Woldeab, Loban L. and Teklu Negash. 1987b. Wheat rust situation in Ethiopia during 1986 crop season. Proceedings of the twelfth annual meeting of the Ethiopian Phytopathological Committee. Nazareth, Ethiopia. EPC

158.Naod Betesellasie. 2004. Resistance sources and variation among Ethiopian cultivated tetraploid wheats (*Triticum durum* and *T. dicoccum*) to stem rust (*Puccinia graminis* f. sp. *tritici*) infection. MSc. Thesis, Alemaya University. Alemaya, Ethiopia. 88 p.

159.Naod Betesellasie, Chemeda Finisa and Ayele Badebo. 2005. The resistance spectra and postulated *Sr* genes of Ethiopian hexaploid and tetraploid wheat cultivars. Paper presented during the 13th Annual conference of CPSE, 11-12 August, 2005, Addis Ababa, Ethiopia.

160.Neman, E., Lemma Kifle, Eshetu Bekele and Awgechew Kidane. 1979. Seed cleaning for wild oat and ergot control in barley fields of peasant farmer's. Paper presented at the 1st Crop Protection Conference SPL. Ambo. June 8-9. 1979. pp. 107-109.

161.Paul, YS., Bekele Hunde, Mesele Alemu and Melkamu Ayalew. 1994a. Studies on seed borne mycoflora of wheat in Ethiopia. *In*: Tanner DG. (ed.). Developing sustainable wheat production systems. Proceedings of the eighth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 305-306.

162.Paul, YS. Melkamu Ayalew, Mesele Alemu, and Bekele Hunde. 1994b. Aerobiology of wheat with special reference to stripe rust. *In*: Tanner DG. (ed.). Developing sustainable wheat production systems. Proceedings of the eighth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 298-300.

163.PPRC (Plant Protection Research Center). 2002. Progress report for the year 2002.Ambo

164.PPRC .2004. Progress report for the year 2003/2004, Ambo.

165.Pretorius, ZA. Singh RP. Wagoire, WW, and Payne, TS. 2000. Detection of virulence to wheat stem rust resistance gene *Sr*.31 in *Puccinia graminus* f.sp. *tritici* in Uganda. *Phytopathology* 84: 203.

166.Rebeka Desta and A. Bainbridge. 1990. Susceptibility of wheat lines to eyespot.. *In*: Tanner, DG, M. van Ginkel and W Mwangi (eds.). Sixth regional wheat workshop for Eastern, Central and Southern Africa. Mexico, D.F.: CIMMYT. pp. 73-77.

167. Sakhuja. PK., Amare Ayalew. 2004. Survey on major cereal and vegetable crop diseases and insect pests in Jijiga and Dire-Dawa regions, eastern Ethiopia. Completed project report submitted to the Research and Extension Office. Alemaya University, Alemaya, Ethiopia. 28 p.
168. SARC (Sinana Agricultural Research Center). Progress report for the period 1989.
169. SARC. Progress report for the period 1990.
170. SARC. Progress report for the period 1991.
171. SARC. Progress report for the period 1992.
172. SARC. Progress report for the period 1993.
173. SARC. Progress report for the period 1996.
174. SARC. Progress report for the period 1997.
175. SARC. Progress report for the period 1998.
176. SARC. Progress report for the period 1999.
177. SARC. Progress report for the period 2000.
178. SARC. Progress report for the period 2001.
179. SARC. Progress report for the period 2002.
180. SARC. Progress report for the period 2003.
181. SARC. Progress report for the period 2004.
182. Serbessa Negera. 2003, Wheat stem rust (*Puccinia graminus* f.sp. *tritici*) intensity and pathogenic variability in Arsi and Bale zones of Ethiopia. MSc. Thesis, Alemay University. Alemaya, Ethiopia. 92 p.
183. Sewalem Amogne. 2004. Host range of tef rust (*Uromyces eragrostidis*). *Tropical Science*: 44 (4): 177-179.
184. Sewalem Amogne, Woubit Dawit and Yeshi Andnew. 2000. Stability of stem rust resistance in some Ethiopian durum wheat varieties. *In*: Proceedings of the eleventh regional workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp 164-168.
185. Sewalem Amogne, Zerihun Kassaye and Eshetu Bekele. 2001. Tef pathology research in Ethiopia. *In*: Hailu Tefera, Getachew Belay and Mark Sorrells (eds). Narrowing the rift: Tef research and development. Proceedings of the International Workshop on Tef Genetics and Improvement, 16-19 October 2000. Debre Zeit, Ethiopia Agricultural Research Organization, EARO. pp. 215-222.
186. Seyfu Ketema. 1993. Tef (*Eragrostis tef*): breeding, genetic resources, agronomy, utilization and role in Ethiopia agriculture. IAR, Addis Ababa, Ethiopia.
187. Shank, R. 1994. Wheat stem rust and drought effects on Bale agricultural production and future prospects. Summarized report. 17-18, February 1994, UNDP, emergency unit in Ethiopia. Addis Ababa. UNDP. 5 pp.
188. SRC. Sheno Agricultural Research Center Progress report, 1998/99
189. Solomon Assefa. 2001. Exploiting alien resistance genes in *Aegilops tauschii* and their utilization for the development of bread wheat genotypes with multiple resistances to major diseases. PhD Thesis. Cuvillier Verlag Goettingen, Germany. 105 pp.
190. Solomon Assefa, Rebka Desta and Eshetu Bekele. 1994. Evaluation of improved bread wheat varieties for their partial resistance to septoria leaf blotch. *African Crop Science Journal* 2 (3): 323-329.
191. SPL (Scientific Phytopathological Laboratory). 1986. Progress report for the period 1985/86. Ambo, Ethiopia
192. SPL. 1987. Progress report for the period 1986/1987. Ambo, Ethiopia
193. SPL. 1988. Progress report for the period of 1987/88. Ambo, Ethiopia.
194. SPL. 1989. Progress report for the period of 1988/89. Ambo, Ethiopia.
195. Stewart R.B. and Dagnatchew Yirgou. 1967. Index of plant diseases in Ethiopia. College of Agric. H.S.I.U. Expt. Stat. Bull. No.30.

196. Temam Hussien. 1984. Distribution and prevalence of physiologic races of *Puccinia graminis* f.sp. *trtici* in some parts of Ethiopia and reaction of wheat cultivars to these races. M.Sc. thesis. Alemaya College of Agriculture, Addis Ababa University.
197. Temam Hussien. 1985a. Occurrence of virulence in *Puccinia graminis* f.sp. *tritici* in some regions and sources of resistance in Ethiopia. EPC Newsletter 26:8.
198. Temam Hussien. 1985b. Occurrence of virulence in *Puccinia graminis* f.sp. *tritici* in some regions and sources of resistance. Proceedings of the 10th Annual Meeting of Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. Pp.87-91.
199. Temam Hussien and DA Solomatin. 1984. Distribution of physiologic races of wheat stem rust in major growing regions of Ethiopia during 1982-83. Proceedings of the 9th Annual Meeting of Ethiopian Phytopathological Committee. Nazareth, Ethiopia. pp. 67-71.
200. Temam Hussien, Anisimoff, BV and DA, Solomatin. 1985. Wheat stem rust race identification in Ethiopia. *In:* Wheat Workshop for Eastern, Central and Southern Africa and the Indian Ocean. Njoro, Kenya. CIMMYT: Nairobi pp. 109-115.
201. Temesgen Kebede. 1999. Variation in virulence patterns of *Septoria tritiic* and sources of resistance in wheat (*Triticum aestivum* L) to the pathogen. M. Sc. Thesis. Alemaya University, Alemaya, Ethiopia. 81p.
202. Temesgen Kebede, Bekele Geleta, Balcha Yai, and Ayele Badebo. 1995. Status of wheat rusts in the major wheat producing regions of Ethiopia. *In*:. Danial DL (ed). Breeding for disease resistance with emphasis on durability. Proceedings of a regional workshop for Eastern, Central and Southern Africa. Njoro, Kenya. CIMMYT. Pp.180-184.
203. Temesgen Kebede, Ayele Badebo and Bekele Geleta. 1996. The current status of stem rust virulence and utilization of bread wheat resistance in Ethiopia. *In*: Tanner DG, Payne, TS and Abdalla OS. (eds). Proceedings of the ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 494-499.
204. Temesgen K., Naod BS., Kebede T., Ayele B., and Melaku D. 2005. Monitoring the resistance of bread wheat cultivars for their resistance to yellow rust in Ethiopia, Paper presented in 13th Annual conference of CPSE, 11-12 August, 2005. Addis Ababa, Ethiopia
205. Temesgen Kebede and TS Payne. 2000. Field response of bread wheat genotypes to septoria tritici blotch. *In*: Proceedings of the eleventh regional workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMY. pp. 169-182.
206. Terefe Deyessa. 1985a. Incidence of ergot disease on wild oats in some wheat and barley fields of Garadella State Farm in 1984/ 85-crop seasons. *In*: Habtu A., Eshetu B., Tadesse T., and AA Agranovsky (eds). Proceedings of the tenth annual meeting of the Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. EPC. pp 13-17.
207. Terefe Deyessa. 1985b. Result on screening of chemicals against stripe and leaf rust of wheat. *In*: Habtu A., Eshetu B., Tadesse T., and AA Agranovsky (eds). Proceedings of the tenth annual meeting of the Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. EPC. Pp.131-135.
208. Terefe Deyessa. 1990. Evaluation of fungicides for control of barley net blotch. p. 15 (Abstract). *In*: Seid Ahmed and Yaynu Hiskias (eds). Proceedings of the fifteenth annual meeting. Addis Ababa, Ethiopia. EPC.
209. Tezera Wolabu, Kefyalew Girma, Ayele Badebo and DG. Tanner. 1996. The effect of Alternative crop management practices on Take-all and Eyespot diseases of bread wheat in southeastern Ethiopia. *In*: Tanner, DG, Payne, TS and Abdalla, OS. (eds). The ninth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 432-436.
210. van Ginkel, M., Getinet Gebeyehu and Tesfaye Tessema. 1989. Stripe, stem and leaf rust races in major wheat producing areas of Ethiopia. IAR Newsletter 3(4): 6-8.

211. Yeshi Andnew. 1988. A review of chemical disease control research on wheat in Ethiopia. *In*: M. van Ginkel and DG Tanner (eds). Fifth regional wheat workshop for eastern, central and southern Africa and the Indian Ocean. Mexico, D.F. CIMMYT. pp. 251-255.
212. Yeshi Andenw and Mengistu Hulluka. 1988a. Bacterial stripe and black chaff of durum wheat at Debre Zeit. Proceedings of the thirteenth annual meeting of Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. EPC. pp. 19-23.
213. Yeshi Andnew and Mengistu Hulluka. 1988b. Incidence of *Sclerotium* wilt on durum wheat at Debre Zeit. Proceedings of the thirteenth annual meeting of Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. EPC. pp. 3-5.
214. Yeshi Andnew and Mengistu Hulluka. 1990. Studies on seed borne mycoflora of durum wheat. *In*: Seid Ahmed and Yaynu Hiskias (eds). Proceedings of the 15th Ethiopian Phytopathological Committee. 13-14 March 1990. Addis Ababa, Ethiopia. pp. 115-119.
215. Yeshi Andnew and Mengistu Huluka. 1995. Response of tef germplasm to tef rust. *In*: Daniel DL (ed.). Proc. regional wheat workshop for Eastern, Central and Southern Africa: Breeding for disease resistance with emphasis on durability. Njoro, Kenya, CIMMYT. pp. 202-205.
216. Yeshi Andnew and Mengistu Hulluka. 1996. Incidence of bacterial stripe on durum wheat at Debre Zeit, Ethiopia. *In*: Tanner DG, Payne, TS and Abdalla OS. (eds). Proceedings of the ninth regional wheat workshop for eastern, central and southern Africa. Addis Ababa, Ethiopia. CIMMYT. 485-489. pp.
217. Yeshi Andnew and Mengistu Hulluka. 1999. Effect of heading date on stem rust development in durum wheat. *In*: The Tenth regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp. 381-383.
218. Yeshi Andnew, Mengistu Hulluka and Rebeka Desta. 1990. Reaction of durum wheat lines to *Septoria* leaf blotch. *In*: Tanner DG, M. van Ginkel and W Mwangi (eds.). Sixth Regional Wheat Workshop for Eastern, Central and Southern Africa. Mexico, D.F. CIMMYT. pp. 229-233
219. Yeshi Andnew, Mengistu Hulluka and Seid Ahmed. 1990. Effect of sowing dates on severity of leaf, stem rust and on yield of wheat at Debre Zeit. *In*: Tanner DG, M. van Ginkel and W. Mwangi (eds.). Sixth regional wheat workshop for Eastern, Central and Southern Africa. Mexico, D.F. CIMMYT. pp. 59-62.
220. Yeshi Andnew and Mengistu Hulluka, Getachew Belay and Tesfaye Tesemma. 1997. Resistance and tolerance to leaf rust in tetraploid wheats from Ethiopia. Plant Breeding 116: 533-536.
221. Yitbarek Semeane and Bekele Hundie. 1996. Disease surveys and loss assessment studies on Barley. *In*: Hailu Gebre and Joop van Leur (eds). Barley Research in Ethiopia: Past work and future prospect. Proceedings of the first barley research review and strategy workshop, 16-19 Oct. 1993. Addis Ababa, Ethiopia, IAR/ICARDA.pp.105-115.
222. Yitbarek Semeane and H. Fehrman. 2002. Pathogenic variation of *Rhynchosporium secalis* isolates from Ethiopia. *Pest. Mgt. J. Eth*. 6: 1-12.
223. Yitbarek Semeane, A. Banbridge & Bekele Hundie. 1997. Evaluation of barley for field resistance to scald. *Pest Mgt. J. Eth*. 1(1&2): 37-42.
224. Yitbarek Semeane and Wudneh Enyew. 1985. Preliminary studies on yield loss due to net blotch in barley. Proceedings of the 10th Ethiopian Phytopathological Committee. Addis Ababa, Ethiopia. EPC. pp. 47-52.
225. Yusuf, A., KM. Makkouk, SPS. Beniwal and Y. Semeane. 1992. Barley yellow dwarf in West Asia and North Africa. *In*: Comeau, A. & K.M Makkouk (eds). Proc. of the Workshop. Rabat, Morocco. ICARDA. pp. 87-90.
226. Zerihun Kassaye and O. Abdalla. 2000. Host range of wheat stem rust in Ethiopia. *In*: The eleventh regional wheat workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia. CIMMYT. pp.160-163.

Weed Research in Small Cereals in Ethiopia

Rezene Fessehaie[1], Taye Tessema[1], Kedir Nefo[2], Agumas Belle[3], Takele Negawo[1] and Assefa Taa[2]
[1]Ethiopian Institute of Agricultural Research
[2]Oromia Agricultural Research Institute
[3]Amhara Agricultural Research Institute

Introduction

Small grain cereals such as wheat, tef, and barley have a wide range of utilization in Ethiopia and in their respective areas of production; they are used as a stable food (Hailu et al. 1991).

The production of tef exceeds that of most other cereals. The census average data of 1996 - 2003 revealed that about 21.6% of the country land under crops was planted to tef and 21.07 % of cereal production was attributed to this crop (CSA, 2004).

According to Hailu et al. (1991), wheat is one of the major cereal crops produced in the Ethiopian highlands, which ranges between 60 and 100N latitude and 350 and 420E longitude, at an altitude ranges from 1500 to 2800m.a.s.l. The Central Agricultural Census commission (CACC) (2003) report indicated that at the national level 12.6% of the crop area was under wheat which is the fourth principal crop in the country and 12.7% of the crop production was drawn from this crop.

Barley is mainly a highland crop grown at altitudes ranging from 2000 to 3000 m above sea level in Shewa, Arsi, Bale Gojam, Welo and Tigray. Barley is the fifth important cereal crop and accounts for about 14% of the total growing areas of major cereal crops and about 11% of the annual cereal production in Ethiopia (CSA 2004).

The wide range adaptation of the small cereals to different climatic and soil conditions expose them to grow in association with diverse composition of weed flora. Most surveys report that, in all growing conditions, weed control in small cereal crops remains to be one of the most expensive, time and energy consuming and least successful means of increasing yields.

In Ethiopia, research on weed control methods in small cereals began in 1967 by the Chilalo Agricultural Development Unit (CADU) in Arsi; in 1969 at Holetta Agricultural Research Center of the former IAR; in 1975 at Debre Zeit Agricultural Research Center; and in 1980 at the Plant Protection Research Center of the then Scientific Phytopathological Laboratory (SPL) in Ambo (Rezene 1986). In spite of the enormous challenge weeds pose to small cereals production, it has not been possible to cover the different aspects of weed problems and the whole range of agro-ecological zones in which the crops are grown. With this background, this paper reviews the available information on weed research of small cereals that has been accumulated in Ethiopia since the last two decades.

Research findings

Composition of the Weed Flora

Weed problems in small cereals have been reviewed by Rezene (1986) and Berhanu (1986). Additional review information were also provided by Fasil (1996); Tanner and GIref (1991); Rezene (2001) and Rezene and Zerihun (2001). Available survey records indicated that there are about 66 species in 61 genera and 24 plant families known to be problematic weed species in small cereals. Species of Poaceae are the most common followed by Asteraceae and Cyperaceae. Major weed species of small cereals recorded in Ethiopia are listed in Table 1.

Problematic Weed Species

Striga hermonthica

While *Striga hermonthica* commonly occurs as a damaging parasite on sorghum, maize and finger millet 'dagussa' in Ethiopia, tef was usually regarded as immune and suitable for rotational cropping in *Striga* infested areas. Scattered *Striga* plants have often been observed in tef in the past, but it has not always been certain whether they were parasitizing tef or some susceptible grass weeds growing with the crop. Fasil et al.. (1989) confirmed that tef is indeed being parasitized by *Striga* in three different areas of Ethiopia.

In Gojam, *Striga hermonthica* was observed in several tef fields in the Valley of Abay River between Motta and Adet at elevations below 2000 m.

In the Abay Gorge, on the south facing slopes of the Gojam side below Dejen *Striga hermonthica* was observed in tef fields at an altitude of 1500 m. In northern Welo, *S. hermonthica* was found growing on tef at several locations of Habru and Guba – Laftor weredas around Weldiya at elevation between 1700 and 2000 m (Fasil et al.. 1989). Gebre Medhin et al.. (1998) reported that tef is considered as occasional host of *Striga* in Tigray because the infestation on tef is considerably high when it follows a severely infested crop, mainly sorghum. Wondimu (1999) also observed *Striga hermonthica* infesting tef fields in Daro Welabu and Habro weredas of west Harerge.

Striga has an extraordinary elasticity and capacity to adapt to new host species. For example, tef, barley and *dagusa* (finger millet), were until recently unaffected by *S. hermonthica* in Ethiopia. Now all of them are attacked. Immunity, once lost, is difficult to restore against such a genetically versatile pathogen as *S. hermonthica* where each seed in a population may have a unique genotype, and in each generation more new genotypes are produced (Jones, 1993).

Parthenium hysterophorus

Parthenium hysterophorus has several built in properties and efficient behavioral mechanisms, which enable this plant to overcome many ecological adversities and thus continue to survive under stress. It has a unique adaptability to wide-agro-climatic conditions and soil types but the growth is most luxurious in black soils.

Parthenium is currently spreading at an alarming rate in Ethiopia. From the earlier reports (1989-1996), the infestation of the weed has been minimal in arable lands. However, this does not imply that its infestation remain restricted to non-arable lands. It is common now to see that *Parthenium* is starting to invade tef and wheat fields in western Harerge and areas in north and south Welo, south Tigray, the central rift valley and neighboring localities of east and west Shewa (HARC 1999; Rezene and Zerihun 2001).

Convolvulus arvensis

Many farmers in Debre Zeit area (Zerihun, 1993); east, west and north Shewa Rezene and Lemlem (HARC1999); reported that *Convolvulus arvensis* is becoming the most problematic weed since recent years, especially on black soils. The importance of the weed stems from its climbing nature on the snall cereal crops. Hence, weeding becomes difficult as the crop plants can be removed together with the weed. The effect of *Convolvulus arvensis* is pronounced during harvest as it causes yield reduction; i.e., the seeds will be trimmed off from the plant and shatter to the ground (Rezene and Zerihun 2001).

Other noxious weeds

As reported by Rezene (1986); Tanner and Giref (1996); Fasil (1996); Rezene (2001); and Rezene and Zerihun (2001) other weed species of small cereal crops that are difficult to control have the following characteristics:

- Those irritating to touch – *Argemone mexicana*, *Xanthium spinosum, X. strumarium, Oxygonum sinuatum*, *Tribulus terristeris* which interfere with weeding or harvesting operations or both and increase cost/time of weeding and/or harvesting;
- Those that cause the biggest problem because of their similarity to the crop and their extended period of germination which makes them difficult to control manually and are virtually impossible to control by the use of herbicides (*Avena spp.*, *Bromus pectinatus*, *Lolim temulentum*, *Snowdenia polystachya*, *Phalaris paradoxa* and *Setaria pumila)*;
- Those that reduce the quality of harvested grains (*Phalaris paradoxa*, *Setaria pumila*, *Plantago lanceolata*, *Amaranthus* spp; *Guizotia scabra* and *Snowdenia polystachya*);
- Those that are hard to pull perennial weeds (*Cyperus esculentus, C. roundus and Rumex bequaertii*); and
- Those that break resistance or do not persist long against commonly used annual grass herbicides (*Bromus pectinatus*, *Lolim temulentum* and *Snowdenia polystachya*) or against the most commonly used broadleaf killer herbicide - 2, 4-D (*Guizotia scabra, Galium spurium*, *Raphanus raphanistrum* and *Convolvulus arvensis*)

Basic Studies

Wheat and Barley

Weed Competition and Predication of Grain Yield loss

Weeds are a significant threat to wheat production in Ethiopia, causing yield loss of up to 70% in some growing seasons (Tanner and Giref 1991). Costs of any weed control strategy, which forms a large proportion of the variable costs of crop production, can be justified if they are used at weed levels above predetermined threshold populations. A review of yield loss assessment in Ethiopia suggested that there is an average yield reduction of 36% due to weed competition (Rezene 1986; Hailu et al., 1991). In experiments conducted to study food barley yield limiting factors in Bale highlands, weed competition on average reduced grain yield by 7.4% (SARC 2000a). In another study of the effect of seed rate by weeding frequency on the grain yield and yield components of food barley at Sinana on-station it was found that weed competition could cause a yield loss of 14.02 and 14.6% (SARC 2000a). The differences in yield loss between barley and wheat is explained by variation in weed population competitive capacity of the crops, where barley competes with weeds better than wheat because of thick stand and fast growth.

Effect of Crop Cultivars for Enhanced Competitive Ability

Differences in the inherent ability of Ethiopian bread wheat cultivars to compete with wild oats have been reported by Tanner et al. 1995, Tanner et al. 1996, Asefa et al. 1999, Taye and Tanner 1999). The grain yield of each cultivar was linearly related to wild oat density, and the slopes of individual regression lines ranged from –11 to –31.8 (kg/ha)/(wild oat seedlings/m^2) (Tanner et al. 1995; Tanner et al. 1996).

The management of weeds is an essential aspect of maintaining crop productivity within an economically viable and ecologically sustainable agricultural system. The effects of crop management practices on weed densities varied with location (i.e., soil, weather, rainfall, and altitudes differences) and weed species biology. Production of crop species and cultivars that are better competitors with weeds is an important component of integrated weed management (IWM) (Tanner 1999). In general, crops/cultivars that can germinate, root, emerge, and establish a dense leaf canopy earlier and faster are more likely to compete strongly with weeds. The higher initial wheat seedling stand and more production canopies for specific wheat genotypes facilitated the suppression of wild oat biomass production (Tanner 1999).

In an experiment conducted to characterize traits that enhance competitiveness of bread wheat (*Triticum. aestivum* L.) against *Avena sativa* at Sinana on-station and green house in both '*genna'* (short rains*)* and '*bona'* (main rain) seasons of 2003 at mixtures ratios of 1:1 indicated that in '*genna'* season, all varieties responded similarly to oat competition. However, *Avena sativa* was more competitive than bread wheat, which resulted in a grain yield reduction of about 79% (1839 kg/ha). Relatively higher percentage of light was penetrated to the lower canopy in monoculture than in wheat-oat mixture suggesting more light capture of *Avena sativa* canopy, thereby high utilization of available light resources ((SARC 2005b).

In '*bona'* season, there was a slight variation among cultivars in response to *Avena sativa* competition. On average yield reduction due to *Avena sativa* competition was about 70%. HAR2346 was very slightly competent (yield reduction = 59%), and HAR1008 and K-6295-4A were susceptible (yield reduction, 64 and 67%, respectively), while the other cultivars were highly susceptible with average yield reduction of 74% due to wild oat competition (SARC 2005b).

Step-wise growth analysis indicated that effects of competition of *Avena sativa* on the important bread wheat yiel parameters were observed starting from 45 days after emergence. *Avena sativa* had relatively high relative growth rate than bread wheat in all parameters, which contributed for its competitive ability (SARC 2005b).

Results of a study conducted at Sinana on farm during '*genna'* and '*bona'* 1999 to determine growth patterns of major weeds (*Guizotia scabra, Avena. fatua, Amaranthus hybridus and Raphanus raphanistrum*) and crop yield loss due to weed densities in food barley mixture revealed that growth rate of food barley was greater than growth rate of any of the above mentioned weed species, indicating that food barley has greater resource utilization and competitive ability. However, the response of food barley to different weed species competition was not similar. As density of *A. fatua* and *R. raphanistrum* increased (320/m^2), grain yield and kernels/m^2 of food barley linearly decreased. Food barley grain yield =2319-0.22*, *Avena fatua* density, R2=0.39, No. =42; Food barley grain yield = 2372-0.92 *

Raphanus raphanistrum density R2=0.47, No. =42). It can be concluded that *R. raphanistrum* was more competitive than *Avena fatua* because the former produced taller and wider canopy above the crop than the later (SARC 2000). *Guizotia scabra* is generally more competitive with wheat than *Amaranthus retroflexus*, while *Galium spurium* appear to be the least competitive (Tanner 1999).

Effect of Wheat Cultivars and Wild Oat Density on N Uptake and Utilization

Total N uptake by the mixed canopy of wheat and *Avena fatua* increased linearly in response to wild oat density. Furthermore, application of fertilizer N markedly increased the density of wild oat panicles (from 180 to 250/m^2), suggesting that *Avena fatua* utilizes fertilizer N more effectively than wheat, thereby exhibiting enhanced competitiveness with the crop under high N conditions (Tanner and Giref 1997). Wild oat density in wheat was increased significantly by as little as 20.5 kg N /ha and reached maximum at about 41 N/ha. Percent N in wheat grain and straw increased linearly in response to wild oat competition, while %N in wild oat seed varied inversely with oat seed yield (Tanner and Giref 1997). Split application of N fertilizer minimized weed competition, reduced the requirement of hand weeding and economic risk levels.

Although basal P application had a minimum effect, relative to that of N, on wheat parameters at Bekoji and Asasa sites, P fertilizer exerted a greater effect on weed parameters than did N. It was found that wild oat is more successful than wheat at utilizing available soil N and P (Asefa and Tanner 1998). The highest rate of fertilizer P decreased wild oat panicle densities and the reduction in panicle density is attributed as a result of an increase in early crop vigor (i.e.) based on visual assessment) and a significant increase in total wheat biomass. This also suggests that wild oat may be less responsive to P than bread wheat under field conditions

In another experiment executed at Selka and Robe locations of Sinana-Dinsho district in '*genna*' 2003 and at Adaba and Doddola districts in '*bonna*' 2003 to examine the effect of seed rate and phosphorous fertilizer rates on the survival, yield and yield components of natural infestation of *A. fatua* under field condition at Robe location, indicated that *Avena fatua* resulted in 33% grain yield reduction. Application of phosphorus had no effect on grain yield and yield components except P effect on spike length and plant height (SARC 2005a).

Increasing seed rates, however, had a negative and significant effect on tillers per plant (or /m^2) and density of wild oat per m^2. Increasing seed rate from 150 to 200 kg/ha was lowered by 30 and 17% wild oat density and tiller number, respectively (SARC 2005a).

Competition Effects of Major Weed Species on Barley

Competitive interactions of food barley cultivar HB-42, with four dominant weed species: *Avena fatua*, *Erucastrum arabicum*, *Guizotia scabra* and *Snowdenia polystachya* at different plant density levels (0, 10, 20, 40, 80, 160 and 320 plants m^{-2}) were studied in experimental fields of the Plant Protection Research Center at Ambo during 2000, 2002 and 2003 in which the competitive effects of the major weed species at various densities on yield and yield components of barley were determined (Takele 2001).

The four weed species were more or less equally competitive at the lower weed density levels; but the grass weeds were relatively more competitive than broad leaf ones at higher densities. Weed densities significantly affected most parameters in barley during each of the three years of the trial. Averaged over the weed species the number of weeds required to cause a significant yield loss in barley was beyond 10 weed plants m^{-2} (Takele 2001). The influential effects of weed density on crop had been confirmed earlier by Taye and Tanner (1999).

Both weed species and weed densities showed statistically significant difference against most parameters considered. However, weed species by density interaction effect was not differed significantly for all parameters. Weed density significantly decreased barley grain yield mainly through reducing number of tiller, number of productive spikes and biomass yield of barley. Barley grain yield decreased linearly with the increasing weed density (r2 = -0.59). The lowest yield was obtained at the maximum density (320 weed plants m^{-2}) (Table 2). As shown in Table 3 grain yield reduction due to weed competition ranged from 22 to 50% across the weed species. *Snowdenia polystachya* was the most competitive causing 50.3% yield reduction while *Erucastrum arabicum* was the least competitive (22.4%) (Takele 2001).

The insignificant weed species by density interaction effect on yield and yield components of the crop indicates the non-considerable difference in the competitive ability among the biologically different weed species at the same density level (Tables 4-9) (Takele 2001).

Tef

Crop Weed Competition Investigations

Weeds cause serious damage to tef plants especially at early growth stage since tef plants are very susceptible to weed competition. According to results of crop/wwed competition study at the Plant Protection Research Center in Ambo, crop competition coefficient (R) is 0.76 for tef compared to 0.92 for wheat and barley, and 0.88 for maize and sorghum. Moreover, negative and significant correlation (-0.75) was found between fresh biomass of weeds and tef yield (Rezene 2001).

Crop/weed competition experiments in tef have often been planned with the objectives of determining the critical period of weed competition and estimating yield loss incurred when weeds are not controlled at all. Few of them considered the economic aspect.

Grain yields losses in tef due to weed competition have been estimated in various studies conducted in Ethiopia. Countrywide yield losses in tef due to weeds varied from 23 to 65%. Table 10 shows a yield loss estimates due to uncontrolled weed growth at various locations. Results of a greenhouse pot experiment indicated that *Cyperus rotundus* alone can cause a yield loss of 52% (Rezene and Zerihun 2001).

At Debre Zeit, tef was found to be most sensitive to weed competition and suffer greatest yield reduction between 15 cm (at early tillering) and pre-heading stage (Birhanu1986). This period is approximately 3-7 weeks after crop emergence.

The critical period of weed competition of some studies was not precisely determined because of problem in treatment selection at Jima (Tilahun et al.., 1997) and low weed infestation of experimental sites at Assosa (Dawit et. al., 1993). In both locations, however, weeds should be removed within the first four weeks after planting for better yield performance of the crop than otherwise.

Emergence Pattern of Weeds in Selected Areas

The types of weeds grown in a particular place vary even in the growing season mainly due to weeding operations and different natural growth rythm of various weed species. Table 11 shows weed composition in the growing season (from April to October) at the Plant Protection Research

Center, Ambo. Some weeds are major weeds at early or crop establishment stage while others are affecting tef growth at a later stage, and may have influence on some cultural practices such as harvesting. In Arsi Region, major weeds reported in early growth period were *Polygonum nepalense, Guizotia scabra, Amaranthus* spp., *Setaria pumila* and *Avena* spp.; while *Phalaris parodoxa* was dominant after the rain season is over (Rezene and Zerihun 2001.

In the Vertisols, areas of Debre Zeit the major weed species during early crop growth in tef field include *Commelina benghalensis, Setaria pumila, Scorpiurus muricatus, Amaranthus hybridus, Polygonum nepalense, Brassica sp., Cyperus spp*. and *Rumex bequaertii* (Berhanu, 1986 and Zerihun, 1993). According to Rezene and Lemlem (HARC 1999) dominant weed species during early season weed emergence in tef fields of the Ginchi Vertisols were *Cyperus spp. Cyanotis barbata, Picris abyssinicus, Erucastrum arabicum, Setaria pumila, Scorpiurus muricatus, Commelina benghalensis* and *Rumex bequaertii.*

Weed Surveys

Weed growth, population density, and distributions vary from place to place depending upon soil and climatic factors, and farmers' management practices. Weed surveys on farm and on regional basis are therefore needed to establish efficient weed management and decision making mechanisms and to evaluate weed control measures. Besides, it is useful to record population changes of potentially dangerous weeds, to highlight areas where changes in species diversity occur, and to give guidelines for setting up research priorities in weed control.

Wheat and Barley

Genale district of Bale zone

General qualitative weed survey was conducted in 1994 in wheat and barley fields of then Genale district of Bale zone. Broadleaved weed species like *Amaranthus hybridus*, *Polygonum nepalense*, *Guizotia scabra*, *Galinsoga parviflora*, *Galium spurium*, were recorded as major ones. Among the grass weed species *Snowdenia polystachya* and *Avena fatua* were most dominant in the large scale state farms (SARC 1994). In earlier reports by Ermias (1993) *Amaranthus spp., Galium spurium, Polygonum nepalense, Galinsoga parviflora*, *Guizotia scabra, Snowdenia polystachya*, *Avena spp*., *Bromus pectinatus,* and *Setaria pumila* were the most frequent and economically important weed species in wheat and barley fields of state farms in Bale and Arsi.

Sinana-Dinsho, Agarfa, and Gassera districts of Bale highlands

Qualitative and quantitative determinations of weeds in wheat and barley fields were conducted at Sinana-Dinsho, Agarfa, and Gassera districts of Bale highlands in 1997. Overall, 52 weed species were recorded among which the families Compositae and Poaceae contributed 8 and 4 species respectively. Two species each were also recorded from Labiate, Polygonaceae and Cruciferae. The most frequent and dominant weed species of the survyed locations were *Guizotia scabra*, *Galinsoga parviflora*, *Chenopodium spp*. *Galium spurium*, *Amaranthus hybridus, Cyperus blysmoides, Erucastrum arabicum, Flaveria trinervia* and *Phalaris paradoxa* (Kedir et al. 1999). Relatively, *Phalaris paradoxa*, *Flaveria trinervia* and *Cyperus blysmoides* were found dominantly at certain localities while *Guizotia scabra*, *Galinsoga parviflora* and *Amaranthus hybridus* were widely spread throughout the '*genna*' and '*bona*' seasons in all locations.

Asasa districts of Arsi Zone

In another weed survey conducted at Asasa districts of Arsi zone; *Galium spurium*, *Guizotia scabra*, *Polygonum nepalense*, *Erucastrum arabicum*, *Euphorbia spp*., *Bromus pectinatus*, *Avena spp*., *Snowdenia polystachya*, *Setaria pumila*, and *Cyperus blysmoides* were the top ten weeds in wheat fields. Among these species three species had the highest mean densities: *Galium spurium* (455/m^2), *Bromus pectinatus* (367/ m^2), and *Cyperus blysmoides* (235/ m^2) (Giref and Workiye 1997).

Adaba and Doddola districts

Weed survey was conducted three times per season at Adaba and Doddola districts in '*bona*' season of 1999 to identify quantify and prioritize weed species in food barley fields (Table 12). There was variation in weed competition, density, and dominance across seasons in both districts in which barley was denser than weeds at tillering stage and most fields were dominated by annual and emerging seedlings of broadleaved weed species. Grass weeds such as *Avena fatua, Snowdenia polystachya, Setaria pumila*, *Bromus pectinatus,* and *Phalaris paradoxa* were very important in wheat fields, the most dominant grass weed species being *Bromus pectinatus* and *Setaria pumila* at Adaba and Doddola districts, respectively.

During anthesis of crop stage, weed species composition was shifted and general weed infestation level was increased, which was dominated by grass weed species (Table 12). At maturity, few noxious grass weed species like *Avena vaviloviana; Phalaris paradoxa* and *Snowdenia polystachya* were the most dominant ones. Weed species like *Avena fatua* and *Guizotia scabra* increased over time in number, frequency and dominance, indicating the ineffectiveness of farmers control practice i.e. use of 2, 4-D which was not effective against the grass species. As a whole, it was observed that use of 2, 4-D enhanced the dominance of noxious grass and resistant broadleaf weeds.

Sinana-Dinsho and Goba districts of Bale high lands

Further, another weed survey was conducted in '*genna*' 2004, at Sinana-Dinsho and Goba districts of Bale highlands to determine priority weed species in these localities. Summaries of the survey records are presented in Tables 13-16.

At Goba district, wheat and barley were severly plagued by six weeds species (Tables 13 and 14), among which *Galinsoga parviflora* and *Amaranthus hybridus* were the most dominant and frequent in wheat and barley respectively. *Galinsoga parviflora* was the most frequent in both crops. Weeds were denser at tillering (499/m^2) and (316/m^2) than that of at maturity (279/m^2) and (344/m^2) in wheat and barley fields, respectively, as broadleaves were controlled selectively in wheat with herbicides. Weeds were denser in wheat than in barley at tillering stage, but denser in barley than in wheat at maturity because of the difference in control practice and competitive ability. The six major weed species accounted for about 49 and 48% at tillering; 56 and 74% at maturity of the total weed population density in wheat and barley, respectively. Thus targeting these species in control strategy is very important. Special attention must also be given to noxious weed species like *Avena spp.*, and *Bromus pectinatus*, even though they were few in number and frequency (SARC 2005a).
At fields of Sinana-Dinsho district, eleven and six major weed species were recorded in bread wheat and food barley respectively (Tables 15 and 16) among which *Amaranthus hybridus, Chenopodium spp.,* and *Commelina benghalensis* were observed at tillering and maturity growth stages of both crops. *Galinsoga parviflora* was the most dominant and frequent weed species at both maturity and tillering crop stage in wheat while *Commelina benghalensis* and *Chenopodium spp.* were mostly dominant and frequent, respectively in barley at both stages. These major weed species accounted

for about 75 and 37% at tillering and 74 and 43% at maturity stages of weed population density in wheat and barley, respectively, indicating the importance of these weed species as targets for control action. The density of these species at tillering stage was 324/m^2 and 132/m^2 and at maturity 168/m^2 and 276/m^2, in barley and wheat fields, respectively, Less weed population in wheat during tillering stage was attributed due to the presence of control measures taken in wheat compared to barley at this growth stage that was targeted to most broadleaved species. However, because barley was more competitive than wheat, weeds were denser in wheat than in barley fields during crop maturity stage (SARC 2005a).

According to farmers' view, the introduction of combine harvester to the area has aggravated the problem of grass weed species and some broadleaf weed species through enhancing on spot return of seed to soil. There are also tremendous build up of some noxious weeds such as *Polygonum convolvulus* ('*gale*'), *Emex australis,* and *G. spurium* in wheat growing areas of Bale highlands, which is related to continuous use of 2,4-D herbicide. Tables 17-19 show abundance and dominance of weed species before 1997 and after 1998 at Bale Agricultural Development Enterprise (BADE) combined over sites of the farms. The weed species were denser in enterprise farm (Tables 17 – 19) than small-scale farmers' farm (Tables 12-16). This is true especially with regard of grass weeds, which might be attributed to continuous use of both grass and broad leaf killer herbicides. There was also variation in weed density over years. Weeds were denser after 1998 than before 1997. The number of species categorized as major ones also greater after 1997 than before. Some of the species like *Oxalis latifolia*, *Digitaria spp*. and *Lolium temulentum* were becoming important after 1998 in the enterprise (Tables 17-19). The most dominant broadleaf species was *Chenopodium spp*. before 1997, but *Polygonum nepalense* became the most dominant after 1998. From grass weed species *Setaria pumila* was the most dominant in number both before and after 1997, except *Bromus pectinatus* in 1998 and *Snowdenia polystachya* in 2000. Some of grass weed species like *Snowdenia polystachya*, even though, is not dominating in number needs great attention because of its vigorous growth characteristics (SARC 2005b).

Tef

Most of the surveys made in the past in Ethiopia were general weed population surveys and collections. The most widespread and problematic weed species were determined based on observations and information gathered from farmers.

Systematic quantitative and qualitative determinations of weeds in the central highlands tef production areas were conducted by Taye and Yohannes (1998) and Rezene and Lemlem (HARC, 1999). In both surveys the frequency, abundance, dominance, and species composition of weeds in different locations of the surveyed areas were determined.

Similarity indices of weed species found in tef growing areas were also determined. Accordingly, locations, which have similar weed communities for the different zones, were:

Tullubolo vs. Awash (68%), Chittu vs. Wolliso (62.1%) and Chittu vs. Gindebret (66.7%) in 1995; while Tullubolo vs. Awash (65.2%) and Chittu vs. Wolliso (66.2%) in 1996 (Taye and Yohannes 1998).

Rob Gebeya vs Welmera (67.6%), Rob Gebeya vs Goha Tsion (62.8%), Welmera vs. Goha Tsion (60.8%), Kuyu vs. Goha Tsion (63.6%), Ginchi vs Denbi (61.5%), Enewari vs. Goha Tsion (64.1%), Enwari vs. Abotie (61.9%), Juhur vs. Goha Tsion (77.1%), Juhur vs. Enewari (65.7%), Debre Sina vs. Ginchi (71.6%), Debre Sina vs. Goha Tsion (67.7%), Debre Sina vs. Enwari (60.6%) and Debre Sina vs. Juhur (64.5%) (HARC1999).

Unger (1989) stated that if the index of similarity is greater than 60%, it can be said that the weed composition represents the same community. But, if the index of similarity is below 60%, it is said that the two locations have different weed communities. Thus, this serves as basic to use the same kind of weed management for the areas having similar weed communities (SI > 60%) and different weed management systems for areas having different weed communities (SI < 60%).

In all surveyed areas, farmers were rather well aware of their most serious weeds. Farmers mentioned species as noxious, which was confirmed through the field observation (Table 20) (HARC1999).

Weed Management Methods

Cultural Methods

Crop Rotation Practices

Wheat and Barley

Crop rotation plays an important role in farming of wheat and barley to reduce weed competition and give favorable conditions for the crops to be established. The long-term mono cropping system of wheat and barley production and the usage of selective herbicides for the control of broadleaved weed species for a number of years has given better opportunity for the development of grass weeds. Grass weeds were previously considered as minor weeds especially in small scale farming systems, but recently they became economically important. In order to overcome the grass weed problem and other mono-crop production drawbacks, rapeseed and faba bean have been used as rotational crops in large scales like Arsi and Bale Agricultural Enterprises. These two crops are mainly sown in the fields where there is high infestation of grass weeds and the methods of weed control used in these crops are: a) repeated cultivation and preparation of better seedbed by using different agricultural implements b) using selective herbicides for the control of grass weeds (Ermias 1993). Wheat rotation with dicots, particularly faba bean, decreased the density of grass weed species by enhancing selective hand weeding thus reducing weed density in the subsequent wheat crops (Asefa and Tanner 1998a). Wheat in dicot-based rotations exhibited a marked reduction in both grass and broadleaf weed densities and weed biomass in contrast to wheat in continues cereal rotations. Similarly, the second wheat crop after any precursor crop was more heavily infested with weeds than was the first wheat crop (i.e., immediately following any break crop)(Asefa and Tanner 1998a). Thus, short cycle rotations of wheat with either faba bean or rapeseed would be beneficial from the perspective of minimizing weed populations and weed competition in wheat (Asefa and Tanner, 1998a; Tanner 1999.). Weed species responded differently to rotations across sites. For example, response to a faba bean vs. a rapeseed precursor was totally opposite at the two sites: at Kulumsa, wheat after faba bean exhibited a reduced weed population; while at Asasa, rapeseed appeared to reduce weed densities in the succeeding wheat crop (s).

Tef

Tef fields were less weedy if preceding crop is noug rather than maize or sorghum (Franzel et al. 1989).

Hand Weeding

Barley

In experiment conducted at Sinana on-station in 1994 and 1995 to identify optimum frequency of hand weeding in food barley production, one-hand weeding at 30 days after emergence increased yield of local food barley from 15 to 22% (SARC 1995).

Tef

The number of required hand weedings depends upon the severity of the weed infestation and crop vigor. In many cases, one handweeding when the crop is 15 cm tall (approximately 3-4 weeks after emergence) has shown to be economic when the weed infestation is moderate. However, if the weed infestation is high, two handweedings are necessary: one at early tillering stage (15 cm) and the second at pre-heading (approximately 8 weeks after emergence). Weeding after heading stage is not recommended since tef is very sensitive to damage from disturbance.

A two year study made at Ginchi indicated that significantly higher seed yield was obtained from one and two handweedings compared to no weeding although the differences due to one and two weedings was not significant (Table 21). According to these results, tef has to be weeded at least once since it is a very susceptible to weed competition (Rezene and Zerihun 2001). Birhanu (1986) recommended one handweeding at early tillering stage of tef, or if weed infestation is high, two handweedings at early tillering and stem elongations stages of tef. In Adet area, one handweeding 45 days after tef emergence was recommended.

Land Preparation

Tef

Frequency of oxen plowing affected number and biomass of weeds (Table 22). Five plowings recorded significantly lower counts and biomass of weeds over other frequencies of tillage (Rezene and Zerihun 2001).

The use of stale seed bed (harrowing + paraquat 1.0 litre ha^{-1}) controlled over 70% of grassy and about 30% of broadleaved weeds compared to conventional method of seedbed preparation (Table 23) Moreover, time for hand weeding was reduced by half in stale seedbed compared to conventional seedbed (Rezene and Zerihun 2001).

Minimum Tillage

Tef

A study conducted at Debre Zeit compared glyphosate and glufosinate-ammonium for use in no-tillage tef production (Zerihun, 1996). Results of this study showed that weed population interms of both counts and biomass were not affected by the treatments. Days to heading and maturity, plant height, panicle length, panicle weight, grain and straw yield of tef were also not altered by the herbicides. In general, this work indicated that tef was highly infested with weeds at different growth stages, since complete control of weeds was not achieved. Hence, emphasis should be given for practices involving complete control of weeds, from tef grown in such system.

Chemical Control

Wheat and Barley

In an experiment conducted to study the efficacy of Puma Super (Fenoxaprop-ethyl from 0.5 to 1 l product/ha) to control grass weeds like *Avena fatua*, *Snowdenia polystachya*, *Setaria pumila* and *Phalaris paradoxa* at Tiyo and Hitosa district of Arsi, tank mixed Puma Super and Starane M gave a yield advantage of 60% over control. However, these chemicals did not control *Lolium temulentum* and *Bromus pectinatus*, and Puma Super cannot be tank mixed with 2,4-D (Giref et al. 1997). Herbicides evaluated for the control of *Bromus pectinatus* in wheat field at Bekoji and in pot experiment at Kulumsa during 1996 showed that the best treatment observed in the pot experiment (Ethiozin) offered only 39% control in the field. Under glasshouse experiment, however, Ethiozin at rates of 1.2 kg a.i/ha and above was gave 100% control of *Bromus* and it was recommended as a potential for use against *Bromus* in wheat (Giref 1998).

Experiment conducted to find alternative weed control options in food barley production indicated that efficacy of weed control measures vary from year to year and from site to site depending on variations in weather conditions and weed growth patterns before and after control applications. Under normal rainfall amount and distribution, effective control of target weeds and better grain yields were obtained. Glyphosate was effective when there is optimum gap between application and crop planting. Granstar 75 DF (Tribenuron methyl and 2,4-D controlled most of broadleaf weed species when applied during and active and succulent growth stage, except for *Galium spurium*. When there is sufficient moisture before application and up to grain filling, 2,4-D was found the most economical treatment under high broadleaf weed infestation in food barley production. As an alternative, selective hand weeding and Tribenuron methyl can be used to avoid continuous use of the same herbicide (Kedir et al. 2005).

Perennial grass weeds like (*Digitaria abyssinica*) are quite problematic in some of the state farms. The use of agricultural implements favors the distribution and multiplication of these weeds. In order to avoid these problems systemic non-selective herbicides are used. Furthermore, reduced rate of non-selective herbicide is used for the control of major annual weeds when there is a shortage of machinery, overlapping of different farm activities and unfavorable weather conditions for the preparation of an ideal seedbed the in large-scale farms (Ermias 1993).

On-station screening of broadleaved herbicides in wheat was conducted in 1991 at Sinana. About 11 broad leaf herbicides were compared with hand weeding. The result showed that one-hand weeding was economical. But because of overlapping of activities during two cropping season in Bale highlands three herbicides (Fenoxaprop-ethyl, Brittox and Starane M + MCPA were effective and recommended as the alternate option (SARC1991). These herbicides gave a yield advantage of 33% over a weedy check treatment (SARC 1991; SARC1992).

Efficacy evaluation of two new grass killer herbicides: Attribut 70 WG (propoxycarbozone-sodium) and Atlantis 30 WG (mesosulfuron-methyl) was carried out by the Weed Science Research Projects at Holetta and Kulumsa Research Centers for 3 consecutive years during 2003-2005 crop seasons. The purpose of this study was to evaluate the efficacy of the aforementioned herbicides relative to other promising standard herbicides on *Bromus pectinatus* and other annual grass weed species in bread wheat (HARC 2005).

Distinct variations were noted on the tolerance levels of the target annual grass weed species to the test treatments (Table 24). For instance, Attribut exhibited significant potential in controlling *Bromus pectinatus* very effectively and showed satisfactory suppression of *Snowdenia polystachya* consistently across all testing locations. *Bromus* and *Snowdenia* are such weed species that recently become prominent in the affected cropping systems due to a weed population shift attributed primarily to continuous cereal cropping and selective pressure of herbicides against common grass weeds such as *Avena fatua* (Tanner and Giref 1991; Rezene and Yohannes 2003). *Lolium temulentum* was highly susceptible to Atlantis and the effect of both test herbicides against *Phalaris paradoxa* and *Setaria pumila* was found to be within an acceptable range of susceptibility.

Major deficiencies observed on Attribut were its poor performance against *Avena fatua* and *Lolium temulentum*. On the other hand, *Avena fa*tua, *Bromus pectinatus* and *Snowdenia polystachya* showed moderate to absolute resistance to Atlantis. Since the majority of the intensive cereal growing areas of Ethiopia are infested with a mixed population of these annual grass weed species, such phenomenon can affect the country wide acceptability of these products as alternative herbicidal potential for the management of annual grass weed species in wheat production(HARC 2005). .

Furthermore, Atlantis is not compatible to the already registered broadleaf killer herbicides (2,4-D or Starane M) and the Technical Product Information received from the Local Agent does not have any information regarding compatibility of Attribut with the same widely used broadleaf herbicides. Thus, simultaneous chemical control of early flash of broadleaf species during the critical period of weed/ crop competition could be difficult with manual weeding due to overlapping of farm operations, prevailing moist weather conditions and shortage of labor(HARC 2005).

The two new test herbicides can be recommended as alternate options of Puma Super but not for complete replacement. Selection of these herbicides for use depends on the merits of their weed control spectrum and dominance of the target grass weeds of a given locality where the herbicides are chosen for intended use. As the problematic grass weed species do not occur simultaneously or uniformly in a given place, it is up to the user to decide the choice of the most appropriate herbicide. In this case, Puma Super is best recommended in areas where *Bromus pectinatus* and *Lolium temulentum* are not dominant weed problems. If the area is severely infested with *Lolium temulentum* the best choice is Atlantis. For areas where *Bromus pectinatus* and *Snowdenia polystachya* are major weed species, it is best to use Attribut. These herbicides can also be used on rotational basis over years to prevent buildup of resistant weed species (HARC 2005).

