Barley Research and Development in Ethiopia

Edited by
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ICARDA

Ethiopian Institute of Agricultural Research
International Center for Agricultural Research in the Dry Areas
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Foreword

Barley is one of the major cereal crops grown in Ethiopia. For millennia it has been supplying the basic necessities of life (food, feed, beverages and roof thatching) for many in the Ethiopian highlands. However, the ever-increasing human and livestock populations are placing increasing pressure on the resources in highland environments. Improving productivity and food security in these areas has become imperative.

Although Ethiopia is a centre of diversity for barley, most of the country's farmers still obtain very low yields due to a combination of genetic, environmental and socio-economic constraints. Research has been on-going since 1955 to address these constraints and improve the livelihoods of farmers by increasing the production and productivity of barley. Over this period, barley research in Ethiopia, with the participation of all stakeholders, has generated appropriate production technologies that have improved production, supplied surplus produce to local markets and provided the malt processing industry with good quality malt barley grain. However, malt barley production in Ethiopia has not expanded as expected, despite the potential of the country to grow malting barley in both the quality and quantity required. Malt barley could serve as a source of cash income and would help to significantly improve the livelihoods of highland farm households.

Documenting, processing and making available barley technologies, and disseminating knowledge and information to users, are some of the basic tasks of the research system. In order to ensure that research is delivering these required outputs, it is of paramount importance that reviews are carried out on a regular basis. The first national review workshop on barley research and development was in 1993, and the proceedings were published and circulated to users. The national review workshop, which is reported here, was held in 2006 and covered results of barley research and development work in the period up to 2005. We are sure that this review publication will add to the findings of the first workshop, and serve as a link between barley research and development in Ethiopia.

The successes of the national barley improvement programme are, primarily, the result of the unprecedented financial support that has been received from the Ethiopian Government and the long-standing, sustainable and fruitful collaboration between EIAR and ICARDA, which has a global mandate for barley improvement.

We are most grateful to the Italian Government for its financial support to the workshop and the publication of these Proceedings. We also wish to convey our appreciation to the organizers for conducting a successful workshop that brought together all researchers in the Ethiopian national research system who have been working on barley and who have thus been able to contribute successfully to this review.

Dr Solomon Assefa
Director General, EIAR

Dr Mahmoud Solh
Director General, ICARDA

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Final editing for conformity of language and style, and subsequent preparation of the text for publication was by Thor Lawrence.

Dedication

Dr Fekadu Alemayehu
(Diploma, B.Sc., M.Sc. and Ph.D.)
(1949–2004)

This book is dedicated to the late Dr Fekadu Alemayehu, who was borne in 1949 in Ethiopia. He earned a B.Sc. in Plant Sciences, an M.Sc. in Breeding and Agronomy and a Ph.D. in Plant Breeding. Dr Fekadu devoted his entire career (1968–2004) to barley improvement research at the Ethiopian Institute of Agricultural Research. He passed away in 2004 after a long and courageous struggle with chronic kidney disease.

Abbreviations used in the text

AARC	Adet Agricultural Research Centre
ABPHC	Arsi-Bale Plant Health Clinic
ACID-PAGE	Acid-polyacrylamide gel electrophoresis
AFLP	Amplified fragment length polymorphism
AMF	Assela Malting Factory
AMMI	Additive Main Effects and Multiplicative Interactions [analysis]
ANOVA	Analysis of variance
AOAC	AOAC International [a.k.a. the Association of Analytical Communities; formerly the Association of Official Analytical Chemists]
ARI	Agricultural Research Institute
ARDU	Arsi Rural Development Unit
ARARI	Amhara Region Agricultural Research Institute
ArARC	Areka Agricultural Research Centre
ATG	Initiation codon
AUDPC	Area under disease progress curve
AwARC	Awassa Agricultural Research Centre
BARC	Bako Agricultural Research Centre
BBM	Broadbed and furrow maker
BYDV	Barley Yellow Dwarf Virus
CACC	Central Agricultural Census Commission
CADU	Chlalo Agricultural Development Unit
CGB	Community Genebank
CIF	Cost-Insurance-Freight
CL	Cluster
COI	Cytochrome oxidase I [gene]
COR	Client-Oriented Research
CP	Crude protein
CPSE	Crop Protection Society of Ethiopia
CSA	Central Statistical Agency [from 9 March 1989; formerly the Central Statistical Office – CSO]
CSO	Central Statistical Office [now Central Statistical Agency – CSA]
CV	Coefficient of Variance
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo/ International Wheat and Maize Improvement Centre
CYDV	Cereal Yellow Dwarf Virus

DA	Development Agent
DAE	Days after emergence
DAP	Di-ammonium phosphate
DBARC	Debre Berhan Agricultural Research Centre
DAS	Days after sowing
DMRT	Duncan's multiple range test
DRC	Domestic Resource Cost [ratio]
EBC	European Brewery Convention
EHNRI	Ethiopian Health and Nutrition Research Institute
EIAR	Ethiopian Institute of Agricultural Research [formerly the Institute of Agricultural Research (IAR)]
EPC	Effective Protection Coefficient
EPC	Ethiopian Phytopathological Committee
ERP	Ethiopian Rock Phosphate
ESE	Ethiopian Seed Enterprise
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistics data base
FEG	Farmer Extension Group
FMFI	Farmer Managed and Farmer Implemented
f.o.b.	Free on board
FRG	Farmer Research Group
FYM	Farmyard manure
G×E	Genotype × environment [interaction]
GIS	Geographical Information System
GRP	Gafsa rock Phosphate
GS	Growth stage
GY/SP	Grain yield per spike
GY	Grain yield
HARC	Holetta Agricultural Research Centre
HBBF	Hand-made broadbed and furrow
He	Hordein Diversity index
HI	Harvest Index
hL	Hectolitre
HBSN	Hulless Barley Screening Nursery
IAR	Institute of Agricultural Research [now the Ethiopian Institute of Agricultural Research (EIAR)]
IARC	International Agricultural Research Center
IBC	Institute of Biodiversity Conservation [Formerly PGRC/E]
IBON	International Barley Observation Nursery
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRA	International Centre for Development Oriented Research in Agriculture
ICTV	International Committee on Taxonomy of Viruses

IDMP	Integrated Disease Management Practices
INDEL	Insertion deletion codon
IPCA	Interaction Principal Component Axes
IPGRI	International Plant Genetic Resources Institute [now Bioversity International]
IVDMD	*in vitro* dry matter digestibility
IVDOMD	*in vitro* digestible organic matter in the dry matter
KRC	Kulumsa Research Centre
LER	Land equivalent ratio
LSD	Least significant difference
MAS	Marker-Assisted Selection
Masl	Metres above sea level
MeARC	Mekelle Agricultural Research Centre
MoA	Ministry of Agriculture
MRR	Marginal Rate of Return
NCIC	National Crop Improvement Conference
NDF	Neutral-detergent fibre
NLDP	National Livestock Development Project
NPC	Nominal Protection Coefficient
NVRSRP	Nile Valley and Red Sea Regional Programme
ODF	Open-drainage furrows
OMD	Organic matter digestibility
OARI	Oromia Agricultural Research Institute
PAM	Policy Analysis Matrix
PADETES	Participatory Demonstration and Training Extension System
PC	Principal Components
PCR	Polymerase Chain Reaction
PGRC/E	Plant Genetic Resources Centre/Ethiopia [now Institute of Biodiversity Conservation (IBC)]
PPRC	Plant Protection Research Centre
PROC GLM	Procedure for General Linear Model
QTL	Quantitative Trait Locus
RAPD	Random amplified polymorphic DNA
RCBD	Randomized Complete Block Design
REAC	Research Extension Advisory Council
RED	Research and Extension Division, HARC
RF	Ridge and furrow
RFLP	Restriction fragment length polymorphism
RMFI	Researcher Managed and Farmer Implemented
RWA	Russian Wheat Aphid
SARC	Sinana Agricultural Research Centre
SARI	Southern Agricultural Research Institute
SAS	Statistical Analysis Software

SDS PAGE	Sodium dodecyl sulfate polyacrylamide gel electrophoresis
ShARC	Sheno Agricultural Research Centre
SiARC	Sirinka Agricultural Research Centre
SMTA	Standard Material Transfer Agreement
SNNPRS	Southern Nations and Nationalities and Peoples Regional State
SSR	Simple sequence repeat
TA	Technical Assistant
TAA	Complete Termination Codon
TARI	Tigray Agricultural Research Institute
TBIA	Tissue-blot immunoassay
TGW	Thousand-grain weight [a.k.a. 1000-grain weight]
TLU	Tropical Livestock Unit
TSP	Triple superphosphate
WADU	Welaita Agricultural Development Unit

Barley research and development in Ethiopia – an overview

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INTRODUCTION

Barley is thought to have originated in the Fertile Crescent area of the Near East from the wild progenitor *Hordeum spontaneum*. It is one of the first cereals to have been domesticated, having been cultivated for more than 10 000 years, with archaeological evidence of barley cultivation in Iran as long ago as 8 000 BC. The primary use of barley at that time was in making alcoholic beverages (e.g. barley wine in Babylonia, 2800 BC). Barley was part of the staple diet of those living in ancient Egypt, Greece and China. It was introduced by Europeans to the New World in the sixteenth and seventeenth centuries.