Tef

Tef was susceptible to a number of herbicides. The two kinds of damages reported were: i) vegetative set-back due to leaf scorch starting a few days after spraying (eg. using substituted ureas), and ii) fusion of leaf edges producing onion-like leaves with subsequent difficulties for the panicle to emerge and distortions of panicle (e.g. using MCPA and 2,4-D amine) (Rezene and Zerihun 2001).

The two problematic grassy weeds, *Phalaris* and *Setaria*, in the Vertisols areas of Ginchi were controlled by 0.85 litres ha^{-1} Gesaten (Rezene 2001). Recently, Wilson (1989) found promising results from screening post emergence herbicides for the control of annual weeds (*Phalaris minor and Snowdenia polystachya*) in the greenhouse study in UK. According to him, tef and rice were the only crops tolerant to 0.05 and 0.01 kg ha^{-1} of CGA.

The time of herbicide application has significant effect on both weeds and tef plant. In high rainfall areas like Kulumsa, time of herbicide application did not have significant effect on seed yield of tef due to the continuous germination of weeds during July and August. Early application of non-residual herbicides fails to control late emerging weeds while late application fails to control older weeds. Herbicides recommneded for use in this area were dichlorprop and MCPA for early application, and 2, 4-D for late (23-33 days) application (Rezene and Zerihun 2001).

For selective control of grass weeds in tef a seed dressing of the herbicide safener naphthalene –1, 8-dicarboxylicanhydride, also known as 1,8-naphthalic anhydride (NA) increased the tolerance of tef to chlorsulfuron by a factor of at least 3, so allowing safe use of doses up to at least 0.015 kg a.i. ha^{-1}. Diclofop-methyl at 0.25 kg a.i. ha^{-1} (pre-emergence) killed unprotected tef, but when protected by NA tef tolerated this dose, at which both weed species were controlled. NA did not give adequate protection against diclofop-methyl applied post-emergence. AC222293 (a mixture of methyl 6-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-m-toluate and methyl 2-4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-m-toluate and methyl 2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-p-toluate), post-emergence at 1 kg a.i. ha^{-1} provided selective suppression of *Phalaris paradoxa*. Pre-emergence there was evidence of protection by NA but it was inadequate to prevent damage by 0.25 kg a.i. ha^{-1} of this herbicide. Other herbicides failing to show selectivity were EPTC pre-planting, with or without the safener R25788 (N, N-dially1-2,2-dichloroacetamide), alachlor and perfluidone pre-emergence and pendimethalin, propanil and metoxuron post-emergence (all tested with and without NA) (Rezene and Zerihun 2001).

Herbicides for weed control in tef fields are grouped into two: pre-sowing and post-emergence. Time and rate of application for potential herbicides are presented in Table 25.

Integrated Weed Management (IWM)

Stuble Management x Tillage x Cropping Sequence

In experiments conducted at Kulumsa, Bekoji, Asasa and Gonde in Arsi zone of Ethiopia to study the effect of stubble management, tillage and cropping sequence on weed populations it was found that the density of *Bromus pectinatus* is markedly reduces by stubble burning under reduced conventional tillage, and after faba bean precursor crop while continuous cereal production greatly exacerbates the problem of *Bromus pectinatus* (Asefa and Tanner 1998b).

Tillage Frequency x Weed Control Methods

In an experiment conducted at Sinana, Agarfa, and Gassera districts to determine the optimum tillage frequency and weed control method in wheat double cropping system it was found that as tillage frequency increased, the weed density was decreased. *Polygonum convolvulus*, *Digitaria* spp., and *Guizotia scabra* were dominant in one times tilled plot. At both locations, however, tillage frequency and weed control methods had no significant effect on grain yield and yield components of bread wheat grown after field pea (SARC 2005a).

The effect of seed rate and methods of weed control on bread wheat grain yield and yield component was conducted in years of 1998 to 2000 in both '*genna*' and '*bona*' seasons. In these experiments, five weed treatments: weedy check, one hand weeding, two hand weeding, Topik + 2,4-D and Magenstan were included. Once, twice hand weeding, Topik + 2,4-D and Magenstan gave a respective yield advantage of 22.5, 25.8, 13.8 and 28.6% over weedy check. The result indicated that once hand weeding was economical, with a marginal rate return of 604.4 birr (SARC 2000b; SARC 2001).

Integrated Weed Management in Wheat

Because of continuous mono cropping of cereals (mainly wheat), the Bale Agricultural Development Enterprise (BADE) faced a multitude of production problems in the late 1990's and the survival of the enterprise was under serious question. After consulting with different experts on the problems, BADE identified the major production constraints and approached appropriate agricultural institutions to look for solutions. Success story at (BADE) with particular emphasis to contribution of weed research outputs are summarized below.

Crop Production Constraints of BADE Farm

The factors that contributed to the low productivity of the enterprise included inadequate awareness on appropriate and improved crop production technologies abiotic stresses (occasional moisture stress and erratic rainfall distribution) and biotic stresses (mainly weeds and diseases) (Rezene and Yohannes 2003).

Among the production bottlenecks grassy weeds ranked first in constraining crop production in BADE State Farms. From the total cost of pesticide, application on average over 90% was spent on herbicides. The use of herbicides of similar mode of action for successive years on mono-cropped land favored the dominance of less affected grassy weed species (Rezene and Yohannes 2003).

The major grassy weeds that required special attention were: *Snowdenia polystachya, Phalaris paradoxa, Avena fatua, Bromus pectinatus, Digitaria scalarum* and *Cyperus* spp. Of the major annual grass weed species *Snowdenia polystachya* was the most problematic in all the farms. Comparatively, the problem was more serious at Herero Farm *Snowdenia polystachya* is a tufted annual grass with more or less erect stems, sometimes lying on the ground and rooting at the lower nodes, growing up to 15 to 200 cm tall. It is most common in good soils and apparently dependent on high fertility for vigorous growth hence, aggressive in well-fertilized annual crops.

Before the intervention, the weed had completely covered most parts of the Herero farm (98.3% of the total area) with an average infestation level of 75 plants m^{-2} and seriously affecting the yield and quality of crop production. Moreover, the control measures, especially herbicide application against *Snowdenia* showed a declining effect. The resilience of weed population *(Snowdenia* in particular) to intensive use of grass-killer herbicides and other supplementary control measures forced BADE to explore more systematic approach to reverse these problems (Rezene and Yohannes 2003).

Technology Development Process

Total production fluctuated but always remained below the attainable or potential yield (BADE 2003). To avert this ominous situation, BADE sought advice and support mainly from research institutions. Several preventive and integrated weed management measures which include: crop rotation, dry plowing, fallowing, machinery sanitation, use of clean seed, and hand weeding frequencies and timings were recommended by the participants of a workshop organized by BADE as alternate solutions to the conventional herbicidal based weed management practices used by the Enterprise

BADE was advised to test the recommendations on reasonably larger plots before full implementation of the recommended practices. Most importantly, BADE formulated a strategy on how to implement the recommendations.

Scaling-up Processes and Results

Details of the scale-up process and results of the respective weed management strategies recommended to alleviate the crop production constraints of BADE farms are presented separately here but were executed in an integrated manner as appropriate for the various aspects of crop production operations under report.

Crop rotation

Rotation of dissimilar crop species has played a significant role in increasing productivity and production and in improving the soil environment for sustained production of the BADE farms. Before the year 2000/01 the share of rotational crops was less than 1.5% of the total cultivated areas of BADE farms. Based on the crop production strategy, the Enterprise started intensive crop rotation schemes with 830 ha of rapeseed (5% of total area) at Herero farm in 2000/01. Area under rapeseed rotation increased steadily and reached 19% (3069 ha) in 2005/06. Similarly, rotation with faba bean started with 293 ha in 2001/02 and reached up to 622 in 2002/03 and 534 ha in 2005/06. Chickpea and field peas together made up only 100 ha in 2004/05 and 2005/06.

Benefits of rapeseed and faba bean rotations as measured by wheat productivity from sampled areas of initial tests during 2001/02, 2002/03 and 2003/04 gave average yield increase of 105% and 64% respectively and weed free fields that persisted until crop harvest (Table 26). Results of this intervention clearly indicated that short cycles of wheat rotations with either dicot crop (i.e., rapeseed or faba bean) were proved beneficial from the perspective of minimizing weed populations and weed competition with wheat.

Dry plowing

This cultural practice has been practiced at Robe and Sinana farms with the intention of controlling perennial weeds such as *Digitaria* and *Cyperus* spp. by exposing their subterranean vegetative growth to direct sun radiation. To prevent re-infestation, infested fields have been plowed every 3 years since the year 2000 with remarkable results.

In fields plowed under dry tillage condition in the year 2003/04, *Digitaria scalarum* population declined from 49 to 10 plant colonies m^{-2} on 2197 ha of land in the year 2005/06. Yield of wheat from the same fields also increased from 2.2 to 3.1 tons ha^{-1} (i.e., 41% increases) (BADE 2005).

Fallowing

In this practice, land was left uncultivated usually at longer intervals to break the growth cycle of the target weed *Snowdenia polystachya* that developed resistance to grass-killer herbicides. Initially, different agronomic practices comprising combinations of tillage and crop type treatments supplemented with herbicide spray or hand weeding; fallow based treatments supplemented with non-selective herbicide applications or intensive cyclic grazing were evaluated in 81.6 ha of land at Herero farm in the year 2001/02. Details of the treatments are shown in Table 27. Results of this study showed highly significant reduction of *Snowdenia* population after the fallow-based treatments (Table 27). Considering the cost comparative advantage fallowing + intensive cyclic grazing was selected as the best alternative and this practice was scaled up in a 3-year cycle on 1/3 of each of the total cultivated land at Herero and Hunte farms covering 3592 and 2215 ha respectively during 2002/03 – 2004/05 (Table 28).

When applied under large-scale condition, quite similar to the initial test *Snowdendia* population was drastically reduced during the first year after fallow with slight increase in the two subsequent years after fallow (Figure 1) indicating that fallowing by itself cannot be considered as the only long-term solution for *Snowdenia* control unless supplemented with other weed control methods. However, the benefits of fallow supplemented with intensive cyclic grazing in terms of yield advantage are demonstrated in Figure 2 where wheat yield was increased substantially in the 3 consecutive years after fallow with mean yield increases of 65% and 83% for Herero and Hunte farms respectively (BADE 2005).

Machinery sanitation and seed cleaning

Strict regulations have been established to prevent dissemination of weed seeds from block to block and from farm to farm by cleaning agricultural machineries. These practices were found to be very effective to prevent spread of weed seeds thereby contributing to the depletion of soil seed bank of the target weed species (BADE 2005).

Hand weeding

Hand weeding was employed to control weeds, which developed resistance to grass-killer herbicides. Hand weeding was also used as a standard preventive mechanism to late-emerging weeds that escaped initial weed control measures within and the peripheries of croplands for the whole farms. Moreover, this practice served well as a main component of the integrated weed management strategy, reduced cost of herbicides purchase and spraying; created employment opportunity for the surrounding community and maximized profit (BADE 2005).

Comparisons of Costs of Weed Control

Tables 29 and 30 show comparisons of pre- and post-strategy implementation costs of weed control for Herero and Hunte farms respectively. Herero and Hunte farms were those farms severely affected by herbicide resistant biotypes of annual grass weed species. Three years before the intervention on average 84% and 93% of the total cultivated lands at Herero and Hunte farms were sprayed respectively with grass weed herbicides. But, average data of 4 years after the intervention from the respective farms indicated that only 15% and 55% of the total cultivated land was sprayed with grass weeds herbicides leading to 87% and 56% reduction for grass weed herbicide purchase and spraying costs (Tables 29 and 30).

Application and costs of broadleaf herbicides remained more or less consistent throughout, but slight increase on person-days and labor costs for hand weeding were observed after the intervention. Main reasons for the latter phenomena are ascribed to the reduced area applied with grass weed herbicides and increase of wages for casual laborers through time. Nevertheless, total average weed control costs after implementation of the strategy at Herero and Hunte farms were only Birr 715,100 and Birr 696,000 respectively with the respective cost reductions of 60% and 46%. As a whole, judicious application of hand weeding practice was the core component of the overall crop production strategy that contributed a big share for the success of the intervention which leads to the effective control of herbicide resistant grass weed species, reducing the total weed control cost and increase of production and productivity of crops in the BADE’s farms.

Table 1 Major weeds of small cereals recorded in Ethiopia.

Family	Species	Characteristics[1]			Interference level[2]			Source(s)[3]
					Wheat	Barley	Tef	
ACANTHACEAE	*Hygrophilla auriculata*	a	d	rs	xx	-	xx	30, 32, 33, 45
	Achyrantes aspera	a	d	rs	x	x	x	15. 30, 32, 33
AMARANTHACEAE	*Amaranthus hybridus*	a	d	rs	xxx	xxx	xxx	15. 30, 32, 33, 45
	Ageratum conyzoides	a	d	rs	x	x	x	30, 32, 33, 45
ASTERACEAE	*Anthemis tigreensis*	a	d	rs	x	x	x	30, 32, 33, 45
	Bidens pachyloma	a	d	rs	xxx	xxx	xxx	15. 30, 32, 33, 45
	Bidens pilosa	a	d	rs	x	x	x	30, 32, 33, 45
	Chrysanthemum segetum	a	d	rs	xxx	xxx	xxx	15. 30, 32, 33, 45
	Cichorium intybus	a	d	rs	xx	-	xx	30, 32, 33, 45
	Galinsoga parviflora	a	d	rs	xx	x	xx	32, 33, 45
	Gnaphalium unionis	a	d	rs	x	-	x	30, 32, 33, 45
	Guizotia scabra	a	d	rs	xxx	xxx	xxx	30, 32, 33, 45
	Launea cornuta	p	d	rs/rv	xx	xx	xx	30, 32, 33, 45
	Sonchus arvensis	a	d	rs	x	x	x	15. 30, 32, 33, 45
	Tagetes minuta	a	d	rs	x	x	x	30, 32, 33, 45
	Xanthium spinosum	p	d	rs/rv	xx	-	xx	30, 32, 33, 45
	Xanthium strumarium	p	d	rs/rv	xx	-	xxx	30, 32, 33, 45
BRASSICACEAE	*Brassica napus*	a	d	rs	xx	xx	xx	15. 30, 32, 33, 45
	Erucastrum arabicum	a	d	rs	xx	xx	xx	15. 30, 32, 33, 45
	Raphanus raphanistrum	a	d	rs	xxx	xx	xxx	15. 30, 32, 33, 45
	Sinapis arvensis	a	d	rs	xx	xx	xx	15. 30, 32, 33, 45
CAPPARIDACEAE	*Gynandropsis gynandra*	a	d	rs	x	-	x	30, 32, 33, 45
	Cleome sp.	a	d	rs	x	-	x	30, 32, 33, 45
	Cerastium octandrum	a	d	rs	x	x	x	30, 32, 33, 45
CARYOPHYLLACEAE	*Corrigiola capensis*	a	d	rs	xx	xx	x	30, 32, 33, 45
	Spergula arvensis	a	d	rs	xx	xx	x	30, 32, 33, 45
CHENOPODIACEAE	*Chenopodium fasciulosum*	a	d	rs	x	x	x	30, 32, 33, 45
COMMELINACEAE	*Commelina benghalensis*	a/p	m	rs/rv	xxx	xx	xxx	15. 30, 32, 33, 45
	Cyanotis barbata	a/p	m	rs/rp	x	x	x	30, 32, 33, 45
CONVOLVULACEAE	*Convolvulus arvensis*	p	d	rs/rv	xxx	xxx	xxx	15. 30, 32, 33, 45
CYPERACEAE	*Cyperus esculentus*	p	m	rs	xxx	xx	xxx	15. 30, 32, 33, 45
	Cyperus rotundus	p	m	rs/rv	xxx	xx	xx	15. 30, 32, 33, 45
LABIATAE	*Leucas martinicens*	a	d	rs	x	x	x	30, 32, 33, 45
LEGUMINOSAE	*Medicago polymorpha*	a	d	rs	xx	xxx	xx	15. 30, 32, 33, 45
	Scorpiurus muricatus	a	d	rs	xxx	x	xxx	15. 30, 32, 33, 45
	Trifolium sp.	a/p	d	rs/rv	xx	xxx	xx	15. 30, 32, 33, 45
MALVACEAE	*Hibiscus trionum*	a	d	rs	x	-	x	30, 32, 33, 45
PAPAVERACEAE	*Argemone mexicana*	a	d	rs	xx	xx	xx	15. 30, 32, 33, 45
PLANTAGINACEAE	*Plantago lanceolata*	b	m	rs/rv	xxx	xx	xxx	15. 30, 32, 33, 45
POACEAE	*Andropogon abyssinicus*	a	m	rs	xx	xxx	xx	15. 30, 32, 33, 45
	Avena fatua	a	m	rs	xxx	xxx	x	30, 32, 33, 45
	Brachiaria eruciformis	a	m	rs	xx	xxx	xx	30, 32, 33, 45
	Bromus pectinatus	a	m	rs	xxx	xxx	x	30, 32, 33
	Cynodon dactylon	p	m	rs/rv	x	x	x	15. 30, 32, 33, 45
	Digitaria scalarum	p	m	rs/rv	x	x	x	15. 30, 32, 33, 45
	Dinebra retroflexa	a	m	rs	X	x	x	15. 30, 32, 33, 45
	Eleusine indica	a	m	rs	x	x	x	15. 30, 32, 33, 45
	Eragrostis spp.	a	m	rs	x	x	xxx	15. 30, 32, 33, 45
	Lolium temulentum	a	m	rs	xxx	xxx	xxx	15. 30, 32, 33, 45

Table 1 Cont'd. Major weeds of small cereals recorded in Ethiopia.

	Setaria verticillata	a	m	rs	xx	xxx	xxx	32, 33
	Snowdenia polystachya	a	m	rs	xxx	xxx	xx	15. 30, 32, 33, 45
	Rumex abyssinicus	p	d	rs/rv	xx	xx	xx	15. 30, 32, 33, 45
	Rumex bequarti	p	d	rs/rv	xx	xx	xx	15. 30, 32, 33, 45
PRIMULACEAE	*Anagalis arvensis*	a	d	rs	x	x	x	30, 32, 33, 45
RESEDACEAE	*Caylusea abyssinica*	a	d	rs	x	x	x	15. 30, 32, 33, 45
RUBIACEAE	*Galium spurium*	a	d	rs	xxx	xxx	x	15. 30, 32, 33, 45
SCROPHULA RIACEAE	*Striga hermonthica*	a	d	rs	xx	xx	xx	15. 30, 32, 33, 45
SOLANACEAE	*Datura stramonium*	a	d	rs	xx	x	xx	15. 30, 32, 33, 45
	Nicandra physalodes	a	d	rs	xx	-	x	15. 30, 32, 33, 45
	Solanum nigrum	a	d	rs	x	-	x	15. 30, 32, 33, 45
UMBELLIFERAE	*Foeniculum vulgare*	a	d	rs	x	x	x	30, 32
TILIACEAE	*Corchorus trilocularis*	a	d	rs	xx	xx	xx	30, 32

[1]a = annual; p = perennial; b = biennial
d = dicot; m = monocot; rs = reproduction by seed
rv = reproduction by vegetative means
xx = recorded as important weed
x = recorded as commonly occuring weed

Table 2 Mean square values for the effects of weed species, weed densities and their interaction on grain yield and yield components of barley at Ambo in 2000, 2002 and 2003.

Source of variation				Mean	C.V. %
d species (S)	density (D)	S x D	Error		
28626.87**	16479.21**	3855.91ns	3462.99	520.01	11.32
11609.86**	5942.71*	2175.82ns	2305.37	298.36	16.09
4168787.7ns	16671855.2**	1053582.6ns	1950707.20	8838.49	15.80
967125.76**	1918099.85**	210008.02ns	163982.71	2744.61	14.75
41.37*	7.40ns	6.46ns	10.35	41.30	7.79
4.83ns	1.92ns	2.96ns	2.30	78.19	1.94

*N.B.:-Degree of freedom was 3, 6, 18 and 54 for the above left to write listed source of variation, respectively. . *, ** ns = significant at 5%, 1% probability levels, and not significant, respectively. . Tm^{-2} = tillers per square meter, PTm^{-2} = productive tillers per square meter, BY = biomass yield (kg/ha), GY = grain yield (kg/ha), TGW = thousand grains weight (g), TW = test weight (kg/hl).*
Source: (Takele 2001)

Table 3 Effects of weed species and density on grain yield (kg/ha) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	3285	3102	2906	2836	2626	2059	1952	2681
E. arabicum	3619	3142	2808	2976	2458	2997	2810	2973
G. scabra	3377	3154	2784	2992	3010	24898	2129	2848
S. polystachya	2867	3007	2835	2337	2556	2316	1424	2477
Density mean	3287	3101	2833	2785	2663	2465	2079	

Source: (Takele 2001)

Table 4 Effects of weed species and density on tillering ability (number of tillers m^{-2}) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	515	561	504	515	457	402	407	480
E. arabicum	608	498	542	553	518	535	526	540
G. scabra	555	589	588	571	566	516	541	561
S. polystachya	539	589	507	521	492	445	399	499
Density mean	554	559	535	540	508	475	468	

Source: (Takele 2001)

Table 5 Effects of weed species and density on heading ability (number of productive tillers m^{-2}) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	337	315	293	287	265	247	231	282
E. arabicum	370	265	315	318	327	306	304	315
G. scabra	332	340	322	341	318	320	278	322
S. polystachya	271	339	268	272	272	284	214	274
Density mean	328	315	230	305	296	289	257	

Source: (Takele 2001)

Table 6 Effects of weed species and density on biomass yield (kg/ha) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	10269	9909	8546	9707	8165	6954	6722	8610
E. arabicum	11101	9892	8916	9555	8604	9264	7442	9253
G. scabra	10422	9776	8967	10038	8803	84405	7749	9166
S. polystachya	9326	9740	9008	8439	874	7931	5085	8325
Density mean	10280	9829	8859	9435	8579	8139	6749	

Source: (Takele 2001)

Table 7 Effects of weed species and density on thousand grain weight (g) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	43.0	43.4	43.0	42.0	41.2	42.7	44.6	42.9 A*
E. arabicum	42.2	41.3	40.9	40.7	36.6	36.5	38.0	39.5 B
G. scabra	41.2	39.4	43.5	42.5	41.0	42.3	41.1	41.6 A
S. polystachya	41.8	42.3	41.5	40.8	41.1	41.4	40.4	41.3AB
Density mean	42.1	41.6	42.2	41.5	40.00	40.4	41.0	

Source: (Takele 2001)

Table 8 Effects of weed species and density on test weight (kg/ha) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	78.1	78.1	77.5	79.1	78.9	78.9	79.1	79.5
E. arabicum	78.4	77.9	77.2	77.8	77.8	78.6	79.1	78.1
G. scabra	77.2	78.5	79.2	79.7	79.6	79.2	77.0	78.6
S. polystachya	78.2	77.4	78.7	77.5	77.6	78.6	75.0	77.6
Density mean	78.0	78.2	78.1	78.5	78.2	78.8	77.6	

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	78.1	78.1	77.5	79.1	78.9	78.9	79.1	79.5
E. arabicum	78.4	77.9	77.2	77.8	77.8	78.6	79.1	78.1
G. scabra	77.2	78.5	79.2	79.7	79.6	79.2	77.0	78.6
S. polystachya	78.2	77.4	78.7	77.5	77.6	78.6	75.0	77.6
Density mean	78.0	78.2	78.1	78.5	78.2	78.8	77.6	

Source: (Takele 2001)

Table 9 Effects of weed species and density on grain yield (kg/ha) of barley at Ambo in 2000, 2002 and 2003

Weed species	Weed density							Species mean
	0	10	20	40	80	160	320	
A. fatua	3285	3102	2906	2836	2626	2059	1952	2681
E. arabicum	3619	3142	2808	2976	2458	2997	2810	2973
G. scabra	3377	3154	2784	2992	3010	24898	2129	2848
S. polystachya	2867	3007	2835	2337	2556	2316	1424	2477
Density mean	3287	3101	2833	2785	2663	2465	2079	

Source: (Takele 2001)

Table 10 Yield losses of tef due to uncontrolled weed growth in selected locations in Ethiopia

Location/region	Yield losses (%)	References*
Kulumsa	30	Anon (1977)
Debre Zeit	45-55	Debre Zeit Res. (Und.)
	23	Rezene (1989)
Ambo	23-33	Slovtsov et al.. (1980)
	52	Strekozov et al.. (1980)
Jima	20-30	Tilahun et al.. (1987)
Shewa	56	Strekozov (1981)
Arsi	24	Strekozov (1981)
Welega	58	Strekozov (1981)
Gojam	48	Strekozov (1981)
Gonder	49	Strekozov (1981)
Country wide	23-65	Stroud (1989)
Country wide	54	EWSC (1987)

*Source (Rezene and Zerihun 2001)

Table 11 Emergence and growth pattern of weeds in tef fields at Ambo

Weed species	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.
Amaranthus Spp.	***	***	**				
Brassica spp.	***	***	**				
Brachiaria eruciformis				**	***	***	***
Commelina benghalensis			*	**	**		
Datura stramonium			*	*	*		
Galinsoga parviflora		**	***	***			
Guizotia scabra				*	**	**	**
Lolium temulentum					*	**	**
Medicago spp.					*	**	**
Nicandra physalodes	*	**	**				
Phalaris paradoxa				**	***	***	***
Polygonum nepalense	***	***	***				
Snowdenia polystachya	***	**					
Plantago lanceolata				*			
Scorpiurus muricatus			**	***			
Trifolium spp.				**			

Source: (Rezene and Zerihun 2001)

Table 12 Major and important weed species in barley and wheat fields according to Survey results and farmers' ranking, combined over Adaba and Doddola, *bona* (meher), 2004, Sinana

Weed species	Fank	Abundance/m²			Frequency (%)			Dominance (%)		
		tiller	Anthesis	maturity	Tiller	Anthesis	Maturity	Tiller	Anthesis	Maturity
P. nepalense	1	96	96	-	65	67.5	-	16	16	-
S. polystachya	2	-	-	7	-	-	27	-	-	2.5
G. scabra	3	30	84	90	40	82.5	90	5.5	14	9.5
B. pectinatus	4	120	108	28	60	80	15	15	17	8
P. paradoxa	6	-	-	88	-	-	37.5	-	-	16
Avena spp.	5	-	16	48	-	25	74	-	2.5	14
S. pumilia	-	112	120	28	61	60	53	19	14	9
C. benghalensis	-	88	40	-	48	30	-	6	3	-
Galium spurium	-	40	36	18	42.5	44	25	7.5	6	5.3

Source: (SARC 2005a)

Table 13 Major and important weed species in wheat fields at Goba districts - '*Genna'* 2004, Sinana

Weed species	Abundance/m²		Frequency (%)		Dominance (%)	
	Tiller	Maturity	Tiller	Maturity	Tiller	Maturity
Polygonum nepalense	145	44	100	68.75	12.7	8.0
Catula arvensis	14	19	100	100	12.0	6.5
Galinsoga parviflora	216	83	100	100	15.5	15.3
Anagalis arvensis	49	64	100	100	3.5	12.0
Corriogola capensis	75	25	100	87.5	5.4	6.2
Bromus pectinatus	-	44	-	50	-	8.2

Source: (SARC 2005a)

Table 14 Major and important weed species in food barley fields according to survey results and farmers' ranking at Goba districts '*genna'* 2004, Sinana

Weed species	Abundance/m²		Frequency		Dominance	
	Tiller	Maturity	Tiller	Maturity	Tiller	Maturity
Amaranthus hybridus	168	90	67	83	23	12.43
Polygonum nepalense	140	-	67	-	19.01	-
Chenopodium spp.	-	39	-	83	-	5.36
Galinsoga parviflora	-	86	-	100	-	38.9
Anagalis arvensis	-	59	-	67	-	8.18
Plantago lanceolata	44	70	33	57	5.95	9.7

Source: (SARC 2005a)

Table 15 Major and important weed species in bread wheat fields according to survey results and farmers' ranking at Goba districts '*genna'* 2004, Sinana

Weed species	Abundance/m²		Frequency (%)		Dominance (%)	
	Tiller	Maturity	Tiller	Maturity	Tiller	Maturity
Amaranthus hybridus	32	24	83.75	58.2	6.91	5.9
Phalaris paradoxa	48	-	73.3	-	10.7	-
Chenopodium spp.	32	32	75	71.6	7.2	8.01
Galinsoga parviflora	56	48	77	68	13.4	12.5
Anagalis arvensis	-	32	-	62	-	9.0
Corriogola capensis	36	-	97.1	-	7.97	-
Guizotia scabra	-	28	-	75.56	-	6.32
Bromus pectinatus	-	52	-	34.4	-	11.75
Erucastrum arabicum	40	-	60	-	9.08	-
Digitaria spp.	40	20	67.5	55	9.61	6.15
Commelina benghalensis	40	40	67.5	87	9.64	11.5

Source: (SARC 2005a)

Table 16 Major and important weed species in food barley fields according to survey results and farmers' ranking at Sinana-Dinsho districts '*genna'* 2004, Sinana

Weed species	Abundance/m^2		Frequency (%)		Dominance (%)	
	Tiller	Maturity	Tiller	Maturity	Tiller	Maturity
Amaranthus hybridus	16	24	78.9	78.6	4.77	6.6
Setaria pumila	28	28	25	25	7.14	7.14
Chenopodium spp.	28	24	85.6	87.15	8.04	6.32
Anagalis arvensis	20	-	73	-	5.66	-
Commelina benghalensis	40	64	73.3	82.9	11.2	16.02
Scorpiurus muricatus	-	28	-	30.7	-	7.15

Source: (SARC 2005a)

Table 17 Weed species abundance and dominance in Bale Agricultural Development Enterprise before 1997 combined over sites of the farm

Weed species	1990		1991		1992		1993		1994		1995		1996		1997	
	Abundance/m^2	Dominance (%)	Abundance /m^2	Dominance (%)	Abundance / m^2	Dominance (%)	Abundance /m^2	Dominance (%)	Abundance /m^2	Dominance (%)	Abundance /m^2	Dominance (%)	Abundance /m^2	Dominance (%)	Abundance /m^2	Dominance (%)
Amaranthus spp.	-	-	-	-	-	-	-	-	24	13.7	27	6.1	46	10.2	5	12.6
Chenopodium spp	-	-	-	-	-	-	-	-	31	17.7	55	12.5	41	9.1	8	20.2
G. scabra	-	-	-	-	-	-	-	-	24	13.7	28	6.4	33	7.3	8	20.2
G. spurium	-	-	-	-	-	-	-	-	8	4.6	3	0.7	61	13.5	1	2.5
G. parviflora	-	-	-	-	-	-	-	-	20	11.4	4	0.9	7	1.5	1	2.5
P. nepalense	-	-	-	-	-	-	-	-	15	8.6	2	0.5	6	1.3	1	2.5
Avena spp.	0	0.3	0	0.5	0	0.3	2	1.5	0.2	0.1	4.8	1.1	6.4	1.4	0	39.5
B. pectinatus	0	3.2	0	0.7	0	2.1	15	10	1.7	1	21	4.7	24	5.4	0	0
S. polystachya	0	16.8	0	6.3	0	11	12	8.2	11.6	6.6	47	10.6	67	14.8	16	0
S. pumila	0	51.4	0	55	0	53	62	44	21	11.8	152	34.6	81	17.9	0	0
Cyperus spp.	0	28.3	0	36	0	33	50	36	18.7	10.7	96.8	22	80	17.7	0	0

Source: (SARC 2005b)

Table 18 Weed species abundance in Bale Agricultural Development Enterprise after 1997 combined over sites of the farm

Weed species	Weed densities /m^2								Average
	1998	1999	2000	2001	2002	2003	2004	2005	
Amaranthus hybridus	43	51	39	54	98	53	73	39	56
Chenopodium spp	48	31	35	26	61	33	46	33	39
Guizotia scabra	53	54	51	46	71	59	38	35	51
Galium spurium	29	39	33	40	75	38	36	36	41
Galinsoga parviflora	10	7	4	5	16	3	3	4	7
Polygonum nepalense	55	65	83	128	50	137	137	135	99
Oxalis latifolia	16	9	3	11	11	8	5	3	8
Digitaria spp.	31	22	3	7	29	12	5	4	14
Avena spp.	14	8	11	11	28	10	10	14	13
Bromus pectinatus	68	9	22	33	44	32	14	31	32
Snowdenia polystachya	45	38	47	41	50	53	26	38	42
Setaria pumila	41	151	113	118	39	46	58	46	76
Cyperus spp.	54	49	37	55	105	43	39	25	51
Lolium temulentum	1	3	0	1	21	2	3	1	4
Phalaris paradoxa	39	11	27	14	20	33	29	4	22
Total	545.2	545.3	506.2	587.9	716.8	560.9	520.8	446.6	

Source: (SARC 2005b)

Table 19 Weed species dominance in Bale Agricultural Development Enterprise after 1997 combined over sites of the farm

Weed species	Weed dominance (%)								Average
	1998	1999	2000	2001	2002	2003	2004	2005	
Amaranthus hybridus	7.8	9.4	7.2	9.9	17.9	9.7	13.5	7.1	10.3
Chenopodium spp	8.9	5.6	6.4	4.8	11.1	6.0	8.4	6.1	7.2
Guizotia scabra	9.7	9.9	9.4	8.5	13.0	10.8	7.0	6.4	9.3
Galium spurium	5.3	7.1	6.0	7.3	13.8	7.0	6.6	6.6	7.5
Galinsoga parviflora	1.9	1.3	0.8	0.9	3.0	0.6	0.6	0.7	1.2
Polygonum nepalense	10.0	12.0	15.2	23.4	9.2	25.1	25.1	24.8	18.1
Oxalis latifolia	2.9	1.6	0.5	2.0	2.0	1.4	1.0	0.6	1.5
Digitaria spp.	5.7	3.9	0.6	1.2	5.3	2.1	0.9	0.6	2.6
Avena spp.	2.6	1.5	2.1	1.9	5.1	1.8	1.7	2.6	2.4
Bromus pectinatus	12.4	1.6	3.9	6.0	8.0	5.9	2.6	5.7	5.8
Snowdenia polystachya	8.2	7.0	8.6	7.4	9.1	9.8	4.8	6.9	7.7
Setaria pumila	7.5	27.7	20.6	21.6	7.2	8.4	10.5	8.4	14.0
Cyperus spp.	9.8	9.0	6.7	10.0	19.3	7.8	7.1	4.5	9.3
Lolium temulentum	0.1	0.5	0.0	0.2	3.9	0.4	0.5	0.2	0.7
Phalaris paradoxa	7.1	2.0	5.0	2.6	3.6	6.1	5.4	0.7	4.0

Source: (SARC 2005b)

Table 20 Noxious weeds according to farmers in east, west and north Shewa tef growing areas

Weed species	Severity level[1]		
	East Shewa	West Shewa	North Shewa
Phalaris paradoxa	VS	VS	S
Medicago polymorpha	S	NP	S
Galium spurium	NS	S	NS
Plantago lanceolata	VS	S	S
Guizotia scabra	VS	VS	VS
Bidens pachyloma	VS	VS	VS
Sorghum arundinaceum	VS	NS	NS
Argemone mexicana	S	NS	NP
Amaranthus hybridus	S	NS	NS
Setaria pumila	VS	VS	VS
Cyperus spp.	VS	VS	S
Trifolium sp.	NS	NS	S
Andropogon abyssinicus	NS	NS	S
Snowdenia polystachya	VS	S	NP
Xanthium strumarium	VS	NS	NP
Xanthium spinosum	S	NS	S
Galinsoga parviflora	S	S	NS

[1]NS = Not serious; S = Serious; VS = Very serious ;NP = Not present

Source: (HARC 1999; Taye and Yohannes 1998)

Table 21 Effect of frequency of hand weeding on seed yield of tef and cost/benefit ratio

Treatment	Seed yield (kg ha^{-1})		Cost /Benefit	
	1996	1997	1996	1997
No weeding	990	130	-	-
One handweeding	2160	2260	10.1	3.4
Two handweedings	2230	2430	7.2	2.8
LSD 5%	1.91	2.86		
1%	2.90	4.34		

Source: (Rezene and Zerihun 2001)

Table 22 Effect of frequency of oxen plowing on weed number and fresh biomass of weeds two weeks after planting tef

Frequency of plowing	Weed counts (No m^{-2})	Weed fresh biomass wt. (g m^{-2})
0	94.5 a*	142.1 a
1	106.0 a	169.1 a
2	122.5 a	216.9 a
3	140.5 a	287.3 a
4	91.b a	167.3 a
5	19.5 b	16.6 b
Mean	95.8	166.6
CV (%)	18.2	13.2

**Means followed by the same letter in a column are not significantly different at 5% level of probability.*
Source: (Rezene and Zerihun 2001)

Table 23 Effect of seedbed preparation and weed control methods on the relative weed weight and seed yield of tef (average of two years)

Seedbed preparation method	Method of weed control	Seed yield (t ha^{-1})	Relative weight of remaining weeds		
			Broad-leaves	Grasses	Total
Conventional	No weeding	1.71	100	100	100
	Handweeding once	2.24	3	9	5
	Dichlorprop[1]	2.00	18	56	28
Stale seedbed[2]	No weeding	1.91	83	18	62
	Handweeding once	2.18	5	17	8
	Dichlorprop	2.15	17	41	28

[1] 2.0 litre ha^{-1} [2] harrowing + paraquat 1.0 litre ha^{-1}

Source: (Rezene and Zerihun 2001)

Table 24 Susceptibility of the individual grass weed species to grass killer herbicides

Test Herbicides	*Avena fatua*	*Bromus pectinatus*	*Snowdenia polystachya*	*Phalaris paradoxa*	*Lolium temulentum*	*Setaria pumila*
Atlantis	MR	MR	R	MS	S	MS
Attribut	R	S	MS	MS	R	MS
Puma Super	S	R	MS* - MR**	S	MS	MS

[a] S = Susceptible; MS = Moderately susceptible; MR = Moderately Resistant; R = Resistant. * = For HARC sites; ** = For KARC sites.

Source: (HARC 2005)

Table 25 Rates and time of application of recommended herbicides for tef and target weeds to be controlled

Herbicide	Rate of application	Time of application	Target weeds to be controlled
Triallate	2-4 l/ha	3 WBS	Wild oats
Barban	3 l/ha	2 WBS	Wild oats
Gesaten	2 kg/ha	2-3 WBS	BLW + GW
Terbutryne	0.5 kg/ha	2-3 WBS	BLW + GW
2, 4-D	2 l/ha		BLW
MCPA	2 l/ha		BLW
MCPA	1 l/ha		BLW
Dichlorprop	2 kg/ha	4 WAS	BLW
Primagram + MCPA	1.0 + 1.2	Tillering	BLW + GW

Source: (Rezene and Zerihun 2001)

Table 26 Benefits of rapeseed and faba bean rotation as measured by wheat productivity

Year	Rotational crop	Area rotated	Yield of wheat (t ha^{-1})		
			Before rotation	After rotation	Percent change
2001/02	Rapeseed	256	1.9	4.4	132
2002/03	Rapeseed	145	1.8	3.4	89
Average			1.9	3.9	105
2002/03	Faba bean	139	1.9	3.2	68
2003/04	Faba bean	177	2.4	3.9	62
Average			2.2	3.6	64

Source: (BADE 2004)

Table 27 Effects of agronomic practices on population density of *Snowdenia polystachya* at Herero farm - 2001/02

Agronomic practices	Area (ha)	*Snowdenia* population (m^{-2})	
		During practice	After practice
Ploughing + discing + wheat + herbicide spray + hand weeding	13.6	115	52
Ploughing + discing + rapeseed + hand weeding	13.6	68	25
Ploughing + discing + Roundup spray + wheat	13.6	35	52
Ploughing + Roundup spray + discing	13.6	21	24
Fallowing + Roundup spray	13.6	38	4
Fallowing + intensive cyclic grazing	13.6	142	3
Total	81.6*		

**Snowdenia* count for the whole experimental field before treatment application was 112 plants m^{-2}.
Source: (BADE 2004)

Table 28 Scaled-up of fallowing practice at Herero and Hunte farms, 2002-2005

Farm	Total area	2002/03		2003/04		2004/05	
		Fallowed (ha)	% of total	Fallowed (ha)	% of total	Fallowed (ha)	% of total
Herero	3592	1205	34	1075	30	1301	36
Hunte	2215	652	30	678	32	790	39

Source: (BADE 2004)

Table 29 Comparison of pre- and post strategy implementation weed control costs: Herero farm

Period	Cultivated area (ha)	Sprayed area (ha)		Herbicide & spray cost* ('000)		Hand weeding			Total weed control cost* ('000)
		BLW	GW	BLW	GW	Area	Man-days	Labor cost*	
3 years mean before strategy	3592	3111	3032 (84%)	625	1,046	2967	32,266	112,933	1,784
4 years mean after strategy	2693	2286	393 (15%)	422	131	2693	45830	162,065	715
Percent cost reduction					87				60

Source: (BADE 2005)

Table 30 Comparison of pre- and post strategy implementation weed control costs: Hunte farm

Period	Cultivated area (ha)	Sprayed area (ha)		Herbicide & spray cost* ('000)		Hand weeding			Total weed control cost* ('000)
		BLW	GW	BLW	GW	Area	Man-days	Labor cost*	
3-yrs. mean before strategy	2215	1735	2049 (93%)	495	707	1678	7372	25,566	1,277
4- years mean after strategy	1685	1143	922 (55%)	268	311	1628	33521	117,358	696
Percent Cost Reduction					56				46

Source: (BADE 2005)

Conclusion and Recommendations

One of the most labor demanding operations in small cereals production is weed control. No single control method will give satisfactory weed control in all small cereal ecologies. It is therefore, important that alternative weed control methods be made available to farmers to increase their options in dealing with weed problems in various agro-ecologies. Increased yield from use of improved small cereal cultivars cannot generally be realized by farmers until improved weed control practices are made part of the overall crop husbandry packages.

The following recent achievements of weed management strategies are recommended for verification and /or scale-up process to alleviate annual and perennial weed problems in small cereal production. The weed management packages are presented separately here but can executed in an integrated manner as appropriate for the various aspects of crop production operations of the target crops.

Benefits of rapeseed and faba bean rotations

Short cycles of wheat / barley/ tef rotations with either dicot crop (i.e., rapeseed or faba bean) are proved beneficial from the perspective of minimizing weed populations and weed competition in small cereals.

Benefits of dry plowing

This cultural practice can been practiced with the intention of controlling perennial weeds such as *Digitaria* and *Cyperus* spp. paricULARY for wheat and tef production areas by exposing their subterranean vegetative growth to direct sun radiation. To prevent re-infestation, infested fields need to be plowed every 3 years.

Benefits of fallowing

Fallowing is the the best option for the management of annual grass weed species which develop resistance to grass killer herbicides. In this practice, land should be left uncultivated usually at longer intervals to break the growth cycle of a target weed (s) that develop resistance to grass-killer herbicides. Fallow-based treatments can be supplemented with non-selective herbicide applications or intensive cyclic grazing. Considering the cost comparative advantage fallowing + intensive cyclic grazing is more preferable.

Benefits of machinery sanitation and seed cleaning

Strict regulations to prevent dissemination of weed seeds from block to block and from farm to farm by cleaning agricultural machineries and use of clean seeds. These practices are very effective to prevent spread of weed seeds thereby contributing to the depletion of soil seed bank of troublesome annual grass and broadleaf weed species.

Benefits of supplementary hand weeding

Supplementary hand weeding can be employed to control weeds, which develop resistance to grass- /broadleaf-killer herbicides. Hand weeding can also be used as a standard preventive mechanism to late-emerging weeds that escaped initial weed control measures within and the peripheries of croplands for the whole farms. Moreover, this practice can serve well as a main component of the integrated weed management strategy, reduce cost of herbicides purchase and spraying; create employment opportunity for communities and maximized profit.

Benefits of alternative grass–killer herbicides in wheat

Two new herbicides Attribut 70 WG (propoxycarbozone-sodium) and Atlantis 30 WG (mesosulfuron-methyl) are recommended as alternate options of Puma Super (fenoxaprop-p-ethyl) but not for complete replacement. Selection of these herbicides for use depends on the merits of their weed control spectrum and dominance of the target grass weeds of a given locality where the herbicides are chosen for intended use. As the problematic grass weed species do not occur simultaneously or uniformly in a given place, it is up to the user to decide the choice of the most appropriate herbicide. In this case, Puma Super is best recommended in areas where *Bromus pectinatus* and *Lolium temulentum* are not dominant weed problems. If the area is severely infested with *Lolium temulentum* the best choice is Atlantis. For areas where *Bromus pectinatus* and *Snowdenia polystachya* are major weed species, it is best to use Attribut. These herbicides can also be used on rotational basis over years to prevent buildup of resistant weed species.

Gaps and Challenges

Among the production bottlenecks of small cereals grassy weeds still ranked first in constraining crop production. The major grassy weeds that required special attention are *Snowdenia polystachya, Phalaris paradoxa, Avena fatua*, *Bromus pectinatus, Digitaria scalarum* and *Cyperus* spp.

Grass weeds were previously considered as minor weeds especially in small and large-scale farming systems, but recently they became economically important. Continuous mono-cropping of cereals or the use of herbicides of similar mode of action for successive years on mono-cropped land favors the dominance of less affected grassy weed species. Monoculture and mono-cropping practices are full of risks. The risks, however, can be averted by judiciously implementing integrated crop production practices.

Controlling grassy weeds and sedges from small cereals' fields should be of prime importance.

Future Prospects

- Yield losses due to weeds and critical period of competition should be studied for semi-arid areas in the rift-valley and other ecologies not covered so far where tef is a major crop and weeds compete for the scarce moisture in the area;
- The main effect of various tillage systems including zero-tillage on weed-crop competition should be studied in relation to their effectiveness in removing weeds;
- Weeding requirements as a result of different cultural practices such as fertilization, planting date crop density and crop rotation need to be quantified under various small cereal production areas;

- Herbicide research has to continue in line with the rapidly growing population and increased pressure on land. New herbicides will continue to be required for future weed problems, which are certain to arise with further changes in agricultural practices, land and water management. The weed flora will continue to change due to increased fertilizer, herbicide usage changes in cropping pattern, which would favor some weeds at the expense of other weeds. Thus, emphasis should be given for further evaluation of the rate and application time of effective and economical broad-spectrum herbicides for small cereals production;
- Where *Striga* occurs on tef, wheat, or barley, full details should be recorded of the cropping history, farmer opinion, and occurrence of *Striga* in sorghum or other crops in the locality. Seeds should be carefully collected from both the crop and the parasite for testing under controlled condition. If the crop seed collected proves more susceptible than standard varieties to samples of *Striga* from sorghum, trials should be conducted in the area to compare crop varieties suitable to the local condition;
- In view of the potential risks of *Parthenium* to small cereals production there is a need to develop control methods (cultural, chemical) through which an integrate management of this devastating invasive weed can be formulated;
- Identification and characterization of the weed flora associated with small cereals need to be done as routine activity on regular basis; and
- Determination of quantitative and qualitative of weed species need to be extended for the various small cereals ecologies not previously covered.

References

1. Alemayehu Assefa, Minale Liben and Tilahun Tadesse. 1999. *Chrysantmum segtum:* Recently identified and highly problematic weed in north Gonder. *Ethiopian Weed Science Society (EWSS) Newsletter 4 (1&2).*
2. Anon. 1987. Report of the National Standing Committee for Parasitic Weed Control. pp. 547-550. *In*: *Proceedings of the Eighteenth National Crop Improvement Conference,* 24-26 Apr. 1986, Nazret, Ethiopia. Institute of Agricultural Research (IAR), Addis Ababa.
3. Asefa Taa and D.G. Tanner. 1998a. Crop rotation and fertilizer effects on weed populations in the southeastern highlands of Ethiopia. *Arem 4: 89-103*.

4. Asefa Taa and D.G. Tanner. 1998b. Stubble management, tillage and cropping sequence effect weed populations in the Southeastern highland of Ethiopia. *Arem 4: 76-88.*
5. Asefa Taa, D.G. Tanner and Duga Debele. 1999. On-farm evaluation of fertilizer response of two recently-released bread wheat varieties in Ethiopia *In CIMMYT*. The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa. Addis Ababa, Ethiopia: CIMMYT.
6. BADE. 2005. Bale Agricultural Development Enterprise progress reports, 1990-2005
7. Birhanu Kinfe. 1986. A review of weed control research activities on Tef in Ethiopia. pp 149-157 *In*: Tsedeke Abate (ed.). A Review of Crop Protection Research in Ethiopia. Addis Ababa, Ethiopia: IAR.
8. Central Agricultural Census Commission (CACC). 2003. Ethiopian Agricultural Sample Enumeration, 2001/02. Statistical report on socio-economic characteristics of the population in agricultural households, land use, and area and production of crops-Part-I. Addis Ababa, Ethiopia.
9. Central Statistical Authority (CSA). 2004. Agricultural Sample Survey of the Federal Democratic Republic of Ethiopia 2003/04. Report on land utilization of private peasant holdings, 'meher' season. *Statistical Bulletin* 302. Addis Ababa, Ethiopia.
10. Dawit Mulugeta, Asefa Teferi and Mosisa Worku. 1993. Determination of optimum time and frequency of handweeding in Tef [Eragrostis tef (Zucc.) Trotter]. pp. 52-56. In: Rezene Fessehaie (ed.). *Proceedings of the 7th Annual Conference of EWSC*. 13-14 April 1989, Addis Ababa, Ethiopia. EWSC: Addis Ababa.
11. Ermias Kebede, 1993. Herbicide use in Small Cereals in the state farm. pp. 8-14. *In:* Rezene Fessehaie (eds). *Proceedings of the 7th Annual Conference of the Ethiopian Weed Science Committee*. 13-14 April 1989, Addis Ababa, Ethiopia. EWSS, Addis Ababa.
12. EWSC. 1987. Yield loss—a summary table. *EWSC Newsletter 2 (4):1*
13. Fasil Reda. 1996. Weed Control Research in Barley. *In*: Hailu Gebre and Joop van Leur (eds). Barley Research in Ethiopia: Past Work and Future Prospects. *Proceedings of the First Barley Research Review Workshop*, 16-19 October 1993, Addis Ababa: IAR/ICARDA. Addis Ababa, Ethiopia.
14. Fasil Reda, Glyn Jones, Chris Parker, Tesfaye Mengistie, Wondimu Bayou, Mark Cheverton and Martin Pullen. 1989. *Striga hermonthica* on tef. *IAR Newsletter of Agricultural Research 4(1): 1-3.*
15. Franzel, S., Mulugeta Mekuria and Chilot Yirga. 1989. Smallholder weed problems and weed control practices: information from four case studies. pp. 25-46. *In*: Ahmed Sherif, Parker C., Stroud, A., and Rezene Fessehaie (eds.). Problems and Priorities for Weed Science in Ethiopia. *Proceedings of the First EWSC Workshop,* Addis Ababa Ethiopia. EWSC, Addis Ababa.
16. Gebre Medhin W/Wahid, Beyenesh Zemichael and Ibrahim Fitwy 1998. The status of the Striga problem in Tigray. *Arem 4: 28-36*.
17. Giref Sahile, Daniel Shamebo and Mohammed Hassena. 1997. Potntial benefit of herbicidal control of grass weeds for small-scale wheat production in Arsi region. *Arem 2& 3: 88-92.*
18. Giref Sahile and Workiye Tilahun. 1997. Results of a weeds survey in the southeastern wheat plain of Asasa woreda. *Arem 2& 3: 100-102.*
19. Giref Sahile. 1998. Evaluation of herbicides for the control of Bromus in wheat. *Arem 4:114-118*.

20. Hailu Gebre-Mariam. 1991. Wheat production and research in Ethiopia. *In:* Hailu Gebre-Mariam, D.G.Tanner, and Mengistu Hulluka, eds. Wheat research in Ethiopia: a historical perspective. Addis Ababa: IAR/CIMMYT.
21. HARC. 1999. Progress Report of Holetta Agricultural Research Center for 1998/1999. Holetta, Ethiopia.
22. IAR. 1991. Holetta Progress Report 1989/90.
23. IAR. 1991. Holetta Progress Report 1991.
24. Jones, B.M.G. 1993. Genetics of resistance to Striga hermonthica. pp. 1-11. *In*: Rezene Fessehaie (ed.) *Proceedings of the 8th Annual Conference of the Ethiopian Weed Science Committee*. 20-21 March 1990, Addis Ababa, Ethiopia. EWSC, Addis Ababa.
25. Kedir Nefo, Feyissa Tadesse and Tlahun Geleto. 1999. Results of a weed survey in the major barley and wheat growing areas of the Bale highlands. *Arem 5: 85-95.*
26. Kedir Nefo, Tilahun Geleto and Feyisa Tadesse. 2005. Alternative weed control Methods for Food Barley in the Bale Highlands. *Arem 6: 69-78.*
27. Melaku Wale. 1993. Weeds of sorghum and tef inRaya-Kobo Awraja, Welo Region. pp. 31-35. *In*: Rezene Fessehaie (ed.). *Proceedings of the Seventh Annual Conference of the Ethiopian Weed Science Committee*, 13-14 Apr. 1989, Addis Ababa, EWSC, Addis Ababa.
28. Rezene Fessehaie 1986. A review of weed Science research activities on wheat and barley in Ethiopia. pp. 121-148. *In:* Tsedeke Abate (ed). A review of crop protection Research in Ethiopia. Addis Ababa, Ethiopia: IAR.
29. Rezene Fessehaie. 1989. Research approach and monitoring weed management practices in Ethiopia. pp. 114-119. In*: Proceedings of the Twentieth National Crop Improvement Conference*, 28-30 Mar. 1988, Addis Ababa, Ethiopia. Institute of Agricultural Research (IAR), Addis Ababa.
30. Rezene Fessehaie and Zerihun Tadele. 2001. Weed Research in Tef. pp. 201-213. *In*: Hailu tefera, Getachew Belay, and Mark Sorells (eds). Narrowing the Rift: Tef Research and Development. EARO, Addis Ababa, Ethiopia.
31. Rezene Fessehaie. 2001. Weed Management in Vertisols. pp.185 -207. In: Paulos Dubale, Asgelil Dibabie, Asfaw Zeleke, Gezahegn Ayele and Abebe Kirub (eds). Advances in Vertisol Management in Ethiopian Highlands. EARO, Addis Ababa.
32. Rezene Fessehaie and Yohannes Lema. 2003. Control of *Snowdenia polystachya* in large scale wheat production: Herbicide Resistance in Context. pp. 79-88. *Proceedings of the Agronomy Workshop,* 20-21 March 2000, Melkassa, Ethiopia. Bale Agricultural Development Enterprise (BADE), Addis Ababa.
33. SARC 1992. Sinana progress report 1991.
34. SARC 1993. Sinana progress report 1992.
35. SARC 1994. Sinana progress report 1994.
36. SARC 1995. Sinana progress report 1995.
37. SARC 2000a. Sinana Agronomy Food Barley Progress Report 2000.
38. SARC 2000b. Sinana Agronomy Bread Wheat Progress Report 2000.
39. SARC 2001. Sinana Agronomy Bread Wheat Progress Report 2001.
40. SARC 2005a. Sinana Agronomy Progress Report 2005.
41. SARC 2005b. Sinana progress report 2005.
42. SPL. 1988. Progress report for 1987/88. Ambo, Ethiopia.
43. Stroud, A. 1989. Weed management in Ethiopia, an extension and training manual. FAO, Technical Cooperation Programme, Rome. 237 pp.

44. Takele Negawo. 2001. Competition effects of major weeds on yield and yield components of Barley. M. Sc. Thesis: Alemaya University, Alemaya, Ethiopia. 85 pp.
45. Tanner, D.G., Giref Sahile. 1991. Weed control research conducted on wheat in Ethiopia. pp. 235-275. In: Hailu Gebre-Mariam, D.G.Tanner, and Mengistu Hulluka, (eds). Wheat research in Ethiopia: a historical perspective. Addis Ababa: IAR/CIMMYT.
46. Tanner, D.G., Giref Sahile and Workiye Tilahun. 1995. Competitive ability of Ethiopian spring bread wheat cultivars with *Avena fatua* L. *African crop science J.3 (1): 83-91.*
47. Tanner, D.G., Giref Sahile and Workiye Tilahun. 1996. Competition of four Ethiopian bread wheat cultivars with varying densities of wild oat. pp.77-95. in: Tanner, D.G. T.S. Payne and O.S. Abdalla, eds. *The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa.* Addis Ababa, Ethiopia: CIMMYT.
48. Tanner D. G. and Giref Sahle 1997. Competition among Ethiopian bread wheat cultivars and varieties densities of *Avena fatua* L. effects on nitrogen and phosphorus up take and utilization. *Arem 2& 3: 45-60.*
49. Tanner. D.G. 1999. Principles and prospects for integrated weed management in the wheat production systems of Ethiopia. *Arem 5: 27-65.*
50. Taye Tessema and Yohannes Lema. 1998. Qualitative and quantitative determination of weeds in tef in west Shewa zone. *Arem 4: 46-60.*
51. Taye Tessema and D.G. Tanner. 1999. Determination of economic threshold densities for the major weed species competition with bread wheat in Ethiopia. In: CIMMYT. *The Tenth Regional Wheat Workshop for Eastern, Central and Southern Africa.* Addis Ababa,
52. Tilahun Mulatu and Aleligne Kefyalew. 1993. Alternative weed control methods in tef (Eragrostis tef) in Nazret area. pp. 22-27. *In*: Rezene Fessehaie (ed.) *Proceedings of the 8th Annual Conference of the EWSC*, 20-21 Mar. 1990, Addis Ababa, Ethiopia. EWSC, Addis Ababa.
53. Tilahun Tadious, Tadesse Eshetu and Tesfa Bogale. 1997. Effect of tillage and hand weeding on weed control and yield of tef. *Arem 2&3: 110-115.*
54. Unger, J. 1989. Problems and prospects of weed management in Ethiopian cereal production. Beitrage zur Tropischen Landwirtsdchaft und Veterinarmedizin. 27(2):227-233. (in English and summary in German, Russian, French and Spanish).
55. Wilson, A.K. 1989. The post emergence selectivity in warm-climate species of some recently developed herbicides; AC 263499, BAS 514 00H, CGA 131036, DPX-L5300 and DPX-A7881. Technical Report, Institute of Arable Crops Research, Long Ashton Research Station, No. 100, UK. 50
56. Wondimu W/Hanna, Shemelis Hassen and Ayenalem Ayele. 1999. The distribution of *Striga* in Oromiya Region. *Arem 5:75-84.*
57. Zerihun Tadele. 1993. Effect of minimized tillage and modified weed management on tef production. MSc. Thesis, Alemaya University of Agriculture.
58. Zerihun Tadele. 1996. Evaluation of non-selective herbicides for use in no-tillage Tef [*Eragrostis tef* (Zucc.) Trotter]. *Arem 1:48-56.*

Review of Research on Post-Harvest Pests

Abraham Tadesse[1], Amare Ayalew[2], Emana Getu[3] and Tadele Tefera[2]

[1] Eithiopian Institute of Agricultural Research, P. O. Box 2003, Addis Ababa, Ethiopia
[2]Haramaya University, P. O. Box 38, Dire Dawa, Ethiopia;
[3]Addis Ababa University, P. O. Box 1176, Addis Ababa, Ethiopia

Introduction

The major durable crops produced in Ethiopia constitute cereals, grain legumes, and oilseeds. The principal cereals are maize, sorghum, tef, wheat, barley and millets. The major grain legumes include common bean, faba bean, field pea, chickpea and lentil. Cowpea, pigeon pea, grass pea, soybean and mung bean are also important in some areas. Among the oilseeds nigerseed (noug), sesame, sunflower, safflower, groundnut, and rapeseed are the most common. These crops are produced mostly during the main growing season which extends from June up to October. Some crops are also planted during the short rains (March to May). In such situations where production is seasonal, food supply and food security are mainly dependent on good storage. It is estimated that about 60 to 90% of the produce is retained by the farm household and stored for 6 to 12 months in Ethiopia (Abraham, 2003).

The relatively low grain moisture contents of cereals, pulses and oilseeds make them durable in storage. However, they are subject to post-harvest losses and deterioration due to biotic and abiotic factors. Insect pests, fungi and rodents constitute the major biotic agents that cause serious problems in storage. With the exception of tef, all of these crops are susceptible to post-harvest losses caused by insect pests. Tef is not susceptible to primary insects in storage (JATS, 1963; McFarlane, 1969a; 1969b; McFarlane and Dobie, 1972), although *Tribolium* spp. are known to infest it. Numerous species of fungi associated with stored grains especially in underground pits have also been recorded (Gilman, 1968; Niles, 1976; Solomon, 1983; Amare, 2002; Mashilla, 2004). However, reports on rodents as post-harvest pests are hardly available, despite their importance in most localities.

Ethiopia has experienced food deficit for the last four and half decades. Substantial amount of food is imported every year (on purchase or donation) to alleviate the deficit (Abraham, 2005a). On the other hand, tremendous amount of food is lost to a number of factors in storage. A national figure for post-harvest losses is not available. Estimations based on limited observations put the grain losses in cereals and pulses due to insect pests alone at about 10 to 21% (Abraham, 2005a). In individual cases, losses can be much higher than these estimates. Losses caused by storage fungi especially in underground pits are tremendous. Analysis of food aid, food import, and food security figures versus post-harvest losses suggest that addressing storage losses could have a significant impact on food security and farm-income without increasing pressure on land (Abraham, 2005a).

The importance of post-harvest losses in developing countries has been recognized worldwide since 1975 when the United Nations General Assembly passed a resolution committing member states to reduce post-harvest food losses by 50% by 1985 (Harris and Lindblad, 1978). In Ethiopia, there was no research work on stored product pest management (except a few preliminary studies) until the late 1980s when some graduate students took the problem as their thesis research topic. Since then several areas of research have been covered by different researchers in different institutions. This review summarizes results of research on post-harvest pests of cereals, legumes and oilseeds in this country. Any availabe information on post-harvest pests of horticultural crops are also touched. Finally, attempts are made to analyse research gaps and to suggest the way forward.

History of post-harvest research

Research on post-harvest pests is of a recent history in Ethiopia (Abraham, 1991; Anon., 1993). Well-organized work in other areas of crop protection began with the establishment of the then Institute of Agricultural Research (IAR) in February 1966. IAR (now the Ethiopian Institute of Agricultural Rsearch, EIAR) has ever since undertaken research on the most important species of pests in the field (Davidson, 1968**;** IAR, 1981). However, the special problems associated with post-harvest losses have been the concern of the Plant Protection and Regulatory Division of the then Ministry of Agriculture (IAR, 1981); though, limited studies on storage pests were made in staggering manner since early 1960s in some higher learning institutions (Hill, 1963; JATS, 1963).

The early studies on post-harvest pests include that of G. A. Gilman of the Tropical Stored Products Research Center, Slough, England, who studied the incidence of mould-induced toxins on stored garins (Davidson, 1968). J. A. McFarlane from the same center made a study of stored products problems in Ethiopia (IAR, 1969; McFarlane, 1969a; 1969b).

Considerable efforts were made to reduce losses under the Freedom from Hunger Compaign (FFHC) of the early 1970s (UNDP/FAO, 1982). As a result of a detailed work by expatriate and local counterparts, a handbook on *Grain Storage* (Anon., 1972), edited by R. O. S. Clarke, was published through the Extension, Project Implimentation Department (EPID). Bendell (1972) indicated that in addition to extension and survey works, FFHC team carried out some investigational studies. Most investgations included assessment of insecticidal treatments in stores, but some specific problems were also studied. In Keffa province, experiments were conducted to improve the drying of maize prior to final storage and to develop methods of storing imperfectly dried maize. In Harar, attempts were made at improving underground pit stores to reduce moulding, and the importance of type and management of pit stores was investigated.

Walker and Boxall (1974) made the first comprehensive survey of insects associated with stored products in Ethiopia during 1971–1972. A short unpublished survey was also carried out by McFarlane (1969a; 1969b). Detailed studies on stored product pests further appeared in the country in the late 1980s and early 1990s (Abraham, 1991; Adhanom and Emana, 1989; Emana, 1993a; Teshome, 1990). Since then the problem of post-harvest pests gained relatively better emphasis by researchers in different institutions, although not well coordinated (Abraham, 2003).

Post-harvest pests of stored grain

Most surveys on post-havest pests focused on recording insect pests, and to a lesser extent, on fungi associated with stored grain. It is obvious that research on storage problems caused by rodents and birds has been almost non-existent so far in Ethiopia. Rodents were reported to be important based on sideline information from surveys of other stoarge pests in different parts of the country (CADU, 1968; ARDU, 1982; Abraham, 1991; 2003; Ferede and Tsedeke, 1992; Berhanu, 1997; Abdirahman, 2002). In few other reports, birds and rats were considered to be important in storage (ARDU, 1982).

Arthropod pests of stored grains

Over the years, more than 100 species of arthropods associated with stored grains have been recorded in Ethiopia (Appendix 1). Out of these, only a dozen species are known to be of major importance. Certain species recorded as uncommon might be important in particular conditions of storage and/or in the presence of the major pest species. The remaining are minor pests, scavengers or fungus feeders. Further periodic surveys would be needed to monitor the status of the common pest species and to ascertain if certain species so far recorded as uncommon have become important.

By far the largest group of storage pests recorded are beetles (Coleoptera) followed by moths (Lepidoptera). *Sitophilus zeamais*, *S. oryzae*, *Acanthoscelides obtectus*, *Callosobruchus chinensis*, *Zabrotes subfasciatus*, *Tribolium* spp., *Carpophillus* spp., and *Cryptolestes* spp. from the Coleoptera and *Sitotroga cereallela*, *Ephestia cautella*, *Plodia interpunctella*, and *Phthorimaea operculella* from Lepidoptera were recorded as major pests. Both *S. zeamais* and *S. oryzae* were common on maize and sorghum samples obtained from on-farm stores. However, *S. oryzae* occurred on neither maize nor sorghum samples obtained from the Bako Research Center farm store (Abraham, 1991; 1996a; 1997). Bruchids pose serious post-harvest problems to grain legumes. *Zabrotes subfaciatus* was recorded on haricot bean in Ethiopia for the first time by Abraham (1991; 1997) and later by Ferede (1994). Tsedeke (1995) mistakenly reported that it had not been recorded until 1994. Previously, only *Callosobruchus* spp and *A. obtectus* were known to be major pests of grain legumes in this country (Tsedeke et al., 1982, Tsedeke, 1990). Infestations by some of the abovementioned pests start in the field long before harvest (McFarlane, 1969a; Abraham, 1991; 2003), and is then carried over to the store where populations can rapidly build up.

Most post-harvest surveys that studied storage pests generally followed stratified sampling in which individual farmers (for group or individual interview and/or for providing grain samples) were identified from selected peasant associations in pre-determined weredas (districts). Certain surveys attempted to categorize sampling sites based on altitude or agro-ecologies: *Dega*, *Woinadega* and *Kolla*.

Arthropod pests of stored cereal grains

The species of storage arthropods associated with different cereal grains were studied in different parts of Ethiopia by different researchers (Appendix 1). Surveys on farm-stored maize conducted in western and northwestern Ethiopia (Gojam, Wellega, Gambella, Illubabor, Jimma, Assosa and Shewa) during 1989 and 1993 showed that *Sitophilus zeamais*, *S. oryzae*, *Tribolium*, *Carpophillus*, and *Cryptolestes* spp., *Sitotroga cereallela*, *Ephestia cautella*, and *Plodia interpunctella* were the most common and dominant pests (Adhanom and Abraham, 1985; Abraham, 1991; 1993a). Recently numerous arthropods associated with farm-stored maize were recorded (Abraham, 2003; Abraham and Basedow, 2004).

In 1986, Adhanom and Emana (1989) sampled maize, sorghum, wheat and barley from farmers´ cooperative or household stores in southern Ethiopia (Sidama, Gardulla and Gofa awurajas). Accordingly, *Sitophlus zeamais* and *Sitotroga cerealella* were major pests of maize and sorghum in most areas. Heavy damage by *T. castaneum* and *Rhizopertha dominica* were also reported on wheat (Adhanom and Emana, 1989). Further surveys of storage pests were conducted in southern Ethiopia (Borena, northern Omo and Sidamo) during the 1986/87 and 1987/88 seasons (Emana, 1993a; Emana, 1993b; Emana and Assefa, 1998). Based on the survey, *Sitophilus* spp. and *Sitotroga cerealella* were the major pests of maize and sorghum, whereas wheat was heavily infested with the lesser grain borer. Mekuria (1995) reported *Sitophilus*, *Sitotroga cerealella*, *Carpophillus*, *Tribolium*, *Cryptolestes* spp. and *Plodia interpunctella* as the most widely spread storage pest of maize in some maize growing areas of southwestern Ethiopia during the 1992 and 1993 seasons. Insect pests of stored sorghum in West Shewa, East and West Wellega zones in the 1996/97 and 1997/98 seasons were recorded in several reports (Firdissa and Abraham, 1998b; 1999b; OADB-ARCS, 1998a; 1998b). Lemma et al. (1997) reported that in relatively low altitude areas of Bale (Alaba, Dodolla, Agarfa and Jara) *S. oryzae* and *S. granarius* were important. Berhanu (1997) surveyed pests of stored grain in 17 weredas in southern, eastern, central and western zones of Tigray in 1996. A number of common storage insects were mentioned to be important in all areas surveyed.

Tafesse (2004) sampled maize, sorghum, wheat, barley and pea from Arsi Zone in 2000 and 2001. The important insect pests were *Sitophilus* and *Oryzaephilus* spp. and *Sitotroga cerealella* on wheat, *Plodia interpunctella* on barley, *Sitophilus* and *Tribolium* on maize and sorghum. Earlier surveys in Chilallo indicated *S. zeamais* as a dominant pest of stored wheat (IAR, 1989; 1990c). *S. zeamais* was a serious problem at Munissa with the infestation of 57% at Metti and 42% at Degaga (IAR, 1992).

Abdirahman (2002) recorded *Sitophilus zeamais, S. oryzae, S. granarius*, *Tribolium* spp. and *Oryzaephilus surinamensis* as storage pests of maize and sorghum around Jijiga in eastern Ethiopia. However, the identifications were reported to be made using identification keys only and the insects are listed to species level, which cannot be trusted, especially for the two *Sitophilus* speices that cannot be distinguished from each other morphologically. This should be confirmed by further research. Moreover, the occurrence of *S. granarius* at the altitudes covered by the study is very questionable. The granary weevil, *S. granarius* is known to be limited in highland areas (2,500–3,000 m) (McFarlane, 1969a). Walker and Boxall (1974) recorded it only from Addis Ababa. Lynch et al. (1986) found that *S. oryzae* was the only *Sitophilus* species and the major pest in underground pits in Alemay Wereda, while Lemessa et al. (2000) reported *S. zeamais* as the major pest in underground pits in the same wereda. The variation in reports should be confirmed by proper identification of the species.

In a survey undertaken in 1996 as part of a broader regional study of crop pests in Amhara Region, five crops stored for different periods (0.5–12 months) in various storage structures were sampled across six agro-ecological zones (seven weredas) and grain weight losses were determined (Table 4) (SSEAD, 1997).

The greater grain borer (*Prostephanus turncatus*) which was introduced in Africa in 1970s and known to be very destructive pest of stored maize (and cassava) has not been recorded in Ethiopia to date (Abraham, 1991; 1996a; 1997; 2003), and remains as a quarantine pest. The information regarding the biological control of this pest presented in EARO annual reports for the periods 2001/02 and 2002/03 is a mistake in identification. The Khapra beetle (*Trogoderma granarium*) is also a quarantine pest in Ethiopia, although Gentry (1965) reported it as a minor pest on barley and Hill (1965) recorded it as common on wheat (Adugna and Kemal, 1985). Recently, it was reported from one sample of maize obtained from the open market in Maichew (Berhanu, 1997). There is a need for further confirmation as it has not been reported later.

The level of pre-harvest infestations of maize by both *S. zeamais* and *Sitotroga cerealella* were studied in three peasant associations (1510 to 2000 m) around Awassa (Mesele, 2003; Mesele et al. 2003). Abraham (1991; 1997) observed severe weevil infestation in fields closer to storage facilities, and the proportion of ears infested was related to the distance from the crop edge and the infested stores. Girma (2006) observed weevil infestations in fields far from storage facilities in the Bako area. Earlier survey in the same area indicated that about 75% of farmers noticed infestation in the field to start over two months before harvest (Abraham, 1991; 1997).

Arthropod pests of stored grain legumes

Zabrotes subfasciatus was first reported on haricot bean in 1989 (Abraham, 1991;1997), and there has been several studies since then (Ferede and Tsedeke, 1992; Tsedeke, 1995). *Acanthoscelides obtectus*, and *Zabrotes subfasciatus* were the major pests of haricot bean in eastern and southern Shewa (Ferede, 1994; Ferede and Tsedeke, 1992). From surveys of storage pests conducted in southen Ethiopia (Borena, northern Omo and Sidamo) during the 1986/87 and 1987/88 seasons, *Callosobruchus* spp. were reported to be important on haricot bean (Emana, 1993a; 1993b; Emana and Assefa, 1998).

Survey of faba bean insect pests in Ethiopia between 1980 and 1982 indicated that *Callosobruchus chinensis* and *C. maculates* were major and minor pests of the crop in storage, respectively (IAR, 1985a). IAR (1990a) reported both *C. chinensis* and *C. maculates* are key pests of haricot bean and cowpea in storage. Another survey conducted in Chilallo in June 1989 indicated that *C. chinensis* was present in most of the faba bean stores visited, with higher infestations in warmer areas (IAR, 1990b; 1990d; 1991b). In the former Yerer and Kereyu *awuraja* of Shewa (1800–1900 m), *C. chinensis* was the only pest of stored faba bean during 1987 and 1988. This pest was also recorded in Chilalo *awuraja* of Arsi, and Selalle *awraja* of Shewa (2200–2800 m) but infestations were very low owing to cooler temperatures that prevail throughout the year (IAR, 1987d; 1987e; Tadesse,1992.).

Survey of 200 farmers' stores in mid (1750–2350 m) and high (> 2350 m) altitude areas of Ethiopia showed that faba bean, field pea, chickpea, lentil and grass pea (*Lathyrus sativus*) were attacked by *C. chinensis,* whereas field pea was attacked by the pea bruchid (*Bruchus pisorum* [L.]) (Mekasha, 2004). Surveys conducted for four years **(**2001–2004**)** on the pea bruchid in different parts of the country revealed that the pest occurs in all areas of the Amhara, Tigray and Oromiya Regional States (EIAR, 2005). Meheret (2003) studied the status of bruchids on chickpea in Enemay Wereda, Amhara Region. Tafesse (2004) recorded *Acanthoscelides* sp. from samples of pea obtained from Arsi Zone. *Bruchus pisorum* attacks peas in the field and infestations may persist for a short time after harvest. However, it is impossible to multiply it in stores. Worku (2002) reported that the pea bruchid was first observed in Ibinat area around 1992. Muluemebet (2003) assessed the status of the cowpea beetle, *C. maculates*, on cowpea in Gambella and found it to be the major pest of the crop. *Tribolium* spp. were also recorded in Gambella area.

Storage insect pests of oilseeds

Apart from accounts of post-harvest infestation of unthreshed sesame seed by the plant bug *Elasmolomus (Aphamus) sordidus*, no instances were encountered of significant infestation of oilseeds. *E. sordidus* was recorded as a major pest of sesame in Humera (IAR, 1970; 1972b; 1975; 1977b and Crowe et al., 1977). It may cause shrivelling and increase in free fatty acid concentration in the seeds (Crowe et al., 1977). According to IAR (1972b), levels of infestation vary very widely from year to year: 1968 (IAR, 1970), 1970 (IAR, 1972b) and 1971 (IAR, 1975) were outbreak years. The bug feeds on the seeds in the ripening pods or stacks of recently cut sesame. The outbreak at the end of 1971 was on bags of stored sesame (IAR, 1975). *Tenebrioides mauritanicus*, *Oryzaephilus* *mercator*, *Tribolium castaneum* and *Cryptolestes pussillus* were recorded on sunflower (McFarlane, 1969a, 1969b). Kemal et al.(1985) also reported the occurrence of *Carpophilus dimidiates* and *T. mauritanicus* on sunflower in the field. Moreover, Getinet et al. (1997) reviewed the occurrence of the rice moth (*Corcyra cephalonica*) and *Tribolium* spp. as major pests of groundnuts and sesame in storage.

Storage insect pests of other crops

Phthorimaea operculella, commonly called potato tuber moth (PTM), is a pest of potato (mainly in the warmer areas) in the field and in storage. The pest is present throughout the year, although populations peak in some months and decline in others (Adhanom, 1983; Adhanom et al., 1985; IAR, 1991a; 1995a; Bayeh and Tadesse, 1994; Crowe et al., 1977). Monitoring PTM in the field and store at Holetta using four sex pheromone traps each placed in about 250 m^2 area for four consecutive years showed that the pest population was higher in the field than in stores in some areas (EARO, 1998a). The storage population was found to be high in August and lower in July and December (Adhanom et al., 1985; IAR, 1991a; 1995a; Bayeh and Tadesse, 1994). Similar surveys conducted in 1997 around Welmera and Tikur Inchini districts indicated that PTM was the most frequently found pest of potato in the field and in storage, although the level of infestation was low, in contrast to warmer areas like Awassa and Arsi-Negele (Adhanom et al., 1985). The highest PTM damage recorded at Holetta was 3 and 5% in defused light stores and in the field, respectively (EARO, 1998a). PTM has been observed in the cooler areas of Injibara at an elevation of 2600 m beyond its natural preference of warm climate, with the highest record in July. At Adet and Debre Tabor, higher levels of PTM population were recorded during the second week of August (Sheno Research Center, 1999).

Dried pods of hot pepper were observed to be severely damaged by the larvae of the Indian meal moth at the Bako Research Ceneter farm-store in 1995 (Abraham Tadesse, personal observation). The larvae totally remove the fleshy part of the pod. A similar observation was also reported latter (OADB-ARCS, 1998a).

The cigarrette beetle (*Lasioderma sericorne*) was reported to be important on tobacco (McFarlane, 1969a). Moreover, IAR (1976a) reported that the problem in tobacco reserach grading room was controlled by fumigation with phosphine and dipping the room curtain in 1% carbaryl suspension.

Survey of mycobiota on stored grains

Fungi are the dominant microorganisms involved in grain storage. Traditionally, fungi associated with grains are classified into two categories: field fungi and storage fungi. The divivsion into storage and field fungi is not taxonomically justified and is based on moisture requirements of the fungi. Storage fungi are species that proliferate at lower grain moisture levels and tend to replace the fungi found in the growing crop. Amare (2002) reported that the distiction between field and storage fungi in cereal grain samples from Ethiopia was not clear-cut. On the other hand, Mashilla (2004) found that at early stage of storage, the frequency of field fungi was high in samples of all store types and the frequency of some species decreased through time. Some of the field fungi may cause discoloration and reduction in germination of cereal grains but they do not actively develop and do not usually cause deterioration of dry grains in storage (Mashilla, 2004).

The major storage fungi associated with grain comprise about a dozen species of *Aspergillus* and several of *Penicillium*. A number of species of these genera have been reported from Ethiopian grain samples (Niles, 1976; Solomon, 1983; Amare, 2002; Mashilla, 204). The most important mycotoxin producing fungi after harvest also belong to these genera (Amare, 2002). Under favourable conditions, certain strains of *Fusaria* (which are normally field fungi) may proliferate in storage and produce mycotoxins as well (Amare, 2002). The species of fungi isolated from cereal grains, particularly barley, wheat, sorghum and tef samples, are presented in Appendix 2.

Fungi associated with sorghum grain stored in underground pits attracted the attention of a number of researchers (Gilman, 1968; Gilman and Boxall, 1974; Niles, 1976; Solomon, 1983; IAR, 1983; Solomon and Mengistu, 1984; Lemessa et al., 2000; Amare, 2002; Mashilla, 2004). Niles (1976) recorded 51 species of mainly storage and soil fungi from sorghum of 1971 harvest stored for one year in experimental pits in Harar province. Twenty-seven (over 50%) of the species isolated belong to the genera *Aspergillus*, *Penicilium* and *Fusarium*, which are the main mycotoxin-producing genera. More than 63 different types of fungi, predominantly members of the genera *Aspergillus* and *Penicillium* and yeasts, were recorded on sorghum grain stored in underground pits at Alemaya (Solomon, 1983; IAR, 1983; Solomon and Mengistu, 1984). Lemessa et al. (2000) recorded 17 genera of fungi on sorghum stored in traditional underground pits while Mashilla (2004) isolated numerous microorganisms from sorghum samples obtained from underground pits in eastern Ethiopia. Amare (2002) determined the mycobiota of sorghum stored in underground pits in Wello (North) and Hararghe (East). In addition, this work also analysed the fungal biota of barley, wheat and tef samples collected at harvest and from various storage systems in central and southeastern Ethiopia (Appendix 2).

From sorghum grain samples obtained from differnt aboveground storage containers in West Shewa, and East and West Wellega Zones, the common fungi isolated were *Fusarium*, *Aspergillus*, *Penicillium*, *Alternaria* and *Helmintosporium* species (OADB-ARCS, 1998a). Mengistu (1982) conducted series of surveys in major sorghum growing areas (1400-1960 m) in Ethiopia from 1972 to 1980 and reported that among the fungi recorded *Fusarium moniliforme*, *Aspergillus* spp., *Penicillium* spp., *Aspergillus niger*, *Alternaria* spp. and *Rhizopus* spp. caused damage in stored grains and also reduced seed germination.

Fusarium, *Aspergillus* and *Penicillium* were the most common genera isolated from maize samples collected around Shashemene and Alemaya (Tesfaye, 1997; Tesfaye and Dawit, 1999; 2000). The researchers found three toxic species of *Fusarium* (*F. moniliforme*, *F. subglutinans*, *and F. graminearum*) to be highly associated with maize samples. A previous survey by Dawit (1982) also indicated that *Fusarium* was the most common genus in maize grain samples. *F. moniliforme* and *F. graminearum* cause maize ear rot in Ethiopia (Tecklemariam, 1985).

Pathogens associated with durum wheat seeds, seed germination and effects of storage systems in fungi development were studied at Debre Zeit Agricultural Research Center (DZARC, 1988). *Aspergillus* and *Penicillium* spp.and the field fungi (*Alternaria*, *Fusarium*, *Helminthosporium*, *Phoma* and *Rhizopus* spp.) were the major fungi identified. Another study on mycobiota associated with wheat seeds obtained from the improvement program and farmers stores in 1987/88 revealed the 15 genera of fungi (DZARC, 1989) with various frequencies of occurrence. These included *Alternaria*, *Aspergillus*, *Cladosporium*, *Epicoccum*, *Fusarium*, *Helminthosporium*, *Penicillium*, *Phoma* and *Rhizopus* spp., among others (DZARC, 1990). *Fusarium oxysporum* and *Rhizoctonia bataticola* are known to cause wheat diseases (DZARC, 1994; 1996).

In chickpea seeds of 1991 harvest sampled from the field, *Alternaria*, *Aspergillus*, *Botrytis*, *Coletotricum*, *Fusarium*, *Helminthosporium* and *Penicillium* spp. were found in association with the grains (DZARC, 1991). *Alternaria* was the most frequent. *Botrytis* and *Colletotrichum* spp. were recorded from samples at lower frequency (< 1%), but they were not reported previously from chickpea seeds in Ethiopia. It is known that *Aspergillus* and *Penicillium* spp. could cause seed deteriration of chickpea in store.

The most common fungi associated with farmers' samples of lentil seed from Shewa Adminstrative Region were *Alternaria*, *Aspergillus*, *Helminthosporium* and *Penicillium*, spp. *Ascochyta*, *Colletotrichum*, *Fusarium*, and *Phoma* spp. also occurred in the samples (DZARC, 1991; 1994). From lentl seeds obtained from granaries and markets in Ada, Akaki, Bora, Limu, Gimbichu and Shenkora areas, *Aspergillus niger*, *Fusarium oxysporum*, *Penicillium* spp., *Rhizoctonia bataticola* were isolated (DZARC, 1994).

Amare et al. (1995) identified 32 species of fungi belonging to 19 genera from 24 groundnut seed samples obtained from markets of Bisidimo, Babile and Gursum in Hararghe province of eastern Ethiopia. Dawit and Berhanu (1985) reported the occurrence of aflatoxin producing species *Aspergillus flavus* in tef, barley, maize and sorghum samples collected from Addis Ababa, Shashemene, Jimma and Dire Dawa, but they did not analyse the samples for mycotoxins.

In most of the investigations cited above, fungi were isolated using whole seed plating method and qualitative data on the species of fungi associated with the seed samples were presented. Moreover, data on the percentage of seed infected by a particular fungus (on species or genus basis) and the frequency of occurrence among the samples were given. Some surveys used several types of media for isolating fungi. The recent report by Amare (2002) employed dilution-plating method and presented quantitative data whereby colony-forming units per gram of seed (cfu/g) was used to express the extent of seed invasion by fungi.

Grain storage systems

Farmers` grain storage methods

Farmers in Ethiopia use different traditional storage containers. These include gotera, gotha, (also known as dibignit, gumbi, godo, gushgush), kefo (togogo, kirchat, schirfa), jute or Hessian sacks, skin bags (aqomada/loqota, aybet), clay jars, gourds, wooden boxes, metal drums/barrels, and underground pits. The storage systems used by farmers in different parts of the country have been reported for most of the major crops (Gilman, 1968; Gilman and Boxall, 1974; ARDU, 1982; Abraham, 1991; 1996b; 1997; 2003; 2005c; DZARC, 1991; Ferede, 1994; Firdissa and Abraham, 1999b; Berhanu, 1997; Meheret, 2003; Muluemebet, 2003).

Some of the traditional storage containers such as clay jars and gourds have capacities of a few kilograms and are generally used for storing small amounts of seed in the house (Abraham, 1991; 2003). Farmers store maize in different forms: on the cob with husks intact, husks removed or shelled or combinations of different forms. The form of maize to be stored determines the method and type of storage containers to be used. Shelled or threshed grain is stored in a container plastered from inside and may be treated with insecticides. Suspending cob maize and head sorghum under the ceiling over the fire place, under the eve of the roof or in tree branches in the field are also commonly practiced methods of storage (Abraham, 1991).

Gotera (above ground bin) is the most commonly used storage container in most parts of the country. It is located outdoor. It is usually a cylindrical structure, flat or conical at the base, placed on raised platform or stones and covered with a conical thatched roof. The size of *gotera* could vary depending upon the volume of production. The capacity of gotera is estimated to be between 1 to 4 t (IAR, 1990b). The unplastered bin type is used for storage of unthreshed maize, which requires further drying.

Gotha, gumbi, dibignit, godo, and gushgush are names given to nearly similar type of containers (capacities may vary) in different parts of the country. These are typically made of mixtures of mud, cow-dung and tef straw. Their sizes vary and they are usually kept indoors. The small ones are made of a single piece, whereas the big ones (with a capacity of more than three tons) are usually made of rings (known as *dengel* in some localities) stacked one above the other so that the vessel can be taken to pieces and reassembled elsewhere. It may have grain outlet spout in some localities. Kefo, togogo or kirchat are also similar to the above but these are usually made up of splitted reeds, bamboo or twigs and may be plastered with cow-dung from inside and are kept indoors or outside abutting on the wall of the house. It is similar to gotha in shape and also may have a spout at the lower side for grain withdrawal.

Ferede and Tsedeke (1992) and Ferede (1994) sampled 100 farm households in Adami Tulu, Buta Jira, Lume-Bora and Adama Bosset awrajas, and they found that the principal containers used for storage of haricot bean were dibignit (34%), gotera (24%), bag (34%) and clay pot, basket and tin together constitute 9%. A survey of five peasant associations in Enemay Wereda (2400 m) revealed that chickpea farmers store their produce for about 8 to 10 months using three types of containers: gotha (80% of the farmers), sacks (13%) and clay pots (7%). On the other hand, most stores (95%) were located indoor (Meheret, 2003). In Debre Zeit, Dukem and Mojo areas, jute sacks were common storage facilities, whereas gotera, dibignit, few jars and very few barrels were used for stoarge of lentil (DZARC, 1991). In Gambella, farmers stored their cowpea for a year or more in clay pots, gourds or by suspending the pods underneath the roof over the fireplace (Muluemebet, 2003).

Extensve surveys covering three agro-ecologies (Dega, Woinadega and Kolla) in Tigray revealed that the traditional storage containers used by farmers in the Region are *gotera*, *golota, shirfa*, *maeqen, godo, walla*, underground pit, clay pot, metal drum, Hessian or jute sacks, skin bags (*Aybet* or *loqotta*) (Berhanu, 1997). Most of these storage containers were found to be common in most areas visited, while pits are used only in the southern zone (Raya Azebo Wereda) for storage of sorghum. Pit storage was introduced in Shiraro Wereda of the western zone in 1981 but failed because of termite problems (Berhanu, 1997). *Goleta* is a wooden structure attached to part of the house wall from inside and may have different compartments for storage of different crops. This type of storage is used in Hintalo-Wajirat Wereda. *Maeqen* is an indoor structure made of stones and plastered with mud. It has grain withdrawal hole at the lower side. *Walla* is a raised structure used for storage of unthreshed sorghum or cob maize for a few months (it facilitates drying). It is used in the western zone of Tigray, and S. *cerealella* is reported to be a problem in this type of storage (Berhanu, 1997), as expected with storage of cob maize or head sorghum.

Underground pits are used in many parts of the country (parts of Hararghe, Somalia, Wello, Tigray, Gonder and in the SNNP Region) (Boxall, 1974; Abraham, 2003). In these areas, there is shortage of wood for the construction of aboveground structures for grain storage suggesting that the use of pits should be encouraged though improvements are mandatory. During a nation-wide survey, more than 12% of the interiewed farmers reported that they use pit stores (Abraham, 2003). Most peasants in Hararghe store their sorghum and sometimes maize in traditional underground pits. Boxall (1974) indicated that in Hararghe province of that time 70–75% of the farmers used underground storage pits exclusively and 8–12% used it in conjunction with other storage methods. Similar observations were made by other researchers (Gilman, 1968; Boxall, 1974; Gilman and Boxall, 1974; Lynch et al., 1986; Niles, 1976; Solomon, 1983; Fikadu, 1994). Thus, it appears that the proportion of farmers using underground pits has increased over the years. Recently, from a survey conducted in Jijiga area Abdirahman (2002) reported that pits and bags were the only storage continers used in all of the sites visisted.

Underground storage pits

Underground grain storage pits were studied relatively more intensively than other storage systems in Ethiopia. Survey results and reports on monitoring of pit temperature and humidity, seed moisture content, and pest damage under different conditions such as geographical locations, extent of fill with grain are reviewed below, but the review on improvements of pit storage is presented under the pest management research section.

Storage pits vary in size and shape. Generally, the shape of pits resembles that of a big clay pot (locally known as *Gan)* or that of a laboratory conical flask. The depth of underground pits ranged from 1.3 to 4.5 m; the base diameter ranged from 1.2 to 3.0 m and the diameter of the mouth ranged from 0.5 to 0.6 m (Boxall, 1974; Lynch et al., 1986; Abdirahman, 2002). Recently, Mashilla (2004) reported dimensions of traditional underground storage pits in seven districts of East and West Hararghe, eastern Ethiopia (Table 1). The walls of the pit are pressed smooth and flat, and may be plastered with a mixture of mud and straw. Pits are sometimes lined only on the flour with straw or threshed sorghum heads. After filling, hay, straw or dry sorghum heads are also placed on top of the grain before the pit is closed. The pits are closed by placing strips of timber or flat stone (as reported by 36.0% of farmers each) across the opening of the mouth and then sealed with dung or with mud and straw on which soil is replaced in the in-fill cavity. In case of outside pits the soil is replaced in such a way that the level is raised above the ground level to avoid flooding (Abraham, 2003).

Although different reports on pit dimensions show some similaries, estimated capacities of pits vary greatly. According to Mashilla (2004), the average capacity of pits in East and West Hararghe ranged from 0.4 to 3.08 t. Abdirahman (2002) estimated that pit capacity around Jijiga varied between 0.8 and 3.5 t. Abraham (2003) indicated that capacities of pits according to the farmers ranged from 0.2 to 10.0 t or more, the common range being 1.0 to 1.5 t. According to Boxall (1974), grain temperature in pits normally fluctuated with the ambient temperature while in insect infested pits temperatures which are as high as 37.5 °C could be encountered. In storage pits studied around Jijiga, temperature range of 10.2 to 24 °C and grain moisture contents of 10.6 to 19.1% were recorded (Abdirahman, 2002). A study in West Hararghe reported that the mean pit temperature range was 24.5 to 33.3 °C, and grain moisture content 15 to 17% after 7 to 9 months of storage (Mashilla, 2004). Pits in the lowlands had higher granary temperatures than pits in the highlands. Moreover, temperatures and grain moisture contents were higher in pits than in aboveground stores (Mashilla, 2004). Lemessa et al. (2000) monitored pits at two locations near Alemaya and found that the average pit temperature ranged from 19 to 28.2 °C for Kille and 20.1 to 28.6 °C for Tinike. In addition, in Alemaya, Lynch et al (1986) monitored three pits and recorded a temperature range of 21 to 32 °C, 21.5 to 26 °C and 23 to 27 °C during 9 months of storage. Oxygen and carbon dioxide concentrations in those pits were 3 to 11% and 8 to 19%, 0 to 5% and 16 to 20%, and 6 to 9% and 11.5 to 14.5%, respectively. Other investigators reported that temperatures of pits at Alemaya ranged from 10 to 23 °C, relative humidity of most pits was 75%, and grain moisture content 11 to 23.5% (Solomon, 1983; Solomon and Mengistu, 1984).

Table 1. Dimensions (cm) of traditional underground grain storage pits in seven districts of East and West Hararghe, (adapted from Mashilla, 2004)

District	Mouth diameter	Rim width	Rim height	Neck depth	Bottom diameter	Total depth
Alemaya	61.3 ± 8.5	25.3 ± 7.6	19.8 ± 5.6	36.3 ± 9.6	178.3 ± 35.7	178.8 ± 46.1
Babile	53.8 ± 7.5	18.8 ± 2.5	16.3 ± 4.8	41.3 ± 7.4	125.8 ± 25.3	145.0 ± 21.6
Chelenko	55.0 ± 5.8	31.3 ± 6.3	24.0 ± 8.0	43.8 ± 5.5	142.3 ± 21.8	143.3 ± 35.5
Hundenie	67.5 ± 11.9	22.5 ± 2.9	30.0 ± 8.2	51.3 ± 5.8	180.0 ± 13.5	189.5 ± 14.2
Kersa	68.8 ± 7.5	33.8 ± 18.9	26.3 ± 9.8	42.8 ± 9.1	147.5 ± 44.1	149.5 ± 30.2
Miesso	64.0 ± 4.9	25.5 ± 7.6	25.0 ± 5.8	50.0 ± 7.1	147.5 ± 33.0	180.0 ± 54.2
Tulo	64.5 ± 9.0	30.0 ± 13.5	31.3 ± 14.3	42.3 ± 9.8	141.5 ± 18.6	174.5 ± 44.2
Range	45.0 - 80.0	15.0 – 50.0	10.0 - 50.0	20.0- 60.0	100.0 - 210.0	115.0 - 260.0
Mean	62.1 ± 9.0	26.7 ± 10.2	24.6 ± 9.1	43.9 ± 9.4	151.9 ± 31.9	165.8 ± 37.8

Means are averages of four pits per district.
Total depth is the height from top of the neck to the bottom of pit including the empty space above the grain

Lemessa et al. (2000) found a steady increase in moisture content during a six-month storage period at two locations near Alemaya. They reported increase in average moisture from 11.0 to 17.6% at Kille (1500 m) and from 12.8 to 22.0% at Tinike (2000 m). According to Amare (2002), there was only a slight increase in moisture content of sorghum grain stored in pits; the average seed moisture contents were 13.5% at harvest and 14.5% after storage in pits for 5 to 6 months. High grain moisture content develops mainly from seepage of soil moisture whereas increased respiration might also be a contributing factor. Boxall (1974) stated that in a soil with higher water retension and under heavy rainfall conditions, the moisture content of the grain might increase to 17% after two months of storage while the same moisture level may be reached after longer time in drier areas with sandy soils. Near Dire Dawa, the moisture content was only 14% after storage in pit for 10 months. Most storage fungi invade stored grain at 20 to 35 °C temperature and 13 to 20% moisture content causing deterioration (Mashilla, 2004).

Pits are dug either inside the house or outdoors within the farmers' compound or even far in the field where the soil is suitable (the last option is not practiced these days due to theft). The location and depth of the pit vary depending on the soil type and rainfall. Grain stored in underground pits is reported to be safe in terms of securing grain from theft as they are usually dug inside the farmer's compound or below his dwelling. Farmers are aware of the danger of entering a newly opened pit and wait some time after opening and before entering the pit. This also contributes to the security of pit storage, as it was reported by some farmers.

McFarlane (1969b), IAR (1973) and Boxall (1974) stated that the underground pits, if filled, fairly well-sealed and covered by a good depth of hard-packed soil, should provide a reasonably air-tight storage chamber. In such a chamber, any insect present in the grain should be killed ultimately by asphyxiation, as the oxygen initially present is gradually used up by their respiration. Asphyxiating insects by using polyethylene sacks for bagged grain is a simple and effective technique. If a container is completely filled with grain, the concentration of oxygen will drop. It has been demonstrated that if oxygen levels can be reduced to 2% or less, then a complete kill of all stages of insects infesting the grain would be achieved (Boxall, 1974). Measurement of the fluctuation in temperature and gaseous compounds in a number of underground pits indicated that the oxygen level dropped to less than 2% mostly after 2–5 weeks of storage. The occurrence of some live insects was possibly because the carbon dioxide produced was absorbed by the grain or by the concrete, if such lining was used, which creates a less lethal environment. Boxall (1974) found that losses due to insects appear to be restricted to the top 10 to 25 cm of grain in a pit but that infestation may be carried down through the pit as grain is removed at subsequent openings.

Niles (1976) reported that pits opened less frequently (once or twice only) showed less visible moulding. Pits opened over 12 times yielded over 50% more species or genera of fungi than pits opened only once. Individual species were also more abundant in the frequently-opened pits. Qualitative differences, however, may be more important than differences in the number of species. *Aspergillus* spp. (with the exception of *A. ustus*) were significantly scarcer in pits opened less frequently. Three important species (*A. flavus, A. candidus and A. ochraceus*) that are common in frequently opened pits were altogether absent from pits opened only once or twice. Gilman (1968) and Boxall (1974) also pointed out that frequent withdrawals expose new grain to the surface, increase grain moisture content and subsequent attack by fungi.

Several studies consistently indicated that the most extensive moulding occurred at the sides of pits (Niles, 1976; IAR, 1983; Solomon and Mengistu, 1984). There was 30% higher total incidence of fungi in samples from the sides of pits (43 species) compared to from center positions (51 species) indicating varied flora. Gilman (1968) observed 5 cm layer of grain. Besides, the wall of the pit was damaged by fungi implying the magnitude of loss drops as the pit size increased. Moisture content and fungal damage decreased from the periphery of the grain bulk to the center where moisture content was below 13.5%, the safe limit for sorghum.

According to Abraham (1991), there was no much difference in insect infestation levels among different storage containers observed. However, most farmers reported that underground pits, clay jars and gourds are less affected by storage insect pests (Abraham, 2003). On the other hand, frequent grain spoilage was reported due to moulds and insect pests that favour high grain moisture and high temperature that develop in the pit (Fikadu, 1994). Amare (2002) also indicated that storage of sorghum in underground pits is inadequate to maintain quality because of increased frequency and levels of mycotoxin contamination of pit-stored grain.

Damage and loss assessments

The term loss when applied to food commodities has been defined in many different ways, and confusion has sometimes arisen when loss has been used synonymously with the term damage. In the context of storage losses, it is generally agreed that loss means a measurable decrease of the foodstuff, which may be quantitative or qualitative. Damage, however, generally refers to the superficial evidence of deterioration, for example, holed or broken grain or bruised fruits or physical spoilage, which may later result in loss. Food losses after harvest can be substantial and are important in terms not only of quantity but also of quality, nutrition and economic value.

Post-harvest losses occur at different points (harvesting, drying, threshing, winnowing, transportation and storage) (Harris and Lindblad, 1978). However, there is no accurate data that quantify the losses at each point in Ethiopia. Some studies suggest that crop losses of 2 to 3%, 1 to 2%, 4 to 6%, 2 to 5%, and 1 to 3% occur in cereals during cutting, drying, threshing, winnowing, and transportation, respectively (Anon., 1993). Storage losses have been the focus of loss assessment studies. Several reports exist on stored grain losses, though the method of assessment and whether the figures refer to the amount of damage, the total amount of grain lost or a reduction in grain quality are not always clear. Attempts are made to present estimates of quantitative and qualitative losses separately.

Damage and losses in quantity

Many investigations were made to assess losses in stored grains in the 1970s and 1980s but comparison of results is difficult because of insufficient information about the methodology used, results aggregated for several different crops and/or different storage systems, and studies had been conducted over different storage periods and in different agro-ecological zones (Boxall,1998).

Boxall (1998) estimated storage losses of food grains due to insects and grain moulds to be about 9%. Based on the annual average production estimate of 9.44 million metric tons of food grains (statistics of 1987–2001), the amount of storage loss alone would be 0.85 million metric tones (Tsedeke, 2004).

The main cause of storage loss at farm-level is insect infestation, although loss caused by mould damage is important in pit storage. Losses of 25 to 50% in traditional farm storages and occasional 100% losses in underground pit storages were reported in the 1950s and 1960s (Boxall, 1998). Boxall (1998) estimated storage losses of food grains in Ethiopia due insects and grain mould to be about 9%. In most literature, post-harvest losses are quoted as 15% but there has never been an organized post-harvest crop loss assessment carried out in the major food and cash crops nationwide. Some reports estimated crop losses at about 2 to 4% and 5% due to insects at high and low altitudes, respectively, and about 3% due to rodents at high altitudes, while grain moulds sometimes result in whole spoilage of grain stored in underground pits (Anon, 1993).

As it has been indicated above, losses recorded in underground pits are mainly due to mould damage, and their levels vary depending on whether the pit is filled or partially filled with grain and on the frequency of opening. Boxall (1974) found considerable losses in pits due to fungi as well as insects. He compared the extent of losses in underground pits which were initially full and half full, and were opened at different frequencies (every month, three-months, six-months or 12-months). They found that in the initially full pits, losses ranged from 2% (when opened monthly) to 25% (when opened after 12-months) due to fungi damage and 3% to 38% due to insect damage. Losses in the half-full pits were 7 to 35% due to fungi and 6 to 55% due to insects. In a previous study, Gilman (1968) estimated losses in grain stored in underground pits to be between 0 and 20% in pits surveyed in Hararghe. Recently, Mashilla (2004) reported 2 to 13% (maximum of 24%) average weight loss of sorghum grain due to fungi in traditional pits on the campus of the Alemaya University and in seven distichs surveyed in Hararghe.

McFarlane (1969b) undertook a six-week survey of storage problems in Ethiopia and attempted to estimate losses based on observation of storage systems. He selected sampling of a range of cereal grains and pulses, and crop production data. It was noted that loss due to insect infestation was negligible at the start of the storage season but that it increased throughout the season at a rate determined by the altitude at which the crop was stored.