Barley is a cool-season crop that is adapted to high altitudes. It is grown in a wide range of agroclimatic regions under several production systems. At altitudes of about 3000 masl or above, it may be the only crop grown that provides food, beverages and other necessities to many millions of people. Barley grows best on well-drained soils and can tolerate higher levels of soil salinity than most other crops. Food barley is commonly cultivated in stressed areas where soil erosion, occasional drought or frost limits the ability to grow other crops (Berhanu Bekele, Fekadu Alemayehu and Berhane Lakew, 2005). Malting barley, however, requires a favourable environment to produce a plump and mealy grain. The diversity of barley ecologies is high, with a large number of folk varieties and traditional practices existing in Ethiopia, which enables the crop to be more adaptable in the highlands (Fekadu Alemayehu, Berhane Lakew and Berhanu Bekele, 2002).

In 2005, barley was grown in more than 100 countries worldwide, with total barley grain worldwide of 138 million tonne from 57 million hectare, with productivity levels at around 2.4 t/ha. The highest commercial yields tend to come from central and northern Europe. The highest productivity is attained in France (6.3 t/ha), whereas national production is greatest in Russia. Research has shown that yields of 10 t/ha can be obtained under intensive management.

World production of barley has remained stable since the 1970s. Consumption has also remained stable. World trade in barley has been around 16 million tonne; this is much less than production, as most of the cereal is consumed locally.

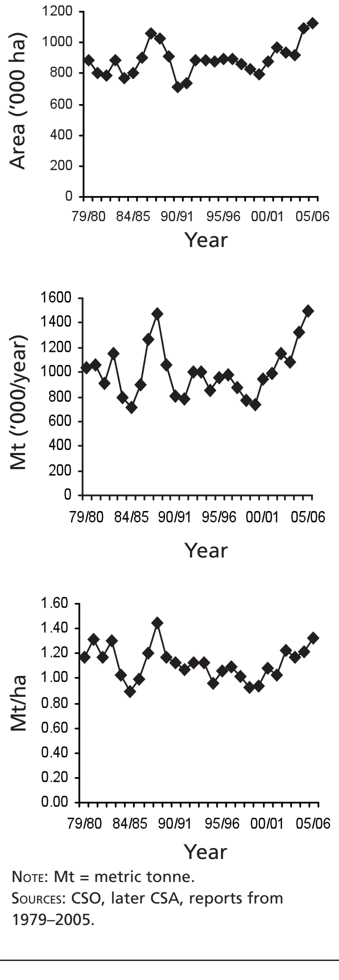
Barley holds a unique place in farming in Ethiopia, and various sources agree that it has been in cultivation for at least the past 5000 years in the country. The first Ethiopians to have ever cultivated barley are believed to be the Agew people, in about 3000 BC (reviewed by Zemede Asfaw, 1996).

BARLEY PRODUCTION IN ETHIOPIA

The area devoted to barley production in Ethiopia over the past 25 years has fluctuated. It was around 0.8 million hectare in the late 1970s, and rose to more than 1 million hectare in the late 1980s. It then declined and remained between 0.8 and 0.9 million hectare until the beginning of the third millennium. The production of barley, by-and-large, has been below 1 million tonne per year for most of the past 25 years, except during the years when the area under barley increased above 1 million hectare. Productivity, however, has never increased above 1.3 t/ha, which is about half the world average (Figure 1).

FIGURE 1

Barley area, total annual production and productivity in Ethiopia between 1978 and 2005



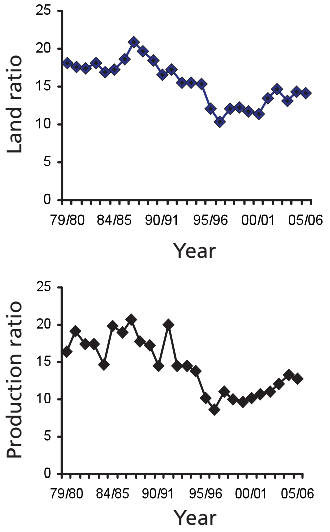
Note: Mt = metric tonne.

Sources: CSO, later CSA, reports from 1979–2005.

The ratio of total area under barley to other cereal crops (including wheat, teff, maize and sorghum) has been decreasing over the past 25 years. The production ratio has also shown a similar trend (Figure 2).

The reduction in the area under barley in the recent past could be attributed to a number of factors, including that most of the area under barley is sown to farmer cultivars. These produce poor yields and have been in the environment for centuries, and often show significant morphological diversity. Zemede Asfaw (1996) recorded up to 12 distinct morphotypes from a single barley field. There is low productivity in farmer barley cultivars compared with bread wheat, the latter having been very recently introduced. Wheat has given significantly higher yields than local barley cultivars in the same niche, where barley has been in production for millennia. The Ethiopian Seed Enterprise (ESE) has not sufficiently emphasized the multiplication and distribution of seeds of improved barley varieties. The average production by the ESE of improved wheat, maize and barley varieties in the period 2000–2007 were 55 194, 51 395 and 3 400 quintal per annum [1 quintal = 100 kg], respectively (Zewdie Bishaw, Yonas Sablu and Belay Simane, 2008). Moreover, extension work on the promotion of improved barley varieties in major barley-growing areas in the country has been very poor compared with that of bread wheat and maize. Fertilizer use on barley is the lowest among all cereals. For instance, in the 2005 main cropping season, only 16.48% of

FIGURE 2
Trends in ratios of barley to cereals land coverage over 25 years (1979–2006) and total production per annum



Sources: CSO, later CSA, reports from 1979–2005.

land of the total area covered by cereals received inorganic fertilizer. The crops that received most of this fertilizer were teff, wheat and maize. From the total area covered by each of the above crops, 25.13, 25.60 and 17.74%, respectively, received fertilizer, whereas for barley it was only 6.92% of the total area that received fertilizer in the same year (CSA, 2008).

Farmers who operate barley-based farming systems—that is, in the highlands of Ethiopia—have very few alternative crops. The ever-increasing human population and grazing animals (often of poor quality) are overburdening the highland environment. Food security in such environments is thus increasingly becoming a daunting task. This is complicated by the fact that farmers have very few cash-generating alternatives, which is critical. Often, the farmers in these places serve as migrant labour in towns and areas where cash crops are grown in order to generate additional income. One source of income could be growing malting barley, which has dependable local buyers in the country. Thus, encouraging farmers in these places to grow malting barley may help to reduce their migration to distant places, which has many unwanted consequences. Nevertheless, to date, the production of malting barley in the country has not expanded enough to benefit most barley growers.

In spite of the importance of barley as a food and malting crop, and the efforts made so far to generate improved production technologies, its productivity in production fields has remained very low (about 1.3 t/ha compared with the world average of 2.4 t/ha). This is primarily due to the low yielding ability of farmers' cultivars, which are the dominant varieties in use; the influence of several biotic and abiotic stresses; and the minimal promotion of improved barley production technologies.

The factors constraining the increased production of barley in the different barley production systems have been identified and documented (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998). The most important abiotic stresses include low soil fertility, low soil pH, poor soil drainage, frost and drought. The important biotic stresses include diseases, such as scald, net blotch, spot blotch and rusts, which can reduce yields by up to 67%, and insect pests such as aphids and barley shoot fly, which can cause yield losses of 79% and 56%, respectively. Moreover, the level of adoption of improved barley production technologies by farmers is low, which is associated mainly with their minimal participation during the research process and the lack of understanding by researchers of the significant positive roles that farmers could have played in the research and development process.

Recently, a concerted effort has been made by researchers, development agents and farmers to increase the outputs and incomes of small-scale farmers by improving the productivity of barley through participatory research and development efforts. This contributes significantly to satisfying the food and malting barley demands of the rapidly growing population and beer brewers. This shows how important participatory research on barley in Ethiopia has become.

HISTORY OF BARLEY RESEARCH IN ETHIOPIA

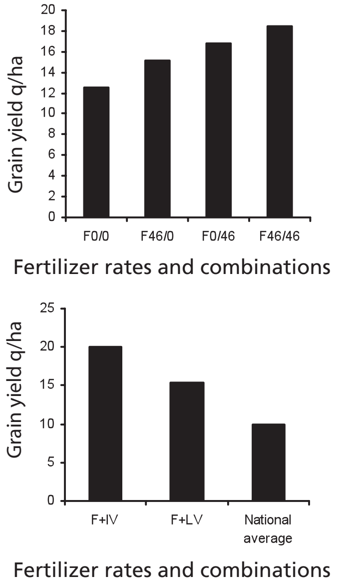
Although research on barley in Ethiopia has been active for more than six decades, it has passed through different phases and has never fully satisfied the needs of farmers in the different barley production systems.

Research was started at Debre Zeit Agricultural Research Centre in the 1950s. More organized research on the crop began in 1966 with the establishment of the Holetta Agricultural Research Centre (HARC) of the then Institute of Agricultural Research (IAR) [now the Ethiopian Institute of Agricultural Research (EIAR)], to represent the central highlands of Ethiopia, with barley being a major focus in crop research. From 1967 to 2005, the centre was responsible for coordinating the national crop improvement efforts on barley. Research on barley began with various activities, including creating nurseries and conducting variety trials targeting increased yields and identifying genotypes with a high level of disease resistance. Moreover, the determination of appropriate planting dates and rates of nitrogen fertilizer application for the highlands were carried out at Holetta on red soil. The first research outcomes were published in 1968 (IAR, 1968). The important findings from that report include the following: there was a highly significant response to N application; and from 196 germplasm lines obtained from foreign sources and evaluated at Holetta, 10% were retained based on apparent yield advantage. At the same time, most of the 354 local lines tested were found to be susceptible to lodging and the major leaf diseases of barley, namely scald and the blotches. The highest yield in the variety trial was obtained from the variety Egypt 5, but it did not out-yield the selection Local Mixed (IAR, 1968).

A more detailed research plan was set up in 1969, with the bulk of the work being conducted at Holetta, including hybridization; selection from large collections from local and foreign sources; variety trials; cultural and fertilizer trials; and seed multiplication. Emphasis was also placed on the development of malting barley varieties. The activities included identification of suitable malting barley production areas, development of suitable malting barley varieties, and development of appropriate cultural practices and associated fertilizer requirements. In the multi-location variety trials, grain yield was between 1.3 and 5.1 t/ha, and protein content on a dry matter basis was between 10 and 21%. Sagure, Sheno and Holetta were found to be promising sites for malting barley production (IAR, 1970).

The early milestones resulting from the trials conducted in the 1970s include the first advance made in identifying barley varieties of good malting quality and suitable locations (IAR, 1971). Optimum cultural requirements (sowing date, seed and fertilizer rates) for both food and malting barley under Holetta conditions were determined (IAR, 1972). Six-row malting barley varieties suitable for Ethiopia were identified (IAR, 1973). The response of barley to the application of fertilizer was found to be very promising from a countrywide fertilizer response trial conducted on half-hectare plots at 92 locations (Bull, 1987). In general, increasing the rate of application raised yields significantly. Better yields were obtained when improved varieties were grown using fertilizer, compared with the farmer cultivars (Figure 3).

FIGURE 3
Grain yield of local and improved barley varieties with application of nitrogen and phosphorus fertilizers



NOTES: F = fertilizer as $N+P_2O_5$; IV = improved variety; LV = local variety; q = quintal (100 kg).
SOURCE: Bull, 1987

RESEARCH APPROACHES AND OUTPUTS

The research approach for barley improvement from the mid-1980s onwards was based on teamwork, wherein relevant disciplines within and among research centres could contribute to the development of barley production packages. The contributing disciplines included: breeding and genetics, agronomy, plant pathology, entomology, weed science, socio-economics and research extension. In general, the improvement work focused on development of varieties with higher yields, resistance to the major leaf diseases, better food or malting grain qualities, and responsiveness to accompanying improved crop husbandry and protection practices.

Breeding and genetics research in the 1980s focused on developing varieties responsive to high external inputs. However, in the 1990s, the research direction became geared towards a participatory and multidisciplinary approach, with major emphasis on on-farm research with the full participation of farmers. In line with this, a research grant was obtained, from 1993 to 1998, from the Royal Netherlands Government to strengthen research and transfer of technology for sustained food barley production. It was a collaborative project between the then IAR and the International Center for Agricultural Research in the Dry Areas (ICARDA). The general goal of the project was to develop and transfer new technologies to small-scale farmers, to increase the productivity of barley and to ensure the sustainability of barley production in the various barley agro-ecologies.

The technology generation and adoption process focused on developing barley technologies responsive to low external inputs, as barley is grown in diverse agro-ecologies and mainly by subsistence farmers. This, however, involved farmers participating as attendants or hosts of researcher-planned technology generation and promotion activities. This required a change of approach to ensure the full participation of farmers. Based on this, in 1998, a client-oriented research (COR) approach was introduced. Prior to implementing COR as a system, a pilot study was carried out by organizing two farmer research groups (FRGs), one in Walmera Goro and the other at Anno Kore, comprising 40 and 49 farmers, respectively. Both locations are in the central highlands of Ethiopia. These FRGs were involved in setting up a research agenda based on identified and prioritized problems, with active participation and the implementation of planned activities, and evaluation of the results obtained. It was concluded that the approach allows the full participation of farmers and other stakeholders in the identification of production problems, and subsequent experiment design, testing and evaluation. Its implementation has facilitated the development and diffusion of barley technologies that address farmers' priority technology needs.

FIGURE 4
Number of improved barley varieties released by decade by the national and regional barley improvement programmes

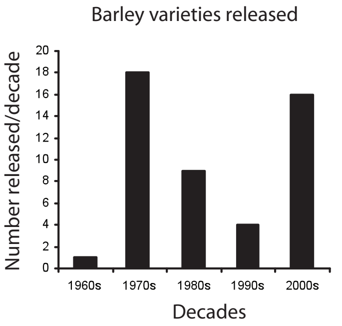


TABLE 1
Food and malting barley varieties in production in major barley-growing areas across the country

Variety	Yield (t/ha)	
	On-station	On-farm
Food barley		
ARDU-12-60B	3.6–6.3	1.8–3.0
HB 42	3.2–5.5	2.0–3.3
Shege	2.3–5.1	2.6–3.4
Misratch	2.5–3.5	2.3–3.4
Dimtu	2.0–4.0	1.5–2.2
Abay	2.5–4.0	1.0–2.0
HB 1307	4.8	3.5
Malting barley		
Beka	2.4–3.8	2.0–2.5
Holker	2.4–3.1	1.4–1.8
Miscal 21	1.9–5.7	1.2–4.6

In general, the breeding programme has given more emphasis to the evaluation of landraces under low to medium inputs rather than replacing the local germplasm by exotic materials. To enrich and improve the germplasm base, exotic germplasm of both food and malt types have been introduced from ICARDA and other sources. A hybridization and selection programme has been carried out at Holetta on both food and malting barleys by aiming to improve grain yield, lodging resistance, disease resistance (scald, net blotch, leaf rust, etc.) and insect pest resistance (aphids and shoot fly), stress tolerance (drought, waterlogging and frost) and grain quality (malting, food or feed). Promising selections made from landraces, exotic germplasm and crosses have been evaluated at several federal and regional research centres for specific or wider adaptation and to assess yield stability.

Since the beginning of the barley improvement programme at Holetta, 50 varieties (42 food and 8 malting barley varieties) have been released for production. More than 15 varieties were released in one decade in the 1970s and 2000s (Figure 4). Nevertheless, most of these varieties have not reached the farmers (Table 1).