Investigations carried out at Kulumsa in 1967/68 on losses and damage of wheat and barley grains stored in indigenous soils and small bins made of corrugated steel sheets showed no damage on barley and little on wheat and that insect damage was of no importance in the area (CADU, 1968). In the 1974 survey, wheat, barley and maize sampled from different stores in the lowlands of CADU revealed that damaged grains amounted to only a maximum of 2.7% and in most cases less than 1% (IAR, 1976b). IAR (1972a) reported a loss of 2.9% in stored maize in a low infestation season at Bako.

Kashi (1985) conducted a preliminary survey of losses in the former administrative regions of Gojam, Hararghe, Wello, Gemu Gofa, Kafa and Shewa. The study included farmers´ co-operative stores (warehouses) and individual farmers whose predominant storage structures were gotera, gotha and underground pit. Aggregate data were presented for maize, sorghum, wheat and beans, and for storage periods of thee to four months. Damage levels (caused by insects, birds and rats) were reported to be 88% in co-operative warehouses and 55% in farmers stores; the respective figures for weight losses were 15.3% and 13.2%. In another study by the same author, damage in cob-stored maize in co-operative warehouses due to insects, mould and other factors was reported to be 65.1%, and the weight loss six months after storage was 7.9% (Kashi, 1985). However, the usefulness and reliability of these figures are questionable because of their aggregated nature and unclear method of loss assessment (Boxall, 1998).

Yemane and Yilma (1985; 1989) carried out a field study of food grain losses in two types of stores mainly, gotera (made from clay or cow dung) and underground pits, at three locations representing different agro-ecological zones. At Ankober (Shewa), representing a high altitude (3110 m), barley was stored in mud plastered gotera for a year. At Akaki (2050 m) tef, wheat, barley, sorghum, chickpea, field pea, and lentil were stored each in a half-ton capacity gotera made from clay or cow dung. In central Hararghe (1789 m) sorghum was stored in underground pits. In each case, grain was weighed in and out of store at the start and end of the season. Samples were assessed for percentage damage before and after storage, and estimates of weight loss were derived by analysing final samples by the ´count and weigh´ method. The damage and weight loss recorded during storage for the different crops studied are presented (Appendix 3). Grain damage and weight loss figures reported from the southern (Emana, 1993a; Emana and Assefa, 1998), southwestern (Mekuria, 1995) and western (Abraham, 1991; 1993a; 1993b; 1997; 2003; Abraham et al., 1993; Firdissa and Abraham, 1999b) parts of Ethiopia are also shown (Appendix 3). In the Bako area, western Ethiopia, 50% loss of maize stored for 3–5 months to weevils was reported (Mang, 1973), whereas Legesse et al. (1992) indicated that farmers in the Bako area reported 25–33% loss in maize, and the price reduction for moderately damaged maize was 25% less than normal maize.

From a survey, conducted in 1996 in Tigray Berhanu (1997) reported weight losses of different crops with overall loss of 25%. Losses in different agro-ecologies and storage container types have also been shown: about 30% loss was calculated for woina dega, while for dega and kolla it was about 21% each. The lack of difference in weight loss figures between the two extreme agro-ecologies (dega and kolla) was difficult to explain. Losses in golota, godo, drum, Hessian sack, Shirfa and jute sacks were reported to be 43%, 35.2%, 34.6%, 31.3%, 30.4% and 23.8%, respectively. Samples from pots, open markets, underground pits, meaqen, and loqota revealed respective weight losses of 23.5%, 22.5%, 14.3%, 9.9%, 9.7% and 6.5%. Grain is marketed on volume bases in Tigray. Hence, the significance of weight loss is not realised. Surveys conducted in eastern and southern parts of Tigray after sorghum was stored for four to six months showed that losses in Abergele and Chercher were 19.2 and 21.5%, respectively. No losses were recoded in some other areas, making the regional average loss of sorghum as low as 6.1%. Sorghum stored in sacks was reported to be more vulnerable to infestation than in gotera or underground pit storage (Mekele Agricultural Research Center, 1998).

Grain samples of wheat, barley, maize, sorghum, tef and beans stored in different traditional storage containers (gotera, dibignit, sacks, underground pits, skin bags, clay jars) in lowlands of Arbagugu in 1981 to determine losses and grain damage due to insects, fungi and rodents showed that insects were the most important storage pests. Sorghum suffered the highest damage of all grains since it was stored in pits for a long time while maize was the second (ARDU, 1982).

In a 9-month storage trial, Kemal (1986) found 72.7% damage and 30.7% weight loss in faba bean. Surveys of faba bean in Chilallo awuraja (2050–2690 m) indicated that more infestations were observed in warmer areas. A maximum infestation of 14% was recorded in Hamsa Gasha followed by 11% in Abichu (2350 m) (IAR, 1990b; 1990d). In higher altitudes (2050–2400 m) 40.2% damage and weight loss of 4.8% were recorded in faba bean stored for 13 months (Yemane and Yilma, 1985). In Yerer and Kereyu (1900–000 m), seed damage in faba beans after 6 to 7 months of storage ranged from 0 to 97% with an average of 41% and a weight loss of 14.4% in 1986 (IAR, 1987e); average damage of 53.6% and associated weight loss of 8.8% after the same period of storage in 1987 (IAR, 1987d). Weight losses were calculated by comparing weights of 25 samples of 50 sound and 50 damaged seeds. The average for 1986 and 1987 was 41.2 and 13.5%, damage and weight loss, respectively (IAR, 1987d). In 1987 and 1988 seasons in Yerer and Kereyu (1800–1900 m) mean amounts of damage and grain weight loss in faba beans stored for 6 to7 months were 43.7 and 13.9%, respectively (Tadesse, 1992). *C. chinensis* was the only pest of stored faba beans in the area. Damage in haricot bean stored for 7 to 9 months ranged from 0 to 80% and the associated grain weight loss was 3.2% (Ferede and Tsedeke, 1992). Seed damage ranged from 0 to 38% for Koka and Oda Nega areas, respectively. Damage differed with haricot bean varieties and type of storage containers used (Ferede, 1994). *C. chinensis* was the only species of bruchid attacking faba bean in Metti (1900 m) and Degaga (2060 m) with infestations as high as 27.3% (IAR, 1991b; 1992).

Bruchids pose serious post-harvest problem to chickpea and lentils in particular with the extent of damage sometimes exceeding 90% after three months of storage (DZARC, 1984). Teshome (1990) reported average damage of 27.5% and loss of 8.2% in chickpea stored for six to seven months in Yerer and Kereyu. Storage pests of lentil in Debre Zeit, Dukem, and Modjo were assessed by collecting seed samples following three months after storage. Most samples did not show infestations by the pest (*C. chinensis*). Damage ranged from 0 to 8% (DZARC, 1991). In a later survey it was also found that most of the chickpea and lentil seed samples obtained from farmers stores in Shewa were free from infestation. Those stored in sisal sacks had some insect eggs. Samples from Tefki and Tulubolo areas did not have any infestations as they were treated with chemicals (DZARC, 1996).

Pea bruchid infestations amounting 80–85% in Sokota and 50–60% in Achefer weredas, respectively, were reported in 2001 (EIAR, 2005). Meheret (2003) reported damage in chickpea stored for six months ranged from 42.1 to 50.6% (mean 46.42%) with the associated weight loss range of 9.7 to 14.01% (mean 11.77%). These figures increased to ranges of 42.1 to 53.5% (mean 49.2%) and 12.2 to 17.3% (mean 14.68%), damage and weight loss, respectively, when the storage period was increased by one more month. Higher losses were recorded in places where storage containers were located nearby fireplaces. In Gambella, Muluemebet (2003) showed the amount of damage to cowpea caused by *C. maculates* sampled (10, 40, 80 and 150 days after storage) ranged from 23 to 29%, and the associated grain weight loss after five months of storage was about 10%. Surveys conducted in eastern and southern parts of Tigray indicated that faba bean stored for four to six months in highlands, Atsbi-Wombera

(2500–2700 m) and Ofla (2300–2500 m), showed no infestation while in the mid altitude Wukro (1850 m) a weight loss of 26.5% (regional mean was 4.4%) was recorded in faba bean (Mekele Agricultural Research Center, 1998). Mekasha (2004) sampled different grain legumes stored for 5–8 months and reported the levels of damage to be 3.9–14.7, 3.4–5.3, 0.1–3.1, 7.1–49.3% for chickpea, grass pea, field pea, and faba bean, respectively. The upper ranges were for samples obtained from mid-altitude areas.

Studies on losses due to *C. chinensis* to three chickpea varieties (Muriye, DZ-10-11 and DZ-local) left to natural infestation for eight months indicated that there was no difference in damage among varieties. Damage was very heavy and seed germination was reduced in all varieties. Losses in Muriye, DZ-10-11 and DZ-local were 16.45, 17.24, 16.72%, respectively, with average loss over varieties of 16.8% (DZARC, 1994).

Correlations between altitude and damage by weevils (Abraham, 1991) and bruchids (Mekasha, 2004) were significantly negative. All reports agree that insect pest problems in storage are more severe in warmer areas than in highlands. Furthermore, improved varieties are more damaged by weevils than local varieties (Abraham, 1991). Maize stored on the cob was more damaged by the larvae of the *Angoumois* grain moth than shelled maize (Abraham, 1991; Emana, 1993a).

Information on post-harvest losses of horticultural crops at farm level was not available (Anon, 1993). At commercial level, average losses of about 1 to 49% and 1 to 20% have been reported for vegetables and fruits, respectively, at the Horticulture Development Corporation (HDC) (Berga et al., 1990). This is estimated to be a loss of about 1300 t of fruits and 400 t of vegetables per annum. It is reported that these losses represent differences between the amount supplied to the market and the amount rejected due to deterioration in quality caused by poor storage. Tilahun and Kebede (2004) reported weight losses in papaya, banana, lemon, orange, and mandarin stored for 32 days at ambient conditions to be 66.5, 42.5, 13.3, 10.3, and 4.1% more, respectively, when compared to the weight losses in these fruits stored in a forced ventilation evaporative cooler. According to Tadesse (1991), post-harvest losses of fruits and vegetables in Ethiopia are estimated to vary between 25 and 35%.

The only insect pest of a vegetable crop in storage observed causing severe damage was the Indian meal moth on dried hot pepper pods stored at the Bako Agricultural Research Center farm-store in 1995 (Abraham Tadesse, personal observation). However, the amount of damage was not quantified.

Losses in quality

In addition to the direct weight loss of seeds, storage pests also reduce seed quality and affect their germination. Dejene (1984) evaluated the germination of three maize populations (Alemaya Composite, Bukuri and Bukuri A) stored at room temperature under greenhouse conditions for three years in 1980 at Alemaya. The seeds were categorized as undamaged, germ side damaged and endosperm side damaged. The seeds in the normal category germinated over 50%, while the germ-side damaged seeds germinated less than 1%. Endosperm side damaged seeds germinated better than germ-side damaged seeds. Similarly, Abraham (1991) found that the germ part of maize kernel was less preferred to other parts, and number of weevil exit holes had significant negative effect on maize seed germination while parts of kernels holed had no effect.

Studies conducted in Sidama in 1992 and 1993 showed reductions in maize seed germination because of insect damage was about 23 and 26%, respectively, with a range of 16 to 43% for samples from individual locations (Emana and Assefa, 1998). Adane and Abraham (1994) found a significant decrease in haricot bean seed germination as the number of damage holes per seed increased. The germination rate of seeds stored for 12 months ranged from 0 to 62% (Adane and Abraham, 1994). Mashilla (2004) reported that germination of sorghum stored in pits for 7 to 8 months decreased from 83 to 27% on the average due to storage fungi. Reductions in seed germination in different crops stored for 6 to 12 months was reported and the major factor for the losses were insects (ARDU, 1982). Lemessa (2000) reported that germination of sorghum seeds stored in underground pits decreased with time (as low as 1% at Kille and 6% at Tinike after six months of storage).

Storage fungi are one of the major factors responsible for loss of seed viability. Storage fungi such as *A. candidus*, *A. flavus*, *A. fumigatus*, *A. glaucus* group, *A. niger*, *A. ochraceus*, *A. parasiticus*, and *Penicillium* species can damage the seed germ and decrease germination in a short time under favourable conditions. Inoculation tests with *A. niger*, *A. flavus*, *A. ochracous* and *F. solani* indicated that there was a marked reductions in germination and emergence ability of seeds of different sorghum varieties. *A. flavus* was the most potent in seed germination and seedling emergence (IAR, 1983; Solomon and Mengistu, 1984). As storage period increased by two months sorghum seed germination decreased by 13% while emergence decreased by 8% (Solomon and Mengistu, 1984). Damage to seeds may be due to diffusible toxic substances such as peptic enzymes, proteases, lipases and toxins released by storage fungi but reports from Ethiopia on the mechanisms involved are not available.

In addition to germination losses, infestation by insects and invasion by storage fungi can result in changes in the percentage chemical components and lower the potential nutritive value of the grain. Some insect larvae may preferentially attack the germ of the grain and they remove a large percentage of the protein and vitamin content, whereas weevils feeding mainly on the endosperm will mostly reduce the carbohydrate content. Other storage factors such as moisture, temperature and fungal infection also lead to changes in vitamin content. Mineral and vitamin losses in different crops during storage reported by Yemane and Yilma (1989) are shown in Table 2**.** It should be noted that the available reports on losses in nutritional values of stored grain generally showed changes over storage period and did not distinguish the role of storage pests from intrinsic changes due to metabolism of the stored grain.

Table 2. Loss of nutrients (ppm) in stored grains (Yemane and Yilma, 1989)

Crop	Calcium	Iron	Vitamin C
Wheat	11 (17.2)	16 (53.8)	-
Wheat (emmer)	31 (81.6)	2 (33.9)	0
Tef	4 (2.8)	7 (33.3)	2 (33.3)
Faba bean	68 (58.1)	12 (63.9)	5 (71.4)
Field pea	9 (9.8)	3 (31.3)	1 (10.0)
Chickpea	33 (13.5)	25 (78.8)	0
Lentil	24 (37.5)	-	12 (80.0)

Figures in parenthesis are percentage values

Mashilla (2004) reported significant variation in organic matter and soluble carbohydrate (SCHO) content of sorghum seed stored in corrugated iron bins and underground pits without and with different linings (Table 3).

Table 3. Mean percentage chemical components of sorghum grain stored for 17 months in bins and pits with different linings at Alemaya, Ethiopia (Mashilla, 2004)

Store type	DM	Ash	OM	N	CP	SCHO
Bin	92.71 ± 0.18	1.92 ± 0.06 b	98.08 ± 0.06 a	1.70 ± 0.01	10.61 ± 0.07	2.46 ± 0.10 a
Cement	92.84 ± 0.13	1.87 ± 0.07 b	98.13 ± 0.07 a	1.68 ± 0.01	10.52 ± 0.06	2.41 ± 0.08 a
Dung pit	92.82 ± 0.15	1.98 ± 0.10 b	98.02 ± 0.10 a	1.69 ± 0.01	10.58 ± 0.07	2.25 ± 0.13 b
Soil pit	92.73 ± 0.15	4.19 ± 0.49 a	95.81 ± 0.49 b	1.68 ± 0.01	10.51± 0.09	1.59 ± 0.13 b
LSD	NS		0.65		NS	0.23

Organic matter decreased from 97.8% to 91.6% and crude protein increased from 10.1 to 11.2% over 17 months of storage in underground pits (Mashilla, 2004). The organic matter and soluble carbohydrate contents were negatively correlated with storage period for poorly stored grain. On the other hand, the use of improved grain storage structures maintained the grain quality and nutritional value of sorghum for a longer period. In the same study, SCHO contents decreased in all of the survey locations with an increase in storage period, especially in the lowland districts (Tables 4). On average, SCHO content of sorghum stored in underground pits in the different districts decreased from 2.4% in the first sampling to 1.2% in the final sampling in 7–9 months after grain filling. It was also found that store types (bin, cement pit, dung pit, and soil pit) had strong effects on the organic matter (OM) and SCHO contents of sorghum grain. Storage period influenced the contents of all chemical components analysed. The OM and SCHO of samples from the soil pits were significantly different in samples obtained from the other stores. The ash content of samples from the soil pit increased from 2.17 to 8.38% in the 17-month storage period, corresponding to a similar decrease in OM, while the SCHO decreased from 2.4 to 0.97% (Mashilla, 2004; Mashilla et al., 2006).

Table 4. Changes in mean percentage SCHO contents of sorghum grain stored in pits at farm-level in seven districts of Hararghe from Februry to August 2001 (Mashilla, 2004)

Time	Survey districts						
	Alemaya	Babile	Chelenko	Hundenie	Kersa	Miesso	Tulo
I	2.68 a	3.13 a	2.03 ab	2.14 a	2.48 a	2.67 a	1.52 ab
II	2.26 ab	2.55 ab	2.23 a	0.97 b	1.92 a	2.56 a	2.04 a
III	1.88 b	1.98 ab	1.67 bc	1.11 b	1.60 b	1.64 b	1.34 bc
IV	1.63 b	1.28 b	1.42 c	0.91 b	1.4 b	0.93 c	0.76 c
LSD	0.75	1.35	0.50	0.90	0.65	0.65	0.65

Invasion of food grains by fungi generally leads to losses in weight and viability, discoloration, heating, mustiness, taints, and a general deterioration in grain quality (Gilman, 1968; Niles, 1976; Lemessa et al, 2000; Amare, 2002). These effects are worsened when grain is maintained at higher moisture contents than the recommended level since considerable damage is also caused by bacteria (Niles, 1976). Moreover, duration of storage plays an important role in the extent of the adverse effects. Studies on the quality deterioration of sorghum stored in the traditional underground storage pits at two agro-ecological zones in eastern Ethiopia showed significant differences in the amount of DM, crude protein, and total carbohydrates (TCH) for different storage days (Lemessa et al., 2000).

Fungi also affect the quality of stored grain through the production of toxic metabolites (mycotoxins) that are extremely harmful to human and animal health (Gilman, 1968; Niles, 1976; Lemessa et al., 2000; Amare, 2002). Reported aflatoxins and ochratoxin A in cereal grains are presented (Table 5).

Natural occurrences of aflatoxin, deoxynivalenol, nivaleol, fumonisins, ochratoxin A and zearalenone and fumonisins were analysed in samples of barley, wheat, tef and sorghum from different types of stores in some of the major growing areas of the crops in Ethiopia (Amare, 2002; Amare et al., 2005;

2006). Ochratoxin was found to be very prevalent; the levels of aflatoxins encountered were lower than reports from other tropical areas, and the remaining mycotoxins (*Fusarium* mycotoxins) were generally less important and were not detected at all in tef samples. In general, sorghum samples from underground pits showed greater contamination by the mycotoxins analysed. Earlier, the occurrence of aflatoxins in maize, sorghum and tef varieties from different stores in Addis Ababa (Aberra and Admasu, 1987), and in market samples of groundnut from eastern Ethiopia (Amare et al., 1995) had been reported (Table 5). Dawit and Berhanu (1985) also found that aflatoxin-producing fungi were associated more with sorghum and maize than with tef and barley.

Table 5. Natural levels of mycotoxin contamination in food grains from Ethiopia

Mycotoxin	Crop	*n*[a]	Mycotoxin positive (%)	Concentration Mean (ppm)[b]
Aflatoxins	Maize		32.4	
	Sorghum (white)		16.9	
	Sorghum (mixed)		15.5	
	Sorghum	82	6.1	10.0
	Barley	115	11.3	3.8
	Wheat	120	4.2	8.7
	Tef (white)		9.8	
	Tef (mixed)		11.3	
	Tef (red)		14.1	
	Tef	35	22.9	5.1
Ochratoxin A	Barley	103	26.2	17.2
	Sorghum	78	21.8	174.8
	Tef	33	27.3	32.7
	Wheat	107	23.4	19.6

Source: (Aberra and Admasu, 1987; Amare, 2002; Amare et al., 2005; 2006)

Environmental factors such as temperature, moisture content, and relative humidity were reported to influence aflatoxin formation in the samples examined. It was also reported that poor storage conditions like open sacks in market areas and warehouses were more conducive to aflatoxin formation than the modern silo bin storage systems (Aberra and Admasu, 1987). There are indications that there is a risk of exposure to mycotoxins especially in those parts of the country where sorghum is used as a staple food (Amare, 2002).

Pest biology

Abraham (1991) and Abraham et al. (1996) studied the biology of the maize weevil at room temperature and relative humidity conditions at Bako. It was found that a female maize weevil remained fecund throughout its lifetime; however, the actual time of oviposition was about 50% of the mean life span of the ovipositing female. Based on the progeny weevils emerged, a female weevil laid 1.24–2.48 eggs per day. The mean total number of adult weevils produced per female was 121.9 ± 22.2, the sex ratio being nearly equal. The female weevil started oviposition three days after its emergence from the grain. Maximum number of adults emerged between 41 and 45 days after oviposition, the overall average being 42.3 days. There was no significant difference in the development time between male and female weevils. However, females lived significantly longer than males under the experimental conditions (Table 6 and Fig. 1). Individual observation indicated that longevities of more than 118 days for males and 123 days for females were possible (Abraham, 1991; Abraham et al., 1996).

Table 6. Maize weevil longevity, fecundity, oviposition and development periods in the laboratory at Bako (Abraham, 1991; Abraham et al., 1996)

Parametres	Male	Female
No. of adults weevils emerged per female	61.40 ± 11.34	60.40 ± 11.99
Progeny /female/day	1.24 - 2.48	
Time required for adult emergence (days)	42.11 ± 0.84	41.48 ± 0.84
Overall mean development period (days)	42.25	
Longevity (days)	66.91 ± 4.12	98.13 ± 5.75
Pre-oviposition period (days)	-	2.73 ± 0.88
Effective oviposition period (days)	-	49.13 ± 5.90
Days oviposition interrupted (mean total)	-	36.53 ± 3.95
Time elapsed between successive ovipositions (days)	-	3.19 ± 0.41
Duration of oviposition (days)	-	90.40 ± 5.90
Time between last oviposition & female death (days)	-	5.00 ± 1.04

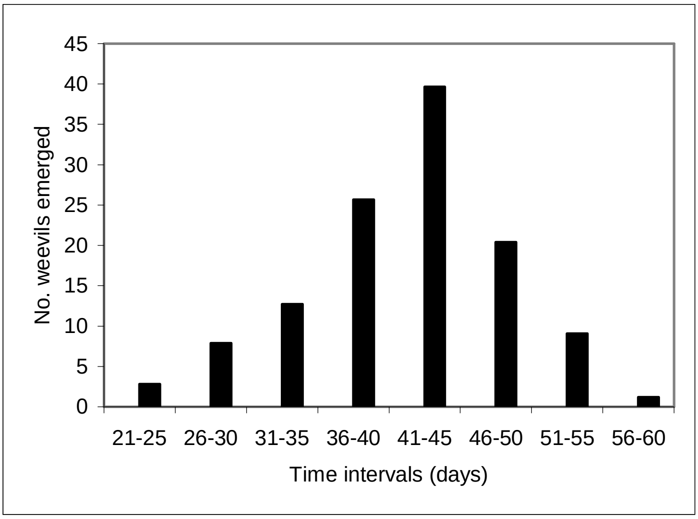


Fig. 1. Mean number of adult maize weevils emerged in different time intervals in the laboratory at Bako (Abraham, 1991)

Teshome (1990) studied the biology of *C. chinensis* on chickpea at Debre Zeit and found that the mean number of eggs laid by the female was 52.8 (ranging from 43 to 69). The development period spanned from 22 to 27 days, the average being 23.2 days. The average life span for the male and female bruchids was 8.3 and 7.9 days, respectively. Both sexes lived for a maximum of 10 days. The female laid 43–69 eggs at the rate of 11–23 eggs per day. The number of eggs laid and adult emergence decreased with the age of the female. Egg hatchability rate of 83 – 96.4% was recorded at 27 $\pm$ 1 °C and 70 $\pm$ 5% r. h. An average of about 83% (77–88.4%) of the eggs hatched into adults. The female (3.8–4.6 mg) was bigger in size than the male (2.9–3.4 mg), and the male to female sex ratio was 1.06: 1. Females started oviposition the same day they emerged (Teshome, 1990).

The biology of *S. cerealella* on shelled and unshelled maize was studied at Awassa, and results indicated that the moth laid eggs singly or in batches of up to 10 eggs on the surface of maize grain. The population growth of the pest was much higher on unshelled-dehusked maize than on unshelled-husked maize. The life cycle was completed within 32 days on unshelled maize. Infested seeds failed to germinate because the insect fed on the embryo (IAR, 1996d).

The biology of fungi associated with stored grain

Limited studies have been undertaken on the biology of storage and/or field fungi in Ethiopia. These studies were limited to characterization of isolates through analysis of secondary metabolite (mycotoxin) profiles or molecular data. Eshetu (1994) evaluated mycotoxin-producing potential of 78 isolates from 17 species of *Fusarium* obtained from stored wheat seed and scabby heads. Most of the isolates did not produce a detectable amount of any of the mycotoxins in potato dextrose brounth liquid medium, whereas a few species and isolates produced some of the mycotoxins on corn grit and rice substrate. Tesfaye (1997) also showed that Ethiopian isolates of *F. graminearum* produce zearalenone and trichothecene compounds.

Dawit and Berhanu (1985) tested aflatoxin producing potential of isolates of *A. flavus* from tef, barley, maize and sorghum samples from Addis Ababa, Shashemene, Jimma and Dire Dawa and found that 80% of the isolates examined were capable of producing aflatoxin *in vitro*. *Aspergillus flavus* isolates from groundnuts were tested for their aflatoxin-producing ability and nearly 85% were found to produce detectable levels of one or more of the four naturally occurring aflatoxin (Amare et al., 1995).

Pest management methods

In addition to surveys for documenting farmes` practices, attempts were made by various researchers to develop pest management measures for storage pests.

Farmers´ practices in storage pest management

Ethiopian farmers practice numerous methods of pest management on their grain in storage. Some of these practices reported by farmers interviewed during surveys are listed (Table 7). However, most of these methods are currently less practiced because of farmers' reliance on chemical pesticides. Farmers store seed grain above the kitchen fire in their hut and such stored maize was less damaged (Abraham, 1991; Emana, 1993a). This retards development and prevents reinfestation since the heat and smoke accelerate drying of the grain. Separation of apparently damaged and infested grain from the rest of the harvest is a common practice of farmers in areas surveyed. Pest control practices reported by Mekasha (2004) include use of botanicals (21%), admixing with tef (23%), mixing with ash (8%), slight roasting (13%), cooling grain overnight after threshing and before storage (8%), storing in cool places (3%), changing crop variety (2%), changing storage structure (2%), treating with chemicals (64%), while 34%.of the farmers did not attempt any control. Of those who did not apply control measures, 59% were in the highlands (Mekasha, 2004). Earlier studies also reported these practices of storage pest management (Abraham, 1991; 2003).

Table 7. Storage insect pest control practices reported by farmers interviewed during surveys

Type of practice	Percent of farmers responded	
	West	South
Consume and/or sell grain immediately	98.5	
Dry sufficienty before storage	98.0	
Clean and repair storage containers	94.5	
Treat with insecticides	73.5	23.0
Place in smoke over fire	70.0	13.2
Store grain in cold place (outside)	65.1	11.1
Re-plaster container with cow dung	63.5	
Retain the husk	61.5	
Select undamaged cobs at harvest	58.6	
Aerate grain as much as possible	52.0	
Store maize on the cob	43.0	
Winnow and screen periodically	40.5	4.5
Mix maize with tef or finger millet	35.0	
grain transfer from container to ontainer	22.0	
Open container less frequently	17.5	
Expose infested grain to the sun to drive off insects	14.0	6.4
Heat grain on clay pan	14.0	
Hang up on trees in the field	10.5	
Mix improved maize with local maize	6.5	
Seal in clay jar or gourd	6.5	
Tie husk tip together for complete coverage	5.5	
Mix with hot pepper	2.0	
Treat with cattle urine	1.0	
No control attempt		23.0
Store shelled maize		11.3
Mix grain with wood ash		4.5
Use Eucalyptus leaves		3.3

Source: (Abraham, 1991; Emana and Assefa, 1998)

Farmers in different parts of the country (Abraham, 1991, 2003) have reported numerous traditional pest control practices. Farmers practices of pest management on stored grain in different parts of Tigray include admixing grain with wood ash, goat/sheep droppings or tef grain; cooling grain before storage; occasional aeration of grain; keeping grain unthreshed for some time; and drying grain before storage (Berhanu, 1997). Warming infested grain over fire, periodical exposure of grain to air, boiling and then drying pulses were reported. Moreover, sweeping inside walls, exposing containers to the sun and cold weather alternately, smearing the inner side of containers with mud or dung, smoking with hot pepper or other botanicals such as *Otostegia integrifolia* (locally *chindog*) are practiced. The use of plants *ere* and *sasa* were also mentioned. Other botanicals such as *Cissus rotundifolia*, *Heliotropium ovalifolium* (locally *amam gimel*) and *chewye* are chopped and spread on the surface of grain in storage (sometimes rock salt may be included). *Anethum* *graveolens* (locally *silean*), *Cisses petiolata* (locally *alke*) and *birbira* (*Milletia ferruginea*) were reported to be used. Birbira leaves were used for scrubbing inside walls of containers. It was also indicated that a farmer who had mixed half kilogram of pounded rapeseed with 100 kg of sorghum grain protected the grain from insect infestations. Use of synthetic chemicals pirimiphos-methyl, malathion and DDT was also reported in the survey areas. Although insecticides like DDT were banned, there is a possibility of getting them from old stocks. The presence of huge stock of expired storage insecticides in the stores of the Bureau of Agriculture and Natural Resources was reported.

Abdirahaman (2002) reported that traditional pest management practices in Jijiga area include spraying salt or hot pepper solutions on the grain, lining the pit floor with crop residues (husk), packing the soil during construction and placing fresh bone over the grain. Grain in market stores were treated with malathion. Farmers in Debre Zeit area store their lentil in cooler places (usually on veranda) and treat seeds for planting with insecticides (DZARC, 1991). Ferede (1994) indicated that sunning at intervals was the only control method reported to be used by haricot bean farmers in central Ethiopia, eastern and southern Shewa. In Enemay Wereda (East Gojam), some farmers apply botanicals when they observe insect eggs and adults on their chickpea (Meheret, 2003). About 40% of the farmers in Gambella reported the use of wood ash, sunning, smoking and suspending pods for the control of the cowpea seed beetle (Muluemebet, 2003). Abraham (2003) interviewed farmers on their views regarding the efficacy of some of the traditional pest control practices. Their responses varied from poor (no protection) to good (effective for over three months).

Research towards improving traditional stoage systems

Most traditional storage containers are extremely poor in construction and maintenance, and they appear to be one of the major causes of storage losses (Abraham, 1991; 2003). The Sasakawa Global (SG) 2000 improved stores have been introduced since 1995 in several parts of the country. They are now being promoted by the Ministry of Agriculture and Rural Development (MoARD). However, the structures are relatively expensive for most farmers (Abraham, 2003) and the farmers did not adopt them. The Freedom from Hunger Compaign (FFHC) of the early 1970s recommended a crib-style grain store, with rat baffles, which was constructed on demonstration sites throughout the country. However, this improved structure had still not been generally adopted, except in localized areas where rodents are a major problem (UNDP/FAO, 1982). The rat baffles are prohibitably expensive for most farmers due to a dramatic rise in the price of metal sheet. Other reasons for the failure to adopt the new design may be shortage of suitable construction materials, fear of fire or theft, or a reluctance to advertise personal resources to neighbours or to the government (UNDP/FAO, 1982).

Gilman (1968) concluded from his studies that underground pits should be cleaned and dried before storing grain and a lining is necessary to harden the walls and reduce the rate of moisture migration from the soil. Three alternative wall linings: plastering the walls with soil cement followed by a bitumen layer on which straw may be used to prevent the grain sticking to the bitumen; P.V.C. sheet lining separating the grain from the soil (after treating the empty pit with persistent insecticide against termites), and using straw or chaff layer between the soil and grain were recommended. Boxall (1974) made a number of different linings and lid improvements, in addition to those made by Gilman (1968). The straw lining was effective in reducing fungal damage particularly for short-term storage. Three types of cement linings were recommended: single layer of cement plaster of 2–3 cm thick which is suitable for dry sandy soils, two layers of cement plaster with chicken wire in between suitable for damp soils subject to contraction and expansion, and a re-enforcement lining rendered vapour proof by sandwiching a layer of hot bitumen between the two cement layers or by applying a special bitumen paint on top of the second layer. The vapour proof reinforcement lining was considered as the best lining possible. Most improvements were identified to be expensive and not suited to small farmers use. The recommendation given to improve the lid of pits was to cover the opening with a sheet of plastic before closing it in the traditional way (with sticks and mud/dung). A sheet metal or cement concrete lid which may be sealed to the mouth of the pit with bitumen was the best lid improvement, especially for use in conjunction with re-inforcement wall lining. Problems of condensation on the underside of the lid may be avoided by covering the inside layer of the lid with some sacking. IAR (1973) indicated that if the pit itself and grain are not thoroughly dry, mould growth is inhabitable.

To reduce storage loss by simple improvement to the traditional pit stores, three types of lyings were introduced. These were matting/straw, polythene and concrete (about 2.5 cm thick). All of the treatments were found to be good, although polythene and concrete lyings were preferred by farmers. However, polythene was difficult to obtain large enough sheets, sheets became damaged or punctured easily at emptying time and sometimes at loading. Termites were found attacking the polythene in some pits. To overcome some of the problems, a switch was made from polythene sheet to polythene sacks with a capacity of approximately 50 kg. The sacks should be filled with grain and sealed at the neck before storing in underground (IAR, 1973). Lynch et al. (1986) compared hollow block pit, cement plastered pit, cement plastered plus plastic sheet, pits with plastic sheet and pits with grass lining. Results showed that fungal development was the highest in the concrete ones and the lowest in the bins, which were located aboveground. Among the underground pits, the concrete/plastic and plastic traditional were better than the hollow blocks of different combinations and the concrete ones.

Mekonnen et al. (1997) studied the effect of different locally available lining materials on the micro-climate (temperature and relative humidity) of underground pits. The linings used were straw of tef, wood shavings, plastic and sacking. Pits resembling the types used by farmers were dug and maize was stored. Changes in the pit environment were measured using a digital hygrometer. The moisture content of the grain was also measured at the end of the experiment. It was concluded that the microclimate in pits lined by plastic and wood shavings were most effective with respect to inhibiting fungal development. Good moisture contents were also measured in pits lined by plastic and wood shavings. For the plastic lined pit, the temperature rose from an initial value of 23.3 to 28.7 ^{0}C. Mashilla (2004) also reported similar findings.

Mashilla (2004) indicated that modification of pits with cement and plastic lining or replacement with improved aboveground bin could maintain the grain storage quality. The grain stored in the bin, cement and dung pits was fresh, not moulded or discoloured, after the same period of storage in the soil pit. He further indicated that if the aboveground bins or underground pits are supplemented with cement lining, the durability of the stores would be longer. This compensates for the initial construction cost. Concerning the aboveground corrugate iron storage bins, Gilman (1968) suggested that their use should be avoided unless adequate pest control methods are available to farmers. Similarly, he indicated that the traditional gotera might prove to be more efficient than a corrugated iron bin because of temperature fluctuations. There is less moisture migration problems in the latter. However, Mashilla (2004) found that thatching the corrugated-metal roof with thick grass stabilized fluctuation and kept the granary temperature at lower levels. IAR (1974) disproved findings of earlier trials that maize stored in newly cow dung dressed gotera was less infested by weevils than old cow dung layer as all were infested 20%.

Comparisons of storage containers on potato tuber moth infestation on potato at Bako in 2003/04–2004/05 indicated that mud brick, mat storage and a simple potato storage adapted from Holetta Research Center increased shelf-life of potatoes and reduced damage by the pest as opposed to pit storage, gotera and storage inside tef straw (local practice) In search of alternative low cost potato storage technique at farm level, Tena (1998) found that a naturally ventilated storage structure was satisfactory to temporarily hold ware potatoes for more than three months. He further indicated that in almost all cases, the losses caused by fungi and bacteria can be reduced by providing good ventilation and reducing temperature to the lowest possible level, but not lower than 3 to 4 °C.

Tilahun and Kebede (2004) indicated that storage in evaporative cooler increased the shelf lives of orange, lemon, mandarin, banana and papaya to more than 29, 24, 23, 20 and 14 days, respectively, compared to less than 8 days of shelf lives for all fruits when stored at ambient conditions. Tefera and Woldetsadik (2007) studied the effects of disinfection treatments, packing and storage environment on the quality of mango fruits at Dire Dawa over a storage period of 28 days. The disinfection treatments included dipping in chlorinated water, hot water (46 and 52 °C), tap water (23 °C) and untreated control, which were subdivided to packaged or held unpackaged and stored under ambient or environmentally cooled storage (EC). The EC maintained the temperature between 14.3 and 19.3 °C and the r.h. between 70.2 and 82.4% during the storage period, compared with temperatures varying from 25 to 36.5 °C and r.h. of 24 to 62.2% under ambient conditions, respectively. The shelf life of mangoes kept in the EC unit was increased from 3 to 28 days compared to storage at ambient conditions. Seyoum and Woldetsadik (2000) reported that a naturally ventilated evaporative cooler constructed from locally available materials reduced storage temperature to 5 °C compared to the surrounding air temperature, and with average rise of 26% r. h. of the air during the storage period. As a result, it was possible to store mango fruits for more than two weeks inside the cooler. Twenty-two percent of mango samples stored under ambient conditions was rot and discarded after 10 days, whereas only 0.87% of the sample stored inside the cooler was discarded after the same time of storage.

Cultural methods

Initial infestation by storage insects might occur in the field. From the field, it is carried over to the store where the population can rapidly build up. Field infestations may result from insects migrating from infested seeds in adjacent granaries to the ripening crop. Thus, pre-harvest cultural methods and storage management can be effective in the control of pests affecting stored grain. Field isolation, prompt harvesting, selection of uninfested grain, proper drying before storage, storage hygiene, etc. are important cultural practices reported for the management of storage pests (Abraham and Firdissa, 2000). Repairing and thorough cleaning of storage containers before filling with grain alone kept the grain for longer time in the traditional (well built and well managed) experimental stores at Melkassa (Abraham, 2003). Differences in insect infestation and grain damage levels among different storage containers were reported. The traditional storage type was better than the modified type (as the former was less heated than the later) (Abraham, 2003).

Abraham (1998a) and Abraham and Firdissa (2000) reported that use of maize varieties with long and tight husk cover and timely harvesting could minimize field infestation. Moreover, grain should be properly dried before storage and fresh grain should not be mixed with old grain in the store. Stored grain insect densities are determined primarily by storage time, management practices, grain moisture and temperature. The impact of moisture content of maize grain on damage by the maize weevil on maize was significant (Abraham, 2003). A number of traditional pest control practices were evaluated in the laboratory and storehouse at Bako: oven heating, smoking over fire, mixing insecticide treated grain with untreated grain and exposure to the sun gave comparable results to the standard insecticide applied at 10 ppm; cleaning, mixing with tef 50% w/w, tumbling twice or three-times a day were among the practices tested (Demissew et al., 2002). Mixing with tef at rates lower than 70% was not effective for long-term storage of maize (Abraham, 2003). Layering tef over sorghum at 20% w/w and mixing sorghum with tef at 30% w/w were tested together with other treatments between 2003/04 to 2004/05 at Bako. The result showed that the tests were not effective in protecting sorghum from storage insects (Anon., n.d).

Studies conducted at the Bako Research Center between 1996 and 1998 compared tumbling two times per day, pod storage, and mixing with some materials (wood ash, termite mound soil, tef) as well as pirimiphos-methyl 9 ppm and untreated check in the laboratory and storehouse for the control of the Mexican bean beetle on haricot bean. Most of these treatments, including the chemical insecticide, were not different from the untreated check in the first year. The ineffectiveness of the chemical was ascribed to old age while pod storage performed poorly because of shattering problem (OADB-ARCS, 1998a; 1998b). In the same study, the tumbling treatment was found to be effective in 1998/99 (Anon., n. d).

Field sanitation (removal of leftover potato tubers in the field soon after harvest) was recommended to minimize the risk of potato tuber moth (Bayeh and Tadesse, 1994). Tena (1998) found that late harvesting caused excessive PTM damage amounting to 85% within 2 to 3 weeks of delay.

Physical methods

Studies on physical methods of pest managements generally involved heat treatment and testing the effectiveness of solar radiation, although few studies also evaluated the role of oven heating. Elevated temperatures due to exposure to solar radiation may kill the developing larvae in the seed. However, conventional solar drying may not provide the level of heat required to kill all stages of insects on or in the grains. It has been widely recognized that the solar energy must be harnessed by some means. In an evaluation of polyethylene bags for effectiveness in trapping solar radiation for disinfesting weevils on maize grain, Fentahun (1995) found that black polyethylene bags covered with a transparent polyethylene sheet killed a higher proportion (90.5%) of the weevils compared to the check (sisal sack) which inflicted 30% mortality after exposure of infested grain to the sun for 24 hours. Grain temperature of 60 °C was attained in the bags. Similarly, the number of progeny weevils emerged after two months was significantly low in this treatment.

Another study compared between high density black polyethylene sheet (HDBPS) covered with high density transparent polyethylene sheet (HDTPS), HDBPS alone and sisal sack for their heat absorbing potential (EARO, 2000). HDBPS achieved the highest temperature (63 °C) and caused 100% mortality of the maize weevil within 3–4 hours of exposure to the sun. The temperature in HDBPS alone reached 53 °C and caused 71% mortality, while the temperature in the sisal sacks was 40 °C and caused only about 8% mortality (IAR, 1995c; Adane et al., 1996; Mohammed, 1996; EARO, 2000; Ferdu et al., 2001).

Mohammed (1996) reported that all eggs and adult maize weevils were killed when infested grain was heated at 60 °C for 2 hours and at 70 °C and 80 °C for 1 hour (at initial grain moisture contents of 13 and 16%, respectively). Larvae were killed at 70 °C and 80 °C after 1 hour. However, temperature, time and depth of grain layering for effective disinfestations are to be determined before recommendation for practical use.

In the 1995/96 investigation, 5 kg of maize placed in black polyethylene sheet covered with transparent sheet and infested with 100 weevils of 15 to 20 day-old were exposed to the sun by placing the bags on asphalted and aluminium painted surface. The maximum temperature recorded was 60 °C causing 45% mortality. Mortality in the lower temperatures was less than 40% (IAR, 1996a). Similarly, the effects of different grain layering depths (1, 2 and 4 cm), and temperatures (50, 55, 60, 65, 70 °C, and room temperature) were compared on maize and wheat for four hours lasting for 11 days in October 1996 (IAR, 1997). Results indicated that temperatures of 50 to 70 °C could be attained depending on the depth of grain layer, type of grain and the intensity of sunshine. Wheat attained higher (60 to 78 °C) temperature in a short time at 1cm than at 2 and 4 cm of grain layer depths. Maize heated to 65 °C in the 1 to 2 cm grain layer depth. Temperatures of 55 to 70 °C caused 80–100% mortality of weevils. Weevil mortality was over 70% at all grain layers, while the highest temperature of 88 °C was attained in the 4 cm layer. Temperatures of 55 to 70 °C caused low progeny emergence in both maize and wheat.

Similarly, Abraham (2003) found solar heating of maize on black polyethylene sheet and covered with white polyethylene sheet for five sunny days caused significantly high (about 72%) mortality of maize weevils at Bako. Heating was among the treatments in laboratory and storehouse studies of diverse measures including botanicals, inert dusts and cattle urine treatments at Bako (IAR, 1996d; Demisew et al., 2002). Grain oven heating, a simulation of farmer's practice of slight roasting (warming) on clay pan over fire, was significantly superior to the untreated check in controlling the maize weevil on maize (Abraham, 2003). Evaluations were made on solar absorbent beds prepared from black polyethylene film of 1 cm thick and 170 x 60 cm size filled with foam, grass straw, tef straw, wheat straw, jute and cotton. Then they are sealed by heating on both sides for their solar heat absorbency (EARO, 2004). It was found that foam, tef straw, jute and cotton filled polyethylene sheets had the highest respective temperature records of about 64, 68, 65 and 67°C at 12 A.M. The ambient temperature recorded during this period ranged from 26.0 to 28.4°C. The preliminary test by exposing adult pea and bean bruchids, maize and rice weevils revealed that 100% mortality could be achieved at 60 °C after 1-hour exposure (EIAR, 2004). However, except the foam, all were reported to have difficulty of flexibility.

Inert dusts

The protection of stored grain with inert substances such as wood ash, lime, sand and tobacco dust is a time honoured universal practice that is still in use for preserving seeds. Its effect consists of removal, by sorption or abrasion, of the epicuticular lipid layer, which protects insects from desiccation. Higher insecticidal efficacy is obtained with finer particles. It has been suggested that free movement of the adults for oviposition is prevented by the ash filling the intergranular spaces. Wood ash was found to have the potential for use on stored sorghum (Adane and Abraham, 1996a). Wood ash 20% w/w and termite mound soil 20% w/w were effective for the control of the Mexican bean beetle on haricot bean (Anon., n.d). Muluemebet (2003) also tested the role of wood ash and found that it must be applied at 30% w/w to provide effective control of bruchids on cowpea at Gambella.

Studies were conducted to compare wood ash, sand, sawdust, tobacco dust, each at 20, 30 and 40% w/w, and their mixture (10% each) and pirimiphos-methyl in the laboratory (Emana, 1993a; Emana and Assefa, 1997; 1998). The damage caused by the Angoumois grain moth was reduced to 15.1–17.5% by sawdust, to 13.5–16.9% by wood ash, and 29–33.6% by sand as compared to damage levels of 44.6–57.5% in the untreated shelled maize. The levels of damage were 9.5–12.5% with pirimiphos-methyl treatment. Tobacco dust and the mixture were more effective than the synthetic insecticide alone (Emana and Assefa, 1997; 1998).

Recently, Mesele (2003) and Mesele et al. (2003) tested saw-dust, coffee husk and wood ash each at 10, 15, 20 and 30% w/w against the maize weevil and the Angoumois grain moth on maize at Awassa. They found that wood ash and coffee husk treatments were superior to the untreated check, wood ash being the best. Sawdust at higher rate was effective against the grain moth while it gave the same results as the untreated check against the maize weevil at all rates tested. Wood ash, cow dung ash, sand, sawdust and termite mound soil each applied at the rate of 5% w/w were tested in the laboratory and storehouse at Bako, and most of the treatments were more effective in the laboratory than in storehouse (IAR, 1996d). Wood ash, sawdust, and termite mound soil at 10% w/w showed good level of control of the maize weevil on maize in the laboratory (Firdissa and Abraham, 1998a). Wood ash, sand and tef admixed with maize provided effective protection of maize grain from insect pests in storage (Abraham, 2003). However, the need in large quantities of these materials makes them unattractive especially for treatment of large quantity of grain. Therefore, research should look for alternative materials, which could be effective at acceptably lower rates.

Diatomaceous earth (DE) was the most efficacious natural dust for grain protection against insect pests. Abraham (2003) and Abraham and Basedow (2004b; 2005) reported that a DE known as SilicoSec at the rate of 0.1–0.2% ensured a long term, effective protection of stored maize and wheat. A similar dust known as Melkabam (filter cake) was also found to be effective against the maize weevil on maize and bruchids on several pulses (Abraham, 2005b; Abraham Tadesse, EIAR, unpublished data).

Botanical control

Plant powders

Mixing a local plant or plant powder with grain is a common traditional practice of farmers. Several attempts have been made to evaluate different botanicals as grain protectants under natural and artificial infestations in the laboratory and storehouse.

Application of neem seed powder at 1% w/w on shelled maize grain in the laboratory caused significantly higher mortality and lower emergence of maize weevil progeny than the untreated check at Bako (Abraham, 1991). Neem leaf and seed powders at 10% w/w were as effective as pirimiphos-methyl against *S. cerealella* (Emana, 1999). Maize treated with neem seed powder at 2% was less infested by the Angoumois grain moth larvae than the untreated maize in the laboratory (Emana and Assefa, 1997). Firdissa and Abraham (1999a) tested several botanicals and concluded that neem seed powder at 5% had the potential for the management of the maize weevil. Its seed powder reduced the population of weevils by 43 to 45% compared with the untreated check (Abraham, 1991; Abraham et al., 1995b). Abraham (1991) also indicated that when infestations are high, neem seed powder at low rates (1%) alone may not provide adequate control of the maize weevil on maize, although it is worth considering as part of integrated pest management in storage (Abraham et al., 1995b). Earlier studies also indicated that neem seed powder at 1 g kg^{-1} of cob maize did not give fair protection at Gambella (IAR, 1978; Yilma and Crowe, 1980).

Among 13 plant species tested as leaf (10% w/w) and/or seed powders (5% w/w) in comparison with pirimiphos-methyl and untreated check in the laboratory and storehouse at Bako. Mexican tea *(Chenopodium ambrosioides*) and neem were more effective in controlling weevils than other botanicals. Generally, the treatments were more effective in the laboratory than in the storehouse (IAR, 1996d). At the same location, mixing sorghum grain with hot pepper at 1% or 2% w/w was effective in controlling storage insects on sorghum (Anon., n.d). Mexican tea powder (MTP) was found to be as effective as pirimiphos-methyl in controlling the maize weevil at rates of 5 to 10% (EARO, 1999; Firdissa and Abraham, 1999a). At 4 to 5%, it caused significantly high mortality and low progeny emergence in maize weevil on maize (Abraham, unpublished). Mekuria (1996) reported that MTP at 2 to 4% was comparable to pirimiphos-methyl in protecting maize from *Sitophilus* weevils.

Abraham (2003) also compared neem leaf and seed powders and other plant products at the rate of 1 and 2% w/w against weevils in stored maize and found that neem oil and seed powder provided complete protection to maize grains for six months, whereas substantial insect infestations were noticed after three months in other treatments.

Similarly, different botanicals such as *Lantana camara*, *Tagetes minuta* (Mexican marigold), Persian lilac, *Croton macrostachys*, *Schinus molle* (pepper tree), Mexican tea, thorn apple/Jimson weed (*Datura stramonium*), *Eucalyptus globulus* leaf powders each at 5 and 10% w/w were evaluated in the presence of pirimiphos-methyl at 10 ppm. The results indicated that *Tagetes* at 5% performed better than all of the other botanicals in controlling the Angoumois grain moth on maize (Mesele, 2003; Mesele et al., 2003). Moreover, all botanicals were superior to the untreated check.

Endod (*Phytolacca dodecandra*) leaf and seed powders, thorn apple leaf powder, oleander (*Nerium Oleander*) leaf powder, pyrethrum (*Chrysanthemum*) flower powder, each applied at the rate of 5% by weight gave good control of the maize weevil on sorghum at Bako (Adane and Abraham, 1996b; Firdissa and Abraham; 1998a). Kernel damage caused by the Angoumois grain moth was reduced to

24.9–27.6% by neem seed powder (2% w/w) and to 3.1 – 4% by tobacco dust (20 to 40% w/w) as compared to damaged levels of 9.5–12.5% with primiphos-methyl (4 and 8 ppm) and 44.6 to 57.5% in the untreated shelled maize. However, treatment with tobacco dust left undesirable taste on the grain (Emana and Assefa, 1997; 1998), which makes it unfit for treatment of grain for consumption. Neem leaf and seed powders showed promising potentials in protecting sorghum in storage (Adane and Abraham, 1996b).

Leaf and seed powders of neem, Persian lilac, pepper tree, Jimson weed, *Tagetes* and *Lanatana* each at four concentrations (1, 3, 5 and 7% w/w) were evaluated for efficacy against the maize weevil on sorghum at Alemaya. All of the botanicals were significantly better in causing adult mortality, reducing progeny emergence and seed weight loss than the untreated check. Neem was the most effective while Jimson weed was the least. Neem at 5 and 7% w/w was comparable to the synthetic insecticide pirimiphos-methyl, whereas the lowest rate (1%) was not effective (Solomon, 1996; Solomon and Abdurahman, 1997).