Agronomy trials on barley have focused on the development of fertilizer rates for specific domains, on the utilization of alternative sources of fertilizer (such as use of farmyard manure (FYM) as organic fertilizer), establishment of location-specific barley planting dates, and determination of specific seed rates for released varieties. Moreover, emphasis has also been given to cropping-system-related activities. This includes a study on crop mixture effects on barley and total yield, fallow improvement by forage legume undersowing, and fertility improvement through double cropping. Cropping systems are found to be useful for replacing fallowing and for intensifying barley production per unit area. Double cropping of barley with chickpea on residual moisture can substitute the traditional fallow-chickpea cropping system on vertisols in northwestern Ethiopia. Rotation with faba bean or field pea can sustain the production of barley. With respect to weed control, it was found that one hand weeding at 30–35 days after crop emergence is required to prevent economic yield reduction. Post-emergence application of 2,4-D 72% a.i. at 1 L/ha controls some broadleaf weeds. Other effective herbicides include Mecoprop, Linuron, Carbyne 2E and Dichlofop-methyl.

Research in plant pathology has focused primarily on regular monitoring of the major leaf diseases of barley in the major barley production regions. This involves the screening of a large amount of barley germplasm from domestic and exotic sources to assess resistance to the major leaf diseases of barley. It has also involved the periodic characterization and documentation of the pathogens that cause barley leaf diseases. In addition, it involved the development of cultural and chemical barley disease control methods for incorporation into integrated barley disease management programmes. The work has also focused on the identification of Barley Yellow Dwarf Virus (BYDV)-resistance gene sources from landraces, which resulted in several resistant genotypes. Virulence studies at Ambo have identified four stem rust and two leaf rust races. Analysis of scald populations at Holetta showed the existence of at least 19 races. Fungicide tests showed that two sprays of Bayleton and Tilt at 0.5 L/ha are effective against scald and net blotch, respectively.

Research into barley entomology has focused primarily on monitoring of the major insect pests of barley. This involved the screening of germplasm, mainly from domestic sources, to develop resistant barley genotypes against the Russian Wheat Aphid (RWA) and barley shoot fly. Line 3296-15, a selection from a landrace population, was found to be tolerant to RWA. Development of cultural and chemical control measures for the two major pests has also been carried out, as well as the development of control measures for local major insect pests (e.g. chafer grubs in soils with high organic matter content, and leaf *Epilachna* spp.).

Research on animal feeds and nutrition has focused on screening of forage crops adapted to barley-growing areas. Browse trees, such as tagasaste (*Chamaecytisus palmensis*), are found to be well adapted in barley-growing areas around Holetta. Preliminary undersowing and cropping sequence studies have been conducted in the central highlands of Ethiopia, where fallowing is a common practice. Some of the undersown forage crops established successfully and none of these species significantly affected the yield of barley. Barley sown following forage legumes and grass/legume mixtures showed improved grain and straw yields.

Research into socio-economics has focused on investigating barley farming systems, marketing of both food and malting barley, the importance of barley in poverty reduction, and assessing the adoption of barley technologies. In the five years of the barley improvement project, the different barley production systems have been characterized through baseline surveys. The baseline surveys have proven useful in providing information that is relevant for promoting and guiding technology development that targets the different farming systems. Five traditional barley production systems are recognized within the major barley-growing agro-ecologies (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998). These are detailed below.

Late barley production system

This is the dominant system, which is important in the high-altitude areas of Ethiopia and is practiced during *Meher,* the main rainy season (June to October). This system is characterized by two distinct planting dates. In South Gonder and North Wollo, the different cultivars are sown in two separate planting seasons. The first cultivar is planted in May, and the second cultivar is planted between mid-June and early July. These cultivars require 5–6 months to mature. Grain yields from this system vary from 0.6 to 2.0 t/ha.

Barley production system with *guie* (soil burning)

This is a system that is practiced during the *Meher* season. It is important in the highlands of north and northwest Shewa, where waterlogging is a major hindrance to barley production. To alleviate this problem, farmers use *guie* (soil burning) and ploughing 3–5 times of fields that have been left fallow for at least five years. Early-maturing farmer cultivars, such as ‘Demoye’ and ‘Magie’, are used in this system, and the grain yield in the first year is about 2.0 t/ha, but declines dramatically in subsequent years. Other cultural practices are similar to the late barley production system.

Early-barley production system

This is also a system practiced during the *Meher* season, and is important in both the mid- and high-altitude areas of Gojam and Gonder (northwest Ethiopia) and in some parts of Shewa. Early cultivars are grown that require 3.5–4 months to mature, such as ‘Semereta’ in Shewa; Gojam and Belga in North Gonder; and Tebele in South Gonder. The cultivars are planted from mid-May to June and harvested in early September to early October. Cultivars ‘Aruso’ in Arsi and Bale and ‘Saesa’ in Tigray, are early types that are also grown. Cultivars such as ‘Ehilzer’ and ‘Tebele’—two-row types—are grown in the early-growing areas of Wollo. The yield of early barley in a normal year varies from 0.7 to 1.5 t/ha.

Belg barley production system

This system is practiced in north and northwest Shewa, North Wollo, Bale and a few areas in Arsi. *Belg* barley is planted in February to early March and harvested in early July. Early-maturing cultivars (3–4 month duration) are usually cultivated. In this system, farmers do not apply fertilizer. Moisture stress and RWA attack are the major threats. The yield of *Belg* barley in a normal year varies from 0.8 to 1.2 t/ha.

Residual barley production system

This system is important in some parts of Gojam, North and South Gonder, and West Shewa. Early-maturing cultivars—'Belga' in North Gonder and 'Semereta' in Gojam—are common in this system. Planting is carried out between September and October, immediately after harvest of the main-season barley crop. The seed of the main-season barley is re-sown in the same field, in the main-season fallow field, or in any other field where the main-season crop has failed. Fertilizer is not generally applied in this system. Harvesting is carried out from December to February. Grain yield from this system is generally low, less than 1.0 t/ha, and mainly used as seed for the next season.

The baseline survey also revealed that, among the crops grown in the study areas, barley showed the highest diversity. A total of 107 major farmer cultivars were reported to be grown (32 in central Ethiopia, 13 in north Ethiopia, 47 in northwest Ethiopia, 9 in northeast Ethiopia and 6 in southeast Ethiopia) by small-scale farmers, with diverse characteristics and use (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998).

The major outcomes of the pre-extension activities have been to link the research with extension by demonstrating and popularizing newly developed barley technologies, which are mainly centred on released varieties, and also by providing feedback to researchers by assessing farmer responses and studying the constraints influencing the transfer of barley technologies.

Stakeholders in barley research and development

Although not substantiated with adoption and impact assessment data, the research system in general has been serving all its stakeholders, which includes the ESE. ESE has multiplied the seed of the released varieties and distributed certified seed to users, which include: small-scale farmers, who have been instrumental in the widespread use of some of the released barley varieties through informal seed multiplication and dissemination mechanisms; major grain barley producers; suppliers to local markets and food and beverage industries; and large-scale farmers who are serving both as contract seed multipliers and grain barley producers, whilst also supplying local industries and wholesale buyers and exporters. End users of barley grain include the Assela Malting Factory (AMF), which is the sole processor of malting barley in the country; the six beer breweries, who consume the processed malt from AMF; and numerous bakeries. Such bakeries have been producing barley bread, creating a higher price in the bread market.

MECHANISMS OF TECHNOLOGY KNOWLEDGE AND INFORMATION COMMUNICATION

In order to transfer the knowledge and information being generated in the research system to the wider users of barley technology, it is of paramount importance that review workshops be implemented on a regular, sustainable basis.

Until the end of the 1980s, the only forum that was available was the National Crop Improvement Conference (NCIC), which had been held annually. Its termination, however, left a large void, until the arrival of of the Crop Science Society of Ethiopia, the Plant Protection Society of Ethiopia, the Soil Science Society of Ethiopia, and the Ethiopian Society of Agricultural Economists. These forums, however, were not large enough to cover all incoming information, knowledge and technology, and to communicate to users. Moreover, communication using these channels does not give a chance to address the research and development activities on a crop, in full, at any time. The solution to this is to conduct theme-based workshops and conferences. Based on this, two conferences have been held on barley in Ethiopia. The first was in Addis Ababa in 1993, under the title *Barley Research in Ethiopia: Past Work and Future Prospects* (Hailu Gebre and van Leur, 1996). This workshop reviewed all research work carried out before 1993. There were 19 papers presented that focused on all aspects of barley production, including breeding and genetics; agronomy; soil fertility management; disease, weed and insect pest management; socio-economics and technology transfer; utilization; and links between botany and tradition. The 2nd Research Workshop was held in November 2006 at Holetta, addressing what has been done in barley research and development, particularly in the 13 years since the first workshop. Thirty-two review papers were presented, of which 10 were on breeding and genetics, four on agronomy, six on barley pathology, five on barley entomology, one on weed science and six on related topics [This volume].

Nevertheless, the research that has been carried out so far to improve the production of barley has not been without its pitfalls and drawbacks. Through discussions held at the culmination of the 2nd Review Workshop, the gaps and challenges that have been faced in the 13 years that this review covered were identified. To fill the identified gaps and overcome the challenges, the future direction of research on barley in Ethiopia was outlined, and is described below on a discipline-by-discipline basis.

GAPS AND CHALLENGES

1. Breeding and genetics

- Lack of improved varieties for the different production systems.
- The breeding efforts made so far, by-and-large, have not involved a detailed analysis of nutritional and malting qualities.
- Inadequate studies on Ethiopian landraces, especially for malting purposes.
- Shortage of high-quality Breeder's seed and Pre-Basic seed of improved varieties.
- Weak coordination and linkage among barley breeders across centres.
- Lack of training and experience-sharing programmes that could further research activity.

2. Agronomy

- Inadequate crop production- and soil testing-based crop response information and knowledge for both malting and food barley.

- Soil fertility improvement work for barley production enhancement does not cover all barley production systems.
- Inadequate information on compatible crop species and varieties for double cropping and intercropping with barley to improve system productivity and profitability in areas receiving dependable *Belg* and *Meher* season rainfall.
- Inadequate efforts made to date to develop appropriate break crops for marginal highland production systems.
- Limited knowledge and experience of geographical information system (GIS) technology for timely operation of farm practices to optimize the use of the limited rainfall available for barley production.
- Inadequate information and technology on barley–weed competition in different production systems.

3. Pathology

- Knowledge is limited of the variability of pathogens of major diseases.
- Loss assessment studies for barley diseases are not exhaustive.
- Disease forecasting techniques are not developed and surveys lack continuity.
- Lack of current information on distribution, occurrence and importance of major barley diseases.
- Physiological races of important pathogens (such as scald, spot blotch and rust) are not fully known.
- Lack of information on integrated disease management practices for the major barley diseases.
- No coordination among phytopathologists at a national level.

4. Entomology

- Loss assessment is not exhaustive, and monitoring of pest status is minimal.
- Lack of current information on different insect pests attacking barley.
- Incomplete information on barley shoot fly, aphids and leaf skeletonizing *Eplichana* beetles.
- Work on cultural practices against pests is limited.
- Germplasm screening against RWA has been halted.
- Integrated pest management (IPM) approaches are not promoted.
- Results on bio-pesticides are incomplete.
- Shortage of budget, transport facilities, lab equipment and chemicals limit the scope of activities.

5. Socio-economics and research extension

- Surveys have not fully covered all barley-growing woredas [woreda - an administrative division equivalent to a district].
- Barley farming systems are not fully characterized.
- Demonstration and dissemination of the available technologies has been limited.
- Adoption study of barley technologies is minimal.

- Limited participatory seed multiplication on farmer fields.
- Weak integration among researchers, farmers, stakeholders and disciplines.
- Limited consideration for inclusion of farmers' indigenous knowledge.
- Lack of extension bulletins in local languages.

FUTURE RESEARCH DIRECTIONS

1. Breeding and genetics

- Improve landraces for higher yields through conventional and advanced plant breeding techniques.
- Develop varieties for low-input (fertilizer) and low-moisture stress areas.
- Introduce genotypes for malt quality and assess them for the trait under the local conditions.
- Maintain continuous screening of genotypes to identify sources of resistance against major diseases and to develop resistant sources of germplasm.
- Establish targeted crossing programme.
- Use participatory approaches for on-farm technology development and dissemination.
- Create strong linkage within and among barley breeders.
- Promote short-term and long-term training for researchers and technical assistants.

2. Agronomy

- Study the agronomic factors limiting barley production under farmers' management conditions.
- Determine appropriate seed and fertilizer rates, and timing of nitrogen application for better quality and yields of malt barley.
- Study frequency and proper timing of weeding.
- Study organic and inorganic sources of fertilizers for sustainable barley productivity.
- Study cropping system options for improved soil productivity and crop intensification (crop rotation, double cropping, mixed cropping) for sustainable barley production.
- Cluster similar barley-growing areas and interpret meteorological data to forecast risks and correct timing of farm operations.
- Investigate the factors that promote the sustainability of barley production in an integrated crop management system.

3. Pathology

- Develop information on disease dynamics by carrying out continuous disease surveys and implementing efficient disease forecasting techniques.
- Make regular assessments of losses incurred in barley due to the major barley diseases.
- Characterize pathogens (scald, spot, net blotch and rust) using conventional and advanced techniques.

- Characterize pathotypes and exploit dominant and virulent pathotypes in refining resistance sources.
- Monitor race patterns and study shift of host–pathogen interactions in different pathosystems.
- Emphasize integrated barley disease management.
- Encourage collaboration among pathologists for better information and technology exchange.

4. Entomology

- Study the biology and ecology of major insect pests and their natural enemies.
- Study control options, including use of botanicals, bio-control, host resistance and cultural control.
- Study the use of appropriate chemical insecticides against the major insect pests.
- Maintain periodic surveys of insect pests and their natural enemies.
- Assess periodically the losses incurred in barley due to the major insect pests.
- Screen germplasm for RWA resistance or tolerance.
- Develop cost-effective, sustainable and environmentally safe IPM packages for the major insect pests.

5. Socio-economics and research extension

- Characterize and analyse barley-based farming systems that have not yet been studied in depth.
- Transfer technology, focusing on participatory technology evaluation and dissemination using Farmer Research Groups (FRGs) and Farmer Extension Groups (FEGs).
- Promote participatory seed multiplication and scaling-up of technologies.
- Conduct a diffusion study to evaluate the rate and extent of diffusion of the disseminated barley varieties.
- Determine the extent of adoption of barley technologies, and their impact.
- Study the feasibility of external interventions in complementing indigenous knowledge, and identify the production and income increases due to improved technologies of barley.
- Verify adoption of intervention technologies on the basis of farmers' typology across agro-ecologies.
- Diagnose barley production problems and constraints, and document indigenous farmer knowledge to combat these constraints.
- Train farmers and development agents.

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Breeding and genetics

Barley genetic resources collection and conservation in Ethiopia

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INTRODUCTION

Ethiopia is an important primary and secondary gene centre for many field crop species, including barley, that were introduced centuries ago and have since adapted and developed wide genetic diversity. However, this broad range of genetic diversity has been eroded due to many factors. With the objective of addressing conservation of this dwindling plant genetic diversity in the country, the Plant Genetic Resources Centre of Ethiopia (PGRC/E), now the Institute of Biodiversity Conservation (IBC), was established in 1976.

The primary mandates of IBC include the preservation of genetic diversity of crop plants, their wild relatives, and native species important to Ethiopian agriculture and biodiversity. Over 65 000 accessions from more than 120 plant species have been collected from across the country and preserved *ex situ* at IBC. This germplasm collection includes a principal base collection of barley with >15 000 accessions. The genebank serves as a reservoir of genes potentially useful for many purposes, including resistance to diseases, pests and other environmental stresses, as well as for traits that increase yield or food quality. Often, however, there is limited awareness of the value and utilization of genebank resources. In addition to genebank materials, distinct landraces (farmer varieties) of field crops, including barley, are conserved *in situ* (on farm) at 12 Community Genebanks (CGBs) established over the last decade by IBC in six agro-ecologies of the four regional States of Ethiopia.