Among 20 species of botanicals (at 4%) for their efficacy to control the maize weevil on sorghum in the laboratory at Sirinka, *Chenopodium ambrosioides*, *Cissus rotundifolia*, *Jatropha curas* and *Phytolacca dodecandra* caused 100% mortality of the pest within 28 days of infestation, whereas tobacco leaf powder and neem seed powder caused around 90% mortality. The control treatments with two synthetic insecticides, pirimiphos-methyl (8 ppm) and malathion caused 100% mortality (Asmare, 2002). However, progeny emergence and grain weight losses in all botanicals were not different from the untreated check (SARC, 2000). *Ayderqe* and *Chobie* were also tested each at 2, 4, 6, 8% w/w against weevils on sorghum at Sirinka for two years (ARARI, 2001).

Neem seed powder at 5 and 7% w/w on sorghum (Solomon and Abdurahman, 1997) and at 2 and 3% on chickpea (Teshome, 1990) showed comparable effects to the standard insecticide, pirimiphos-methyl. Bayeh and Tadesse (1996; 2000) reported that neem and pyrethrum flower powder controlled the cowpea beetle on faba bean.

Endod (type 44) dry seed powder caused 61 to 93% mortality of adult weevils and low number of progeny when compared to the untreated check at Ambo (EARO, 1999). From the 1996/97 trial, crude seed and leaf powders of endod (type 44) were reported to cause 58–68% mortality of adult weevils (IAR, 1997). Endod at concentrations of 10^5 and 10^4 ppm caused adult bruchid mortalities of 90% and 93%, respectively, after 72 hours (IAR, 1995c). Mortality in the untreated check was also reported to be as high as 23%. In a similar study on endod at the concentrations of 0, 10^2, 10^4, 10^5 ppm spread on filter paper for 30 minutes showed that there were differences in cumulative mortality of weevils after 7 days. The highest mortality was in the highest concentration. The remaining concentrations caused mortalities of less than 50% and did not differ from the untreated check, although in a previous test 95% mortality was recorded in all concentrations. The difference in results was attributed to the possible variations in culture, age, and method of application of the teatment. There was no difference in mortality of bruchids among treatments including the untreated check (IAR, 1996a). Furthermore, seed powder and crude water extract of the botanical were tested in two different methods: dipping weevils for 3 seconds or dipping filter paper for some time and then dried under shade before weevils were exposed. Dipping weevils caused about 40% mortality, while dipping filter paper caused mortality of 18–37%. Treatment with dry seed powder caused significantly higher mortality (61–93%) and lower number (40–75) of progeny emergence than the untreated check (IAR, 1997; EARO, 1998b). A factory by-product of endod known as *triplex* at the rate of 4 g kg^{-1} was reported to be effective against weevils on maize (Tesfahun Fanta, ESTA, 2006, pers. com.). Lower rates of Triplex were reported to be effective on the maize weevil on maize (Girma, 2006).

Tsedeke and Gashawbeza (1991) compared leaf and fruit powders of pepper tree and Persian lilac (at the ratio of 1 part of plant powder to 3 parts of seed) with Actellic and Actellic super (each at 4 ppm) and an untreated check. Both botanicals were as effective as the chemical insecticides. The doses used were too high and further tests with lower rates were suggested. Tsedeke et al. (1993) reported that pepper tree reduced the number of eggs laid by the cowpea bruchid. Ferede and Tsedeke (1992) and Ferede (1994) evaluated *Tagetes* flower, Persian lilac leaf and seed powders, pepper tree leaf and seed, neem leaf and seed and *Lantana* species seed each at 10% w/w in the presence of pirimiphos-methyl at 4 ppm for effectiveness against *Zabrotes subfaciatus* on haricot bean. Except neem seed, other botanicals protected less than the chemical insecticide in oviposition. However, all of the botanicals reduced F_1 generation and seed damage compared to the untreated check. Neem seed powder protected haricot beans for 120 days. Seven days exposure to both treatments caused 85–100% mortality of adult bruchids and as a result the damage inflicted in the two treatments was low. Seeds of pepper tree and Persian lilac also yielded lower damage than the other treatments for 120 days. In all of the treatments damage increased with storage time.

Tebikew and Mekasha (2002) evaluated thirteen botanicals, i.e., *Eucalyptus globulus*, *Croton macrostachys*, *Capsicum frutescens* fruit, *Cyphostemma* sp., *Pycnossachus abyssinica*, *Calpurina aurea*, *Cissus quadrangularis*, *Schinus molle* leaf and fruit, *Tagetes minuta*, *Phytolacca dodecandra* seed, *Millettia ferruginea* leaf and seed, *Nicotiana tabacum* and *Curcuma domestica* rhizome. Each of them was evaluated at 5% w/w for its efficacy to control Adzuki bean beetle, *C. chinensis* on chickpea at Debre Zeit. Only *Milletia ferruginea* and fermented tobacco provided complete protection for six months. *M. ferruginea* deterred egg lying, while 33% of the seeds treated with tobacco contained eggs. Turmeric protected chickpea for only two months. All other botanicals were not effective in controlling the pest. Most of the botanicals were traditionally used by farmers as grain protectants (Blum and Bekele, 2001). Bekele (2002) reported toxicity of the acetone extract of *M. ferruginea* seed and the powder itself against *S. zeamais*. Seed powder at 10% to maize seeds was also toxic to the weevil and caused significant reduction in F_1 progeny production.

Neem, chinaberry (*Melia azedarach*), Mexican tea, *Lantana*, and *Tagetes*, each at the rate of 4%, were evaluated against *Zabrotes subfasciatus* on haricot bean (Tigist, 2004). It was found that botanical treatments increased adult mortality, reduced F_1 progeny number, percentage seed damage and seed weight loss. Mexican tea seed and leaf, *Tagetes* seed and leaf and neem seed powders gave better protection than the other botanicals. Lantana was the least in protecting haricot beans from damage by the bruchid (Tigist, 2004).

In an investigation on the botanicals *Eucalyptus globulus* leaf and seed powders, *Schinus molle* seed powder, *Hagenia abyssinica* seed powder, *P. dodecandra* seed powder, *Chrysanthemum cinerariaefolium* flower powder, and oils of *Azadirachta indica* and *M. ferruginea* (each at three rates [50, 100, 150 mg 100 g $^{-1}$ seed]) against *C. chinensis* on faba bean in the 1993 and 1994 seasons at Holetta, .*Chrysanthemum cinerariaefolium* (pyrethrum) flower powder and kernel oils of *A. indica* and *M. ferruginea* were effective in controlling the pest. The plant oils in the investigation were also equally effective (Bayeh and Tadesse, 1996; 2000; EARO, 1998a; IAR, 1995b).

Neem leaf powder at 0.5, 1, 3 and 5% w/w and neem seed powder at 0.5, 1, 2 and 3% w/w were evaluated together with vegetable oils in the laboratory and storehouse It was found that neem seed powder at 2–3% w/w was the most effective treatment in controlling *C. chinensis* on chickpea. The treatments reduced oviposition, egg hatch and progeny emergence (Teshome, 1993).

Meheret (2003) compared powders of neem seed and leaf, pepper seed and leaf, Hagenea leaf, endod seed, eucalyptus leaf, Persian lilac seed and leaf, each at 4% w/w. It was reported that the botanicals (except Persian lilac), neem leaf and endod powders minimized seed damage, maintained seed germination, and reduced weight losses over the control during 90 days test period. In addition, eucalyptus leaf powder significantly delayed the development period of the pest.

Muluemebet (2003) carried out three sets of laboratory experiments: pre-treatment infestation, post-treatment infestation and persistence test (at 1–3 months after application of elevated doses) evaluating the efficacy of neem leaf and seed powders, Mexican tea powder and other treatments including plant oils and inert dusts. Mexican tea seed and leaf powders at higher doses (3 and 6% w/w) significantly reduced oviposition, egg hatchability and adult emergence of *C. maculates* on cowpea. Pre-infestation treatments were better than post-infestation treatments. Neem seed at 3% w/w was better than all other botanicals and had longer persistence as it was effective even after three months of application. It also delayed progeny emergence. Neem seed at 2–3% w/w, neem and Mexican tea leaf powders each at 6% w/w, Mexican tea seed at 3% w/w gave better protection to cowpea seeds, especially when applied before infestation.

Neem seed extract (500 g extracted in 10 litres of water), neem leaf and seed powders, pyrethrum flower powder, eucalyptus and pepper tree leaf powders were evaluated for the control of PTM under natural infestation in diffused light stores (DLS) at Holetta Agricultural Research Ceneter between April and November 1997 (EARO, 1998a). Botanicals significantly reduced tuber damage over the untreated check. However, PTM infestation was low in the season and treatment differences were not apparent (EARO, 1998a). In a similar experiment at Holetta, neem leaf and seed powders, eucalyptus and pepper tree leaf powders provided less amount of tuber damage. PTM infestation in the season was also low in the store (IAR, 1996b). In another investigation, *Lantana camara*, *Eucalyptus globulu*, *Tagetes minuta*, neem leaf powders, and pyrethrum flower powder each at the rate of 40–50 g per 600–650 potato tubers were tested for the control of PTM at Bako between 2003/04 and 2004/05. *Lantana*, *Eucalyptus* and pyrethrum were as effective as diazinon at 60% EC at 3.5 ml per 650 tubers (Anon., n.d).

Twenty-six plant species with potential antifungal activity from Ethiopia and tested in the laboratory in Germany on the fungi *Eurotium amstelodami*, *Cladosporium cucumerinum*, *Bipolaris sorokiniana* and *F. graminearum*. The test revealed antifeedant activity in chloroform extracts of *Echinops* sp., *Ruta chalepensis* and *Thymus serrulatus*. Further evaluations of extracts with a slide culture technique indicated that they inhibited spore germination and hyphal growth of *B. sorokiniana* and *F. graminearum* (Amare, 2002).

In conclusion, neem has been studied since 1970s and was found to be better in its efficacy than other botanicals for storage pest control in Ethiopia (IAR, 1978; Yilma and Crowe, 1980). Almost all studies on botanicals have included neem in their treatments. Generally, seed powders of botanicals were more effective than leaf powders (Ferede, 1994; Solomon, 1996; Solomon and

Abdurahman, 1997; Muluemebet, 2003). None of the studies have been carried out under conditions of traditional storage practices. Moreover, no attempt was made to extract active principles of the botanicals.

Vegetable oils

Several edible and non-edible oils have been tested as stored grain protectants against different insect pests. Abraham (2003) compared oils of maize, sunflower, sesame, noug and neem against the maize weevil on maize at Bako. He obtained effective control of the pest with all oils at rates ranging from 5 to 10 ml kg $^{-1}$. However, higher rates of oils suppressed seed germination.

On-farm evaluation of different oils at 5 ml kg $^{-1}$ for the control of inset pests of stored maize in the Bako area showed that most of the oils caused over 50% cumulative mortality of adult weevils and resulted in lower amount of grain damage (Girma et al., 2004). Combined treatment of noug oil with pirimiphos-methyl was found to be as effective as pirimiphos-methyl alone applied at the recommended rate. Neem oil provided complete protection to maize grain for six months (Abraham, 2003).

Teshome (1990; 1993) evaluated oils from groundnut (*Arachis hypogea*) and noug (*Guizotia abyssinica*) each at 0.5, 1, 3 and 5 ml kg $^{-1}$ together with other botanicals and pirimiphos-methyl on chickpea against *C. chinensis* in the laboratory and storehouse at Debre Zeit. It was found that both oils at 3 - 5 ml kg $^{-1}$ protected the seed effectively, but groundnut oil is more potent and persistent than noug oil at the same rate. Hatchability of eggs on chickpea was completely hindered by higher rates of groundnut oil and significantly reduced by noug oil treatments (Teshome, 1990; 1993). Oils of *A. indica* and *M. ferruginea* gave best control of *C. chinensis* on faba bean (Bayeh and Tadesse, 1996; 2000; EARO, 1998a; IAR, 1995b). It was suggested that further studies are required to test lower rates and identify optimum doses, their effects on seed germination and the safety of treated seeds for consumption. Noug oil at the rate of 0.6 and 0.9 kg $^{-1}$ against *Zabrotes* on haricot bean was as effective as malathion, but seed germination was reduced by the oil treatment (Tigist, 2004).

Noug oil at 4 ml kg $^{-1}$ seed was as effective as the synthetic insecticide on bruchids in adult mortality, and it also reduced initial number of eggs laid, amount of grain damaged, progeny emerged and seed weight loss, and delayed the development period. Lemon oil also showed promising potential. The rate of seed germination was 100% in noug oil, and 98% with lemon oil treatments, while it was 66.7% in the untreated check 90 days after treatment.

Noug oil at 3, 6 and 9 ml kg^{-1} grain reduced oviposition, egg hatchability and adult emergence of *C. maculates* on cowpea (especially at pre-infestation) (Muluemebet, 2003). However, after three months the oil treatment was not different from the untreated check. Similarly, the effectiveness of the synthetic insecticide (primiphos-methyl at 5 ppm) declined after two months. On the other hand, the rate of germination decreased in the oil treatment. Thus, noug oil should not be applied for seeds since it has negative effect on them. The effect of vegetable oils on adult mortality was gradual. Thus, it was concluded that oils mainly affect oviposition, egg hatchability and progeny development.

Biological control

Parasitoids and predators

Natural enemies undoubtedly play a part in reducing pest numbers in many traditional storage systems, but they may not give economically acceptable level of control. Many natural enemies have been recorded from grain storage systems in Ethiopia (Table 8). Abraham (2003) reported the occurrence of predator bugs (*Xylocornis* spp.*),* spiders and lizards in simulated on-farm storage facilities at Bako and Nazareth agricultural research centers. Muluembet (2003) also recorded lizards feeding on adult bruchids and ants on bruchid eggs in storage at Gambella. Moreover, Abraham (1991; 1996a; 1997; 2003) recorded six species of wasps from farm-stored maize in Ethiopia (Table 8). *Anisopteromalus calandrae* (Walker and Boxall, 1974; Abraham, 1991; 1996a; 1997; Emana and Assefa, 1998) and *Choetospila elegans* (Abraham, 1991; 1996a; 1997) were the most common natural enemies of farm-stored maize. *A. calandrae* is a well known cosmopolitan parasitoid of Coleopterans, and perhaps some Lepidopterans associated with grain in storage. Similarly, *C. elegans* is a cosmopolitan parasitoid of small beetles on stored grains (Abraham, 1991; 1996a; 1997).

Although a number of parasitoids have been recorded, they do not appear to reduce the host population to any serious extent. This might be that as stored grain and other food commodities are frequently moved and disturbed, the more delicate hymenoptrous wasps fail to survive the disturbance, while the more robust beetles and moths or their larvae are little affected (Abraham, 1991). However, the presence of considerably high number of natural enemy species and individuals of each species may indicate the possibility of using predators and parasitoids in insect management (Abraham, 1991; Abraham et al., 1993). There may be a scope for modifying storage systems to increase the role of natural enemies.

However, biological control is not suitable in all crop protection contexts. There are many situations in which this type of approach does not work. A major problem with biological control is its incompatibility with chemicals, since natural enemies of insects are often more susceptible to the pesticide applied than are the insect pests themselves.

Table 8.. Parasitoids and predators of arthropods recorded in grain stores in Ethiopia

Scientific name	Common name	Status
Aranea		
Spider spp.	Spiders	Common
Hemiptera	Bugs	
Anthocoridae	Flower bugs	
Xylocoris afer (Rauter)	Africa store bug	Uncertain
Xylocoris spp.	Warehouse pirate bug	Uncommon
Heteroptera		
Reduviidae	Assasian bugs	
Amphibolus /Peregrinator sp.?	Predacious bug	Uncommon
Hymenoptera	Parasitic wasps	
Bethylidae		
Holeypyris sylvanidis (Brethes)	Bethylid wasp	Uncertain
Braconidae		
Bracon hebetor Say		Uncommon
Chalcidae		
Antrocephalus sp.	Chalcid wasp	Uncertain
Eupelmidae		
Eupelmus sp.	Eupelmid wasp	Uncertain
Pteromalidae		
Anisopteromalus calandrae (How)	Pteromalid wasp	Common
Choetospila elegans Westwood	Pteromalid wasp	Common
Habrocytus sp.	Pteromalid wasp	Uncommon
Lariophagus distinguendus (Foerst.)	Pteromalid wasp	Uncommon
Pteromalus sp.	Pteromalid wasp	Uncertain

Entomopathogenic fungi

Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* are known for their effectiveness against different insect pests. Adane et al. (1997a; 1997b; 1998) exposed adult maize weevils and cowpea bruchids to spore suspensions (10^4 to 10^8 conidia ml $^{-1}$) of B. *bassiana* isolates. All 10 isolates tested were capable of infecting both test insects but differed in their degree of virulence. I89-481, I90-520, I89-447, I90-533 and I90-907 were the most virulent (median lethal time (MLT) = 2.8-4.2 days); I92-736, I93-906, I92-761A intemediate (MLT = 4.2-6 day) and I93-86, I93-870 weak virulent (MLT= $\geq$ 7.5 days) (Adane et al., 1998; Ferdu et al, 2001). Adult mortality of the maize weevil and damage to maize seeds treated with different levels of dry conidia were not significantly different from pirimiphos-methyl treated maize after 14 days of storage period, but the chemical pesticide killed all target insects within 24 hours, whereas mortality began at day three for the best *B. bassiana* isolate. In another study, *B. bassiana* isolates obtained from chaffer grub and sweet potato butterfly were found to be pathogenic to the maize weevil causing 60–89% mortality in a preliminary test at Ambo (IAR, 1997).

In another study, eight isolates of *B. bassiana*, and one isolate (from each) of *Paecilomyces* sp. and *M. anisopliae* isolated from dead insects collected from different localities in Ethiopia were tested against the maize weevil and differences were observed among the isolates in terms of adult weevil mortality and median lethal time. Further virulence test showed that three of the *B. bassiana* isolates caused 83–89% mortality at 10^7 conidia ml^{-1}, while *M. anisopliae* caused 77–98% mortality at 10^6 and 10^7 conidia ml^{-1} (EARO, 2000). The *Paeciliomyces* isolate caused the lowest mortality while *M. anisopliae* isolate EE was the most potent. The LD_{50} values of the isolates tested ranged from 3.3 x 10^5 to 2.62 x 10^6 conidia ml^{-1} (EARO, 2002; 2003).

Isolates of *B. bassiana* and two unidentified insect pathogens from chaffer grubs and Wello bush crickets caused mortality of maize weevils in 4 to 6 days after treatment when inoculated with a solution of 10^7 conidia ml^{-1} in distilled water (IAR, 1995c). Entomopathogenic fungi at different concentrations (3.7875 x 10^8, 3.7875 x 10^7, 3.7875 x 10^6, 3.7875 x 10^5, 3.7875 x 10^4 conidia ml^{-1}) were evaluated for the control of storage pests and found that in the first test all isolates caused less than 50% mortality (EARO, 1998b). In the second test all isolates caused 68 to 80% mortality. However, high mortality was also recorded in the untreated check, indicating the need for further tests under improved experimental conditions.

Varietial resistance

Resistant varieties are integral part of integrated pest management of storage pests. Substantial data has been accumulated from varietal screening researches in Ethiopia. Differences in resistance among maize genotypes to weevils (Abraham, 1991; Abraham et al., 1994; 1995a; Firdissa et al., 2001; Demissew et al. 2004) and to the Angoumois grain moth (Emana, 1993a; Emana and Assefa, 1995) have been reported. Maize genotypes 27/2, Birkata, UCA and UCB were resistant to weevils while SC22 (the male parent of Gutto, BH-140 and BH-540), Jimma-Bako, Alemaya Composite, Gutto, KCB, Alemaya-28 (Pop corn), KCC, Ambo-Bako, BH-140, NSCM-41, H-625, Bukuri, A-511 and Bako Composite were susceptible (Abraham, 1991; Abraham et al., 1994; 1995a). In another study, UCB, H-8151 and H-501 in free choice test and H-8151 and H-501 in no-choice test were found to be resistant to the Angoumois grain moth while Gutto and Katumani in free choice and Katumani and Alamura Early in no choice test were highly susceptible (Emana, 1993a; Emana and Assefa, 1995). Dejene (1975) tested 10 opaque-2 maize kernels for resistance to weevils. However, results were not consistent and further investigations into the storing ability of opaque-

2 and normal maize grains were suggested. Grain texture (flint or dent) was not the only factor responsible for weevil resistance (Abraham, 1991; Demissew, 2004). Demissew (2004) screened 40 maize genotypes for weevil resistance and found that there were heritable quantitative traits controlling some aspects of weevil resistance that could be exploited in a suitable breeding procedure to develop acceptable resistance. Lines 2, 3, 4, 5, line 3 x Gutto LMS5, line 4 x Gutto LMS5, Gutto LMS5 x line 2 were found to be resistant.

Resistance to maize weevils has been detected in many sorghum varieties (Adane and Abraham, 1993; Adane and Abraham, 1997; Solomon, 1996). The genotype 84MW4138 was relatively resistant while Asfaw White and D-1057 were highly susceptible (Adane and Abraham, 1993). Similarly, the genotypes 91-AL5030, ETS-789, 91-AL4346, 91-AL5153, 91-AL5048, 91-AL5090 and ETS-993 showed consistent resistance to the pest (Solomon, 1996). In another set of sorghum genotypes evaluated for resistance to the maize weevil, no significant difference was detected (Adane and Abraham, 1997).

Teshome et al. (1999) collected traditional farmers' knowledge and opinion on storability of sorghum landraces with respect to the major insect pest *Sitophilus oryzae*, rice weevil. He calculated farmers` index of storability for each landrace. The landraces were then assessed for rice weevil susceptibility and it was found that the mean farmers` index for the landraces was inversely related to the susceptibility parameters of F_1 emergence, oviposition, weight loss and Dobie Index but less closely related to the median development period. The conclusion was that farmers' knowledge can be an excellent guide to characterize susceptibility of sorghum to storage pests (Teshome et al., 1999).

Ramputh et al. (1999) reported that eight landraces of sorghum collected in Ethiopia showed significant variation in soluble phenolic content measured as catechin equivalents. Significant inverse linear relationships were found between resistance parameters such as weight loss of grain, the Dobie index of susceptibility, number of eggs laid and progeny of *S. oryzae* emerged and the phenolic content of the grain (r^2 = 0.85, 0.55, 0.46 and 0.52, respectively). The results suggested that the soluble phenolic content, which previous studies have shown to consist primarily of proanthocynidins, could be used as an indicator of resistance.

Tef artificially infested with *S. oryzae* or *Acanthoscelides* sp. was not damaged and all the insects died within 20 days of storage (JATS, 1963). McFarlane and Dobie (1972) also reported the resistance of tef to insect pests in storage.

Evaluation of 40 local accessions of chickpeas for resistance to the bean bruchid under free and no-choice conditions in the laboratory indicated the presence of significant differences among accessions in suitability for oviposition with the least number of eggs recorded on genotypes ICC-3528, ICC-11320 and ICC-595 under both test conditions (Teshome, 1990; 1994). It was reported that all of the genotypes evaluated had rough seed coat.

Comparisons between two varieties of faba beans, Dobie and Mariye, which differ in their seed size, seed colour and seed texture, showed differences in weight losses caused by *C. chinensis* (DZARC, 1993). Among four released faba bean cultivars (Kassa, CS20DK, NC58, and Kuse) evaluated for resistance to *C. chinensis* in the laboratory and on-farm, Kassa was less susceptible than the other cultivars (IAR, 1995c; 1996b). These four faba bean cultivars from Ethiopia were also evaluated (both as whole seed and decorticated) together with eight other varieties from the Sudan and Egypt for their resistance to two strains of *C. chinensis* (Kemal, 1988; Kemal and Smith, 1996; 2001). It was found that the genotypes differed significantly in their reaction to the bruchid. The variation in resistance of the varieties might be due partly to the properties of seed coats or biochemical antibiosis as development was very successful on coatless seeds (Kemal and Smith, 1996). In an earlier study, 50 faba bean varieties were screened and significant differences were observed among them. PGRC/E 203128-2 was with the highest amount of eggs (39.9%) while the highest (62.3%) amount of adults emerged from CS20 DK-3-4-1-5. Only 4% emergence was recorded on PGRC/E 203131-2. However, development periods were similar in all of the varieties. Susceptibility index showed CS20DK3-4-1-5, PGRC/E 027082-2-2-1 and L82094-13 were susceptible, while EH86120-2, PGRC/E 203131-2 and 582383-5-1 were resistant to *C. chinensis* (IAR, 1991b).

High level of resistance was detected in RAZ lines and Roba-1 among 56 haricot bean genotypes from Melkassa, Bako and CIAT and screened for resistance to the Mexican bean beetle at Bako (OADB-ARCS, 1998a; 1998b; Firdissa et al., 2000). Ferede and Tsedeke (1992) also reported the resistance of RAZ lines to the same pest. Some RAZ lines were also resistant to two major bean diseases: anthracnose and common bacterial blight. Stem maggot resistant bean genotypes did not resist *Zabrotes* damage.

One hundred haricot bean genotypes (73 *Zabrotes* resistant lines from CIAT and 27 lines from Melkassa Bean Breeding Program) were screened and least oviposition was observed on genotypes Raz -8, Brown Speckled and RAZ 20-1. Several genotypes were less preferred for oviposition and a number of genotypes were identified as resistant based on absence of bruchid emergence hole. Varieties obtained from the breeding program at Nazareth Agricultural Research Center were all with higher number of damage holes. Varieties ICA155141, AWASH-1 and RAZ 5 were susceptible – had higher number of holes (Ferede and Tsedeke, 1992). Further tests with 20 selected accessions confirmed that most CIAT accessions showed high level of resistance as compared to local or commercial varieties. RAZ 1, RAZ 7, RAZ 8 and RAZ 11 were consistently resistant and can be used as reliable sources in breeding programs (Ferede, 1994; Tsedeke, 1995). Under no-choice test *Zabrotes* oviposited on all accessions, but in free choice tests they prefer to oviposit on seeds of susceptible varieties. Hence, data on the number of eggs in no-choice test is not a good measure of resistance to the pest (Ferede and Tsedeke, 1992). Moreover, high number of eggs did not always result in correspondingly high number of progeny bruchids. Thus, number of eggs per female cannot be used as criteria for resistance evaluation (Ferede and Tsedeke, 1992; Ferede, 1994). Morphological characters such as seed size, seed color and seed texture did not seem to influence ovipositional preference of female bruchids and subsequent adult emergence and damage (Ferede and Tsedeke, 1992; Ferede, 1994). Most accessions received from CIAT were reported to be known for their arcelin content–a toxin that affects the survival and development of Mexican bean beetle (Ferede and Tsedeke, 1992).

According to Tigist (2004), among 15 haricot bean varieties tested, Red Wolaita, A-197, and Ayenew were relatively resistant to *Zabrotes*. Roba-1 and Brown Speckled, which were reported by Ferede (1994) as resistant to the same pest, were found susceptible in her study. She also reported that high number of eggs resulted in low number of F_1 progeny indicating that number of eggs does not show varietal differences in *Zabrotes* resistance (Tigist, 2004).

In an earlier study, nine cowpea lines introduced for their bruchid resistance and a commercial variety White Wonder Trailing were evaluated for resistance to bean bruchids for two seasons; all the introduced varieties had significantly lower levels of infestation and seed damage than White Wonder Trailing (Ferede, 1989). Superior results were obtained from IT 81 D-1137, IT D-985 for the two seasons, and IT 81 D-944 for the 1985/86 season. Tsedeke (1995) indicated that the IITA accession IT-81D-85 showed high level of resistance to the bruchid, and the commonly recommended variety White Wonder Trailing was highly susceptible. However, the resistant varieties were reported to be poor yielders. Hence, it was suggested that the trait should be transferred to high yielding varieties (Ferede, 1989).

Twenty chickpea varieties were tested for their resistance to bruchids (DZARC, 1987). Based on the number of eggs, infested seeds and seed damage data recorded at different periods during 18 days of exposure, no difference was observed among the varieties. In another investigation, 23 chickpea varieties were kept in a circular tray open to bruchid infestation in the store. Significant differences were observed among varieties in the number of eggs oviposited during a 60 days, after which eggs were found on all seed of all varieties

(DZARC, 1988). Emergence of progeny bruchids began 60 days after storage in some varieties. Four varieties DZ-10-4, JG-62, NEC-756, and DZ-10-11 did not show damage holes within 75 days. Some variations among varieties were observed in the number of holes up to 105 days. However, after 180 days, all varieties were highly attacked and some were completely destroyed. Three or more damage holes per seed reduced seed germination of all varieties. Although some variations among varieties in susceptibility to bruchid, all genotypes appeared to be more vulnerable to damage as storage time extended longer than two months under experimental conditions (DZARC, 1988).

Research on resistance to fungal attack received hardly any attention. Amare et al. (1995) evaluated 11 groundnut cultivars at Babile for their resistance to different species of fungi with emphasis on seed resistance to *A. flavus*. He found that the cultivars differed significantly from each other in the degree of seed infection by *Aspergillus* and *Penicillium* spp. The genotypes ICG-2519, ICG-9088, and NC-4X showed lower *in vitro* seed colonization by *A. flavus* than the resistant check J-11.

Various potato cultivars were tested for their resistance to PTM at Nazareth in 1980–1983 seasons, and reported differences in the degree of resistance among the potato materials (IAR, 1985a). However, 25 potato varieties stored for 90 days at Awassa to test their resistance to PTM were 100% infested (Adhanom and Emana, 1989).

Chemical control

Chemical treatment include preventive application of residual insecticides that are intended to limit the invasion and development of damaging insect infestations and remedial fumigation that provide rapid control of existing insect populations. The use of chemical insecticides in the form of sprays, fumigants or dusts against stored grain pests has been reported by many researchers. Insecticides representing organophosphorus compounds and pyrethroids were tested widely, although the organochlorine lindane was also evaluated in few studies (Tables 9, 10, 11, 12). From studies in 1970s at Gambella, Yilma and Crowe (1980) recommended that maize cobs should be dusted layer by layer with 0.5% lindale at the rate of 100 g per sack of cobs (800 g per crib basket) at the time of filling the basket. The crib should be sited in an area away from strong winds. Adhanom (1989), Abraham (1991; 1993b) and Abraham et al. (1993; 1995b) reported that deltamethrin, malathion, permethrin, a cocktail of malathion with permethrin, methacrifos, fenitrothion and pirimiphos-methyl effectively protected maize and sorghum (Adane and Abraham, 1996a) from the maize weevil. Emana (1996) reported pirimiphos-methyl, deltamethrin, pirimiphos-methyl + permethrin and malathion + permethrin treated maize was kept for six months without being damaged by the Angoumois grain moth at Awassa (Table 12). Pirimiphos-methyl gave long time protection to haricot bean from the cowpea bruchid as compared to methacrifos or lindane (Tsedeke and Adhanom, 1985).

Table 9. Effects of insecticides against the Angoumois grain moth at Awassa (Emana, 1993a)

Insecticides	Rate (ppm)	Initial		Reinfested 3 MAT	
		No. of F1	Grain damaged (%)	No. of F1	Damaged (%)
Pirimiphos-methyl 2% D	5	0.00 a	0.50 a	0.33 a	0.67 a
Pirimiphos-methyl 2% D	10	0.00 a	0.25 a	0.33 a	0.33 a
Deltamethrin 2.5%	2	0.00 a	0.17 a	0.00 a	0.33 a
Pirimiphos-methyl + Permethrin 0.4%	10	0.00 a	0.08 a	0.67 a	1.33 a
Permethrin 1%	2	19.67 b	7.25 a	5.67 b	19.33 b
Malathion 1.6% + Permethrin 0.4%	10	0.33 a	0.25 a	0.00 a	1.00 a
Neem seed powder (w/w)	2%	35.67 c	16.42 b	16.67 c	33.67 c
Untreated check	-	38.67 d	52.75 c	26.00 c	58.00 d
C.V.		55.93	25.70	47.69	31.73

A storage trial conducted by researchers at CADU (1969) compared three insecticides with an untreated check and found that the two insecticides, phostoxin 1 tab 100 kg^{-1} and malathion 1% 125 g 100 kg^{-1} were equally effective while the botanical (pyrethrum + piperonyl butoxide 0.2 + 1%, 125 g 100 kg^{-1}) showed insufficient effect. The difference in hectoliter weight (assumed to represent weight loss) between the untreated and phosphine and the untreated and malathion treated were 8% and 7.2%, respectively.

Other studies showed that methacrifos (damfin), fenitrothion (folithion), pirimiphos-methyl and lindane were effective against the maize weevil on maize (IAR, 1984; 1985a; 1985b; 1987c) (Table 10). In another instance, the above insecticides including deltamethrin were effective in the numbers of adult weevils dead and alive, and number of damaged maize kernels (IAR, 1987b). In the 1983/84 experiment (IAR, 1984; 1985b), damfin 950 EC at 9.5 ppm, and pirimiphos-methyl 50 EC at 5 ppm were included together with dusts. All of the chemicals performed better than the untreated check. However, all of the EC formulations were excluded in the subsequent season because of their application difficulty.

Table 10. Effects of different insecticide dusts against the maize weevils on maize at Awassa (Adhanom, 1989)

Treatments	Rate (ppm)	Number of weevils & grain damaged			Grain weight loss (%)
		Dead	Live	Damaged kernels	
Methacrifos (Damfin) 2p	5.0	2.16 a	0.28 a	5.46 a	2.15
Methacrifos 2p	7.0	2.12 a	1.12 a	4.47 a	2.40
Methacrifos 2p	10.0	2.30 a	0.25 a	4.07 a	1.98
Fenitrothion (Folithion) 1%	7.5	2.58 a	0.47 a	4.73 a	6.85
Pirimiphos-methyl 2%	7.0	2.90 a	0.45 a	4.38 a	1.90
Lindane 0.5%	15.0	4.01 a	0.37 a	5.89 a	13.35
Deltamethrin (K-othrin) 2.5%	1.0	4.01 a	0.37 a	5.89 a	5.50
Untreated check	-	29.29 b	65.58 b	92.74 b	16.48
S.E.		2.35	2.63	5.65	-

Deltamethrin, methacrifos, permethrin, a cocktail of malathion with permethrin and pirimiphos-methyl were found to be effective against weevils in storage (Table 11) (Abraham, 1991; Abraham et al., 1995b).

Table 11. Effects of insecticide dusts on mortality, survival and progeny emergence of the maize weevil at Bako on maize (Abraham, 1991)

Insecticides	Rate (ppm)	Number of Adult Maize Weevils			
		Parent weevils Dead 1WAI	Parents survived	Progeny Emerged	Re-infested Dead ®
Deltamethrin 0.2%	1	25.75 a	0.00 c	0.00 c	15.00 a
Deltamethrin 2.5%	2	25.75 a	0.00 c	0.25 c	15.00 a
Lindane 0.5%	5	25.50 a	0.25 c	0.00 c	15.00 a
Malathion 1%	10	25.50 a	0.00 c	4.00 b	14.00 a
Malathion 1.6% + Permethrin 0.4%	10	23.50 a	0.00 c	0.00 c	15.00 a
Methacrifos 2 DP	10	25.25 a	0.00 c	0.00 c	15.00 a
Neem seed powder (w/w)	1%	11.25 b	13.50 b	5.75 b	6.75 b
Permethrin 1%	2	25.50 a	0.00 c	0.00 c	15.00 a
Pirimiphos-methyl 2% D	5	25.75 a	0.00 c	0.00 c	15.00 a
Pirimiphos-methyl 2% D	10	25.00 a	0.00 c	0.00 c	15.00 a
Untreated check	-	1.00 c	24.25 a	164.00 a	0.00 c
L.S.D. 5%		0.70	0.73	0.67	0.97
L.S.D. 1%		0.95	0.99	0.91	1.29
S.E.		0.24	0.25	0.23	0.34
C.V.		10.88	37.39	22.39	5.22

Dp = dustable powder
® = mortality of weevils re-infested 5 months after treatment

Methacrifos 2P at 5, 7 and 10 ppm; fenitrothion 2% at 7.5 ppm; pirimiphos-methyl 2% at 7 ppm; Lindane 0.5% at 15 ppm; deltamethrin 2.5% at 1 ppm were evaluated in the presence of untreated check for effectiveness against weevils on sorghum at Awassa in the 1984/85 season (IAR, 1986a). Insect mortality and grain damage records made at fortnight basis for seven and half months indicated that all of the chemicals, except deltamethrin, controlled the pest effectively. Adane and Abraham (1996a) and Firdissa and Abraham (1998a) evaluated several insecticide chemicals against the maize weevil on sorghum at Bako in the 1991 and 1992 seasons and reported that pirimiphos-methyl 2% dust, deltamethrin 0.2%, malathion 1%, malathion 1.6% + permethrin 0.4% were effective against the weevil.

Malathion 5% D at 30, 50, 75, 100 and 120 g per 100 kg grain was evaluated in the presence of pirimiphos-methyl at 30 g and an untreated check for the control of weevils on maize and sorghum in the laboratory at Bako for seven months. Malathion at rates of 75–100 g per 100 kg grain was effective in controlling the pests on both crops. The two lower rates of malathion and pirimiphos-methyl were not effective (Anon., n. d).

Pirimiphos-methyl at 4, 5 and 6 ppm provided effective control of *C. chinensis* on haricot bean at Nazareth (IAR, 1985a; 1986c; Tsedeke, 1985). Pirimiphos-methyl 2% D at 8 ppm, fenitrothion (folithion) 1% at 10 ppm, methacrifos (damfin) 2% at 8 ppm, lindane 0.5% D at 7.5 ppm, a vegetable oil at 2 ml kg^{-1} and phostoxin were tested for the control of *C. chinensis* on faba bean at Holetta (IAR, 1986b; 1986c; Anon., 1990). The insecticide dusts and vegetable oil treatments were reported to be effective. The amount of damage in treated seeds ranged from 0 to 12% as compared to 97.7% (with a corresponding loss of 25.1% in seed weight) in the untreated check. Use of vegetable oil at the rate tested was reported to be more economical for the farmer. This rate should not be exceeded because an excess had a tendency to induce more infestation (Anon., 1990). Moreover, four insecticide dusts and a vegetable oil each at two rates were evaluated against *C. chinensis* on faba bean in the laboratory at Holetta in the 1985/86 season. It was found that treatments with insecticides or oil reduced damage significantly better than the untreated check (IAR, 1987a) (Table 12). All treatments did not reduce seed germination, but seedlings/plants germinated from seeds in the untreated bags (damaged) were not as vigorous as that of treated seeds.

Table 12. Control of *C. chinensis* in the laboratory at Holetta Research Center (IAR, 1987a)

Treatments	Rate (ppm)	Amount of seed damage (%) after months of treatment			Percent seed germination (9 MAT)
		3 months	6 months	9 months	
Pirimiphos-methyl 2% D	6	0.9 a	1.6 b	1.3 ab	93 ab
Pirimiphos-methyl 2% D	8	0.7 a	1.0 a	0.7 a	93 ab
Lindane 0.5%	5	0.9 a	1.0 a	1.0 a	70 c
Lindane 0.5%	7.5	0.7 a	0.2 a	0.7 a	97 a
Fenitrothion (Folithion) 2%	5	0.9 a	0.7 a	0.7 a	100 a
Fenitrothion 2%	10	0.7 a	0.7 a	0.7 a	100 a
Methacrifos (Damfin) 2%	8	0.7 a	0.7 a	0.7 a	100 a
Methacrifos 2%	12	0.7 a	0.7 a	0.7 a	97 a
Vegetable oil	20	0.7 a	1.0 b	0.7 a	83 a
Vegetable oil	30	0.7 a	1.5 b	2.7 b	90 ab
Untreated check	-	2.7 b	9.5 c	9.7 c	40 d
S. E.		1.9	0.27		3.8

Based on laboratory results (IAR, 1990b, 1991a), verification studies made with pirimiphos-methyl 2% (10 g 25 kg $^{-1}$), phostoxin (1 tablet 50 kg $^{-1}$) and noug oil (25 ml per 25 kg faba bean) in the 1988/89 season under farmers storage conditions showed that pirimiphos-methyl provided better protection than the oil and phostoxin. It protected about 47% of the seeds for six months. After nine months, the synthetic insecticide protected about 44% of the seeds, whereas the oil and the fumigant protected less than 7 and 13% of the seeds, respectively, although the latter two treatments showed acceptable control in the laboratory (IAR, 1990d; ICARDA, 1990).

Studies conducted with pirimiphos-methyl, methacrifos and fenitrothion each at three rates against bruchids at Debre Zeit in the 1985 season showed that pirimiphos-methyl and fenitrothion were equally effective for about six months (DZARC, 1987; 1988).

Three insecticide dusts and three chickpea varieties were tested in a factorial experiment in 1986/87 at Debre Zeit. The highest rate of pirimiphos-methyl 2% D was effective 15 days after treatment. Methacrifos 2% D showed better persistence in that it was effective 180 days after infestation (DZARC, 1987). In 1987/88, three varieties (Duble, DZ-10-2, 850-3/27xF_{378}) and three insecticides (pirimiphos-methyl 2% D, methacrifos 2% D, fenitrothion 1% D) each at three rates were evaluated at Debre Zeit (DZARC, 1988). The results showed that following 45 and 60 days after exposure, all of the three chemicals and rates were effective in reducing eggs when compared with the untreated check. After 75 days of exposure, pirimiphos-methyl and fenitrothion showed similar and better effects in reducing the number of eggs. The higher rates were found to have better effects. Emergence holes appeared in some seeds at this stage. However, after 120 days, the insecticides were not effective.

Preliminary studies in Humera in 1971 showed that sesame seed bug could be controlled by carbaryl 5% dust (IAR, 1977b). In 1974, a replicated trial that compared commercially formulated 5% dust with locally diluted dust (by letting down 85% WP with locally milled sorghum flour) was not successful because of high re-infestations that occurred from untreated sesame. However, the commercial dust was much more convenient to use due to the finer and more uniform milling, but the sorghum flour dust could be used in an emergency.

Different insecticides were compared for their efficacy to control PTM in the store between 1980 and 1983 cropping seasons at Melkassa and Awassa (Adhanom, 1985; IAR, 1985a). Tubers (500) were dipped in solutions or suspension of profenofos 50% EC (3750 ppm), deltamethrin (decamethrin) 2.5% EC (2.5 ppm), diazinon 60% EC (300 ppm), fenitrothion 5% (10 ppm), methacrifos 50% (500 ppm) and in plain water for 2 minutes. In the first year, profenofos gave better control than the rest of the chemicals (Adhanom et al., 1985b). However, in the subsequent seasons, there were higher infestations and low level of control was obtained by all of them.

Integrated pest management (IPM)

The IPM concept emphasises the integration of disciplines and control measures such as varietal resistance, cultural methods, physical control, insecticidal plants, natural enemies, and pesticides into a total management system to prevent pests from reaching damaging levels. These should be combined into an integrated pest management strategy, taking into account costs and feasibility of the control methods, toxicity, environmental safety, and sustainability. This is because none of the various methods alone can ensure safe storage. However, no report on integrated management of post-harvest pests in Ethiopia has been so far available.

Conclusions and recommendations

Research on post-harvest pests is a relatively recent area of plant protection in Ethiopia. It is about one and a half decade since relatively concerted efforts on post-harvest pest research began. However, considerable information has been generated by research at different institutions since then. Major insect pests of some major crops have been identified and losses caused by some of these pests determined. Traditional grain storage systems used in different parts of the country have been surveyed and documented. Relatively extensive information has been accumulated from studies of underground storage pits. Estimates of weight losses in stored grain have been reported widely although the results are difficult to compare. Data on losses in quality including mycotoxin contamination have begun to accumulate. Studies on the management of the major storage insect pests have been made in the area of insecticide screening; potentials of varietal resistance; cultural methods; botanical, physical and biological control. Most of these studies generated base-line information rather than technologies for immediate use. Nonetheless, there are some technologies that lend themselves to immediate use or after some modification and on-farm verification. Such technologies are outlined below in general terms:

Cultural control

It has been shown that some of the major storage pests start infestation in the field. Therefore, their control should start from there. Field isolation, prompt harvesting, selection of uninfested/uninfected grain for storage, proper drying before storage, removal of all residues, appropriate construction, repair of storage structures and hygienic measure are some of the cultural practices recommended. Modification/improvement of the storage containers including underground pits is very important if effective pest control and long-term storage of grain without significant losses in quantity and quality is desired.

Admixing grain with inert dusts/small-seeded grains

Mixing grain with Silicoses, Melkabam (filter cake), wood ash, sand or with tef at appropriate rates can control storage pests effectively and extend the period of storage.

Use of resistance varieties

Since infestation starts in the field, use of maize cobs with tight and complete husk cover that extends beyond the tip protects the grain better than bare tipped ears. The existence of crop genotypes resistant to storage pests has been confirmed. Hence, breeders should consider storability in their breeding programs.

Plant powders

Among the numerous plant species evaluated, only a few are consistently effective in controlling insect pests of stored grains. These include neem seed powder, MTP and pyrethrum flower powder. Such plants can be used for the protection of grain from insect pests in storage.

Vegetable oils

Almost all of the vegetable oils evaluated were effective against some of the major storage insect pests, especially bruchids. The commonly available noug oil can be used for treatment of grain that is meant for consumption. For seed treatment, the rate of oil should be less than 5 ml kg^{-1} seed to avoid its adverse effect on seed germination.

Biological control

Biological controls especially entomopathogenic fungi showed great potential for the management of storage pests at experimental levels.

Physical control

The traditional method of warming grain on clay pans over fire and exposure of grain to the sun were effective for the management of insect pests on stored grain. Effectiveness was improved by harnessing solar heat through the use of black polyethylene sheets, which raises the temperature sufficient enough to disinfest grains.

Chemical control

A number of insecticide dusts have been recommended for use against insect pests of stored grain. These include pirimiphos-methyl, malathion, methacrifos, fenitrothion, deltamethrin, cocktails of pirimiphos-methyl and permethrin, malathion and permethrin. Fumigation with phosphine has also been recommended for large-scale use, although the use of fumigants in peasant farm-stores calls for closer examination as these stores are not sufficiently airtight, and their use requires special care to avoid toxicity.

IPM

IPM is the most sustainable method of pest control both in the field and in storage. However, it has received hardly any attention to date.

Gaps and challenges

Although encouraging results have been generated so far, the current state of post-harvest knowledge pinpoints unaccomplished research gaps and priorities.

The major gaps include:

- Lack of survey information for most of the crop pests (i.e., data on the incidence, distribution, level of damage and economic impact), without which it is difficult to prioritize problems and determine the level of investment a particular pest may deserve. Resources and competent professionals are needed to conduct effective surveys on post-harvest pests;
- There is little or no information on the biology of major storage pests;

- The biology of natural enemies and the contribution of predators, parasitoids and bioagents present in large numbers in the storage environment have been hardly studied;
- Attention has been focused on storage problems so far and there is lack of research on losses that occur at different points in the post-harvest system (during harvesting, threshing, winnowing, transporting, and marketing) and effective crop loss reduction programs. It is also essential to try and obtain more accurate estimates of post-harvest losses;
- Lack of adequate efforts to improve traditional storage structures including underground pits with due considerations given to the culture, availability of construction material and financial capacity of target farmers;
- Inadequate attention is given to indigenous knowledge and traditional pest management methods which are being forgotten and replaced by chemical pesticides. This has brought a great tendency to concentrate on a unitary approach to pest control (reliance on chemical pesticides only);
- Less attention has be given to the development of suitable and economical storage pest management strategies that could minimize the qualitative and quantitative losses of stored products due to storage pests;
- For effective disinfestation of stored grain using solar heat treatment, temperature, time and depth of grain layering should be determined;
- Some of the insecticides tested in Ethiopia so far have been or will soon be taken out of the market for various reasons. Thus the need to evaluate new generation products is foreseeable;
- A variety of fungi have been already isolated from certain stored grains, but grain mycobiota should be studied intensively for each crop in different field and storage conditions;
- Lists of fungi associated with grain serve important purposes especially in providing researchers with information, but the role of the fungi in grain deterioration should be studied and understood well;
- Little is known about the mycotoxins of the major food crops in general, and about the situation in the various traditional storage systems and agro-ecological zones of the country in particular;
- The major sources of storage fungi and/or other post-harvest pests have not been yet established. Efforts should be made in this direction;
- Research on vertebrate pests especially the problem of rodents and birds was not addressed; and
- There is lack of cost-benefit analysis data on post-harvest pest management.

Post-harvest research should fill in the above gaps if sufficient knowledge base is to accumulate to minimize the adverse effects of pests on the harvested and/or stored products. In addition, research should address the following challenges of different nature:

- Outcomes of post-harvest research–be it on the nature and extent of problems or the potential of innovative measures to overcome the problems–should be more compelling than ever to policy makers. Traditionally emphasis is placed on improving food security through increased crop production. There is some awareness that post-harvest problem exists, but strong policy support is needed so that specific strategies for reducing the losses in storage could be adopted. Policy support is also needed for effective popularization of new technologies and for improving farmers' perception through training;

- Considering the history of limited adoption of improved storage structures, there is a need to devise suitable improvements in traditional storage systems based on sound research and sufficient evaluation under practical farmers' conditions. More efforts are needed to find out simple, low-cost alterations to traditional stores that overcome problems of moisture and pests;
- Despite the relatively long history of research on grain storage in underground pits, problems of pit storage especially soil moisture percolation and mold damage are still not overcome. Since pit storage has advantages (it is safe from theft and fire, easy to construct, does not require wood for construction and can be used for very long time, etc.), research should make appropriate improvements before use of pits is discouraged;
- To ensure that farmers' gains acceptability for local processing and/or export, there is an urgent need for research on grain quality (such as discoloration, shriveling and other types of pest damage) and safety (such as mycotoxins). The local consumer also pays higher prices to quality premiums;
- There is a need to give emphasis to effective, non-chemical pest management technologies for stored grains; and
- It is inevitable that IPM will be the new approach that Ethiopia should follow both in the field and in post-harvest pest management. Thus, research on suitable component measures and specifically on their integration is indispensable. Research on IPM that addresses all the diverse post-harvest problems of importance is needed.

Finally, certain limitations deserve serious attention by all concerned. The attention given to extension and education in crop protection is inadequate. Post-harvest issues are given scanty coverage by agricultural schools and universities curricula (both undergraduate and postgraduate). Moreover, there is a need to establish independent research unit with adequate budget, laboratory facilities and manpower to coordinate and carry out crop protection research in general and research on post-harvest pests in particular. Up to now research efforts are scattered, uncoordinated and at times duplicated in the different research centers and/or institutions. The dissolution of the department of crop protection and its merger with other disciplines severely weakened plant protection research in general. Meaningful research in the area of post-harvest research could flourish by addressing such organizational and logistical problems.

Future prospects

In view of the huge losses of stored grain and the very little that has been done so far, there is ample potential for bringing about substantial impact on the availability of food through minimizing the losses. According to Boxall (1998), of the 1 million tons or so of grain lost after harvest, more than half is lost during storage on peasant farms. This quantity (about 580,000 t) is equivalent to the 1997 estimate of the Disaster Prevention and Preparedness Commission (DPPC) on the amount of food required for people in immediate need of assistance. Research towards developing effective and efficient post-harvest pest management measures will continue to attract research attention in Ethiopia for sometime to come. The use of adequate storage systems alone would minimize grain losses substantially. Research on post-harvest pests thus offers diverse areas yet to be explored. Post-harvest improvement programs that target peasant farmer storage can therefore be expected to achieve a significant impact in reducing losses, increasing farm incomes and improving rural household food security.

A wealth of indigenous knowledge exists on natural materials that can be used as grain protectants. Some of these materials (dusts, ashes, and plant materials) are being evaluated at laboratory scale by various researchers in the country. Well coordinated activities reducing the interval between screening of materials and field-scale trials on promising materials are likely to come up with effective indigenous materials.