Ethiopian barley is recognized to have typical botanical varieties with a group of inter-fertile lines distinguished by spike characters (Zemede Asfaw, 1988). Five convarieties: *deficiens, distichon, hexastichon, intermedium*, and *labile* have been identified from different types, of which *deficiens* and *labile* are endemic to Ethiopia (Giessen, Hoffmann and Schottenloher, 1956). Five *distichon* accessions of Ethiopian origin were repatriated from China, and are now conserved in the IBC. Other studies noted the unique features of the cultigens of barley grown in Ethiopia (Orlov, 1929; Ciferri, 1944; Vavilov, 1951). These and several other observations and views strengthen the argument that barley also originated independently in Ethiopia (Endeshaw Bekele, 1983; Mulugeta Negassa, 1985), although the site of domestication is debated (e.g. Endeshaw Bekele, 1983; Mulugeta Negassa, 1985). Evidence from a flavonoid study raised doubt of a monophyletic origin of barley, arguing that through long-term introgression, the relatively fewer wild relative genes remain swallowed up in the gene pool of cultivated barley in Ethiopia (Åberg, 1938; Endeshaw Bekele, 1983; Molina-Cano *et al.*, 1987) and initial barley cultivation in Ethiopia may date to 3000 BC (Gamst, 1969). Furthermore, very recent work considered Ethiopia an independent centre of barley diversification and a potential domestication site (Orabi *et al.*, 2007).

STATUS OF GENETIC EROSION

Ethiopia is known as a centre of genetic diversity and origin for a number of cultivated and wild plants (Vavilov, 1951; Harlan, 1969). The richness and range of genetic diversity in Ethiopia, particularly of landraces, is currently subject to serious genetic erosion and irreversible losses due to the changing nature of agricultural production. Widespread adoption of modern varieties, technological change (such as use of fertilizer and irrigation), land use change, habitat destruction, and drought, among other important factors have lowered the demand for landraces adapted to marginal growing conditions in Ethiopia (Melaku Worede and Hailu Mekbib, 1993; FAO, 1998; Tripp and van der Heide, 1996). Harlan (1931) sounded the first alarm about the loss of crop diversity caused by modern agriculture. The loss of landraces is a big concern, and hence preservation of crop genetic diversity is absolutely essential, since they are potential sources of materials for modern plant breeding, stability in crop production, and for resistance to biotic attack. They are important in more marginal and diverse agricultural environments, and with the advent of plant variety protection (Tripp and van der Heide, 1996). The extent to which native seeds are displaced varies between regions and crops. Native barley is probably among the crops most threatened by market-oriented products in the highlands of Shewa, Arsi and Bale regions; similarly in the central highlands, including northern Shewa and Gojam. Strategies are urgently needed to address conservation of particularly the native plant genetic diversity before it is forever lost.

GERMPLASM ACQUISITION, MANAGEMENT, AND STATUS OF CONSERVATION

Since the establishment of PGRC/E in 1976, there have been systematic crop germplasm collections as a primary step in capturing and conserving crop genetic resources. The collection priorities have been expeditions for agriculturally important, rare and threatened genotypes, to minimize genetic erosion and loss of varieties. Over the last thirty years, the barley collection has grown to about 15 400 accessions, primarily landraces. At present the collection is one species (*Hordeum vulgare* subsp. *vulgare* L.), with 10 277 accessions collected from Ethiopia and 1101 donated from nine countries worldwide. However, there were 3982 accessions of unknown origin that required further investigation.

There are two widely accepted strategies to conserve barley accessions in Ethiopia: *ex situ* genebanks and *in situ* on-farm approaches. The *ex situ* collection is managed in accordance with international standards for genebanks, with optimum treatment developed for seeds of most food crops (Harrington, 1970). In this regard, the Ethiopian national genebank relies purely on cold storage facilities for seed maintenance, which depends on a reliable electricity supply. Countries with the problem of unreliable power supplies have developed alternatives to low temperature storage, including 'ultra-dry seed' technology (Walters and Engels, 1998) that requires storing seeds when adequately dried (moisture contents as low as 5% for starchy seeds such as barley), careful production of high quality seed for maximum longevity, and carefully avoiding any sub-optimal effect of very low moisture content (Rao and Jackson, 1996). Hermetically sealed aluminium foil bags are used for long-term (-10°C) [base collection] and short-term (+4°C) [active collection] seed storage.

From the base and active collections, the seeds are regularly regenerated and multiplied, based on thresholds for viability or seed quantity. Immediately after harvest or after acquisition, the viability of the barley seed is tested to determine the best candidates for storing. The initial viability test is a key first step to minimize genetic change and to retain the maximum genetic variation *ex situ* for future uses (Crossa *et al.*, 1994) and should be >85%. Depending on the initial seed viability, for base collections, monitoring is done periodically (after 5–10 years storage). When viability of accessions falls below 85% then regeneration of selected accessions is undertaken; since 1976, about 7600 barley accessions have been regenerated. The conserved barley materials are readily available for characterization and evaluation and accessible for research and use. The field management used when regenerating germplasm is the same as for routine farming, and cultivation methods are adapted to local circumstances. However, care has always been taken to maintain the genetic integrity of each accession, and management is designed so that natural and artificial selections within and between accessions are avoided.

In Ethiopia, *in situ* on-farm conservation sites were established to ensure the roles of both environmental factors and farmer intervention in landrace development. Therefore, IBC established 12 *in situ* crop conservation sites on six agro-ecologies of the four regional States of Ethiopia to promote on-farm conservation and maintain genetic integrity of plant populations in their natural sites (Ortiz, 1999). This is a rewarding approach as evolutionary conservation also allows continuing natural selection in diverse environments, with low direct costs and yet with increased control by farmers over their genetic resources (IPGRI, 1993). The 12 CGBs established in the 12 woreda have a symbolic role in the maintenance of crop germplasm and local seed systems. In this process, distinct landraces of barley have been conserved *in situ* in all CGBs, including 43 landraces and a number of important genotypes. The seeds have been distributed seasonally or annually on a loan basis to farmers ensuring the seed supply system for the local community. Moreover, barley germplasm collected by IBC was tested and multiplied by breeders and then provided to farmers through CGBs for further multiplication and selection. This allows farmers to experiment with landrace lines while the indigenous populations are maintained in the genebank (Melaku Worede and Hailu Mekbib, 1993).

CHARACTERIZATION OF BARLEY GENETIC RESOURCES

Among cultivated cereals, barley has the most accessions preserved in the Ethiopian genebank, with well over 15 300 samples (Table 1). This is approximately 23% of the total landraces in the genebank, and among them valuable traits and genotypes have been identified. Several traits, such as disease resistances to barley yellow dwarf virus, powdery mildew, leaf rust, loose smut, and barley stripe mosaic virus, and high lysine content are unique to Ethiopia (Abebe Demissie, 2006). Although approximately 93% of the barley collection originated from Ethiopia, the collection is not unique as it is duplicated in several international collections.

International collections have been widely used in barley improvement programmes, in particular in breeding for resistance to biotic and abiotic stresses (FAO, 1998; St Pierre, 2006). Ethiopia contributed a major share of accessions to the world's largest collections: Canada (5460 accessions supplied) and the Generation Challenge Program (GCP) (314 accessions supplied) (St Pierre, 2006; Konopka, 2007). However, the Ethiopian barley collection is one of the world's ten largest *Hordeum* collections (Konopka, 2007). Of the world total of 129 000 accessions, 51% is considered to be landraces, mostly originating from developing countries, of which Ethiopia accounts for 23.3% (Konopka, 2007).

von Bothmer *et al.* (1995) described the major groups of barley genetic resources as obsolete, elite and modern cultivars of past and current use; landraces; and breeding lines. The last two are the basis of barley production in Ethiopia. Landraces—a major component of barley collections—are rich in variability for diverse traits of high value in crop improvement programmes. However, modern agriculture has lagged behind, despite landrace improvement being long recommended as a strategy for crop improvement (e.g. Qualset, 1981). In the 1960s and 1970s, barley research in Ethiopia focused primarily on breeding using exotic lines, such as introduction and adaptational breeding of malting barley lines (Zemede Asfaw, 1990). However, >80% of barley produced in Ethiopia is derived from landraces (Fekadu Alemayehu and Hailu Gebre, 1987). Due to their wide genetic basis, landraces are gaining attention in several breeding programmes, particularly in resistance to abiotic and biotic stresses, and in participatory research.