Tailoring survey and loss assessment studies using well defined and, as much as possible, standardized methodologies, in which estimates of losses will not be aggregated for different crops, storage containers/systems, ecologies and storage periods, it is possible to generate reliable data that allow comparisons of loss figures among different studies and across locations or storage periods are possible.

Post-harvest pests should be regularly monitored and the situation of quarantine pests should be continually updated. This should form the basis for strengthening the quarantine activity and for enforcing serious control of materials moving within the country and from abroad. Surveys should be watchful for devastating pests such as *Prostephanus truncatus*, the most destructive pest of stored maize and cassava in many African countries (first introduced to Africa in 1970s), which is already introduced to neighbouring Kenya. Unequivocal proof of its absence in Ethiopia could justify more check points and efficient quarantine services.

Pesticide use should be rationalized in the context of sustainable agriculture through research towards IPM with emphasis on non-chemical alternatives. Future research can benefit users by addressing judicious use of synthetic pesticides.

Research on storability and varietal resistance against post-harvest pests has given encouraging results. Therefore, entomologists/plant pathologists and plant breeders should closely collaborate and exploit the potential for the development of varieties with pest resistance and desirable agronomic and storage traits.

The use of biological control agents (predators, parasites or specific microorganism) as well as tolerant and even trap varieties will increase in importance in farm storage in the future and there will be opportunities for research findings in the area. The efficacy of bio-pesticides should be enhanced - finding more suitable, more virulent, and specific strain(s), develop formulations and additives which extend persistence and increase the toxic effect of the bio-pesticides. Moreover, efforts should be made to commercialize by linking it with the industry. There may be possibilities for environmental manipulation to enhance the effect of natural enemies in storage on the bais of thorough knowledge of their biology and ecology.

Finally, post-harvest pest management research in Ethiopia should embrace areas such as physical methods, e.g. the use of short-wave radiation, or biotechnological methods such as baiting, pheromones, growth regulators, repellants and attractants, which are already in use elsewhere in the world.

Appendices

Appendix 1. Arthropod species on stored grains in Ethiopia (species listed under respective family)

Scientific name	Common name	Status	References*
COLEOPTERA	**BEETLES**		
ANOBIIDAE	**FURNITURE BEETLES**		
Lasioderma sericorne (F.)	Cigarette beetle	Major	11, 130, 179, 231
Stegobbium paniceum (L.)	Biscuit beetle	Uncommon	179, 231
BOSTRICHIDAE	**WOOD BORERS**		
Rhizopertha dominica (F.)	Lesser grain borer	Common	4, 11, 121, 231
BRUCHIDAE	**PULSE SEED BEETLES**		
Acanthoscelides obtectus (Say)	Dried bean beetle	Common	179, 231
Callosobruchus chinensis (L.)	Adzuki bean weevil	Major	121, 19, 231
C. maculates (F.)	Cowpea weevil	Minor	231
Zabrotes subfasciatus (Boheman)	Mexican bean beetle	Major	7, 9, 20
Callosobruchus spp.	Cow pea beetle	Common	179
CARABIDAE	**GROUND BEETLE**		
Somoplatus substriatus Dejean		Minor	231
CLERIDAE			
Necrobia rufipes (Deg.)	Red-legged ham beetle	Minor	231
N. violacae (L.)		Minor	231
Opetiopalpus sp.		Minor	231
CORYLOPHIDAE			231
Sacium sp.		Minor	231
CRYPTOPHAGIDAE			231
Henoticus californicus (Mann.)		Minor	231
CUCUJIDAE			
Cryptolestes pusillus (Schoen.)	Rust red/minute grain beetle	Uncommon	4, 20, 121, 179, 231
C. ugandae Steel & Howe	Flat bark beetle	Uncommon	4, 7, 20
C. ferruginues Stephhens	Flat bark /rusty grain beetle	Major	20, 92, 231
Cryptolestes spp.	Flat grain beetle	Common	11, 92
CURCULIONIDAE	**WEEVILS**		
Sitophilus oryzae (L.)	Rice weevil	Major	4, 11, 20, 64, 121, 179, 196, 231
S. zeamais Motsch.	Maize weevil	Major	4,9, 11, 20, 179,231
S. granarius L.	Granary weevil	uncommon	2, 113,121, 179, 231
CERYLONIDAE			

Appendix 1. Arthropods species recorded (contd).

Scientific name	Common name	Status	References*
Murmidius ovalis (Beck)		Minor	231
DERMESTIDAE	**MUSEUM BEETLE**		231
Anthrenus coloratus Reitt.		Minor	231
Attagenus cyphonoides Reitt		Minor	231
Attagenus fasciatus (Thun.) (= *A.. gloriosae* (F.)		Minor	231
Attagenus megatoma (F.)		Minor	231
Attagenus pellio (L.)	Four/two spotted carpet beetle	Minor	231
Attagenus sp.	Case-bearing cloth moth	Minor	231
Dermestes ater Deg.	Black larder/incinerator beetle	Minor	231
Dermestes frischii Kugel.	Hide beetle	Minor	231
Dermestes maculatetus Deg.	Hide/leather beetle	Common	179, 231
Trogoderma granarium Evert.	Khapra beetle	Minor	2, 40, 69, 113, 231
LATHRIDIIDAE	**PLASTER BEETLES**		
Cartodere constricta (Gyll.) (=*Coninomus constrictus* (Gyll.)		Uncommon	231
Cartodere sp.		Minor	231
MONOMMIDAE			231
Monomma sp.		Minor	231
MYCETOPHAGIDAE	**FUNGUS BEETLES**		231
Litargus balteatus Lecont.		Minor	231
Mycetophagus sp.	Fungus beetle	Uncommon	4,7,9, 20, 231
Typhaea stercorea (L.)	Hairy fungus beetle	Uncommon	4, 7, 11, 20, 231
NITIDULIDAE	**SAP FEEDING BEETLES**		
Brachypeplus sp. (nr *caffer* Boh.)		Minor	20, 231
Brachypeplus sp. (nr *pilosellus* Murr.) (= *B. depressus* Er)		Minor	231
Carpophilus dimidiatus (F.)		Common	4, 7, 9, 11, 20, 231
C. hemipterus (L.)	Dried fruit beetle	Uncommon	231
C. zeaphilus Dobson		Uncommon	231

Appendix 1. Arthropods species recorded (contd).

Scientific name	Common name	Status	References*
Carpophilus freemani Dobson		Minor	4, 7, 9, 11, 20
Carpophilus sp. (nr *bipustulatus* Heer)		Minor	231
Carpophilus spp.		Common	11, 110
PTINIDAE	**SPIDER BEETLE**		
Gibbium psyllooides (Czemp.)	Hump beetle	Uncommon	231
Pseudeurostus hilleri (Reitt.)		Minor	231
Ptinus tectus Boieldieu	Australian spider beetle	Minor	231
Trigonogenius globulus Solier	Globular spider beetle	Minor	231
Trigonogenius particularis Pic.		Minor	231
SILVANIDAE			
Ahasverus advena (Waltl)	Foreign grain beetle	Common	4, 7, 9, 20, 179, 231
Oryzaephilus gibbosus Aitken	Flat dark beetle	Minor	4, 11, 20
O. mercator (Fauv.)	Merchant grain beetle	Common	4, 7, 9, 11, 179, 231
O. surinamensis (L.)	Saw toothed grain beetle	Common	4, ,9, 11, 20, 92, 179, 231
STAPHYLINIDAE	**ROVE BEETLES**		
Paedrus duplex Eppels		Common	231
TENEBRIONIDAE	**DARKLING BEETLES**		
Alphitobius diaperinus (Panz.)	Lesser mealworm beetle	Uncertain	179, 231
Alphitobius laevigatus F.	Black fungus beetle	Ucommon	11
Anthrenopsis scriptipennis (Fairm)		Minor	231
Curimosphaena villosus Haag		Minor	231
Gnatocerus cornatus (F.)	Broad-horned flour beetle	Common	4, 7, 9, 11, 179, 231
Gonocephalum sp.	Dusty brown beetle	Uncommon	4, 7, 9, 11, 20
Lathericus oryzae Waterh.	Long-haired flour beetle	Minor	231
Lophocateres pusillus Klug.	Siamese grain beetle	Uncertain	11
Palorus laesicollis (Fairm.)	Darkling beetle	Common	2, 4, 20, 231
P. ratzeburgii Wissmann	Small-eyed flour beetle	Uncertain	11

Appendix 1. Arthropods species recorded (contd).

Scientific name	Common name	Status	References
Tribolium castaneum (Herbst)	Red flour beetle	Major	4, 11, 121, 179, 231
T. confusum J. De Val	Confused flour beetle	Common	4, 11, 179, 196, 231
Tribolium destructor Uttenb.	Dark/large flour beetle	Uncommon	113, 121,179, 231
Tribolium sp.	Flour beetles	Common	4, 20, 110
TROGOSSITIDAE			
Tenebroides mauritanicus (L.)	Cadelle beetle	Common	4, 7,9,11,20,179,231
DICTYOPTERA	**COCKROACHES**		
BLATIDAE			
Periplaneta americana (L.)		Uncommon	231
DIPTERA	**FLIES**		
DROSOPHILIDAE			
Drosiphilus spp.	Small fruit flies	Common	4, 121
HEMIPTERA			
LYGAEIDAE			
Elasmolomus (Aphanus) sordidus (F.)	Sesame seed bug	Major	65, 128,179, 231
ISOPTERA			
Termite spp.	termites	common	52, 59
LEPIDOPTERA	**MOTHS**		
GELECHIIDAE			
Sitotroga cerealella (Olivier)	Angoumois grain moth	Major	4,9,11,98,179, 231
Phthorimaea operculella Zeller	Potato tuber worm	Major	20, 34, 35, 38, 65, 152, 155
PYRALIDAE			4
Ephestia cautella (Walker)	Tropical warehouse moth	Major	4,7,9,11, 121, 179, 196, 231
Anagasta/Ephestia kuhniella Zell.	Meditrerranean flour moth	Common	179, 231
Corcyra cephalonica (Staint.)	Rice moth	Uncommon	179, 231
Ephestia sp.		Common	11
Plodia interpunctella (Hubner)	Indian meal moth	Major	4,7,9,11,20,92,98, 231
PSEUDOSCORPIONIDAE	**PSEUDOSCORPIONS**		
CHELIFERIDAE			
Withius somlicus (Beier)	False scorpions	Common	4, 7, 9
Stenowithius bayoni (Ellingsen)	False scorpions	Uncommon	4, 7, 9
Pseudoscorpion spp.	False scorpions	Uncommon	11

Appendix 1. Arthropods species recorded (contd).

Scientific name	Common name	Status	References*
PSOCOPTERA	**PSOCIDS/BOOK LICE**		
LIPOSCELIDAE			
Liposcelis spp.	Cereal psocid/book lice	Uncommon	11, 92, 98
THYSANURA	**BRISTLE TAILS**		
LEPISMATIDAE			
Lepisma saccharina L.	Silver fish/moth	Uncommon	231
Thermobia domestica Packard	Firebrat	Minor	4, 20
ACARINA	**MITES**		
ASTIGMATA			
ACARIDAE			
Acarus siro L.	Grain /Flour mite	Common	92, 98, 110, 231
Tyrophagus putrescentiae Schrank		Uncertain	231
Tyrophagus sp.		Uncommon	231
GLYCYPHAGIDAE			
Glycyphagus destructor Schrank	Long-haired/ food mite	uncommon	179, 231
MESOSTIGMATA			
UROPODIDAE			
Leiodinychus sp.		Uncommon	231
PROSTIGMATA			
CHEYLETIDAE			
Cheyletus eruditus Schrank		Uncommon	179, 231
TYDEIDAE			
Tydeus sp.		Common	179, 231

Note: Macrotermes spp., Odontotermes and Ancistrotermes spp. are among the expected termites in storage. Birds and rats (ARDU 1982) rats (CADU 1968) were reported to be important in storage.

Appendix 2. Fungi associated with stored cereal grain samples collected from different parts of Ethiopia

Species	Grain invaded[1]	Store type[2]	Occurrence[3]	References*
Acremonium fusidioides	b	aboveground	mid	41
Acremonium spp.	s	pit	rare	41, 192
Acremonium strictum	s	pit	rare	176
Alternaria sp. cf. *infectoria*	b, w	aboveground	common	41
Alternaria alternata	b,w,s	both	common	41, 176
Alternaria sp.	s,t	aboveground	common	41
Apiospora montagnei	t	aboveground	rare	41
Arthrinium anamorph	t	aboveground	rare	41
Arthrinium sp.	b,w,s	both	rare	41, 192
Ascochyta sorghi	s	pit	mid	176
Aspergillus candidus	b,s,w	both	common	41, 176, 192
Aspergillus flavus	b,s, t,w	both	mid	41, 176, 192
Aspergillus fresenii	s	pit	mid	192
Aspergillus fumigatus	b,w	aboveground	mid	41
Aspergillus glaucus	s	pit	common	176
Aspergillus niger	b,s, t,w	both	common	41, 176, 192
Aspergillus ochraceus	b,s, t,w	both	common	41, 176, 192
Aspergillus spp. (others)	s	pit	common	176
Aspergillus sydowi -	s	pit	rare	192
Aspergillus umbrosus	s	pit	rare	192
Aspergillus ustus	s,t	both	rare	41, 192
Aspergillus versicolor	b,s,t	both	common	41, 192
Bipolaris anamorph	b	aboveground	common	41
Bipolaris sorokiniana	b,w,s	both	rare	41, 176
Bipolaris sorghicola	s	pit	common	176
Bipolaris sp.	b,s, t,w	both	rare	41
Botryosporium sp.	b	aboveground	rare	41
Botrytis cinerea	b,s	both	rare	41, 176
Byssochlamys nivea	s	pit	rare	192
C. cladosporioides	s	both?	rare	41
Chaetomium cochliodes	s	pit	rare	192
Chaetomium elatum	b	aboveground	rare	41
Chaetomium erectum	w	aboveground	rare	41
Chaetomium funicola	b	aboveground	rare	41
Chaetomium globosum	b,s	both	common	41, 176
Chaetomium indicum	b	aboveground	rare	41
Chaetomium sp.	b, t,w	aboveground	common	41
Chaetornium bostrychodes	w	aboveground	rare	41
Circinella mucorales	s	pit	mid	176, 192
Cladosporium herbarum	w	aboveground	rare	41
C. cladosporioides	w,s	both	common	41, 176
Cladosporium sp.	b, t	aboveground	common	41
Cochliobolus lunatus	s	pit	mid	176
Colletotrichum graminicola	s	pit	rare	176
Colletotrichum sp.	w	aboveground	rare	41

Appendix 2. Fungi associated with stored cereal grains (contd.)

Species	Grain invaded	Store type	Occurrence	References*
Coniothyrium minitans	W	aboveground	rare	41
Curvularia sp.	w	aboveground	rare	41
Cylindrocarpon lichenicola	s	pit	rare	176
Cylindrocarpon tonkiense	s	pit	common	192
Drechslera anamorph	b	aboveground	mid	41
Dreschslera sp.	s	pit	rare	192
Emericella nidulans	b, t	aboveground	rare	41
Epicoccum nigrum	b, w,s	both	common	41, 176
Epicoccum sp.	t,s	both	common	41, 192
Eupenicillium sp.	b, w	aboveground	rare	41
Eurotium amstelodami	b,s, t, w	both	common	41, 192
Eurotium chevalieri	s	pit	rare	192
Eurotium herbariorum	b,s, t	aboveground	common	41
Eurotium repens	s	pit	rare	192
Eurotium rubrum -	s	pit	rare	192
Fusarium avenaceum	b, w	aboveground	common	41
Fusarium chlamydosporum	s	pit	common	176
Fusarium equiseti	s, t, w	both?	rare	41
Fusarium graminearum	b,s, w,s	both	rare	41, 176
Fusarium moniliforme	s	pit	common	176, 192
Fusarium oxysporum	s	pit	rare	192
Fusarium poae	b	aboveground	rare	41
Fusarium semitectum	s	pit	rare	192
Fusarium solani	s	pit	common	192
Fusarium sporotrichioides	w	aboveground	rare	41
Fusarium spp. (others)	s	pit	common	176
Fusarium subglutinans	s	both	rare	41
Fusarium verticillioides	s	both	mid	41
Gleoecercospora sorghi	s	pit	rare	176
Gliocladium roseum	s	pit	common?	192
Gonatobotrys simplex	s	pit	rare	176
Graphium putredinis	s	pit	rare	192
Hyphopichia burtonii	s	both	common	41
Lasiodiplodia theobromae	s	pit	rare	192
Lecythophora mutabilis	b, w	aboveground	common	41
Lewia sp.	b, w	aboveground	rare	41
Mammria echinobotryoides	s	pit	rare	176
Melanospora zamiae	b	aboveground	rare	41
Monascus purpureus	s	pit	rare	192
Monographella nivalis var.neglecta	b, w	aboveground	mid	41
Mucor hiemalis	s	pit	common	176
Mucor racemosus	s	pit	rare	192
Mucor sp.	s, t, w	both	rare	41
Nigrospora sphaerica	b, w,s	both	common	41, 176
Nodulisporium africanum	s	pit	rare	192
Nodulisporium cf gregarium	S	pit	rare	176
Nodulisporium sp.	b	aboveground	rare	41
Paecilomyces variotii	s	pit	common	176, 912
Papularia sp.	w	aboveground	rare	41
Penicillium aurantiogriseum	s	pit	common	176

Appendix 2. Fungi associated with stored cereal grains (contd.)

Species	Grain invaded	Store type	Occurrence	References*
Penicillium chrysogenum	s	Pit	common	192
Penicillium corymbiferum	s	pit	common	192
Penicillium funiculosum	s	Pit	common	192
Penicillium glabrum	s	pit	common	192
Penicillium islandicum	s	pit	common	192
Penicillium lilacinum	s	pit	common	192
Penicillium pallidum	s	pit	common	192
Penicillium rugulosum	s	pit	common	192
Penicillium spiculisporum	s	pit	common	192
Penicillium spp.	b,s, t, w	both	common	41, 176, 192
Penicillium variable	s	pit	common	192
Penicillium viridicatum	s	pit	common	192
Penicillium wortmanii	s	pit	common	192
Periconia sp.	b	aboveground	rare	41
Pestalotia sp.	t	aboveground	rare	41
Phaeosphaeria nigrans	b, w	aboveground	rare	41
Phialophora sp.	w	aboveground	rare	41
Phoma glomerata	b,s, w	both	common	41
Phoma sorghina	t,s	both	common	41, 176
Phoma sp.	t, w	aboveground	common	41
Pyrenophora graminea	b	aboveground	rare?	41
Pyrenophora teres	t	aboveground	rare	41
Rhizopus sp.	b, t, w	aboveground	common	41
Rhizopus stolonifer	s	pit	common	176, 192
Scopulariopsis brevicaulis	s	pit	common	192
Scopulariopsis candida	s	pit	rare	176
Scopulariopsis sp.	s, w	both	rare	41
Sordaria fimicola	t, w	aboveground	rare	41
Stagonospora nodorum	b	aboveground	rare	41
Stemphylium botryosum	s	pit	rare	176
Stemphylium sp.	b	aboveground	rare	41
Streptomyces spp.	s	pit	rare	176
Talaromyces flavus	b,s, w	both	rare	41
Thapriuum sp.	s	both	rare	41
Trichoderma harzianum	s	pit	rare	176, 192
Trichothecium roseum	s	pit	mid	176
Trichothecium sp.	b,s, t	both	rare	41
Trichurus spiralis	s	pit	rare	176, 192
Veronaea sp.	s	pit	common	192
Verticillium sp.	b, w	aboveground	rare	41
Wallemia sebi	b, t, w	aboveground	rare	41
Xylaria sp.	b	aboveground	mid	41
Yeasts	s	pit	common	176, 192
Candida spp.	s	pit	mid	192
Hansenula spp.	s	pit	mid	192
Bacteria including Actinomycetes	s	pit	common	192

1/ M = maize, S = sorghum, W = wheat, B = barley, T = tef;

2/ aboveground = gotera and/or othr storag containers; both = aboveground and underground pit storage systems

3/ Frequency (> 16% = common, > 10% medium, < 10% = rare) in the samples analysed

Appendix 3. Storage losses of different crops in Ethiopia

Crop	Sample Area	Storage Time (Month)	Pest(s)	Damage level (%)	Weight loss (%)	Storage/loss method	References*
Maize	Bako area	6 - 8	Weevils	5.9 - 39.2 (23)	2.1 - 13.8 (7.5)	C & W	4, 5, 15
Maize	Bako area	6 - 8	Grain moth	0.9 - 47.6 (17)	0.2 - 17.9 (6.3)	C & W	4,15
Maize	Bako area	6 - 8	Insects	40	4.8 - 29.8 (16.3)	C & W	4, 9, 15
Maize	Nationwide	8 - 10	Insects	29.3	5.6	C & W	11
Maize	Amhara	8 - 10	Insects	25.3	2.6	C & W	11
Maize	B. Gumuz	8 - 10	Insects	46.6	3.7	C & W	11
Maize	Gambella	8 - 10	Insects	21.7	2.7	C & W	11
Maize	Oromiya	8 - 10	Insects	30.6	7.7	C & W	11
Maize	Somalia	8 - 10	Insects	0.32	-	C & W	11
Maize	SNNPR	8 - 10	Insects	22. 0	1.9	C & W	11
Maize	Tigray	8 - 10	Insects	6.8	1.0	C & W	11
Maize	Amhara	7.8	Insects	-	3.9	C & W	62
Maize	Oromiya	7.4	Insects	-	6.0	C & W	62
Maize	SSNP	8.4	Insects	-	7.6	C & W	62
Maize	Nationwide	7.4 - 8.4	Insects	-	6.1	C & W	62
Maize	Akaki	12	Insects	11.1	3.5	C & W	233, 234
Maize	-	-	Insects	-	13.0	-	179
Maize	-	2	Insects	-	4.11	-	4
Maize	-	9.5	Insects	-	2.9	-	15, 124
Maize	-	10	Insects	-	20.0	-	15, 127
Maize	Awassa	-	Weevils	-	1.9 -16.5	-	36
Maize	S. West Ethiopia	5 - 9	Insects	43.1 - 81	2.7 -17.3	C & W	185
Maize	-	3 - 6	Grain moth	-	11.2 - 13.5	-	98
Maize	-	-	Weevils	-	5.6 - 6.4	-	98
Maize	-	2 - 12	Insects	-	2.3 - 15.9	-	206
Maize [a]	Bure Wombera	2	Insects	-	2.32	-	204, 236
Maize [b]	Gozamin	12	Insects	-	13.94	-	204, 236
Maize	Gozamin	12	Insects	-	15.99	-	204, 236
Maize [c]	Fogera	4	Insects	-	2.02	-	204, 236
Maize (cob)	-	6	Complex	65.1	7.9	Coop. warehouse	164
Maize	Jibi Tehinan	6	Insects	64.7	19.2	C & W	62, 236
Maize	Tigray	4 - 13	Insects	-	46.1	C & W	59
Maize			Insects	-	18.0	estimated	45
Sorghum	Amhara	5.7	Insects	-	4.9	C & W	62
Sorghum	Oromiya	6.2	Insects	-	4.0	C & W	62
Sorghum	SSNP	4.3	Insects	-	0.9	C & W	62
Sorghum	-	-	Insect, R & M	-	5	-	179
Sorghum (lowland)	Hararghe	8	Insects	34.6	15.4	Underground pit	233, 234

Table 4. Storage losses contd.

Crop	Sample area	Storage time (Month)	Pest(s)	Damage Level (%)	Weight loss (%)	Storage/loss Method/ Remark	References*
Sorghum (highland)	Akaki	13	Insects	19.2	14.1	Gotera	233, 234
Sorghum	Bako area	-	Insects	38.7	14.5	C & W	108, 110
Sorghum	-	-	Insects	-	30.0	-	61
Sorghum	-	1 - 12	Insects	-	3.0 - 38.0	Full pits	61
Sorghum	-	-	Insects	-	6.0 - 55.0	Half full pits	61
Sorghum	Gozamin	0.5	Insects	-	1.45	-	204, 236
Sorghum	Guangua	12	Insects	-	4.02	-	204, 236
Sorghum	Guangua	2	Insects	-	0.68	-	204, 236
Sorghum	Mettema	3	Insects	-	0.92	-	204, 236
Sorghum	Adarkay	2	Insects	-	0.82	-	204, 236
Sorghum	Sanja	2	Insects	-	0.96	-	204, 236
sorghum	Belessa	4	Insects	-	0.63	-	204, 236
Sorghum	Danbi	6	Insects	10.9	1.17	-	62, 236
Sorghum	Abergele	4 - 12	Insects	-	19.2	C & W	59, 183
Sorghum	Chercher	4 - 6	Insects	-	21.5 (6.1)	-	183
Wheat	-	-	Insects	-	4	-	179
Wheat	Akaki	13	Insects	2.0	4.2	Gotera	2, 233, 234
Wheat (Emmer)	-	13	Insects	0.5	0.6	Gotera	233, 234
Wheat	Amhara	5 - 7	Insects	-	0.7	C & W	62
Wheat	Oromiya	7.2	Insects	-	0.2	C & W	62
Wheat	Nationwide	5 - 7	Insects	-	0.5	C & W	62
Wheat	Gozamin	12	Insects	-	0.1	-	204, 236
Wheat	Tigray	11- 13	Insects	-	15.2	C & W	59
Wheat	-	-	Weevils	-	24.0	estimated	45, 206
Kerkata	Tigray	13	Insects	-	12.9	C & W	59
Barley	Amhara	5.9	Insects	-	0.1	C & W	62
Barley	Oromiya	7.8	Insects	-	< 0.1	C & W	62
Barley	Nationwide	-	Insects	-	0.1	C & W	62
Barley	-	-	Insects	-	1	-	179
Barley (high)	Ankober	13	Insects	1.0	4.0	Gotera	233, 234
Barley (mid)	Akaki	13	Insects	5.5	5.0	Gotera	233, 234
Barley	-	3	Insects	-	1.7	-	204
Cereals (av.)	-	8 - 13	Insects	(9.2)	(6.1)	-	234
Barley	Gozamin	3	Insects	-	1.72	-	204, 236
Barley	Tigray	5 - 13	Insect	-	8.4	C & W	59
Teff	-	-	Insects	-	0	-	179
Teff	Akaki	13	Insects	0	1.9	Gotera	233, 234
Cereals & P	-	4.3 - 8.4	Insects	-	4.0	-	62
Cereals & beans	Nationwide	3 - 4	Complex	88	15.3	Coop. warehouse	165
Cereals & beans	-	3 - 4	Complex	55	13.2	Farmer stores	165
Beans	Amhara	5	Insects	-	0.3	C & W	62
Beans	Oromiya	6.6	Insects	-	5.5	C & W	62
Beans	Nationwide	5 - 6.6	Insects	-	(5.2)	C & W	62

Table 4. Storage losses contd.

Crop	Sample area	Storage time (Month)	Pest(s)	Damage level (%)	Weight loss (%)	Storage/loss Method/ Remark	References*
Chickpea	Akaki	13	Bruchids	26.3	1.9	Gotera	233, 234
Chickpea	Yerer & Kereyu	6 - 7	Bruchids	23.2 - 31.6 (27.5)	6.8 - 9.7 (8.2)	-	62, 217
Chickpea	Libo	9	Bruchids	74.6	6.37	-	62, 236
Chickpea	Tigray	10	Bruchids	-	43.4	C & W	59
Chickpea	Nationwide?	5 - 8	*C. chinensis*	3.9 - 14.7	-	-	182
Chickpea	Gojam	6 - 7	Bruchids	42.1-56.6 (46.4)	9.7- 14.01(11.8)	-	181
Chickpea	Gojam	7 - 8	Bruchids	42.1- 53.5(49.2)	12.2-17.3 (14.7)	-	181
Chickpea [d]	Guangua	12	Bruchids	-	3.77	-	204, 236
Chickpea*	-	8	*C. chinensis*	-	36.9 - 51.9	-	75
Cowpea	Gambella	5	*C. maculates*	23-29	10	-	191
Faba bean	Akaki	13	Insects	40.2	4.8	Gotera	233, 234
Faba bean	-	9	Bruchids	-	25.1	-	166
Faba bean	Yerer & Kereyu	6 - 7	Bruchids	41.2	13.5	-	146, 206, 145, 207
Faba bean	-	9	*C. cinensis*	72.7 30.7	-	-	166
Faba bean	Adet	6	Bruchids	59.6	1.9	-	62, 236
Faba bean	Tigray	13	Bruchids	-	36.1	C & W	59
Faba bean	Yerer and Kereyu	6 -7	*C. chinensis*	43.7	13.9	-	146
Faba bean	Nationwide?	5 - 8	*C. chinensis*	7.1 - 49.3	-	-	180
Faba bean	Wukro	4 - 6	Bruchids	-	26.5 (4.4)	-	183
Field pea	Akaki	13	Bruchids	6.6	6.0	Gotera	233, 234
Field pea	Ibanat	9	Bruchid	38.0	12.1	-	62, 236
Field pea	Tigray	10 - 12	Bruchid	-	24.2	C & W	59
Field pea	Nationwide?	5 - 8	*B. pisorum.*	0.1 - 3.1	-	-	182
Grass pea	Nationwide?	5 - 8	*C. chinensis*	3.4 - 5.3	-	-	182
Haricot bean	-	12	Bruchid	76	14.0	-	26
Haricot bean	Tigray	1	Bruchids	-	3.9	C & W	59
Haricot bean	E. & S. Shoa	7- 9	*Acan. & Zab.*	0-80	3.2	C & W	104
Haricot bean	Adami Tulu	7- 9	*Acan. & Zab*	15	1.8	C & W	103, 104
Haricot bean	Buta Jira	7- 9	*Acan. & Zab*	18.85	1.8	C & W	103, 104
Haricot bean	Limu Bora	7- 9	*Acan. & Zab*	24.8	2.1	C & W	103, 104
Haricot bean	Adama Bosset	7- 9	*Acan. & Zab*	21.13	1.81	C & W	103, 104

Table 4. Storage losses contd.

Crop	Sample area	Storage time (Month)	Pest(s)	Damage level (%)	Weight loss (%)	Storage/loss Method	References*
Legumes (av.)	Akaki	13	Bruchid	(19.5)	(4.0)	-	234
Lentil	Akaki	13	Insects	12.8	4.4	Gotha (dung)	233, 234
Lentil	Akaki	13	Insects	5.4	1.8	Gotha (clay)	233, 234
Lentil	-	-	*C. chinensis*	-	12 - 63?	-	74
Pulses	-	-	Insects	-	5.0	-	179
Vetch	Akaki	13	Insects	25.6	4.9	Gotera	233, 234
Oilseeds	-	-	Insects	1?	-	-	179
Potato	Holetta	-	PTM	3	-	DLS	83

Note: Figures in parenthesis are overall means

*DLS = difused light store ; [a] unshelled smoked, [b] ; shelled & untreated; [c] treated with wood ash, [d] treated with DDT, * two varieties, Dubie & Mariye, Complex = all pests*

Table 4b. Losses caused by rodents and mold

Crop	Sample area	Storage time (Month)	Pest(s)	Damage level (%)	Weight loss (%)	Storage/loss method	References*
Maize	-	-	Rodent and Mold	-	2.0	-	179
Maize	Amhara	7.8	Mold	-	5.2	-	62
Maize	Oromiya	7.4	Mold	-	6.6	-	62
Maize	SNNPR	8.4	Mold	-	2.5	-	62
Maize	Nationwide	-	Mold	-	5.1	-	62
Sorghum	Amhara	5 - 7	Mold	-	8.9	-	62
Sorghum	Oromiya	6.2	Mold	-	0.5	-	62
Sorghum	SNNPR	4.3	Mold	-	1.0	-	62
Sorghum	Nationwide		Mold	-	4.1	-	62
Sorghum	-	1 - 12	Mold	-	2.0 - 25.0	Full pits	61
Sorghum	-	-	Mold	-	7.0 - 35.0	Half full pits	61
Sorghum	Hararghe	17?	Mold	-	2.0 - 13.0	Underground pit	176
Wheat	Amhara	5 - 7	Mold	-	12.7	-	62
Wheat	Oromiya	7.2	Mold	-	2.5	-	62
Wheat	SNNPR	-	Mold	-	ns	-	62
Wheat	Nationwide	-	Mold	-	5.7	-	62
Wheat	-	-	Rodent & Mold	-	1.0	-	179
Barley	Amhara	5.9	Mold	-	2.3	-	62
Barley	Oromiya	7.8	Mold	-	<0.1	-	62
Barley	SNNPR	-	Mold	-	ns	-	62
Barley	Nationwide	5 - 8	Mold	-	1.4	-	62
Barley	-	-	Rodent & Mold	-	1.0	-	179
Teff	-	-	Rodent & Mold	-	1.0?	-	179
Beans	Amhara	5.0	Mold	-	17.4	-	62
Beans	Oromiya	6.6	Mold	-	12.4	-	62
Beans	SNNPR	-	Mold	-	ns	-	62
Beans	Nationwide	5 - 7	Mold	-	14.4	-	62
Pulses	-	-	Rodent & Mold	-	1.0	-	179
Oilseeds	-	-	Rodent & Mold	-	1.0?	-	179
Fruits	-	-	Rot	-	1.3 - 49.2	-	58
Vegetables	-	-	Rot	-	1.1 - 19.7	-	58

NS = not significant, - = not available

References

1. Abdirahaman A. 2002. Survey of insects associated with stored sorghum and maize and methods of grain storage in Jijiga Wereda. M. Sc. Thesis. Alemaya University.
2. Abdurahman A. and Adugna H. 1991. Research on the control of insect and rodent pests of wheat in Ethiopia. Pp. 219–233. *In:* Hailu Gebre-Mariam, D. G. Tanner and Mengistu Hulluka (eds.). Wheat research in Ethiopia: A historical perspective. Addis Ababa: IAR/CIMMYT. Addis Ababa, Ethiopia.
3. Aberra G. and Admassu M. 1987. A survey of aflatoxin contents in maize, sorghum and tef samples. *Ethiopian Journal of Health Development* 2: 59–70.
4. Abraham T. 1991. The biology, significance and control of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on stored maize. M. Sc. Thesis, AUA, Alemaya, Ethiopia.
5. Abraham T. 1993a. Stored product insects associated with farm-stored maize in the Bako area, western Ethiopia. Proceedings of the Joint Conference: Ethiopian Phytopathological Committee (EPC)/Committee of Ethiopian Entomologists (CEE), 5–6 March 1992, Addis Ababa, Ethiopia.
6. Abraham T. 1993b. Coleopteran pests attacking maize in the store and their managemet. Paper presented for training on maize protection held at Awassa College of Agriculture, Awassa, 17–26August 1993 (unpublished).
7. Abraham T. 1996a. Insects and other arthropods recorded from stored maize in western Ethiopia. *African Crop Science Journal* 4 (3): 339–343.
8. Abraham T. 1996b. Maize storage and insect pest management practices of farmers in the Bako area (Abstract). P. 11. The Fourth Annual Conference of the Crop Protection Society of Ethiopia, 23–24 May 1996, Addis Ababa, Ethipioa.
9. Abraham T. 1997. Arthropods associated with stored maize and farmers' management practices in the Bako area. *Pest Management Journal of Ethiopia*. 1(1&2): 19–27.
10. Abraham T. 1998a. Control strategies and future needs for research on insect pests of maize in Ethiopia. Pp. 291–305. *In:* Beyene S. and Aberra D. (eds.) agricultural reserach and technology transfer attempts and achievements in northern Ethiopia. Proceedings of the 4th Technology Generation, Transfer and Gap Analysis Workshop. 18–21 March 1997, Bahir Dar, Ethiopia.
11. Abraham T. 2003. Studies on some non-chemical insect pest management options on farm-stored maize in Ethiopia. Ph. D. Theses, Justus-Liebig-University of Giessen, Germany.
12. Abraham T. 2005a. Pre- and post-harvest losses caused by pests and their implications for food insecurity in Ethiopia. A review paper presented at the Awareness Creation and Action Plan Workshop on Obsolete Pesticide Programme. 23–24 June 2005, CRDA, Addis Ababa, Ethiopia.
13. Abraham T. 2005b. Filter Cake: A promissing inert dust for the control of the maize weevil (*Sitophilus zeamais* Motsch.) and the bean bruchid (*Zabrotes subfasciatus* Boh. (Coleoptera: Bruchidae). (Abstract). 13th Annual Conference of the CPSE. 11–12 August 2005. CPSE, Addis Ababa, Ethiopia.
14. Abraham T. 2005c. Some on-farm maize storage containers used in Ethiopia. P. 41. 13th Annual Conference of the Crop Protection Society of Ethiopia (CPSE). 11–12 August 2005, Addis Ababa, Ethiopia.
15. Abraham T., Ferdu A., Assefa G. A. and Adhanom N. 1993. Research highlights on maize insect pests and their management in Ethiopia. Pp. 34–42. *In:* Benti Tolessa and J. K. Ransom (eds.). Proceedings of the First National Maize Workshop of Ethiopia. 5–7 May 1992, Addis Ababa, Ethiopia. IAR/CIMMYT, Addis Ababa.

16. Abraham T., Tadesse G. M. and Mengistu H. 1994. Evaluation of some maize genotypes for resistance to the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) in the laboratory at Bako. P. 31. *In:* Proceedings of the First Annual Conference of the Crop Protection Society of Ethiopia (CPSE). 14–15 April 1993, Addis Ababa, Ethiopia.
17. Abraham T., Tadesse G. M. and Mengistu H. 1995a. Comparison of some maize genotypes for resistance to the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) in Ethiopia. *In:* D.C. Jewell, S.R. Waddington, J.K. Ransom and P.V. Pixley (eds.). Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference held in Harare, Zimbabwe, 28 March- 1 April 1994. Mexico D.F. CIMMYT.
18. Abraham T., Tadesse G. M. and Mengistu H. 1995b. Evaluation of insecticide dusts for the control of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on stored maize in the laboratory (Abstarct). P. 25. Proceedings of the Second Annual Conference of the Crop Protection Society of Ethiopia, CPSE, 26–27April 1994, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
19. Abraham T., Tadesse G. M. and Mengistu H. 1996. Some laboratory observations on the biology of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera:Curculionidae) at Bako. P. 62–67. *In:* Eshetu B., Abdurahman A. and Aynekulu Y. (eds.) Proceedings of the Third Annual Conference of the Crop Protection Society of Ethiopia, 18–19 May 1995, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
20. Abraham T. and Adane K. 1998. Some arthropod pests of agricultural importance in western Ethiopia. A handbook. Addis Ababa. IAR, Addis Ababa, Ethiopia.
21. Abraham T. and Firdissa E. 2000. Insect pests of farm-stored maize and their management practices in Ethiopia. Integrated Protection of Stored Products, *IOBC* Bulletin 23(10): 47–57.
22. Abraham T. and Basedow, Th. 2004a. A survey of insect pest problems and stored product protection in maize in Ethiopia. *Journal of Plant Diseases and Protection* 111: 257–265.
23. Abraham T. and Basedow, Th. 2004b. Comparative evaluation of SilicoSec, Mexican tea powder and neem oil against the granary weevil, *Sitophilus granarius* L., on wheat in the laboratory. *Mitteilungen Deutschen Gesselschat für Allgemeine und Angwandte Entomol.* 14: 343–346.
24. Abraham T. and Basedow, Th. 2005. Laboratory and field studies on the effects of natural control measures against pests on stored maize in Ethiopia. *J. Plant Diseases and Protection* 112(2): 156 –172.
25. Adane K. and Abraham T. 1993. Comparison of sorghum genotypes for resistance to the maize weevil, *Sitophilus zeamais* Motsch., damage at Bako. P. 27. *In:* Proceedings of the Joint Conference: Ethiopian Phytopathological Committee, Committee of Ethiopian Entomologists, 5–6 March 1992. Addis Ababa, Ethiopia. CPSE. Addis Ababa.
26. Adane K. and Abraham T. 1994. Damage to weight and germination of haricot bean caused by the Mexican bean weevil, *Zabrotes subfasciatus* (Boheman) at Bako (Abstract). P. 22. Proceedings of the First Annual Conference of the Crop Protection Society of Ethiopia (CPSE), 14–15 April 1993, Addis Ababa, Ethiopia, CPSE, Addis Ababa.
27. Adane K. and Abraham T. 1996a. Comparison of some insecticides for effectiveness against the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculinidae) on stored sorghum at Bako. P. 113–119. *In:* Eshetu B., Abdurahman A. and Aynekuklu Y. (eds.). Proceedings of the Third Annual Conference of the Crop Protection Society of Ethiopia, 18–19 May 1995, Addis Ababa, Ethiopia.
28. Adane K. and Abraham T. 1996b. Evaluation of some botanicals for effectiveness against the maize weevil, *Sitophilus zeamais* Motsch. on stored sorghum at Bako. P. 120–126. *In:* Eshetu B., Abdurahman A. and Aynekulu Y. (eds.). Proceedings of the Third Annual Conference of the Crop Protection Society of Ethiopia, 18–19 May 1995, Addis Ababa, Ethiopia. CPSE, Addis Ababa, Ethippia.

29. Adane K., Senishaw A. and Fantahun M. 1996. Evaluation of polyethylene sheet as solar heat collector for disinfestation of cereals: part I. Paper presented at the Third Cycle Local Research Grant Workshop organized by Ethiopian Science and Technology Commission, 28–29 November 1996, Addis Ababa, Ethiopia.
30. Adane K. and Abraham T. 1997. Comparison of some sorghum genotypes for resistance to the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae), damage in the laboratory. Paper presented at the 5th Annual Conference of CPSE, 22–23 May 1997, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
31. Adane K., Tsehay A. and Tsedeke A. 1997a. Experience in biological control of insect pests in Ethiopia: A review. Pp. 12–23. Integrating biological control and host plant resistance. Proceedings of a CTA/IAR/IIBC Seminar, 9–14 October 1995, Addis Ababa, Ethiopia.
32. Adane K., D. Moore, and Archer, S. A. 1997b. Potential of *Beauveria bassiana* for the control of the maize weevil, *Sitophilus zeamais* and the cowpea bruchid, *Callosobruchus chinensis* in the laboratory. P. 13 (Abstract). CPSE 5th Annual Conference, 22–23 May 1997. Addis Ababa, Ethiopia.
33. Adane K., D. Moore, and Archer, S. A. 1998. Potential of *Beauveria bassiana* for the control of maize weevils and bean beetle in the laboratory. PMJOE 2 (1&2): 56–65.
34. Adhanom N. 1983. Potato tuber moth in Ethiopia. CEE Newsletter 2 (2): 10–12.
35. Adhanom N. 1985. Chemical control of potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). Pp. 720–730. *In:* Proceedings of 16th NCIC, Part II. IAR, Addis Ababa.
36. Adhanom N. 1989. Insecticidal control in stored maize insects with special reference to the maize weevil, *Sitophilus zeamais* Motsch. Awassa, Ethiopia. P. 253–256. *In:* Gebrekidan, B. (ed.). Maize Improvement, Production and Protection in Eastern and Southern Africa: Proceedings of the Third Eastern and Southern Africa Regional Maize Workshop. Nairobi, Kenya.
37. Adhanom N. and Abraham T. 1985. A review of research on insect pests of maize and sorghum in Ethiopia. P. 7–19. *In:* Tsedeke Abate (ed.). A review of crop protection research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium, 4–7 February 1985, Addis Ababa, Ethiopia.
38. Adhanom N., Tsedeke A. and Emana G. 1985. Research on insect pests of root and tuber crops in Ethiopia. Pp. 423–431. *In:* Tsedeke Abate (ed.). A review of crop protection research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium, 4–7 Feb. 1985, Addis Ababa, Ethiopia.
39. Adhanom N. and Emana G. 1989. Survey, collection and identification of stored product insect pests in the southern region of Ethiopia. 24–26. Awassa Progress Report for 1986. IAR, Addis Ababa.
40. Adugna H. and Kemal A. 1985. A review of research on the control of insect pests of small cereals in Ethiopia. Pp. 57–77. *In:* Tsedeke Abate (ed.). A review of crop protection research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium, 4–7 Feb. 1985, Addis Ababa, Ethiopia.
41. Amare A. 2002. Mycoflora and mycotoxins of major cereal grains and antifungal effects of selected medicinal plants from Ethiopia. Doctoral Dissertation. George-August University of Göttingen, Göttingen, Germany.
42. Amare A., Dawit A. and Mengistu H. 1995. Mycoflora, aflatoxins and resistance of groundnut cultivars from eastern Ethiopia. *SINET Ethiopian Journal of Science* 18: 117–131.
43. Amare A., Febrman, H., Beck, R. and Dawit A. 2005. Occurrence of mycotoxins in freshly harvested and farm-stored cereal grains. Pp. 29–31 (Abstract). CPSE 13th Annual Conference, 11–12 August 2005. Addis Ababa.
44. Amare A., Hartmut Fehrmann, Johann Lepischy, Robert Beck and Dawit A. 2006. Natural occurrence of mycotoxins in staple cereals from Ethiopa. *Mycopathologia* 162: 57–63.

45. Anon. 1972. EPID grain storage handbook. Extension and Project Implementation Department (EPID), MoA. Ethiopia. 151 pp. (unpublished).
46. Anon. 1990. Faba bean protection in store. *Committee of Ethiopian Entomologists (CEE)* 9(2):10.
47. Anon. 1993. Food production, food security and nutrition. Sub-program 4: Pre- and post-harvest losses. Addis Ababa, Ethiopia.
48. Anon. n. d. Bako Agricultural Research Center Crop Protection Reserach Division Progress Report for various years (1995/96–2004) (unpublished).
49. ARARI (Amhara Regional Agricultural Research Institute).2000. Sirinka Agricultural Research Center Progress Report for 1999. ARARI, Sirinka.
50. ARARI (Amhara Regional Agricultural Research Institute). 2001. Research Directory for 2001/2. Biometric and Information Technology Unit, ARARI, Bahir Dar.
51. Asmare D. 2002. Evaluation of some botanicals against the maize weevil, *S. zeamais* Motsch. (Coleoptera: Curculionidae) on stored sorghum under laboratory conditions at Sirinka. *Pest Mgmt. J. Eth.* 6: 73–78.
52. ARDU (Arsi Rural Development Unit). 1982. Storage pest survey in lowlands of Arbagugu. Pp. 237–242. *In:* Report on survey and experiments carried out in 1980. Plant Husbandary Departement. ARDU Publication No. 21. MoA and Settlement, ARDU, Asella.
53. Bayeh M. and Tadesse G. M. 1994. Studies on insect pests of potato. Pp. 202–208. *In:* Edward Herath and Lemma Desalegn (eds.). Horticultural Research and Development in Ethiopia. Proceedings of the Second National Horticultural Workshop of Ethiopia. 1–3 December 1992. Addis Ababa, IAR. Addis Ababa, Ethiopia.
54. Bayeh M. and Tadesse G. M. 1996. Suppressing effects of different botanicals on the Adzuki bean beetle (*Callosobruchus chinensis* L.). Pp. 127–133. *In:* Proceedings of the Third CPSE Annual Conference, 18–19 May 1995. Addis Ababa, Ethiopia. CPSE, Addis Ababa.
55. Bayeh M. and Tadesse G. M. 2000. Oviposition detetrrent and toxic effects of various botanicals on the Adzuki bean beetle, *Callosobruchus chinensis* L. *Insect Sci. Applic. 20* (1): 33–38.
56. Bekele J. 2002. Evaluation of the toxicity potential of *Milletia ferruginea* (Hochest) Baker against *Sitophilus zeamais* (Motsch.). *Int. J. Pest Mgmt.* 48: 29–32.
57. Bendell, P. J. E. 1972. Problems of grain storage in Ethiopia. P. 40. *In:* Proceedings of Annual Research Seminar. 22–24 September 1971. IAR, Addis Ababa.
58. Berga L., Fekadu T. and Mengistu K. 1990. The nature and extent of crop post-harvest losses in Ethiopia. Pp. 101–109. *In:* Proceedings of the 21st National Crop Improvement Conference (NCIC), 10–12 April 1989, IAR, Addis Ababa.
59. Berhanu A. 1997. Grain storage pest situation and management program in Tigray: A Survey Report. (unpublished).
60. Blum A. and Bekele A. 2001. Ethiopian farmers practice of on-farm grain storage. *Trop. Sci.* 41: 23–30.
61. Boxall, R. A. 1974. Underground storage of grain in Harar province, Ethiopia. *Trop. Stored Prod. Inf.* 28: 39–48.
62. Boxall, R. A. 1998. Grain post-harvest loss assessment in Ethiopia. Report No. 2377. NRI, University of Greenwich.
63. CADU (Chilallo Agricutural Development Unit). 1968. Results of trials and observations on field and forage crops at Kulumsa farm and in Assela in 1967/68. CADU, Addis Ababa.
64. CADU (Chilallo Agricutural Development Unit). 1969. Report on surveys and experiments. Crop Production Department. CADU publication No. 46.

65. Crowe, T. J., Tadesse G. M. and Tsedeke A. 1977. An annotated list of insect pests of field crops in Ethiopia. IAR. Addis Ababa, Ethiopia.
66. Davidson, A. 1968. Research in Agricultural Entomology in Ethiopia. Institute of Agricultural Research (IAR), Addis Ababa, Ethiopia. 29 pp.
67. Dawit A. 1982. A preliminary study of the fungal flora of Ethiopian cereal grains with special emphasis on the prevalence of toxigenic groups. M. Sc. Thesis. Addis Ababa University. Addis Ababa, Ethiopia.
68. Dawit A. and Berhanu A. G. 1985. Prevalence of *Aspergillus flavus* in Ethiopian cereal grains: A preliminery survey. *Ethiopian Medical Journal* 23: 143–148.
69. Debre Zeit Agricultural Reseach Center (DZARC). 1984. Crop Protection Annual Reports for 1977-1983. Debre Zeit, Ethiopia: DZARC. Addis Ababa University.
70. DZARC.1987. Annual Research Report for 1986/87. Debre Zeit, Ethiopia.
71. DZARC.1988. Annual Research Report for 1987/88. Debre Zeit, Ethiopia.
72. DZARC.1989. Annual Research Report for 1988/89. Debre Zeit, Ethiopia.
73. DZARC.1990. Annual Research Report for 1989/90. Debre Zeit, Ethiopia.
74. DZARC.1991. Annual Research Report for 1990/91. Debre Zeit, Ethiopia.
75. DZARC.1993. Research Progress Report for 1992/93. Debre Zeit, Ethiopia.
76. DZARC.1994. Annual Research Report for 1991/92. Debre Zeit, Ethiopia.
77. DZARC.1996. Annual Research Report for 1993/94. AUA, Debre Zeit, Ethiopia.
78. Dejene M. 1975. Detection of research in opaque-2 and normal counterpart kernels of maize under weevil infestation. Pp. 118–119. *In:* Proceedings of the 5th Annual Research Seminar, 30 October to 1 November 1974. IAR, Addis Ababa, Ethiopia..
79. Dejene M. 1984. Germination, grain yield and other agronomic charactristics of maize as affected by weevils. Paper presented at the Ethiopian Agricultural Research Conference (EARC), 19–21 April 1984. Addis Ababa.
80. Demissew K. 2004. Line x Tester analysis of maize lines for resistance to weevil (*S. zeamais* Motsch.). M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia. 79 pp.
81. Demissew K., Abraham T. and Firdissa E. 2002. Effects of cultural methods in controlling maize weevil (*Sitophilus zeamais* Motsch.). *Pest Mgmt. J. Ethiopia* 6: 59–64.
82. Demissew K., Firdissa E. and Abraham T. 2004. Response of commercial varieties and other genotypes of maize for resistance to the maize weevil (*Sitophilus zeamais* Motsch.) (Coleoptera: Curculonidae). Proceedings of the Seventh Eastern and Southern Africa Regional Maize Conference, 5–11 February 2002, Nirobi, Kenya.
83. EARO (Ethiopian Agricultural Research Organization). 1998a. Holetta progress report for 1997/98. EARO. Addis Ababa.
84. EARO. 1998b. PPRC (Plant Protection Research Center) progress report for 1997/98. EARO, Addis Ababa.
85. EARO. 1999. EARO Annual Report for 1997/98. EARO, Addis Ababa.
86. EARO. 2000. EARO Annual Report for 1998/99. EARO, Addis Ababa.
87. EARO. 2002. EARO Annual Report for 2000. EARO, Addis Ababa.
88. EARO. 2003. EARO Annual Report for 2001/02. EARO, Addis Ababa.
89. EARO. 2004. EARO Annual Report for 2002/03. EARO, Addis Ababa.
90. EIAR (Ethiopian Institute of Agricultural Research). 2004. Plant Protection Research Center (PPRC) Report of Completed Research Projects from 1999–2004. Volume II: *Entomology, Weed Science, and Highland Maize. PPRC*, Ambo, EIAR.
91. EIAR. 2005. PPRC Progress Report for 2004/5. PPRC, Ambo, EIAR.
92. Emana G. 1993a. Studies on the distribution and control of Angoumois grain moth, *Sitotroga cerealella* (Oliv.) (Lepidoptera: Gelechiidae), in Sidamo Administrative Region. M.Sc. Thesis, Alemaya University of Agriculture, Alemaya, Ethiopia.
93. Emana G. 1993b. The status of stored product insect pests in southern Ethiopia. P. 29 (Abstract). *In:* Proceedings of the Joint Conference: Ethiopian Phytopathological Committee

(EPC) and Committee of Ethiopian Entomologists (CEE), 5–6 March 1992, Addis Ababa, Ethiopia. CPSE: Addis Ababa.