TABLE 1
Barley holdings of IBC seed bank and distribution in altitude range in regions of origin

District of origin	Holdings	Characterized accessions	Altitude range (masl)
Arsi	1335	889	1100–3220
Bale	474	256	1550–3570
Gamo Gofa	350	272	1000–3030
Gojam	607	272	1660–3150
Gonder	1524	865	2338–3220
Hararge	736	522	1650–2680
Illubabora	67	40	1580–2200
Kefa	296	204	1030–2230
Shewa	3109	2103	1550–3600
Sidamo	348	285	1150–3020
Tigray	1001	832	250–3940
Wellega	221	130	1680–2770
Wollo	787	489	1440–3900
Unknown	4193	3478	1630–2950
Total	**15360**	**10868**	**250–3940**

NOTES: masl = metres above sea level.

GEOGRAPHICAL DISTRIBUTION

In Ethiopia, barley grows well at altitudes of 1500–3500 masl and is predominantly

TABLE 2.
The different agro-ecological zones where barley landraces are grown in Ethiopia

Traditional zones	Altitude (masl)	Rainfall (mm)	Soil type	Seasonal pattern
Sub-alpine 'wurch'	3200–3700	>1400	Black, highly degraded	Bimodal
Sub-alpine 'wurch'	3200–3700	900–1400	Black, degraded	Uni-modal
Highland 'dega'	2300–3200	>1400	Dark brown clay	Bimodal
Mid-altitude 'woyna dega'	1500–2300	>1400	Widespread drainage	Uni-modal
Mid-altitude 'woyna dega'	1500–2300	900–1400	Red brown drainage	Uni-modal

SOURCE: MoA, 1998.

grown at 2000–3000 masl (MoA, 1998) (Table 2). However, the IBC barley collection has an altitude range of 250–3940 masl, indicating a wide array of agro-ecological origins (IBC database, see www.ibc-et.org). The crop is produced in all regions, with Shewa, Gojam, Arsi, Gonder, Wollo and Bale contributing >85% of total production. It is a dependable food source during the main (*Meher*) and short (*Belg*) rainy seasons, as well as using residual moisture in dry seasons. *Belg* barley is important in Wollo, Bale and North Shewa, and in some highlands of Gonder (Adugna Abdi, 2008). As barley is a low input crop used where soil fertility, drainage conditions and topography are diverse, it is a crop recommended for improving agro-ecological health. In Ethiopia, only about one-third of the one million hectare of barley receive fertilizer annually (CSA, 1999).

DIVERSITY ANALYSIS

Barley accessions being regenerated from the active collections are characterized and evaluated as an important element of genebank operation and basic agro-morphological assessment. Of the 15 360 accessions of the genebank, there were 10 869 characterized in different agro-ecologies, using 16 descriptors, which included nine quantitative (Table 3) and seven qualitative traits (Table 4). Here, regions of origin and altitude ranges were used as classifying variables. The characterization results showed differences in the level of variation in agronomic traits analysed. Similarly, the level of variability and genetic diversity within and among populations of barley accessions was determined across an altitudinal gradient (Table 3). There was a high level of variation in accessions from the mid- and high-altitude ranges for all traits. Previous observations showed that gradients in altitude and differences in agro-ecology also influenced diversity variation in barley (Abebe Demissie and Bjornstad, 1996, 1997). This also holds true for the barley landraces analysed.

The frequency distribution for the seven qualitative traits by region and altitude (data not shown) showed a similar trend of variation to distributions of variability in agronomic traits for all regions and altitude ranges.

The phenotypic frequency data of the seven qualitative traits were analysed by the Shannon–Weaver diversity index (Table 4):

$$H' = \sum_{i-1}^{n} P_i \log_e P_i$$

TABLE 3

Patterns of variation in agronomic traits (mean ± SE) of *Hordeum vulgare* L. by region of origin and by altitudinal range

Regions	Agronomic traits analysed							
	DF	DM	GF	PLH (cm)	NSP	NKS	NKP	TGW
Arsi	78.08 ± 0.40	119.84 ± 0.4	41.76 ± 0.39	97.64 ± 0.50	5.87 ± 0.11	40.16 ± 0.53	197.26 ± 2.58	34.8 ± 1.77
Bale	65.19 ± 1.23	69.57 ± 3.48	39.92 ± 1.02	61.1 ± 2.83	11.22 ± 3.41	29.49 ± 1.05	135.58 ± 5.68	26.28 ± 2.58
Gamo Gofa	73.24 ± 0.73	111.6 ± 1.22	38.38 ± 0.87	98.84 ± 1.34	5.59 ± 0.24	38.23 ± 0.97	190.49 ± 4.52	32.8 ± 0.0
Gojam	78.42 ± 0.98	117.3 ± 1.11	39.32 ± 0.73	100.3 ± 1.14	5.81 ± 0.22	32.51 ± 0.93	169.96 ± 4.7	28.5 ± 1.07
Gonder	79.70 ± 0.44	119.14 ± 0.52	39.44 ± 0.44	93.46 ± 0.58	5.68 ± 0.18	37.83 ± 0.78	189.36 ± 2.53	16.99 ± 2.76
Harar	75.06 ± 0.38	116.53 ± 0.44	41.7 ± 0.38	98.48 ± 0.7	6.15 ± 0.13	47.74 ± 0.66	232.29 ± 3.61	37.3 ± 4.26
Illubabor	73.11 ± 2.43	114.84 ± 2.15	41.73 ± 1.82	93.76 ± 1.74	–	40.81 ± 2.87	183.6 ± 11.4	–
Wellega	71.02 ± 1.01	110.34 ± 1.22	39.32 ± 0.81	100.5 ± 1.57	6.9 ± 0.57	30.37 ± 1.43	151.34 ±6.06	24.6 ± 1.46
Kefa	73.69 ± 0.74	113.99 ± 0.82	40.3 ± 0.75	94.87 ± 1.07	5.92 ± 0.14	38.68 ± 1.23	186.33 ±5.38	–
Shewa	75.85 ± 0.32	116.68 ± 0.35	40.9 ± 0.26	93.67 ± 0.58	6.14 ± 0.3	38.03 ± 0.38	182.2 ± 1.65	19.92 ± 2.16
Sidamo	72.83 ± 0.57	113.5 ± 0.87	41.17 ± 0.53	98.25 ± 1.02	5.78 ± 0.11	35.7 ± 0.96	179.94 ± 4.29	21.5 ± 0
Tigray	70.04 ± 0.52	112.95 ± 0.62	42.64 ± 0.39	88.15 ± 0.66	–	29.43 ± 0.51	143.8±2.25	15.79 ± 1.53
Wollo	75.88 ± 0.45	115.12 ± 0.51	39.49 ± 0.35	93.38 ± 0.70	5.3 ± 0.17	41.6 ± 0.62	204.23±3.04	–
Ethiopia	73.61 ± 1.10	114.11 ± 1.10	29.24 ± 5.14	94.84 ± 1.20	3.81 ± 0.8	36.72 ± 1.41	180.48 ± 6.3	18.0 ± 3.59
Altitude (masl)								
<2000	66.52 ± 0.78	108.53 ± 1.26	42.16 ± 0.77	92.56 ± 1.36	6.21 ± 0.17	30.4 ± 0.82	156.02 ± 3.97	18.10 ± 3.38
2000–3000	73.98± 0.34	114.85 ± 0.45	40.85 ± 0.23	96.74 ± 0.44	6.64 ± 0.41	37.40 ± 0.34	188.03 ± 1.70	18.35 ± 2.2
>3000	77.06 ± 0.94	114.75 ± 1.38	38.45 ± 0.66	91.19 ± 1.31	5.82 ± 0.14	41.5 ± 0.78	208.74 ± 3.83	21.74 ± 4.72
Unknown	76.05 ± 0.14	117.38 ± 0.16	41.32 ± 0.13	96.27 ± 0.34	5.69 ± 0.14	37.74 ± 0.19	184.32 ± 0.84	24.63 ± 1.37
Ethiopia	73.40 ± 2.38	113.88 ±1.88	40.7 ± 0.80	94.19 ± 1.37	6.09 ± 0.21	36.76 ± 2.31	184.3 ± 10.8	20.70 ± 1.55

NOTES: DF = Days from emergence to 50% flowering; DM = Days from emergence to maturity; GF = Grain filling; PLH = Plant height from ground to top of spike excluding awns; NSP = Number of spikes per plant; NKS = Number of kernels per spike; NKP = Number of kernels per plant; TGW = 1000-grain weight, g; masl = metres above sea level.