94. Emana G. 1996. Chemical control of Angoumois grain moth, *Sitotroga cerealella* (Olivier). Paper Presented at the Fourth Crop Protection Society of Ethiopia. 23–24 May 1996. Addis Ababa.
95. Emana G. 1999. Use of botanicals in the control of stored maize grain insect pests in Ethiopia. Pp. 105–108. *In:* CIMMYT and EARO. Maize Production Technology for the Future: Challenges and opportunities. Proceedings of the 6th eastern and southern Africa Regional Maize Conference, 21–25 September 1998, Addis Ababa, Ethiopia, CIMMYT and EARO.
96. Emana G. and Assefa G. A. 1995. Response of some maize varieties to Angoumois grain moth, *Sitotroga cerealella* (Olivier). P. 92–97. *In:* Eshetu Bekele, Abdurahman Abdulahi and Aynekulu Yemane (eds.). Proceednigs of the Third Annual Conference of the Crop Protection Society of Ethiopia. 18–19 May 1995, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
97. Emana G. and Assefa G. A. 1997. Attempts to control Angoumois grain moth, *Sitotroga cerealella* (Olivier), using locally available materials on maize grain (Abstract). Paper Presented at the 5th Annual Conference of CPSE, 22–23 1997, Addis Ababa, Ethiopia.
98. Emana G. and Assefa G. A. 1998. Arthropod pests of stored maize in Sidama zone: Economic importance and management practices. *Pest Mgmt. J. Eth.* 2(1&2): 26–35.
99. Eshetu B.1994. Mycotoxin production potentials of *Fusarium* species identifid from Ethiopian wheat. Pp. 47–48. *In:* Proceedings of the First CPSE Annual Conference, 14–15 April 1993. Addis Ababa, Ethiopia. CPSE.
100. Fentahun A. 1994. Important storage pathogens in Sidama Zone. P. 30. Proceedings of the 2nd Annual Conference, CPSE, 26–27 April 1994. Addis Ababa.
101. Fentahun M. 1995. Polyethylene sheet as a solar heat collecting device to disinfest grains from storage pests. P. 26. Proceedings of the Second Annual Conference of CPSE, 26–27 April 1994. Addis Ababa, Ethiopia. CPSE.
102. Ferede N. 1989. Screening of cowpea lines for their resistance to bean bruchids. *CEE* 7 (2): 7– 9.
103. Ferede N. 1994. Studies on the economic importance and control of bean bruchids in haricot bean (*Phaseolus vulgaris* L.) in eastern and southern Shewa. M. Sc. Thesis, Alemaya University of Agriculture, Alemaya, Ethiopia.
104. Ferede N. and Tsedeke A. 1992. Progress in bruchid management. Pp 144–149. *In:* Third SADC/CIAT Bean Research Workshop. Mbebane, Swaziland, 5–7 October 1992. CIAT Africa Workshop Series No. 27.
105. Ferdu A., Demissew K. and Berhane A. 2001. Major insect pests of maize and their management: A review. Pp. 89–96. *In:* Mandefro Nigussie, D. Tanner and S. Thumasi Afriyie (eds.). Enhancing the contribution of maize to food security in Ethiopia. Proceedings of the Second National Maize Workshop of Ethiopia. 12–16 November 2001. IAR and CIMMYT, Addis Ababa, Ethiopia.
106. Fikadu L. 1994. The influence of lining on quality of sorghum (*Sorghum bicolor* L. Moench) stored in underground pits in eastern Oromia, Ethiopia. Doctoral Thesis, Humboldt University, Berlin, Germany.
107. Firdissa E. and Abraham T. 1998a. Insect pests, their control recommendations and future needs for research in western Ethiopia. Pp. 151–158. In: Beyene Soboka and Aberra Deressa (eds.). Agricultural Research and Technology Transfer Attempts and Achievments in western Ethiopia. Proceedings of the 3rd Technology Generation, Transfer and Gap Analysis Workshop. 12–14 November 1996, Nekemte, Ethiopia.

108. Firdissa E. and Abraham T. 1998b. Insect pests associated with and extent of damage caused to stored sorghum in the Bako area (Abstract). P. 14. Paper presented at the 6th CPSE Annual Conference. 3–5 June 1998. Addis Ababa.
109. Firdissa E. and Abraham T. 1999a. Effects of some botanicals and other materials against the maize weevil (*Sitophilus zeamais* Motsch.) on stored maize. Pp. 101–104. *In:* CIMMYT (International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organization). Maize production Technology for the future: Challenges and opportunities: Proceedings of the six eastern and southern Africa Regional Maize Conference, 21–25 September, 1998, Addis Ababa, Ethiopia: CIMMYT and EARO.
110. Firdissa E. and Abraham T. 1999b. Insect pests of farm-stored sorghum in the Bako area. *Pest Mgt. J. Eth.* 3(1&2): 53–60.
111. Firdissa E., Dagne W. and Abraham T. 2000. Varietal resistance in haricot beans (*Phaseolus vulgaris* L.) to post-harvest infestation by *Zabrotes subfasciatus* Boheman. *Pest Mgmt. J. Ethiopia* 4(1&2): 65–75.
112. Firdissa E., Demissew K. and Abraham T. 2001. Evaluation of maize genotypes for resistance to *Sitophilus* weevils (Abstract). *In:* Pests and Vectors Management for Food Security and Public Health in Africa: Challenges for the 21st Century. 14th African Association of Insect Scientists and 9th Crop Protection Society of Ethiopia Joint Conference, 2–8 June 2001, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
113. Gentry, J. W. 1965. Crop insects of Northeast Africa and Southeast Asia,. ARS, USDA. Agricultural Handbook No. 273. Washington, DC.
114. Getinet A., Geremew T. Kassahun Z. and Bulcha W. 1997. Lowland oil crops: A three-decades research experience in Ethiopia. Research Report No. 31. IAR, Addis Ababa, Ethiopia.
115. Gilman. G. A. 1968. Storage problems in Ethiopia with special referene to deterioration by fungi. Reports of Tropical Products Institute. R48.21. 52 pp + appendices.
116. Gilman, G. A. and Boxall, R. A. 1974. The storage of food grains in traditional underground pits. *Tropical Stored Prod. Inf* 28: 19–38.
117. Girma D. 2006. Field infestation by *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) and its management on stored maize at Bako, western Ethiopia. M. Sc. Thesis, Haramaya University, Ethiopia.
118. Girma D., Addis T. and Demissiew K. 2004. Evaluation of cooking oils against the maize weevil on stored maize under farmers´ conditions at Bako (Abstract). Paper presented at 12th CPSE Annual Conference, 26–27 May 2004. Addis Ababa.
119. Harris, K. L. and Lindblad, C. J. 1978. Post-harvest grain loss assesment methods. American Association of Cereal Chemists (AACC), League for International Food Education (LIFE), Tropical Products Institue (TDRI), Food and Agricultural Organization (FAO) and Groups for Assisstance on Systems Relating to Grain After Harvest (GASGA).
120. Hill, B. G. 1963. How to protect stored grain from insects. Imperial Ethiopian College of Agriculture and Mechanical Arts, Haile Selassie I University, *Ethiopia. Experimental Station Bulletin No*. 27.
121. Hill, B. G. 1965. Insects of cultivated and wild plants, Harar Province, Ethiopia. 1960-1964, *Bulletin of Entomological Research* 56: 659–670.
122. IAR.1969. Holetta Guenet progress report for 1968–1969. IAR, Addis Ababa, Ethiopia.
123. IAR.1970. Holetta Guenet Research Station progress report 1969–1970. IAR, Addis Ababa, Ethiopia.
124. IAR.1972a. Bako Research Station Progress Report for April 1971 to March 1972. IAR, Addis Ababa, Ethiopia.
125. IAR.1972b. Holetta Guenet Research Station Progress Report for April 1971 to March 1972. IAR, Addis Ababa, Ethiopia. P.196.

126. IAR. 1973. Proceedings of Annual Research Seminar. October 25-27, 1972. IAR, Addis Ababa.
127. IAR.1974. Bako Research Station Progress Report for April 1973 to March 1974. IAR, Addis Ababa, Ethiopia. 171 pp.
128. IAR.1975. Holetta Gunet Research Station progress report for 1972 to 1973. IAR, Addis Ababa, Ethiopia.
129. IAR.1976a. Holetta Guenet Research Station progress report for 1973-1974. IAR, Addis Ababa, Ethiopia.
130. IAR.1976b. Results of the national crop trials and others 1974. National Crop Improvement Committee, IAR. Addis Ababa, Ethiopia.
131. IAR.1977a. Crop Protection Department Research Programme for 1977/78. Addis Ababa. Ethiopia.
132. IAR.1977b. Holetta Guenet Research Station progress report for 1974 to 1975. IAR, Addis Ababa, Ethiopia.
133. IAR.1978. Crop Protection Department Research Program titles 1978/79. Part I: *Entomology*. IAR, Addis Ababa, Ethiopia.
134. IAR.1981. Crop Protection Research in Ethiopia: 1970 to 1973 E.C. (1977/78 - 1980/81). IAR. Addis Ababa, Ethiopia.
135. IAR.1983. Ethiopian Sorghum Improvement Program (ESIP) Progress Report No. 11. January 1 to December 31. IAR, Addis Ababa, Ethiopia.
136. IAR.1984. Department of Field Crops: National Maize Research Team Progress Report for April 1982 to March 1983. IAR, Addis Ababa, Ethiopia.
137. IAR.1985a. Crop Protection Department Progress Report 1980/81 to 1982/83. IAR, Addis Ababa, Ethiopia.
138. IAR.1985b. Department of Field Crops: National Maize Research Team Progress Report for 1983//84. IAR, Addis Ababa, Ethiopia.
139. IAR.1986a. Department of Crop Protection Progress Report for 1984/85. IAR, Addis Ababa, Ethiopia. 120 pp.
140. IAR.1986b. Protection of stored faba bean seeds against the Adzuki bean beetle. Entomology Program, Holetta Progress Report for 1985/986. IAR, Holetta.
141. IAR.1986c. Department of Field Crops: Lowland Pulse Research Program for April 1983 to March 1984. IAR, Addis Ababa, Ethiopia.
142. IAR 1987a. Department of Field Crops: Maize Research Program Progress Report for 1984/85. IAR, Addis Ababa, Ethiopia. 120 pp.
143. IAR.1987b. Department of Field Crops: Maize Progress Report for 1985/86. IAR, Addis Ababa, Ethiopia.
144. IAR.1987c. Highland Pulse Progress Report for 1985/86. IAR, Addis Ababa.
145. IAR.1987d. Faba bean research in Ethiopia under the IAR/ICARDA/IFAD Nile Valley Project on faba bean 1985–1987 crop seasons. Progress report. Pp. 97–100.
146. IAR. 1987e. Results of Research done on faba bean in Ethiopia under the IAR/ICARDA/IFAD Nile Valley Project during the 1986 crop season for presentation in the VIII Annual Coordination Meeting 13–17 September 1987, Cairo, Egypt. Addis Ababa, Ethiopia. IAR.
147. IAR.1989. Research Program Review. Preliminary survey of field and storage insect pests of wheat at Chilalo awraja. IAR, Addis Ababa, Ethiopia.
148. IAR.1990a. Nazareth Progress Report for the Period 1988. IAR, Addis Ababa, Ethiopia.
149. IAR.1990b. Nile Valley Regional Program Cool Season Food Legumes Research Results of 1989 Crop Season. Annual Coordination Meeting, 2–5 May 1990. IAR, Addis Ababa.
150. IAR.1990c. Annual Report for the Period 1989. IAR, Addis Ababa, Ethiopia.
151. IAR. 1990d. Research results, 1989 crop season. Annual Coordination Meeting, 2–5 May 1990. Nile valley Program Cool Season Food Legumes.

152. IAR.1991a. Holetta Progress Report for April 1989 to March 1990. IAR, Addis Ababa, Ethiopia.
153. IAR. 1991b. Research results, 1990 cropping season. Nile valley Research program cool season Food legumes. Annual Coordination Meeting 16–23 September 1991. Cairo, Egypt. Addis Ababa, Ethiopia, IAR.
154. IAR.1992. Annual Report for 1990. Addis Ababa, Ethiopia.
155. IAR.1995a. Holetta Progress Report for 1990 to 1991. IAR, Addis Ababa.
156. IAR.1995b. Holetta Progress Report for 1994 to 1995. IAR, Addis Ababa.
157. IAR.1995c. Plant Protection Research Center (PPRC) Progress Report for 1994/95. IAR, Addis Ababa, Ethiopia.
158. IAR.1996a. PPRC Progress Report for 1995/96. IAR, Addis Ababa.
159. IAR.1996b. Holetta Progress Report for 1991 to 1992. IAR, Addis Ababa.
160. IAR.1996c. Holetta Agricultural Research Center Progress Report for 1992/93. IAR, Addis Ababa, Ethiopia. P. 202.
161. IAR.1996d. Bako National Maize Research Program Progress Report for 1995/96. IAR, Addis Ababa, Ethiopia.
162. IAR.1997. PPRC Progress Report for 1996/97. IAR, Addis Ababa, Etiopia.
163. International Center for Agricultural Research in the Dry Areas (ICARDA). 1990. Nile Valley Regional Program on Cool-season Food Legumes and Barley. Annual Report 1989/90, ICARDA. Alepo, Syria.
164. JATS (Jimma Agricultural Technical Scool). 1963. Annual Report for January 1963, volume 10, 92 pp.
165. Kashi, K. P. 1985. Report of the post-harvest losses consultancy mission to Ethiopia. 24 February – 25 April 1985. Food and Agriculture Organization of the United Nations, Rome.
166. Kemal A. 1986. Protection of faba bean seeds against the bean bruchid, Callosobruchus chinensis L. P. 39. *In:* Bhardwaj, Bhup D.(ed.). Proceedings of the 7th Coordination Meeting of the ICARDA/IFAD Nile Valley Project on faba bean, September 23–27, 1986. Addis Ababa, Ethiopia.
167. Kemal A. 1988. Biology of C. chinensis (Coleoptera: Bruchidae) and varietal resistance in Vicia faba. M. Sc. Thesis. Department of Pure and Applied Zoology. Reading University, Reading, UK. 137 pp.
167b. Kemal A., Alemayehu R. And Adhanom N. 1985. Review of oil crop Entomology in Ethiopia. Pp. 281-289. In: Tsedeke A. (ed.). Review of crop protection research in Ethiopia, Proceedings of the First Ethiopian Crop Protection Symposium, 4-7 February 1985, Addis Ababa, Ethiopia.
168. Kemal A. and Tibebu H. 1994. Research on insect pests of cool-season food legumes. Pp. 367–396. *In:* Asfaw Tilaye, Geletu Bejiga and Mohan C. Solh (eds.). Cool-season food legumes of Ethiopia. Proceedings of the First National Food Legume Review Conference, 16-20 December 1993, Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA: Alepo, Syria.
169. Kemal A. and Smith R.H. 1996. Varietal resistance in *Vicia faba* L. to *Callosobruchus chinensis* L. *Eth. Journal Agric. Sci*. 15 (1&2): 55-66.
170. Kemal A. and Smith R. H. 2001. The effect of seed coat on the susceptibility of faba bean to *Callosobruchus chinensis* L. *African Crop Scince Journal* 9(2): 421– 430.
171. Legesse D., Asfaw N. and Franzel, S. 1992. Marketing maize and tef in the Bako area: Implication for post market liberalization policies. *In:* S. Franzil and H. V. Houten (eds.). Research with farmers: Lesson from Ethiopia. CAB International, UK. 303 pp.
172. Lemma E., Bekele H. and Dereje T. 1997. Crop protection research and recommendations for southeastern Ethiopia. Pp. 60-63. *In:* Aberra D. and Beyene S. (eds.). Research Achievements and Technology Transfer Attempts in Southern Ethiopia. Proceedings of the 2nd Technology Generation, Tranfer and Gap Analysis Workshop. 9–11 July 1996, Nazareth, Ethiopia.

173. Lemessa, F., Bultosa G. and Wakgari, W. 2000. Quality of grain sorghum (*Sorghum bicolor* L. Moench) stored in traditional underground pits: Case studies in two agro-climatic zones in Hararghe, Ethiopia. *J. Food Science and Technology* 37: 238–244.
174. Lynch, B., Reichel, M., Solomon B. and Kühne, W. 1986. Examination and improvement of underground grain storage pits in Alemaya wereda of Harerghe region, Ethiopia. Alemaye University of Agriculture.
175. Mang, W. 1973. Marketing of selected agricultural products in the Bako area, Ethiopia. Occassional paper No. 66. Employment and Income Distribution Project, Department of Agricultural Economics, Cornell University.
176. Mashilla D. 2004. Grain storage methods and their effects on sorghum grain quality in Hararghe, Ethiopia. PhD Thesis. Swedish University of Agricultural Science. Uppsala, Sweden. 101 pp.
177. Mashilla D., Yuen, J. and Sigvald, R. 2006. Effects of storage methods, storage time and different agro-ecological zones on chemical coponents of stored sorghum grain in Hararghe. *Ethiopia. J. Stored Prod. Res.* 42: 445–456.
178. McFarlane, J. A. 1969a. Special study of stored products problems in Ethiopia. Preliminary report and recommendations. IAR. Addis Ababa, Ethiopia. 30 pp + xxiv.
179. McFarlane, J. A. 1969b. A study of storage losses and allied problems in Ethiopia. ODRI (TPS) Report R40. Supplementary account of investigations. 67 pp. + xii.
180. McFarlane, J. A. and Dobie, P. 1972. The susceptibility of tef (*Eragrostis abyssinica* Schrad.) to infestation by some insect pests of stored grain. *J. Stored Prod Res.* 8: 177–182.
181. Meheret A. 2003. Post-harvest losses in chickpea caused by bruchids and management of *C. chinensis* (Coleoptera: Bruchidae) using botanicals in Enemay Wereda, Eastern Gojam. M. Sc. Thesis, Alemaya Uiversity, Alemaya, Ethiopia. 60 pp.
182. Mekasha Ch. 2004. Utilization of solar heat for the control of cowpea seed beetle, Callosobruchus maculates (F.) (Coleoptera: Bruchidae). PhD Thesis submitted to the School of Graduate Studies, University of Putra, Malaysia.
183. Mekelle Agricultural Research Center. 1998. Progress report for 1998. Mekelle, Tigray.
184. Mekonnen A., Habtie A. and Eshetu S. 1997. Improving the micro-climate of underground grain stores using indigenous lining materials. AMA, *Agricultural Mechanization in Asia, Africa and Latin America.* 28(1): 47 - 49.
185. Mekuria T. 1995. Maize storage insect pest status in southwestern Ethiopia. P. 24. In: Proceedings of the Second Annual Conference of the CPSE, 26–27 April 1994, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
186. Mekuria T. 1996. Botanical insecticides to control stored grain insects with special reference to weevils (*Sitophilus* spp.) on maize. P. 134-140. *In:* Eshetu B., Abdurahman A. and Aynekulu Y. (eds.). Proceedings of the Third Annual Conference of the CPSE. 18-19 May 1995, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
187. Mengistu H. 1982. Diseases of sorghum at some locations in Ethiopia. *Eth. J. Agric. Sci.* 4(1): 45-53.
188. Mesele G. 2003. Pre-harvest assessment and post-harvest management of *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) and *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae) in maize. M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia.
189. Mesele G., Emana G. and Abdurazak Y. 2003. Pre-harvest assessment and post-harvest management of *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) and *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae) in maize (Abstract). Pp. 34-35. CPSE 11th Annual Conference, 5–6 June 2003. Addis Ababa, Ethiopia.
190. Mohammed D. 1996. Heat treatment for the control of the corn weevil, *Sitophilus zeamais* Motsch. in stored corn (Abstract). P. 13. Paper presented at the Fourth Annual Conference of the CPSE. 23–24 May 1996. Addis Ababa, Ethiopia.

191. Muluemebet, D. 2003. Survey of cowpea storage methods, extent of loss due to pulse beetles, *Callosobruchus maculates* Fab. (Bruchidae: Coleoptera) and its management in Gambella. M.Sc. Thesis, Alemaya University, Alemaya, Ethiopia.
192. Niles, E. V. 1976. The mycroflora of sorghum stored in underground pits in Ethiopia. *Tropical Science* 18: 115-124.
193. OADB-ARCS (Oromia Agricultural Development Bureau Agricultural Research Coordination Sevice). 1998a. Bako Agricultural Research Center Progress Report for the Period 1996/97. OADB-ARCS.
194. OADB-ARCS. 1998b. Bako Agricultural Research Center Progress Report for the Period 1997/98. OADB-ARCS.
195. Ramputh, A., Teshome A., Bergvinson D. J., Nozzolillo, C. and Arnason, J. T. 1999. Soluble phenolic content as an indicator of sorghum grain resistance to *Sitophilus oryzae* (Coleoptera: Curculionidae). *J. Stored Prod. Res.* 35 (1): 57 - 64.
196. Schmutterer, H. 1971. Contribuion to the knowledge of the crop pest fauna in Ethiopia. Z. Angew. *Entomol*. 67: 371-389.
197. Seyoum T. W. and Woldetsadik K. 2000. Natural ventilation evaporative cooling of mango. *J. Agric. Biotechnol. Environ.* 2 (1-2): 1–5.
198. Sheno Agricultural Research Center. 1999. Annual report for 1997/98. Sheno, ARARI, Sheno.
199. SARC (Sirinka Aggricultural Research Center). 2000. Progress Report for the Period 1999 season. Sirinka Aggricultural Research Center, Sirinka.
200. Solomon B. 1983. The mycoflora associated with the grain sorghum in pits and the role of four different species of fungi on the quality of sorghum grains in Alemaya district, Hararghe, Ethiopia. Addis Ababa University, Alemaya College of Ageiculture. Alemaya, Ethiopia. M. Sc. Thesis. 89 pp.
201. Solomon B. and Mengistu H. 1984. The mycoflora associated with the grain sorghum in pits and the role of four different types of fungi in the quality of sorghum grains in Alemaya district, Hararghe, Ethiopia. Pp. 119-121. In: Proceedings of the 9th Annual Meeting of the Ethiopian Phytopathological Committee (EPC). February 2–3, 1984, Nazareth, Ethiopia.
202. Solomon G. 1996. Effects of some botanicals and varietal resistance in the management of *Sitophilus* spp. on stored sorghum. M. Sc. Thesis, Alemaya University, Alemaya, Ethipia. 121 pp.
203. Solomon G. and Abdurahman A. 1997. Efficacy of some botanicals against weevils of *Sitophilus* spp. attacking sorghum (Abstract). P. 11. Paper presented at the 5th Annual Conference of CPSE, 22 – 23, May 1997, Addis Ababa, Ethiopia.
204. SSEAD Consultancy. 1997. Amhara National Regional State, Bureau of Agriculture, Regional Crop Pest Survey Report on Insect Pests. Addis Ababa.
205. Tadesse, F. 1991. Post-harvest losses of fruits and vegetables in horticultural state farms. *Acta Horticulture* 270: 261–270.
206. Tadesse G. M. 1987. A counry report: Presented at the regional study workshop on on-farm and post-harvest losses of cereal crops in Africa due to pests and diseases. ICIPE, Nairobi, Kenya. 11–15 October 1987.
207. Tadesse G. M. 1992. Survey of faba bean storage pests in the central zone of Ethiopia. *Eth. J. Agric. Sci.* 13: 101 - 104.
208. Tafesse G. 2004. Survey of post-harvest insect pests of major crops in Arsi zone. P. 53. (Abstract). Paper presented at the 12th Annual Conference of CPSE, 26-27 May 2004. Addis Ababa, Ethiopia.
209. Tebikew D. and Mekasha Ch. 2002. The efficacy of some botanicals in controlling Adzuki bean beetle, C. chinensis, in stored chickpea. Tropical Science 42: 192–195.

210. Teclemariam W. 1985. A review of research on maize and sorghum in Ethiopia. pp. 21-34. In: Tsedeke Abate (ed.). A review of crop protection research in Ethiopia: Proceedings of the First Ethiopian Crop Protection Symposium. 4-7 February 1985, Addis Ababa, Ethioipa.
211. Tefera A., Seyoum T. and Woldetsadik K. 2007. Effect of disinfestation, packing, and storage environment on the shelf life of mango. *Biosytems Engineering.* 96 (2): 201-212.
212. Tena Alamirew. 1998. Construction and evaluation of naturally ventilated consumer potato storage. Pp. 164- 180. In: Proceedings of the First Annual Conference of the Ethiopian Society of Agricultural Engineers (ESAE). 26–27 May 1997, Addis Ababa.
213. Tesfaye W. 1997. *Fusarium* and *Fusarium* toxins in maize in some regions of Ethiopia. M. Sc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.
214. Tesfaye Wubet and Dawit Abate. 1999. Toxigenic Fusarium species in Maize grain in Ethiopia. Pp. 132-134. *In:* CIMMYT (International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organization). Maize production Technology for the future: Challenges and opportunities: Proceedings of the six eastern and southern Africa Regional Maize Conference, 21–25 September, 1998, Addis Ababa, Ethiopia: CIMMYT and EARO.
215. Tesfaye W. and Dawit A. 2000. Common toxigenic *Fusarium* species in maize grain in Ethiopia. *SINET Ethoian J. Sci.* 23: 73–86.
216. Teshome A., Torrance J. K., Baum B., Fahring L., Lambert J. D. H., Arnason, J. T. 1999. Traditional farmers' knowledge of sorghum (*Sorghum bicolor* Poaceae) landrace storability in Ethiopia. *Economic Botany*. 53 (1): 69–78.
217. Teshome L. 1990. The biology and control of the Adzuki bean beetle (*Callosobruchus chinensis* L. (Coleoptera: Bruchidae) on chickpea (*Cicer arietinum* L.) in Ethiopia. M. Sc. Thesis, Alemaya University of Agriculture, Alemaya, Ethiopia. 106 pp.
218. Teshome L. 1993. Evaluation of neem (*Azadrachta indica*) and vegetable oils against the Adzuki bean beetle (*Callosobruchus chinensis*) (Abstract). P. 31. *In:* Proceedings of the Joint Conference: Ethiopian Phytopathological Committee (EPC) and Committee of Ethiopian Entomologists (CEE), 5-6 March 1992, Addis Ababa, Ethiopia. CPSE: Addis Ababa.
219. Teshome L. 1994. Screening of chickpea geneotypes against the Adzuki bean beetle (*Callosobruchus chinensis* L.) P. 32. *In:* Proceedings of the First Annual Conference of CPSE, 14-15 April 1993, Addis Ababa, Ethiopia. CPSE, Addis Ababa.
220. Tigist S. 2004. Management of bean bruchids, *Zabrotes subfasciatus* Boheman (Coleoptera: Bruchidae), on haricot bean (*Phaseolus vulgaris* L.) using botanicals and host resistance. M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia.
221. Tilahun Seyoum and Kebede Woldetsadik. 2004. Forced ventilation evaporative cooling: A case study on banana, papaya, orange, mandarin, and lemon. *Trop. Agric. (Trindad).* 81(3): 179–185.
222. Tsedeke A. 1985. Evaluation of insecticides for the control of the bean bruchids (*Callosobruchus chinensis* L.) on stored haricot beans. *Eth. J. Agric. Sci.* 7: 109–118.
223. Tsedeke A. 1990. Bean Entomology. Pp. 54-57. Research on haricot bean in Ethiopia: An assessment of status, progress, priorities and strategies. Proceedings of a national workshop held in Addis Ababa, 1–3 October 19990. Addis Ababa, Ethiopia.
224. Tsedeke A. 1995. Pest management in lowland pulses: Progress and prospects. Pp. 181-194. *In:* Habtu Assefa (ed.). Proceedings of the 25th Anniversary of the Nazareth Agricultural Research Center. 25 years of experience in lowland cropps research. 20–23 September 1995, Nazareth, Ethiopia. Nazareth Research Center, Nazareth.
225. Tsedeke A. 2004. Pest problems vis-a-vis food security. Pp. 105–116. *In:* Modernizing Agriculture: A way out of food insecurity. Proceedings of a National Workshop, February 19–20, 2004. The Biological Society of Ethiopia. Addis Ababa, Ethiopia.

226. Tsedeke A., Tadesse G. M. and Kemal A. 1982. Arthropod pests of grain legumes in Ethiopia: Their management and distribution. IAR, Addis Ababa, Ethiopia. 55 pp.
227. Tsedeke A. and Adhanom N. 1985. Current state of stored products research in Ethiopia. Pp. 645-652. *In:* Tsedeke Abate (ed.). A Review of Crop Protection Research in Ethiopia. Proceedings of the First Ethiopian Crop Protection Symposium, 4–7 February 1985, Addis Ababa, IAR, Addis Ababa, Ethiopia.
228. Tsedeke A. and Gashawbeza A. 1991. Botanicals for protecting stored cowpea against bruchids. *Committee of Ethiopian Entomologists (CEE)* 12(1&2): 2-3.
229. Tsedeke A. Ferede N. and Gashawbeza A. 1993. Botanicals in pest management: Preliminary results (Abstract). P. 15. *In:* Proceedings of the Joint Conference: Ethiopian Phytopathological Committee and Committee of Ethiopian Entomologists. 5–6 March 1992. Addis Ababa, Ethiopia. CPSE. Addis Ababa.
230. UNDP/FAO. 1982. Action program for improved plant protection in Ethiopia. Report of Survey on Plant Protection. 7 April to 2 May 1981.
231. Walker, D. J. and Boxall, R. A. 1974. An annotated list of the insects associated with stored products in Ethiopia, including notes on mites found in Harar province. *East African Agriculture and Forestry Journal* 39: 300–335.
232. Worku T. 2002. The importance and distribution of the pea weevil (Bruchus pisorum) in the Amhara Region. Pp. 30–36. *In:* Proceedings of a National Workshop on the Management of the Pea Weevil (Bruchus pisorum). ARARI, Bahir Dar, November 25–27, 2002. Bahir Dar, Ethiopia.
233. Yemane K. and Yilma H. 1985. Food grain losses in traditional storage facilities in three selected areas of Ethiopia. Ethiopian Nutrition Institute, Addis Ababa.
234. Yemane K. Yilma H. 1989. Food grain losses in traditional storage facilities in three areas of Ethiopia. Pp. 407–30. *In:* Towards a Food and Nutrition Strategy for Ethiopia. Proceedings of the National Workshop on Food Strategies for Ethiopia, held at the Alemaya University of Agriculture, 8–12 December 1986. Alemaya, Ethiopia.
235. Yilma G. and T. J. Crowe. 1980. Storage of maize at Gambella. 2 pp. (unpublished).
236. ›=ƒÄåÁ Ów`“ U`U` É`Ïƒ (›=.Ó.U.É.). 1993. ¾ÉI[-U`ƒ UÓw ´ÓÏƒ“ ¡U‹ƒ ¾Ów`“ }[ð-U`ƒ ›ÖnkU ,¡•KÁÍ= U`U`“ e`çƒ& ®¬Å Ø“ƒ“ ›?Ó²=y=¡”'Ó”xƒ 29–c’ 2 1992 ¯.U. ›Ç=e ›uv' ›=ƒÄåÁ:: (EARO. 2000. Post-harvest food preparation and storage, research and extension of technologies for agricultural by-products utilization: Workshop and Exhibition. May 29 to June 2, 1992 E.C., Addis Ababa, Ethiopia).

Status and Prospects of Plant Quarantine in Ethiopia

[1]**Merid Kumsa**, [2]**Dereje Gorfu**, **and** [3]**Adane Abraham**
[1]*Ministry of Agriculture and Rural Development, P.O.Box 62347, Addis Ababa, Ethiopia.*
[2, 3] *Ethiopian Institute of Agricultural Research, P.O. Box 2003, Addis Ababa, Ethiopia.*

Introduction

Agricultural development in Ethiopia requires importation of improved plant varieties and germplasm for variety development in many crops. The introduction of plant material is accompanied by a risk of introducing exotic pests (Neergaard, 1979). The process of food grain import to the country appears to have little regard for quarantine principles and the risks associated with pest introduction (MOA, 1991; Fikre and Navaratnam, 1991). There is comparatively higher risk of introduction of foreign weeds mixed with crop seed, as they are difficult to remove by ordinary treatments at the point of entry (MOA, 1991). In addition, the enhancement of agricultural investment at present greatly involves import of plants materials such as seed, plant products and seedling, which could be associated with high risk of introduction of exotic pests unless due attention is given to proper quarantine measures. Furthermore, Ethiopia shares a long distance borders with its neighbors, and hence, is likely to receive continuous flow of people, animal and plants/plant products that create favorable pathway for the introduction of new pests of quarantine significance.

In the past three decades alone, more than 20 dangerous pests are believed to have been accidentally introduced into the country among which groundnut rust, coffee berry disease, Cyprus aphid, pea bruchid, water hyacinth, *Parthenium*, and *Prosopis* have received highest attention presently by public and the government due to the tremendous damage they caused to the Ethiopian agriculture and environment (Dereje *et al.*, 2006). Fore instance, the exotic species *Parthenium hysterophorus* and *Prosopis juliflora* are invasive weeds in crop and pasture areas as well as in residential areas, drainage channels and vacant places such as roadsides (Rezene, 2006). So far, these two species have encroached over 264,100 hectares of land comprising 82,395 hectares of crop area, 90,923 hectares of pasture and 82,088 hectares of wasteland hove been covered by *Parthenium* (MOARD, unpublished data).

In addition, countries to which Ethiopia exports diverse kinds of agricultural products often require accompanying phytosanitory certificate. Due to inadequate phytosanitory services, export shipments have faced rejection at destinations or low price offer in the international market. A good example is the rejection of noug seed due to contamination by a parasitic weed called dodder. Regular complaints were also received from Israel due to heavy infestation of tef by a noxious weed species, *Striga*. Similarly, cut flower and pulse exported to the Netherlands were sometimes rejected and disposed due to infestation by African bollworm (report from Bole quarantine station). Hence, these situations have negative impact on foreign market of the country in addition to direct losses. All these problems could be attributed to a weak quarantine system in the country.

Results of plant quarantine activities in the research system were reviewed by Awgechew *et al.* (1985) and more recently by Dereje *et al*. (2006). A total of 342, 024 samples imported for research were inspected up to 1983 alone and many serious pests were intercepted. These include *Colletotrichum graminicola* on maize, *Ascochyta rabei* on chickpea from India, *Bruchus dentipes* Baudi on faba bean from Syria, *B. rufimanus* Bohemas on faba bean from USA, scale insect on cowpea from West Africa, *Cuscuta* spp. on linseed, and many weed species from genus *Amaranthus*, *Polygonum*, *Rumex*, and family Poacae from Europe and America. The quarantine policy for wheat importation was discussed by Fikre and Navaratnam (1991) who also presented critical evaluation of the national quarantine operation. All reviews to date agree that there was no strong and effective national plant quarantine regulation in Ethiopia until 1992 and the quarantine was loose and weak as far as operation was considered.

This paper reviews important policy issues of plant quarantine in Ethiopia, status of services, threats of alien pests to the agriculture and environment, pest interception in the last 20 years, major achievements in export and import control and discusses gaps and future considerations.

An overview on Ethiopian Plant Quarantine Regulations

Quarantines are promulgated by governments or group of governments to prohibit, restrict and limit the entry of alien pests with plants, plant products, soil, culture of living organisms, packing materials and commodities as well as their containers and means of conveyance (Mathur and Lal, 1996). Ethiopia proclaimed plant quarantine regulations in 1992 for national use that centrally operates under the Ministry of Agriculture and Rural Development. The bases of Ethiopian plant quarantine services are (1) the Plant Protection Decree No. 56/1971 which empowers the then Ministry of Agriculture to establish and run plant quarantine services in the country and (2) the Plant Quarantine Regulation No. 4/1992.

In turn the basis of these regulations is the International Plant Protection Convention (IPPC) of 1951, which has undergone revision in 1997 (FAO, 2005). Hence, as a signatory of IPPC, the country should periodically revise and update its phytosanitary legislations and regulations in accordance with the most recent version of IPPC. Ethiopia is also a signatory of Inter African Phytosanitory Counsil (IAPC) of 1967.

Plant quarantine regulation No.4/1992 provides terms to control pest movement with import and export of plant commodities. The regulation has 15 major articles with two annexes. It consists of provisions that aim at controlling the spread of plant pests. It stipulates that any plant or other articles found infected or infested shall be treated, destroyed or disposed; and that a premise or conveyance infected or infested with plant pests shall be treated. In addition, it requires that all imported plants and other articles that are potentially or actually infested or infected with pests undergo quarantine control and be accompanied by phytosanitary certificate.

The regulation puts restriction on the import of some plant species. It prohibits the import of many plant species without a permit from the Ministry of Agriculture and Rural Development (Dereje *et al.*, 2006; *Nagarit Gazeta*, 1992). The regulation totally prohibits the import of plant species unless for a purpose of scientific study under strict quarantine control upon issuance of permit from the Ministry. Furthermore, it provides that an area infected or infested with plant pest shall be declared as such and shall be treated and quarantined. Nonetheless, the regulation does not provide any term for quarantine control to prevent the spread of plant pests within the country. This is one of the serious shortcomings in the current quarantine regulation of the country.

Status of Plant Quarantine Services

Institutional development

To implement effective plant quarantine, a division (service) was established, for the first time, under the then Ministry of Agriculture in 1975 (MOA, 1975). Following this, additional four quarantine stations were established at Bole airport, Dire Dawa, Moyale and Nazaret to monitor and protect the spread of plant pests. Until 1993, Ethiopia used to operate under a national plant quarantine service in the stations mentioned above. These quarantine stations were enforcing plant quarantine laws under the direct supervision of the head office (Sholla laboratory) of national plant quarantine service.

Later on with the formation of National Regional States in the country, the quarantine stations were transferred to the respective regional states and hence the phytosanitory measures were detached from the national plant quarantine services. As a result, the Ethiopian plant quarantine service was devoid of proper organizational set up that brings the Federal Plant Quarantine Service and plant quarantine stations together, which seriously limited its effectiveness. Although the Decree and the Regulations proclaimed gave strong responsibility to control the entry of foreign plant pests, there was no harmonized and effective plant quarantine system in the country until recently. Each station used to carry out its quarantine activity independently and there were no information exchange among the stations.

Realizing this, the ministry has taken serious measures since September 2005 to harmonize the quarantine service of the country. The plant quarantine stations under the regional states became directly affiliated to the federal plant quarantine service both technically and administratively. Quarantine personnel were recruited and assigned to the stations by the national quarantine office. Necessary materials were purchased and being sent to the stations periodically. Communication radios were installed at some of the stations to facilitate communication between quarantine stations and the federal quarantine service office.

The plant quarantine division of the MOARD stationed at Sholla Laboratory in Addis Ababa is responsible for operating and coordinating quarantine services at national level. It is involved in inspecting plant materials with many stakeholders. The stakeholders include the Custom Department, the Ethiopian Institute of Agricultural Research, several Regional Agricultural Research Institutes, and many universities; many import and export companies. EIAR provides post-entry quarantine service on imported plants for research purposes while the quarantine office and its stations provide other required services. EIAR especially operates a post-entry quarantine at 10 Research Centers and has developed a guideline to be used by agricultural researchers in the country (Dereje, 2006).

Facilities of plant quarantine services

The effectiveness of a quarantine operation to fulfill proper quarantine principles, standards and guidelines, however, depends on availability and adequacy of inspection, detection and treatment facilities. Among these, post-entry quarantine facilities, indexing, detection and therapy equipment, seed health testing laboratory and trained manpower are important (Feliu, 1988). The crop protection department of the MOARD at Sholla has three teams, one of which is crop protection and quarantine team that has modest laboratory facility. The inspection is carried out primarily by visual observation using hand lens and compound microscope whenever necessary. The plant pathology, pesticide chemistry, entomology and weed science laboratories serve the identification of pests encountered during inspection. Except at Holetta (EIAR), Moyale and Nazeret, there is no laboratory facility. Most of the stations lack basic quarantine facilities such as greenhouse, fumigation and treatment facilities (Table 1).

Lack of equipment, reagents and other supplies markedly affects the routine quarantine work. However, the pesticide chemistry laboratory can perform limited chemical analysis using gas chromatography and quality processes that validate test methods. In addition, lack of supplies, parts, and maintenance services were problems.

Among post-entry quarantine methods, field test of plant samples are carried out at 10 research centers of EIAR by well-trained plant protection personnel. The stations and the plant species they deal with were given in Table 2. Seeds and plant products of health plants are released to users while those showing any symptom are destroyed at this stage.

Lack of access to Internet and reference materials limited our effectiveness. The personnel in the division were not even aware of pest problems that may have significant impact on emerging horticultural and floriculture industry. The communication facility was not satisfactory at all (Table 3).

Means of communication is important in order to obtain pertinent information on the distribution of pests and the status of planting materials coming to the country as well as to acquire data that enable to run pest risk assessment (PRA) from stakeholders and international and regional quarantine organizations.

Table 1. Quarantine facilities* at MOARD and EIAR

Facility	Locations						
	Main office (Sholla)	Nazareth	Dire Dawa	Bole Airport	Moyale	Metema	Holetta (EIAR)
Greenhouse	+	-	-	-	-	-	+
Laboratory	+	-	-	-	+	-	+
Store	+	-	-	-	+	-	+
Fumigation premises	-	-	-	-	+	-	+
Fumigation chamber	-	-	-	-	+	-	+
Incinerator	-	-	-	-	-	-	-
Isolated field	-	-	-	-	-	-	+**

** + = available and - = absent ; ** quarantine fields available at 10 research centers (Table 2)*

Table 2. Post-entry quarantine fields under the EIAR and plant species they deal with

Location	Mandate crops and other plants*
Ambo Plant Protection Research Center	Highland and mid-altitude maize, highland sorghum
Awassa Agricultural Research Center	Sweet potato, cassava and taro
Bako Agricultural Research Center	Maize (hybrid), forest trees
Debre Zeit Agricultural Research Center	Durum wheat, buck wheat, Triticale, tef, chick pea, lentil, grass pea, grain amaranthus, fenugreek, garlic, shallot, grape vine, sunflower, safflower
Essential oils research center (Wendo Genet)	Medicinal plants
Forestry Research Center (Addis Ababa)	Forest tree species
Holetta Agricultural Research Center	Barley (food and malt), faba bean, field pea, temperate fruits, highland oil crops and highland spices (brassica, linseed, cumin, coriander, etc.), potato, forage crops (grasses and legumes)
Jima Agricultural Research Center	Coffee, spices (ginger, turmeric, cardamom, vanilla, etc.), tea, tropical fruits and nuts, multipurpose trees
Melkassa Agricultural Research Center	Fruits (orange, avocado, banana, etc.), vegetables (tomato, pepper, onion, etc.), lowland pulses (haricot bean, pigeon pea, cowpea etc.), sorghum (low land), millet (finger, pearl, fox), mulberry
Werer Agricultural Research Center	Maize (open pollinated), cotton, rice, date palm, caster bean, sesame, groundnut, forage crops (grasses and legumes for low land)

* Special permission from the ministry (MOARD) is required for crops/plants outside this list.

Table 3. Communication facilities available at MOARD and EIAR.

Locations	Communication facility*			
	Radio	Telephone	Computers	Internet
Headquarters (Sholla)	+	+	+	+
Bole airport	-	+	+	-
Nazaret	-	+	+	+
Dire Dawa	-	+	+	-
Moyale	+	+	-	-
Metema	+	-	-	-
Holetta (EIAR)	-	+	+	+

** + = available and - = absent*

Human resources

The personnel at the Quarantine service of MOARD consists of M.Sc and one B.Sc. holders (Table 3). The rest were diploma holders from the former junior colleges of Ambo and Jima. Efforts were made to employ additional staff for vacancies in some stations in recent years. However, in some stations are such as Moyale and Metema still there is a manpower limitation to properly take quarantine measures. Even in areas where enough manpower was available, knowledge and skill required to handle quarantine problems is a limiting factor. This calls for proper development of human resources at the MOARD. At EIAR, well-trained research staff is involved in plant quarantine service. The laboratory at Holetta (EIAR) is engaged also in seed health research having trained workforce(Table 4) and good research facility.

Table 4. Plant quarantine personnel and their qualifications at MOARD and EIAR

Locations	Education level				
	Ph.D.	M.Sc.	B.Sc.	Diploma	Certificate
Headquarters	0	4	0	0	0
Bole airport	0	2	0	1	0
Nazret	0	1	0	2	1
Dire Dawa	0	1	1	1	1
Moyale	0	0	0	2	0
Metema	0	1	0	1	0
Holetta (EIAR)	1	0	1*	1	1

** On training leading to M.Sc. in plant virology*

PROBLEMS OF ALIEN PESTS IN ETHIOPIA: salient examples

The main question is whose responsibility was exotic pest problem? Charles (1980) discusses on this issue and blames primarily professionals who are paid by the public to protect plants from pests, regulatory people and plant pathologists, entomologists, herbologists who can supply regulatory agencies with better strategies and tools. Feliu (1988) also pointed out that safe and expeditious exchange of seed and other propagating plant products have been the subjects of serious concern. And hence, sound quarantine practices and procedures should be applied to safeguard the country from exotic pests. This requires concerted efforts at national, regional and international level in accordance with IPPC.

There are several ways by which we can understand the origin of pests, whether it is pathogen, insect pest or invading weeds. These include: (i) recent and past records (e.g. *Parthenium* in Ethiopia), (ii) spreading pathways of a pest (e.g. coffee berry disease pathway), (iii) host range data including origin and line of domestication of a plant (e.g. late blight follows the potato crop), (iv) quarantine interception records (e.g. *Ascochyta fabae*, *Bruchids*, *Cuscuta*) in Ethiopia, and

(v) the origin and diversity of the host and pest (e.g. rapeseed and *Phoma lingam*, Cypress aphid and *Cupressus* forest). By considering these criteria, many diseases, insect pests and weed species were believed to be introduced in the last 50 years. As they spread from the point of accidental introduction through seed importation, grain aid, or germplasm exchange or even deliberate introduction for intended purposes (like that of *Prosopis* and *Lantana*), most became destructive to major economic crops. Special mentions could be made for some pests.

Coffee berry disease

This disease is caused by a fungal pathogen called *Colletotrichum coffeanum.* The origin of this pathogen is a wild coffee species (*Coffea eugenioides*) endemic to west Kenya and passed to cultivated coffee (*Coffea arabica*) in the beginning of the 19th century (Bayetta, 2001). This disease advanced to Zaire, Uganda, Cameroon, and to southern Ethiopia (Sidamo), Kefa, and then to Harar as accidental introduction during early 1970s (Bayetta, 2001). This spreading pathway indicates the origin and how it invaded the coffee growing regions of Ethiopia. It costs up to 150 million Birr per year to save yield and quality losses of coffee due to CBD in this country (Bayetta, 2001).

Pea bruchid (*Bruchus pisorum*)

This pest is important because it starts in the field and attacks the grain in the store (Berhane, 2002). It is spreading at an alarming rate in the northeast (Amhara) and central pea growing areas (Ada, Shenkora, Ejere, Sendafa) (Dereje, 2004). A 30% reduction in germination and sometimes a complete destruction of pea grain was observed in a survey conducted in 2002 in these places. Over 13 weredas are infested with pest at present.

The Cypress aphid (*Cinara cupressivora*)

The origin of this pest was thought to be eastern Greece and just south of the Caspian Sea. In Africa, it was first observed in Malawi in 1986 and then in a relatively short period of time spread to many countries in eastern and southern Africa (Day *et.al.* 2003). This aphid was highly aggressive and a devastating pest in our Cupressess forest (Negash and Mohamed, 2004). Almost all forests of this introduced tree species were devastated by the pest in central Ethiopia in recent years. Fortunately, it didn’t attack the native Cupressess species as it was observed in Suba state forest near Addis Ababa.

Parthenium

This weed species (*Parthenium hysterophores*) is originated and is among major vegetations in tropical America and West Indies. It was not recorded in Ethiopia until 1980s, but in the early 1980s this invasive weed invaded the eastern part of the country (Harergae). Now, it is spreading to the north, west, and south parts of the country. It is one of the invasive weeds of national concern that causes up to 60% losses (Takele, 2004). Originating from its homeland in America, *Parthinum* spread to Australia, Asia and Africa through seed. It was, most probably, introduced to Ethiopia accidentally with wheat grain during famine period of 1985.

Witch weed (*Striga* spp.)

Many believe that these weed species were introduced to the country long ago (ESIP, 1982; Takele, 2004), although some workers contrarily consider that striga co-evolved with the main host sorghum (Fasil, 2003). They are spreading at great economic and ecological consequences. They are parasites of cereals (sorghum, maize and finger millet) in arid and semi-arid agro-ecologies of Amhara, Tigray, Oromiya and Southern Ethiopian People Nation and Nationalities Regional State. Particularly *S. hermontica* and *S. aesiatica* could cause a yield reduction of up to 70% (Fasil, 2003). Most of us know how much research concern and investment is incurred on *Striga* problems today.

Generally, pests of alien origin became very devastating types of problems costing millions every year to the country, limited some crops to only off-season culture, invaded vegetation and caused health problems, heavy grain losses in crop and store, etc. The impact of alien pests on the Ethiopian agriculture is immense. Thus, the nation as a whole should be aware of this and try to combat this silent disaster through systematic interception of introductions and limitation of secondary spread after accidental establishment. This serious foreseen problem necessitates the establishment of more effective quarantine posts at different entry ports of the country. This will enable the nation to effectively protect its agriculture and environment through shared responsibility and development of external (county to country) and internal (state to state, or location to location) quarantine services.

Major Achievements in Import Control

In the existing system, all plant materials, which could carry pest, have been subjected to inspection. These mainly included seeds, seedlings and cuttings imported from namely India, Holland, Zimbabwe, South-Africa, Australia, Nigeria, Ghana, Israel, France, Turkey and Germany (Tables 5 and 6). Post-entry quarantine was carried out in the field and in the greenhouse (Dereje, 2006).

Import control could involve embargo, inspection of seed lots at the entry ports, follow up inspection generally through post-entry quarantine, and seed treatments. The measures taken in the last 20 years for research samples included all of these approaches. There were some cases where embargo was appropriate, during importing germplasm by EIAR for research based on sound biological evidence. In addition, all incoming planting materials including seeds were inspected before planting in isolated fields (Dereje, 2006). Out of 176,397 inspected samples, about 87.2% of the incoming samples were released to the importers. Until 1990 alone, 2208 barley and 33 faba bean from Egypt, 557 durum wheat and 1135 bread wheat from Mexico, 45 maize from Nigeria and 159 lowland pulses (beans) from India were rejected and burned due to infestation with serious and dangerous pests. Over 5,000 samples were grown in a greenhouse and seeds were harvested only from pest-free plants and then were dispatched to users. Host plants handled under this measure included barley, cotton, groundnut, haricot bean, maize, pepper, and wheat.

Table 5. Plant and plant products imported in to the country during 2001-2005 through Sholla Plant Protection Laboratory of the Ministry of Agriculture and Rural Development

Item(s)	Unit	2001	2002	2003	2004	2005
Cereals	kg	-	20	4860	375	6487
Pulses	kg	904	60	-	469	1446
Oil crops	kg	150	-	-	-	4
Vegetable*	kg	7189	7641	14453	43493	72377
Flower**	Piece	-	680062	329332	130770	30005
Forest seeds	kg	100	-	-	-	-
Grass seeds	kg	-	400	-	200	-
Sugar cane	Piece	-	-	50	-	-
Fruit crops**	Piece	105	-	1200	-	4598
Fruits (apple)	Piece	-	-	-	21462	20500
Others	Piece	-	-	-	-	32396
Import permits issued	Number	54	72	70	155	267

Country of origin: *India, Holland, Zimbabwe, South Africa, Australia, Nigeria, Ghana, Israel France, Turkey, Germany.*
** Cutting, **Seedling*

Table 6. Number of imported research samples and inspected in the laboratory, greenhouse and field at EIAR during 1985-2004

Plant/Crop	1985-1989	1990-1994	1995-1999	2000-2004	Total samples
Cereals	46048	869	41522	55284	143723
Rice	18	433	0	1617	2068
Pulses	10348	627	8284	5761	25020
Oil crops	424	0	8	474	906
Vegetables	63	0	56	55	174
Roots and tubers	100	59	0	0	159
Fruits	1555	0	0	0	1555
Spices	26	0	0	2	28
Forage	205	0	854	630	1689
Cotton	1	0	0	25	26
Tobacco	4	0	0	0	4
Tea	0	0	0	31	31
Others	7	0	0	7	14
Total samples	58799	1988	50724	63886	175397

Samples found infested with insect pests or pathogens that could be inactivated by means of seed treatment, were subjected to fumigation and seed treatment measures. As a result, fumigation of 23 consignments and seed treatment of 12,516 samples were carried out to eliminate imported pathogen inocula or insects.

Interception of pathogens

Among samples imported for research, some of the most important disease causing pathogens detected and/or intercepted during the last 20 years shown in Table 7. The pathogens include those having major seed borne nature for which seeds are the major transmission vehicle; they cause very serious diseases in the country of origin. Some non-seed transmitted pathogens like *Barley yellow dwarf virus* on barley indicated in previous reports are excluded from Table 7 as it could possibly be a mistake.

Interception of insect pests

Several insect species have been intercepted from imported seeds and planting materials (Table 8). Risky materials were pea bruchid, unidentified insects and their bodies were found in many accessions introduced on several occasions.

Interception of weed species

Seed and planting materials introduced for research purposes were inspected for noxious weed species. Weed species which include *Cuscuta* spp. on linseed, *Amaranthus* spp., *Polygonum* spp. and *Rumex* spp. on alfalfa, and various grass seeds on many crops were intercepted in the last 20 years in research samples.

Table 7. Pathogens intercepted in post-entry evaluations of germplasm for research purposes at EIAR

Crop	Pathogen	Disease it causes	Country/origin
Barley	*Bipolaris graminearum*	Barley stripe	Syria/ICARDA
Cassava	?Fungi sclerotia (mixed with cassava)	Ergot	Kenya
Chickpea	*Ascochyta rabei*	Blight	India/ICRISAT
Cotton	*Xanthomonas malvacearum*	Black arm	The Sudan
Maize	*Helminthosporium carborum*	Southern leaf spot	Zimbabwe
Pigeon pea	*Colletotrichum caganee*	Anthracnose	Zimbabwe
Potato	*Synchitrium* sp.	Black wart	Holland
Rice	*Helminthosporium oryzae*	Brown leaf spot	Philippines/IRRI
	Pyrcularia oryzae	Blast	Philippines/IRRI
	Trichoconis padwickii	Stalk brown disease	Philippines/IRRI
Sorghum	*Sphacelia* spp.	Ergot	India
Sunflower	*Plasmopara holistedie*	Downy mildew	France
Trifolium	*Botrytis* sp.	Grain mold	Czech and Slovakia
	Anthophilla sp.	-	Czech and Slovakia
Wheat	*Fusarium nivale*	Snow mold	Germany
	Tilletia indica	Kernel bunt	Mexico/CIMMYT
	Urosystis agropyri	Flag smut	Syria/ICARDA

Source: Dereje et al. (2006)

Table 8. Insect pests intercepted in post-entry evaluations of imported germplasm for research purposes at EIAR

Crop	Pest*	Country of Origin
Barley	*Bruchus* spp. (several species)	Egypt, Syria, Yemen
Cotton	*Anthonomus gradis* (cotton boll weevil)	USSR, Greece, Sudan
Faba bean	*Bruchus* spp. (several species)	Egypt, Sudan, Syria, USA
Field pea	*Bruchus pisorum* (pea weevil)	USSR/Vavilov Institute
Groundnut	*Hilda patruelis* (ground nut hopper)	India, Zimbabwe
Maize	*Prostephanus truncates* (greater grain borer)	Zimbabwe
Rice	*Chilo poilehrysa* (dark header rice borer)	China, IRRI
	Tryporyza inntata (white rice borer)	Philippines
Sorghum	*Marasima trapezalia* (maize web worm)	India
Wheat	*Bruchus* spp. (several species)	Yemen, Egypt

Common names are given in paranthesis;* ***Source:* *Awgchew (2002)*

Major Achievements in Export Control

The quarantine regulation of Ethiopia states that plant and plant products exported from the country must be inspected and accompanied by phytosanitary certificate. Thirty-six commodities including cereals, legumes, oilseeds, spices, stimulants, fiber crops and vegetables were exported to over 30 countries of Asia, Africa, Europe, and America. There were about twenty-seven large export consignments to Europe and America. The samples were inspected and phytosanitary certificates of international standard that meet requirements of importing countries were issued (Table 9).

Table 9. Plants and plant products inspected and exported from Ethiopia during 2000-2005 (MT)

Year	Total export (MT*)	Phytosanitary certificates
2000/01	146 768	48 663
2001/02	273 035	41 408
2002/03	301 014	37 754
2003/04	278 245	38 634
2004/05	456 864	35 437

MT = metric tones* **Source: *MOARD, unpublished data*

Gaps and challenges

Ethiopia is a large country with varied ecology and diversified of crop husbandry. This diversity in both plants and ecology permits the diversity of existing pests and increases chances of establishment of newly introduced pests. The country is also bordered with different countries, which share vast frontiers the demands effort to safeguard the country from alien pests..

Many institutions and individuals involve in importing planting materials. These include regional and federal research centers, universities, commercial farms, seed firms, non-governmental organizations, and individuals. The increased number of importers complicated the quarantine problem of the country.

Isolating and growing high-risk foreign and/or domestic plants long enough to either break the lifecycle of harmful pests and/or extend beyond the incubation period of these organisms is important measure in quarantine that demands good post-entry quarantine facility. For research germplasm imports post-entry sites are well established at ten different locations in EIAR, Ethiopia (Dereje, 2006), but there is none for other samples.

Ethiopia exports large number of agricultural produces to many countries that need certification for appropriate sanitary and phytosanitary measures. The certification service rendered by the country should cope up with ever increasing stringent requirements of importing countries and world market. Hence, international standards are compulsory in our certification.Each signatory country to the International Plant Protection Convention (IPPC) has the responsibility to establish plant protection service for the purpose of surveying of growing plants under cultivation and wild flora, plants and plant products in storage or in transportation, particularly with the objective of reporting occurrence of outbreaks and spread of pests, and measures taken to control those pests (OAU, 1988; FAO, 1998; 1999). The IPPC dictates the establishment of cooperation among contracting parties on the exchange of information on plant pests particularly reporting on the occurrence, outbreak or spread of pests that may have an immediate or potential danger; participate in any special campaign for combating pests that may seriously threaten crop production or environment; and cooperate in providing technical and biological information necessary for pest risk assessment (FAO, 1999). Such relations would help the country benefit from international cooperation. This aspect was neglected in the past.

There is a lack of training for young agriculturists to provide basic knowledge on quarantine, product standards and post-harvest handling of products in schools, colleges and universities. There is lack of awareness in the whole society including policy makers about impacts of introduction of both host and pest, and the position and measures of quarantine as a strategic pest management option at the national and farm level. Hence, spread of quarantine pests increased from time to time due to lack of awareness and education.

New research findings become available with time that should guide the act and legislation of the country. In addition, new demands come from the country or outside as science and technology advances. The list of quarantine pests, which are part and parcel of the regulation 4/1992 and given as regulated pests/ plant materials and prohibited materials is out dated. The existing database is not organized and arranged in such a way to serve and enrich the current quarantine regulation. In addition, there is a lack of proper quarantine policy that involves all stakeholders, i.e. regional governments, research institutes, universities, companies, large farms, etc. encompassing external and internal quarantine that prescribes appropriate quarantine measures on risky materials and prevention the spread of pests to and within the country. Hence revision of the quarantine information and regulation seems timely.

Lack of appropriate laboratory facilities at all the stations limited inspection procedures to only visual observations. However, most pathogens (e.g. fungi, bacteria or viruses) associated with seeds or planting materials could not be detected by visual inspection and various laboratory procedures for seed health testing are necessary. This hampered the exercise of proper handling of quarantine materials. Fumigation premise and chamber are important facilities to operate proper quarantine measures. This is necessary to treat consignments ready for export, on transit or arrived plant and plant products when such measures were required. Incinerators became compulsory at different quarantine stations to dispose consignments found to harbor pests.

Future Considerations

It has been shown that numerous insect pests, diseases and weeds were introduced into Ethiopian agriculture due to lack of appropriate measures and/or inability to take strong and effective quarantine measures. The list of introduced pest will increase unless appropriate quarantine measures at international standards are followed and applied in order to safeguard the agriculture and environment of the country. Similarly, promotion of foreign export of our agricultural commodities would need meeting phytosanitary requirements set by the importing countries. Suggested considerations for future improvement are briefly discussed as follows.

Capacity building

Development of strong plant quarantine laboratory at central place that is equipped with necessary facilities including quarantine stations at all air- and land-ports, laboratory, store, greenhouse and isolated fields with necessary equipments. Furnish necessary consumables from time to time. Mandate to coordinating all stakeholders should be given to this referral and central laboratory with enough independence and autonomy. It has to develop a strong quarantine and pest database for the country. When materials arrive, the custom system of the country should operate hand in hand with quarantine and all imported plant materials should be channeled to quarantine for inspection at all quarantine ports. Development of facilities and human resources could be attained through projects that operate in phases.

There is also a need to establish new quarantine stations along the border with Somalia through Jijiga, the port Djibouti, along the border with the Sudan through Benishangul Gumuz Regional National State (Kumruk and Gizan) and the border of Gambela People Regional National State. Quarantine stations at Bahir Dar and Mekele International airports are also very important.

Pest risk assessment and surveillance

Pest risk assessment is made to identify pest importance and/or their pathways with relevance to quarantine and to separate endangered areas and to work out management options suited to the conditions of the country. Hence, regular pest surveillance provides necessary data to establish priority and high-risk areas. Such operations could be handled in collaboration with other stakeholders namely research and other academic institutions equipped with necessary manpower and facilities. Development of extensive pest database is very important to take proper quarantine measures. Hence, there is a need to develop a strong pest risk assessment and pest surveillance programs to render sustainable quarantine service.

The need to update the existing plant quarantine regulations

Regular revision of acts and legislations is important to fulfill the requirements of international standards that incorporate new research findings and results of pest risk assessment. The existing act and regulation have serious deficiencies as discussed above. And hence, revision is timely to provide adequate policy coverage.

Information system and public awareness

Specific information on the recognition of pests, diseases and weeds is of critical importance for detecting infestation of plant materials so that appropriate treatment or destruction may be effected. Information on available quarantine treatments has considerable value for confining and/or eliminating pests in infested consignments. Olembo (1999) indicated that rapid access, throughout Africa, to information on current pest problems and potential threats is vital if food security is to be achieved and sustained. Accordingly, sound information exchange system is required among national quarantine stations and International and Regional plant protection organizations. Hence, development of strong network with international and regional organizations is required to effectively discharge national and international responsibilities. Furthermore, no quarantine safeguard may be effectively implemented unless it was preceded by public awareness and support. The curricula should accommodate this aspect at different levels. General public, scientists, private industry, students, farmers, nurserymen and traveling public should be made aware of the importance of plant quarantine. Therefore, effective measures regarding public awareness and information dissemination should be aggressively taken.

References

1. Agarwal, V.K. and Sinclair, J.B. 1997. Principles of seed pathology, 2nd edition. CRC Press, Lewis Publishers. New York. 647pp.
2. Awgchew, K. 2002. Quarantine precautions and intercepted alien pests in the laboratory of the Ethiopian Agricultural Research Organization. Pages 22-26 In Proceedings of a national workshop on the management of pea weevil, *Bruchus pisorum.* ARARI/EARO, Bahir Dar.
3. Awgechew Kidane, Rebeka Desta and Elleni Taddesse.1985. A review of plant quarantine activities in the Institute of Agricultural Research. In Tsedeke Abate (ed) Review of Crop Protection Research in Ethiopia: Proceeding of the first Ethiopian Crop Protection Symposium. Addis Ababa, Ethiopia. Pp 635 - 642.
4. Bayetta, B. 2001. Arabica coffee breeding for yield and resistance to coffee berry disease (*Colletotrichum kahawae* sp. nov.). Ph.D. Thesis, University of London, London.
5. Berhane, A. 2002. The biology and ecology of pea weevil (beetle) (*Bruchus pisorum*) L. Coleoptera, Bruchidea. In Proceedings of a national workshop on the management of pea weevil, *Bruchus pisorum.*ARARI/EARO, Bahir Dar. Pages 37-46
6. Charles, L.W. 1980. Whose responsibility is exotic pest problems? Plant Disease 71:863
7. Day, R.K., Kairo, M.T.K., Abraham, Y.J., Kfir, R., Murphy, S.T., and Mutitu, E. 2003. Biological control of homopteran pests of conifers in Africa. In P. Neuenschwander, C. Borgemeister and J. Langewald (eds) Biological Control in IPM Systems in Africa. CABI, CTA and SDC. Cromwell Press, UK. Pages 101-112.
8. Dereje Gorfu. 2006. Plant quarantine for agricultural research. EIAR Technical Manual. EIAR, Addis Ababa.
9. Dereje Gorfu, A. Kidane, M. Bimrew and S. Ahmed. 2006. Plant quarantine in the agricultural research system. Proceedings of the National Workshop on Alien Invasive weeds and insect pests held during 6-8 June 2005 at Bahir Dar. ARARI and EIAR, Bahir Dar.
10. Dereje G. 2004. Seedborne nature of *Ascochyta* and its significance on disease progress and yield of field pea in Ethiopia. Ph.D. thesis. Kasetsart University, Bangkok. 162pp
11. ESIP. 1982. Sorghum improvement in East-Africa. Proceedings of Regional Workshop. 17-21 Oct 1982, Addis Ababa.
12. Fasil, R. 2003. *Striga hermontica* in Tigray (North Ethiopia). Ph.D. Thesis. University of Amsterdam, Amsterdam.
13. FAO. 1999. International Plant Protection Convention: New Revised Text. Rome, Italy.
14. FAO. 2005. International Standards for Phytosanitary Measures: Pest Risk Analysis for Quarantine Pests, including Analysis of Environmental Risks and Living Modified Organisms. Rome, Italy.
15. Feliu, E. 1988. Bases for fixing quarantine regulations for seed. In Mathur, S. B. and John J. (eds.). Seed Pathology. Proceeding of the CTA Seminar. Copenhagen, Denmark, 20 -25 June 1988. Pp 351 - 357.
16. Fikre, M. and Navaratnam, S.J. 1991. Quarantine policy for wheat introduction into Ethiopia. In H. G/Mariam (ed.) Wheat Research In Ethiopia. IAR/CIMMYT, A.A. Pages 301-310
17. Mathur, B. and Lal, S. 1996. Plant quarantine at IBGRC. IBGRC Press, New Delhi.
18. MOA (Ministry of Agriculture). 1991. Plant Quarantine Training Manual. Crop Protection and Regulatory Department Plant Quarantine Division of the Ministry of Agriculture. Addis Ababa, Ethiopia.

19. Neergaard, P. 1979. Seed pathology, 2nd Edition. Macmillan Press, London. 1191pp.
20. Negash, M. and Mohamed, A. 2004. Managing *Cupressess lusitanica* plantation. Research Report No. 61. EARO, Addis Ababa. Ethiopia
21. Olembo, S. A. H. 1999. Status of Plant Quarantine and Import Regulations in Africa. Proceeding of African Crop Science Conference. Vol. 4. PP 445 - 450. Uganda.
22. Pankhurst, R. 1964. Notes on a history of Ethiopian agriculture. Ethiopia Observer 7: 210-240.
23. Rezene, F. 2006. Status of alien invasive weeds in Ethiopia: challenges and responses. Pages 1-14 *In:* Proceedings of the National Workshop on Alien Invasive weeds and insect pests. 6 - 8 June 2005, Bahir Dar. ARARI and EIAR. Bahir Dar, Ethiopia.
24. Takele, N. 2004. Risk, impacts and management of invasive alien plant species in Ethiopia. Country Report on Sub-Sahara Africa and Pan African Conference, 27 Sept – 01 Oct 2004. Tuskegee University and USDA/APHIS Project, Addis Ababa.
25. Turkensteen, L.J. and Yaynu, H. 1989. Report of survey of potato diseases in Ethiopia. 33pp (consultant report, unpublished).

Review of Seed Health Research in Ethiopia

Dereje Gorfu[1], Adane Abraham[1] and Amare Ayalew[2]
[1]Ethiopian Institute of Agricultural Research, P.O.Box 2003, Addis Ababa, Ethiopia
[2]Haromaya University, P.O.Box 138, Dire Dawa, Ethiopia

Introduction

Infected seeds play considerable role in the establishment of economically important plant diseases in the field resulting in heavy reduction of crop yields. Infected seeds also have lower seed quality leading to reduced market value, poor germination and field establishment. Apart from this, infected seeds act as a vehicle in carrying pathogens to uninfected areas within a country and from one country to the other (Neergaard, 1979). As a result, seed health is generally considered as one of the major attributes of seed quality alongside purity, viability and vigor. Information on seed health situation of any country is therefore relevant to the actual policy towards seed improvement in seed systems and plant protection (Neergaard, 1986). Many countries have therefore established seed research institutes and in almost every country, there are seed health testing laboratories.

In Ethiopia, the seed health research and practice did not develop well to satisfactorily serve the national seed system and information on seed health situation is not adequate. Although there was a good start around the mid 70s and early 80s at Holetta (Awgechew, 1985), it quickly declined by the end of the 1980's. Recently, however, studies directly or indirectly related to seed health aspects have been carried out and encouraging results were reported.

Awgechew (1985) reviewed the information on the seed health up to mid 1980's. Awgechew (1993) compiled a checklist of seed borne diseases for Ethiopia. The checklist included many seed-borne pathogens that had not been reported but of potential danger in Ethiopia, and listed 64 fungi, eight viruses, 10 bacteria and a nematode as recorded for Ethiopia. It should be noted however that the information particularly on the viruses and bacteria was not based on seed health assays but was rather based on records of field observation. The checklist by Awgechew (1993) also included some viruses of potato that could be transmitted with seed tubers but not with botanical seeds.

Neiman and Awgechew (1980) published a monograph that includes the principles and objectives, routine methods for treated and untreated seeds, basic literature in seed health testing and pathology. This publication was meant to serve those laboratories just starting the venture of seed health research and possibly became a good reference material for postgraduate students who generated most information utilized here. This review paper summarizes the information generated in seed health particularly in the last two decades, identifies the gaps, and discusses the need to strengthen coordinated research and points out future direction.

Major Findings

Detection and identification of seed-borne microorganisms

The detection and identification of microorganisms associated with seeds of the major crops in a country is the first and major step towards efficient seed health testing system. Hence**,** seed-borne microorganisms were assessed in a number of crops sampled from field or storage as well as germplasm accessions in Ethiopia. For convenience, the findings of assays for seedborne fungi, bacteria viruses and nematodes will be presented separately.

Seed borne fungi

Sorghum

Mashilla (2004) assessed fungi associated with sorghum grain in different storage structures and identified over 40 fungi species. The dominant fungi were species of the genera *Penicillium* and *Aspergillus*, the two most common storage fungi. Another study conducted on storage microorganisms in sorghum samples were collected from east and west Wellega (Fekede, unpublished data) showed that *Phoma* sp. and *Colletotrichum graminicola* were common on stored sorghum while *Fusarium moniliforme,* several species of *Penicllium, Aspergillus, Alternaria, Helminthosporium*, *Rhizopus* and a few unidentified ones were frequently observed. Adane (1994) on a number of sorghum samples with grain mold collected from Bako indicated a high incidence of *Phoma sorghina* and *Colletotrichun lindemuthanum*. *Phoma sorghina* was also among the dominant fungi isolated from grain sorghum during storage (Mashilla 2004). In another investigation, *Curvularia lunata* and *Fusarium verticilliodes* were the most frequent pathogenic fungi isolated from freshly harvested grain sorghum; the latter was by far the most dominant fungus which occurred in 60% of the samples at relatively high density with an average of 3850 cfu/g (Amare, 2002). More recently, *Fusarium moniliforme* (=*F. verticillioides*) was isolated from about 40% of sorghum seeds collected just prior to harvesting while only 1.5% of the seed collected from threshing grounds yielded the fungus (Mashilla, 2004).

Wheat

Eshetu (1990) identified thirteen *Fusarium* species from wheat seed where *F. nivale* and *F. avenaceum* were dominant in samples collected from cool, moist and high altitude areas while *F. graminearum* was more frequent at lower altitudes. Recently, Zewdie (2004) identified the same *Fusarium* spp. and two other fungi namely *Dreschlera sativum* and *Septoria nodorum*. Eighty-four percent of the samples showed a mean seed infection of 1.9% with *D. sativum* while 74% of the samples showed *F. graminearum* with mean infection of 1.5% and 31% of the samples showed *Septoria nodorum* a mean seed infection of only 0.5%. *Ustilago*, and *Tilletia* were also recorded by Zewdie (2004). Yeshi and Mengistu (1990) also reported the same species of seed mycobiota and some additions on durum wheat. Their additions were *Geotrichum*,*Cephalosporium*, *Epicoccum* and *Humicola* species. Earlier, Niemann *et al.* (1980) reported the occurrence and importance of bunt (*Telletia* spp.) in Ethiopia; occurrence of bunt varied with location. In wheat from West Shoa, Arsi and Bale, *Cochliobolus* sp. and *F. graminearum* were relatively prevalent while *Stagonospora nodorum* occurred at lower frequency (Amare, 2002)

Barley

Assessment of barley seed samples from different zones of Shewa (HARC, 2004) showed that many seed-borne fungi that include *Helminthosporium* species: *Helminthosporium teres, H. graminea, H. sativum, H. hawaiiense, H. rostratum, H. tetramera, H. halodes, H. cynodontis* and *H. dematioidea* were identified with *H. teres* being the most frequently encountered fungus on barley seed. The identification of these all *Helminthosporium* species seem to be subject to verification of specialists, as we lack taxonomist in the area. Adane (1994) detected 18 fungi species on barley seed, of which, five *Helminthosporium* species were also included. Finally, he specified five fungi namely

Rhynchosporium secalis, Drechslera teres, D. sativum, Ustilago nuda, and *U. hordei* being prevalent seedborne pathogens of barley in Ethiopia. In a study of the internal mycobiota of cereal grains from Ethiopia, Amare (2002) isolated several potentially seedborne pathogens in barley samples which were collected at harvest from West Shoa, Arsi and Bale, *Pyrenophora teres* and *P. graminea* (two of the four species of the genus known to attack barely) were detected.

Tef

In tef seed collected from fields infected with head smudge, *Dreschlera miyakei* was detected with an average frequency of 41% while *D. frumentacei* and *D. ellisia* were isolated at lower frequency (Melaku, 1993). This seems a very serious fungus in tef in the humid areas of western Ethiopia. Earlier, Awgechew and Mathur (1978) assessed tef seed from Ethiopia and reported as high as 58% infection by *Drechslera miyakei*. When the disease was severe at Wereta in the 70's 30 – 50% yield losses were estimated. 32% of the infected seeds were badly rotted in soil.

Field pea

Dereje (2004) studied the seed mycobiota of field pea and reported 16 fungi species associated with pea seeds that include *Alternaria alternata, Ascochyta pinodes, A. pisi, Aspergillus niger, A. flavus, Aspergillus* spp., *Cladosporium cladosporioides, Chaetomium funicola, Curvularia brachyspora, Fusarium oxysporum, F. avenaceum, Monilia* spp., *Penicillium* spp., *Phoma medicaginis, Rhizoctonia solani* and *Trichoderma spp.* Among these, *A. pinodes, C. cladosporioides* and *Penicillium spp.* were most frequent with mean occurrence of 7.1, 6.6 and 3.9%, respectively, while the others were with less than 1.3% frequency (Dereje, 2004; Dereje and Sangchote, 2005).

Haricot bean

Mohamed (2005) studied the seedborne nature of bean anthracnose pathogen and found that *Colletotrichum lindemuthianum, Phaeoisariopsis griseola* and *Ascochyta phaseolina* were most spread and damaging seedborne fungi associated to bean seeds harvested in different parts of the country. There was a high correlation between seed infection level and seedling infection for the anthracnose fungus.

Chickpea

Alemu and Sinclair (1979) assessed chickpea seeds from Ethiopia and reported 15 fungal and one bacterium species were associated to chickpea seeds in the country. Out of these fungi only *Fusarium oxysporium* was known to cause wilt in chickpea and is the most important pathogen. The rest were seed-borne microorganisms some of which are involved in seed decaying and grain deterioration in storage.

Lentil

Seid (1987) identified *Ascochyta lentis* from lentil seed collected from plants affected by ascochyta blight; the fungus was detected in 20.1% of the seed tested. The same investigator reported for the first time isolation of *Colletotrichum* sp. from lentil seed and indicated possible involvement of the fungus in anthracnose on lentil around Debre Zeit.

Soybean

Alemu and Sinclair (1979) assessed soybean seeds and reported 38 fungi and a bacterium species from sorghum seeds. The bacterium was *Bacillus subtilis*, which was similar to what reported from chickpea in a similar work. They indicated that most of the fungi reported for Ethiopia were also new world records. Of the fungi identified, *Cercospora kikuchii, Macrophomina phaseolina, Colletotrichum dematium, Phomopsis* sp. (perfect stage is *Diaporthe phaseolorum*), *Fusarium oxysporium* and *Pithium* sp. were known to cause field diseases at varying degree in soybean. The rest that were associated with seed may play roles in seed deterioration in storage as indicated by results of the studies carried out on soybean and chickpea seeds.

Groundnut

Several seedborne fungal pathogens were identified among the mycobiota of groundnut seed from eastern Ethiopia; the most prevalent were *Sclerotium* sp., *Aspergillus nigur* and *A. flavus* which occurred in 83.3%, 75% and 70.8% of the seed samples, respectively (Amare *et al*, 1995)

Seedborne viruses

Seed pathological research in Ethiopia has for long been restricted to fungal pathogens and there was no information on viruses and bacteria associated with seeds (Awgechew, 1985). Although some seed-borne viruses and bacteria have been mentioned in the checklist by Awgechew (1993), the results were based on their report on field occurrence and information from literature and no seed health assays were done at that time for this group of pathogens. In the last decade, however, some efforts were made to study some crop seeds with respect to viruses. Adane and Albrechtsen (1998) who assessed the health status of seeds of some important crops in Ethiopia reported the occurrence of *Bean common mosaic virus* on haricot bean, *Pea seed-borne mosaic virus* (PSbMV) on faba bean and field pea, *Soybean mosaic virus* on soybean, *Tobacco mosaic virus* on pepper, *Lettuce mosaic virus* on lettuce. Similarly, Mohamed and Albrechtsen (1998) in addition to detecting some of the viruses reported by Adane and Albrechtsen (1998), detected *Cowpea aphid-borne mosaic virus* and *Cucumber mosaic virus* in cowpea and *Tomato mosaic virus* and *Tobacco mosaic virus* on tomato. A more comprehensive study of seed-borne viruses in farmer-saved lentil (270 samples) and field pea (219 samples) seedlots as well as germplasm accession was made recently by Adane and Makkouk (2002). Accordingly, 43.7% of the lentil seedlots were infected by viruses of which 31.1% is by PSbMV. Other viruses detected in lentil seeds included *Broad bean stain virus*, *Bean yellow mosaic virus*, *Alfalfa mosaic virus* and *Cucumber mosaic virus*. The result indicated the high contamination of lentil seeds with PSbMV. On the other hand, none of the pea seed lots was infected with PSbMV and only few were infected by *Pea early browning virus* and *Bean yellow mosaic virus*. In the same study, 40 lentil and 228 pea germplasm accessions were tested for PSbMV. Of these, 38% lentil accessions were contaminated with PSbMV whereas only 1.8% of pea accessions were contaminated. Interestingly, the four pea accessions (1.8%) were of exotic (Australian) origin, indicating the need to strengthen the quarantine system.

Mih and Hansen (1998) studied the seed health status of several forage legume species at the International Livestock Research Institute, Ethiopia with respect to Alfalfa mosaic virus, a highly seed-transmitted virus in forage legumes. The type of viruses detected from seeds of 21 species included members from important plant genera such as *Desmodium, Macroptilum, Medicago, Trifolium* and *Vicia*.

Seedborne bacteria

Awgechew (1993) listed *Corynebacterium flaccumfaciens* on bean, *C. tritici* in wheat, *Pseudomonas glycinea* on soybean, *Erwinia sp*., and seven *Xanthomonas* spp. in various crops as seedborne bacteria in Ethiopia. Cabbage seeds were assayed for *Xanthomonas campestris* and 13% of the seeds were found to be infected (Temam and Amare, 1989). Adane (1994) also identified *X. campestris* from rapeseed after testing seeds of six crops grown in Ethiopia. In his study, the few seed samples of barley, wheat, haricot bean, soybean and sesame were free of seedborne bacteria. Chemeda and Tadele (2001) studied the effects of primary inoculum of *X. campestris pv. phaseoli* from bean seed, crop debris and soil on common bean blight development. Although the difference in severity and incidence was not statistically significant, they reported that common bacterial blight (CBB) was more severe on plots that received inoculum from treated seed and infested debris than infested soil. Tadele (2001) assessed seed transmission of the same pathogen and found that high rates of failure in seedling emergence were recorded from seeds used from severe CBB symptoms and transmission is genotype dependent.

It should be noted that a number of bacteria that were known to infect various crops in Ethiopia under field condition are seed-borne although their association with crop seeds was not confirmed in seed health assays. These include economically important pathogens such as *Xanthomonas vesicatoria* on pepper, *X. malvacearum* in cotton, *X. sesami* in sesame and *Pseudomonas glycinea* in soybean. The lack of information on seed-borne nature of these bacteria in their respective hosts and their role in disease development in the field indicates a serious gap that should be addressed in seed health research in the country in near future.

Seedborne nematodes

The only report on seed-borne nematodes from Ethiopia is that of ear cockle disease caused by *Anguina tritici* on wheat collected from Arsi. Many reports, however, mention this nematode for wheat in Ethiopia (Eshetu, 1990). No other serious seed-borne nematodes were reported from Ethiopia in both field inspection and also in seed health assays.

Seed treatment

Realizing the importance of seed-borne inoculum in disease development, various workers have attempted to control fungal diseases through seed treatment by various means. Dereje (2004) studied seed treatment using nine fungicides at different rates against *Ascochyta* in field pea. Radial growth of *A. pinodes* culture was completely inhibited by carbendazim and thiabendazole at the lowest concentration tested (0.001 g/L), benomyl at 0.01 g/L, thiram, thiophanate-methyl and iprodione at 0.1 g/L. Other fungicides affected the growth at various degrees. Seed treatment with carbendazim, chlorothalonil and iprodione had completely inhibited the recovery of *A. pinodes* from treated seeds while 2 to 3% incidence was obtained for thiram, benomyl and thiabendazole. In further studies, seedling infection in growth chamber was completely controlled by carbendazim and iprodione and a reduction of 4.6% by chlorothalonil. In field trial, seed treatment with fungicides didn't affect emergence date while there was significant difference ($p = 0.05$) due to variety. Generally, treating seeds with carbendazim improved seed yield by 13.2% and with iprodione by 12.5% over the untreated control (Dereje and Sangchote, 2003). Seed treatment with fungicides could be used as a component of integrated blight management in field pea production.

Partial but significant inhibition of *Ascochyta* sp. in lentil through hot water treatment at 50 and 55°C for 10, 15, 20 or 25 min was reported with improved effectiveness as exposure time increased; however, all but the 10 min exposure drastically affected seed germination (Seid, 1987). The same worker found comparable partial control of the pathogen using exposure to dry heat at 70°C for 12/24 h or sun-drying of infected lentil seed for 10, 15, 20, 25, or 30 days.

In another investigation (Berhanu, 1992), hot water treatment at 50°C for 105 or 135 min, and at 52°C for 75, 105 or 135 min completely controlled sugar cane smut, but some of the treatments affected seed cane germination.

Seed treatment in wheat varieties with the systemic fungicides carboxin and carbendazim gave complete control of loose smut (*U. segetum tritici*) at the levels tested, i.e. 1.5, 2.0 and 2.5 g/kg seed; carboxin @ 1.5 and 2.0 g and carbendazim @ 2.0 and 2.5 significantly increased tiller number, plant height and crop yield (Endale, 2005). Three physical treatments, viz. direct solar heat from 11a.m – 4 p.m., solar heat treatment similar to previous but seed covered with thin transparent polyethylene sheet, and anaerobic seed treatment in which seed was kept in screw capped bottles for 48 hours followed by drying in the sun from 11 a.m. – 4 p.m., were evaluated for the control loose smut (Endale, 2005). These treatments reduced the disease by 61.5, 69.2 and 76.9%, respectively, in variety Hirane. All the treatments were preceded by soaking seeds in water for five hours in order to activate dormant mycelia.

The fungicides thiabendazole and Benlate as 0.25 and 0.3% seed dresser provided complete control of *Ascochyta lentis* (ascochyta blight) in lentil seeds, while other fungicides tested, i.e. Calixin M, Bravo 500, Vitavax, Dithane M-45 and Oxychlor provided only partial control of the fungus, and Oxychlor was also toxic to the seed (Seid, 1987).

In an experiment to control bean anthracnose by fungicides, Tesfaye and Pretorius (2005) found that seed treatment with benlate followed by foliar spray with difenoconazole reduced anthracnose severity by 62%.

Conclusion and Recommendation

Information on seedborne diseases in Ethiopia is insufficient reflecting that these diseases did not get due research attention so far. Data have accumulated on the extent of occurrence of seedborne infections in certain crops. Since the review by Awgchew (1985), it appears that little attention was given to seed health research at institutional level in Ethiopia. This can be partly reflected by the fact that majority of the information in the last two decades was generated by postgraduate students (Melaku, 1993; Adane, 1995; Amare, 2002; Dereje, 2004; Mashilla, 2004; Mohammed, 2005). Although such kind of research generates useful information, it mostly lacks continuity if not taken over by a mandated national research system. In light of this, a nationally coordinated and comprehensive seed health research system is required.

Recommendations on fungicidal seed treatments were given against *Aschochyta* in field pea, *Ascochyta* in lentil, *Ustilago segetum trici* (loose smut) in wheat, and anthracnose in bean. Hot water treatments were recommended for the control of smut in sugar cane and *Ascochyta* in lentil. For the near future, lessons from Western Europe where more than 95% of cereal seed is routinely treated could be useful until health standards are established and use of certified seed is widely adopted in Ethiopia. In other words, it is advisable to use 'blanket seed treatment' on the basis of available research data on fungicidal products for particular crops.

Gaps and Challenges

Although some in formation is available on the identity of important fungal pathogens in the country, information on seedborne bacteria and viruses is meager. Moreover, most studies were limited to detection and identification of seedborne fungi, and there was very little attempt to correlate laboratory results with field transmission. There is also a gap in information on the biology/epidemiology of seedborne pathogens/diseases in Ethiopia. Data on crop losses due to seedborne diseases are hardly available. The available information on the management of seedborne diseases is by far insufficient to devise appropriate recommendations.

It is a challenge for the seed health research system to satisfactorily address the problems of the small farms, where farm-saved seed is used for planting, the commercial farms and the seed industry. This is a single challenge with several facets. It involves determining the seed health problems, principal epidemiological factors and suitable management options for particular situations.

It is also a challenge to serve the diverse agroecological regions in the country. The diversity of crops and ecological conditions would pose diverse disease problems and seedborne diseases are no exception.

With increasing recognition of the importance of clean seed (traditionally described as "disease free seed") for economic production of crops, seed health research in Ethiopia will face greater pressure to deliver more meaningful information and effective technologies.

There are some problems that need to be overcome if the seed health research is ever to effectively serve the country's agriculture. These include lack of: (1) trained manpower in seed technology, (2) research emphasis on seed quality and treatments, (3) proper seed development policy, and (4) awareness on the importance of seed health at various levels. Set-up of regional seed laboratories in different research centers and universities and a referral seed laboratory at a central place and allocation of enough resources to research and development in the seed system are urgently needed.

Future Directions

The first step in seed health research schemes is to know the most important seedborne pathogens in the country and the role of seedborne infections in diseases epidemics, i.e. the level of seed-transmission for particular seedborne pathogens. This information is vital for further research order to develop seed certification systems and plant quarantine measures. While seedborne fungal pathogens still deserve further investigations, due attention should to seedborne bacteria and viruses.

Occurrence and severity of pathogens varies from year to year and form region to region according to the prevailing weather conditions during the growth of the crop as well as seed harvest. Change in cultural practices or the use of more susceptible varieties could also increase the inoculum levels of some pathogens. Thus, there is a need for regular monitoring of seedborne pathogens to determine their relative importance.

Studies on the importance of seedborne diseases (data on incidence, transmission rate and crop losses) are important to set research priorities. In view of the difficulty to conduct such loss assessment experiments, effects of seedborne pathogens can at least be indirectly estimated by measuring improvements in crop yields and quality when seedborne infections are eliminated.

Seed health standards are important tools in disease management and research is necessary to establish realistic standards based on sound scientific data. These should be backed up with the development of efficient and reproducible test methods. Research on development of simple and cheap serological techniques such as that described for virus identification by Adane and Albrechtsen (2000) should be given emphasis.

Research to develop methods/measures for the management of economically important seedborne diseases is urgently needed which should go beyond seed treatment with Biological control using local antagonists being another potential line of approach.

Attention should be given to measures that can be easily adopted by the subsistence farmer while the needs of the seed producer and commercial farmer should not be ignored. In other words, there should be no scale bias in seed health research. Research on the management of seedborne diseases should not be confined to the traditional fungicide or hot water seed treatments alone, but integrated approaches at times involving multidisciplinary research should be emphasized in seed health research of the future. Seed health research should also not ignore traditional seed systems and rich indigenous knowledge and attempts should be made to study traditional approaches and build on them.

In conclusion, future research should focus on identifying the seed health problems of important crops and establishing seed health standards for major seedborne diseases, developing suitable detection methods as well as measures for the management of seedborne pathogens.

References

1. Adane Abraham. 1994. Report on seed pathology diploma course. Danish Government Institute of Seed Pathology for Developing Countries, Copenhagen (monograph). pp. 28.
2. Adane Abraham. 1995. Alternative enzyme immunoassay techniques and the detection of seed-borne viruses from legume crops of Ethiopia. MSc. Thesis

The Royal Veterinary and Agricultural University, Denmark.

3. Adane Abraham and S.E. Alberechtsen. 1998. Seedborne viruses infecting some important crops in Ethiopia. Pest Man. J. of Ethiopia 2:94 – 101.
4. Adane Abraham and S.E. Albrechtsen. 2000. Petri dish-Agar dot immunoenzymatic assay (PADIA) - a new and inexpensive method for the detection of plant viruses. *International Journal of Pest Management* (UK) 46(3):161-164
5. Adane Abraham and K.M. Makkouk. 2002. The incidence and distribution of seed-borne viruses in pea and lentil seed lots in Ethiopia. Seed Science and Technlogy 30:567-574
6. Alemu Mengistu and J.B. Sinclair. 1979. Seedborne microorganisms of Ethiopian grown soybean and chickpea seeds. Ethiopian J. Agricultural Sciences 1: 48 – 58.
7. Amare Ayalew. 2002. Mycoflora and Mycotoxins of Major Cereal Grains and Antifungal Effects of Selected Medicinal Plants from Ethiopia. PhD Thesis, University of Göttingen, Göttingen, Germany. 118 pp.
8. Amare Ayalew, Dawit Abate and Mengistu Huluka. 1995. Mycoflora, aflatoxins and resistance of groundnut cultivars fron eastern Ethiopia. SINET Ethiopian Journal of Science 18: 117 - 131
9. Awgechew Kidane. 1985. A review of research on seed pathology in Ethiopia. Pages 617-633 *In*: A review of crop protection research in Ethiopia (Tsedeke Abate ed.). IAR, Addis Ababa.
10. Awgechew Kidane. 1993. A checklist of seedborne pathogens in Ethiopia. Technical Manual, No. 5. IAR, Addis Ababa. Pp18.
11. Awgechew Kidane and S.B. Mathur. 1978. Seed transmission of *Drechslera miyakei* on *Eragrostis tef* from Ethiopia. Plant Disease Reporter 62: 70 – 71.
12. Berhanu Abrha. 1992. Prevalence of Sugarcane Smut (*Ustilago Scitaminea* Syd.) at Wonji/Shoa Sugar Estate and Evaluation of Hot Water and Fungicidal Treatments as Control Measures. M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia. 106 p.
13. Chemeda, F. and Tadele, T. 2001. Effects of primary inoculum sources of bean common blight on early epidemics, seed yield and quality aspects. International Journal of Pest Management 47: 221-225.
14. Dereje Gorfu. 2004. Studies on seedborne nature of Ascochyta and its significance of disease development and yield of field pea in Ethiopia. Ph.D. Thesis, Kasetsart University, Bangkok.
15. Dereje Gorfu and S. Sangchote. 2005. Fungi associated with field pea seeds from Ethiopia and seed transmission of *Ascochyta pinodes. Seed Science and Technology* 33: 387-396.
16. Dereje Gorfu and S. Sangchote. 2003. Effects of seed treatment fungicides on *Ascochyta pinodes* on field pea under controlled and field conditions. *Kasetsart Journal (Natural Science)* 37: 429-444.

17. Endale Hailu. 2005. Studies on loose smut of wheat (seed treatments). M.Sc. Thesis,. Alemaya University. Ethiopia.
18. Eshetu Bekele. 1990. Identification of *Fusarium* spp. and mycotoxins associated with head blight of wheat in Ethiopia. Ph.D. Thesis, University of Missouri.
19. HARC (Holetta Agricultural Research Center). 2004. Progress report for 2003/04. HARC, Holetta.
20. Mashilla Dejene. 2004. Grain Storage Methods and Their Effects on Sorghum Grain Quality in Hararghe, Ethiopia. PhD Thesis. Swedish University of Agricultural Sciences. Uppsala, Sweden.
21. Melaku Jirata. 1993. Distribution of Head Smudge Disease of Tef (*Eragrostis tef*) and Variability of the Pathogen (*Drechslera* species) in Wollega, Ethiopia. M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia. 130 p.
22. Mih, M. A. and Hansen, J. 1998. Alfalfa Mosaic Virus: occurrence and distribution in Ethiopia. Tropical Grassland Vol.
23. Mohamed Yusuf. 2005. Seedborne nature of *Colletotrichum lendimutanum* and its significance of epidemic development and yield of common bean. Ph.D. Thesis, Kasetsart University. Bangkok.
24. Mohamed Yesuf and Albrechtsen, S.E. 1998. Detection of seed-borne viruses infecting grain legumes and vegetable crops in Ethiopia. Abstract of the paper presented at the six Annual Conference of the Crop Protection Society of Ethiopia. 3-5 June, 1998. Addis Ababa.
25. Neergaard, P. 1979. Seed pathology. Revised Edition, Vol. I and II. The Macmillan Press Ltd.
26. Neergaard, P. 1986. Screening for plant health. Ann. Rev. Phytopath. 24: 1-16.
27. Niemann, E. and Awgechew Kidane. 1980. Seed health principles and methodology. IAR, Addis Ababa. Pp 30.
28. Niemann, E., L. Kifle and A. Kidane. 1980. Occurrence and importance of bunt (*Tilletia* spp.) on wheat in Ethiopia. EJAS 2: 1-11.
29. Seid Ahmed. 1987. Ascochyta Blight of Lentil (*Lens culinares* Medik): Identification of the Causal Fungus and its Seed Transmission. M. Sc. Thesis, Alemaya University, Alemaya, Ethiopia.
30. Tadele Tefera. 2001. Seed transmission of bean common bacterial blight and its influence on yield. Tropical Science 41: 185-191.
31. Temam Hussien and Amare Ayalew. 1989. Research on prevalence, distribution, biology and control of black rot of cabbage (*Xanthomonas campestris* pv. *campestris*) in Hararghe. In Crop Protection Research 1988/89 Annual Report, Alemaya University of Agriculture. Pp. 16 – 20.
32. Tesfaye Beshir and Z.A. Pretorius. 2005. Effect of seed treatment and foliar applications of fungicide on the control of bean anthracnose., Crop Protection Society of Ethiopia. Pest Management Journal of Ethiopia. pp 57 - 62. Crop Protection Society of Ethiopia.
33. Yeshi Andnew and Mengistu Huluka. 1990. Studies on seedborne mycoflora of durum wheat. Pages 115 – 119 In Proceedings of 15th EPC annual meeting. 13-14 March 1990, Addis Ababa.
34. Zewdie Bishaw. 2004. Wheat and barley seed systems in Ethiopia and Syria. Ph.D. Thesis. Wageningen University, The Netherlands.

Panel Discussion

After the four-day long presentation of two decades of plant protection research in the country, selected issues were presented by the organizing committee for panel discussion. These panel discussion points were the following:

- **Critical evaluation of 20 years endeavor:** Where did we fare well and where did we fell short?
- **Charting the future research and development (R&D) in plant protection:** What are the current major plant protection concerns and what are the anticipated ones in the near future? What should be our focus areas of undertaking? What new areas to initiate?
- **Technology transfer:** How do we evaluate the success in transfer of plant protection technologies? What new ways to follow to enhance transfer of plant protection technologies?
- **Role of PPSE in plant protection R&D:** What are the successes of PPSE and its shortcomings? What should be the role of PPSE to move forward meaningful R&D in plant protection? What should be the role played by PPSE in agricultural professional associations?
- **Plant protection in emerging areas:** What is the future of plant protection in floriculture, green houses, organic farming, high value crops, etc.?
- **The role of higher learning institutions (HLIs) in plant protection R&D:** What are the strengths and weaknesses of plant protection education, research and development in HLIs? What should be the future undertakings of HLIs in plant protection?

Panelists

Moderator:	Dr. Seme Debela	Plant breeder
	Dr. Brhane G/ Kidan	Plant breeder
	Dr. Tessema Megenassa	Entomologist
	Dr. Dereje Ashagari	Plant Pathologist
	Dr. Chemeda Fininsa	Plnat Pathologist
	Mr. Rezene Fessehaie	Weed Scientist
Rapporteurs:	Dr. Ferdu Azerefegne	Entomologist
	Dr. Seid Ahmed	Plant Pathologist

Each panelist gave his/her view on the issues mentioned above. However, only the overall idea of all panelists was recorded here, and are summarized as follows:

Communiqué of the 14th Annual Conference of PPSE

The plant protection research and development has come long way during the last twenty years. One of the notable achievements is the improvement of the human resource profile. Currently, there are many researchers of plant protection with second and terminal degrees. The opening of graduate programs in the country has immensely contributed to the human resource development in plant protection. Previously, the number, diversity and quality of research work on crop protection were low owing to the small number of researchers. The 14th Annual Conference of PPSE has witnessed the presence of diverse and wide research undertakings in terms of discipline and commodity coverage across the country.

The Conference has shown that major plant pests have been identified, biology for most is known and yield losses determined for some. IPM developed against stalk borers, bean stem maggot, grassy weeds, and development of disease resistant varieties are some of the remarkable achievements. However, the single factor studies still dominate the plant protection research. It is known that IPM is information intensive and the weak information flow about available technologies has slowed down the adoption and implementation of IPM. There is a problem of research coordination as a result of weak linkages between different national and regional research centers and higher learning institutions. Lack of focus and redundancy in research undertakings are some of the manifestations for the low level of coordination and institutionalization of plant protection research. Research-Extension–Farmer linkage in IPM research and implementation need to be strengthened.

Biosystematics of plant pests and beneficial organisms is one of the areas hanging back and need attention. Attempts have been made to organize reference collection of pests at some centers mainly at Ambo Plant Protection Research Center. However, the center does not have appropriate facility and organization to handle reference collections. Absence of trained personnel and lack of interest in initiating projects are some of the obstacles in building biosystematics of pests in the country. The conference agreed that there is urgent need of developing data base on pests and natural enemies records. The center should design a mechanism of acquiring duplicates of expertly identified specimens of pests from different institutions and professionals.

The conference discussed on the current use of pesticides. It was agreed that the society has to make every effort to assist the government in regulation/

legislation enforcement of pesticides and their use. One of the immediate tasks is the evaluation and registration of pesticides for the currently flourishing floriculture industry. On the other hand, it was noted that the members of the society have to work very hard to prevent further accumulation of pesticides. Researchers were also urged to give due attention to safe use of pesticides, safety of consumers and the environment in their evaluation of pesticides, recommendation and training.

Biological control has largely remained as a theoretical exercise, rhetoric and not been tapped by the Ethiopian agriculture. One of the hindrances is the long delay on the approval of the proposed draft on introduction of biocontrol. It was also noted that the few existing biocontrol researches are uncoordinated, not continuous, and lack technologies for mass production. Similar shortcomings were observed on botanicals which are becoming redundant, terminated after preliminary efficacy work and with no aim of product development.

Emerging pest problems that need research attention were also raised. Termites have been serious problems in many areas of the country mainly in west and southern Ethiopia, but there are very few research undertakings. Protected agriculture is continuously expanding in recent years. This industry has its own pest problems where our plant protection professionals have less experience in dealing with these types of pest problems and production system.

Biotechnology has been very much exploited in plant protection in other countries which is not the case in Ethiopia. Therefore research endeavors in this area should be encouraged. Researches on seed health and post-harvest handling in terms of certification should assist the regulatory body in the country.

Researches of plant protection are being conducted in EIAR, RARIs and HLIs. It was strongly suggested that the various institutions need to focus on important research problems and try to develop excellence.

The conference observed that the available plant protection technologies have not been fully utilized and the issue of technology and knowledge transfer is still a lingering task. It is believed that the proceedings of this workshop will become invaluable source of information for educators, researchers, extension workers, producers and policy makers.

Researchers were urged to make use of the newly established Farmers Training Center (FTC) and, AgTVET for their research and training undertakings and dissemination of technologies.

PPSE has performed commendable job and contributed immensely for advancement of plant protection in Ethiopia. As a professional association, PPSE need to actively involve in policy advise, research and advocacy. In addition, it should involve in curriculum development.

The society need to improve its international and national networks. Development of data base for all plant protection activities in the country and organizing of periodic trainings to its members as well as the agricultural community are some of the tasks expected to be performed by PPSE.