TABLE 4

Estimate of Shannon–Weaver diversity index (H') of seven qualitative traits of *Hordeum vulgare* L. by region of origin and by altitudinal range

Regions	H' of qualitative traits analysed							Mean ± SE
	AWN	SA	SD	AWR	RN	KC	LC	
Arsi	0.94	0.95	0.97	0.91	0.89	0.93	0.50	0.87 ± 0.06
Bale	0.75	0.94	0.85	0.57	0.67	0.52	0.25	0.65 ± 0.04
Gamo Gofa	0.57	0.65	0.73	0.58	0.57	0.69	0.48	0.61 ± 0.07
Gojam	0.76	0.81	0.57	0.98	0.63	0.58	0.50	0.69 ± 0.03
Gonder	0.85	0.91	0.84	0.97	0.78	0.92	0.47	0.82 ± 0.08
Hararge	0.78	0.65	0.81	0.83	0.65	0.66	0.38	0.68 ± 0.04
Illubabor	0.45	0.64	0.52	0.66	0.45	0.41	0.30	0.49 ± 0.09
Kefa	0.56	0.76	0.45	0.92	0.53	0.43	0.34	0.57 ± 0.02
Shewa	0.89	0.95	0.96	0.98	0.96	0.91	0.86	0.93 ± 0.05
Sidamo	0.66	0.59	0.78	0.87	0.78	0.49	0.45	0.66 ± 0.08
Tigray	0.84	0.94	0.85	0.89	0.79	0.69	0.46	0.78 ± 0.06
Wellega	0.45	0.57	0.49	0.75	0.51	0.55	0.32	0.52 ± 0.03
Wollo	0.89	0.89	0.84	0.96	0.80	0.58	0.43	0.77 ± 0.05
Unknown	0.91	0.93	0.93	0.90	0.96	0.98	0.62	0.89 ± 0.07
Altitude (masl)								
<2000	0.70	0.76	0.59	0.87	0.57	0.51	0.29	0.61 ± 0.07
2000–3000	0.70	0.90	0.96	0.91	0.72	0.71	0.41	0.76 ± 0.05
>3000	0.73	0.79	0.65	0.79	0.87	0.78	0.59	0.75 ± 0.08
Unknown	0.84	0.75	0.82	0.78	0.68	0.68	0.49	0.72 ± 0.06
Ethiopia	0.74	0.80	0.76	0.84	0.71	0.67	0.45	0.71 ± 0.06

NOTES: AWN = Awnness; SA = Spike attitude; SD = Spike density; AWR = Awn roughness; RN = Row number; KC = Kernel covering; LC = Lemma colour; masl = metres above sea level.

where n is the number of phenotypic classes for a trait and P_i is the proportion of the total number of entries in the i^{th} class. Seven qualitative traits were used to compute H', which was estimated for each trait, using regions of origin and altitude ranges as classifying variables.

Estimates of H' for Ethiopian barley landraces were very high due to ecological heterogeneity. The minimum was H' = 0.45 for the entire region for lemma colour and the maximum was H' = 0.84 for awn roughness, with an overall mean of H' = 0.71 ±0.06, showing apparently high landrace diversity. Except for lemma colour, there was high diversity estimated for all traits. The mean H', pooled over traits within region of origin and altitude ranges, varied from 0.49 for Illubabor to 0.93 for Shewa, and from 0.61 for altitude <2000 masl to 0.76 for altitudes of 2000–3000 masl. The differences in altitude gradient and agro-ecological setting gave high diversity variation for the barley landraces analysed. The high H' for Shewa is probably related to the region's eco-geographic setting, which favours a wide diversity of landraces, and reflects it being a major source of barley production in the country. The high overall mean (H' = 0.71) shows remarkable variability in most traits and this may indicate desirable genotypes of interest for barley improvement and breeding programmes.

GERMPLASM EVALUATION AND POTENTIAL UTILIZATION

The 15 360 accessions are of diverse taxonomic and ecogeographical origin, and so have potential to be utilized in diverse research projects oriented to cytogenetic, molecular, phylogenetic, phytochemical, agronomic and environmental adaptation studies. Also, there is long-term value in terms of specific genes for disease resistance and other potentially important characteristics. Barley germplasm is one of a number of crop species of Ethiopian origin that have been introduced into various national and international crop improvement programmes by public and private seed companies, with around 2500 accessions reported (FAO, 1998). Ethiopia is one of the countries of origin for accessions resistant to various disease-causing pathogens, confirming the importance of the ecogeographical variation in the barley collection. For instance, screening for resistance to Fusarium Head Blight done in Canada revealed that Ethiopian materials were resistant (St Pierre, 2006). Locally, IBC rated some accessions for a number of characters, including protein, oil, fibre, mineral ash and moisture content (Table 5). This was based on dry weight of 111 randomly selected accessions to indicate the importance of barley landraces in high yield and dry matter composition, as with sorghum (Adugna Abdi, Endeshaw Bekele and Zemede Asfaw, 2002). Ethiopian landraces have very high protein levels, up to 18% (FAOSTAT, 2004) and supply some 10% of caloric consumption (RAFI, 1997). Most of the barley varieties released by the barley improvement programme of Ethiopia have been developed using genetic resources from the landrace accessions of barley of mainly Ethiopian origin (ICARDA, 2008).

There has been an effort to link conservation and utilization strategies in Ethiopia, since the genebank's long-term conservation is justified only when the collected accessions are used (Engels and Visser, 2003). Options were developed for crop collections, including barley, as an optimal combination of long-term conservation with immediate or imminent utilization. To this end, accessions stored for research and distribution in the active collection use the same storage facility and are linked to long-term conservation of germplasm in the base collection. As part of utilization, one IBC responsibility is ensuring the free and unrestricted exchange of germplasm with all nations, permitting access to the collection by plant breeders and other plant biologists under the conditions of the Standard Material Transfer Agreement (SMTA). In the last 30 years there have been 18 619 barley accessions distributed, with, since 2000, an average of 621 accessions per year locally and 58 per year internationally (Tables 6a and 6b).

TABLE 5
Nutritional analysis of barley (dry weight basis) for percentage crude protein (PCP), fat (PCF), fibre (PCFB), mineral ash (PMA) and moisture (PM)

Mean	PCP	PCF	PCFB	PMA	PM
Maximum	15.33	2.01	9.07	4.63	12.01
Minimum	9.31	1.52	6.30	2.10	8.30
Average	12.02	1.79	7.37	2.74	11.03

TABLE 6A
Local barley seed distribution since 1983 for utilization in variety development

Organization	Year of delivery	No. of accessions
Addis Ababa University	1995 & 1996	273
Mekelle University	1994–2002	641
Jimma University	1990	20
Adet Research Centre	1988–1995	1597
Ambo Research Centre	1988–2000	2602
Bako Research Centre	2004	670
Holetta Research Centre	1988–2006	2821
Jimma Agricultural Research Centre	1990	20
Kulumsa Agricultural Research Centre	1991–2003	1385
Melkassa Agricultural Research Centre	1988	360
Mekelle Research Centre	1997	1582
Sheno Research Centre	1993–1998	1183
Sinana Research Centre	1993–2006	4124
Sirnka Research Centre	1995–2004	861
Oromia Regional Agricultural Office	1989	41
Others	1983–2006	1160

TABLE 6B
International transfers of Ethiopian barley landraces since 1983

Organization	Country	Year of delivery	No. of accessions
University of Birmingham	UK	1990	370
Svalov AB International	Sweden	1990	200
Wageningen University	Netherlands	1991	37
Agricultural University of Norway	Norway	1991	40
Agricultural University of Norway	Norway	1992	322
University of Califonia, Berkeley	USA	1995	77
Jordan Agricultural University	Jordan	1998	60
Institute of Seed Pathology	Denmark	1999	40
Wageningen University (Vincant-Lucasse)	Netherlands	2000	120
John Innes Centre	UK	2001	70
Ancona University	Italy	2005	77
Munich University	German	2006	220
ICARDA	Syria	1983–2003	1340
University of Queensland	Australia	Unknown	498
Canadian Gene Bank	Canada	Unknown	5460
Generation Challenge Programme	Unknown	Unknown	314

Although the barley collection in Ethiopia is increasing in size and there is more distribution, the accessions lack effective management and characterization with sufficient descriptors. As a result, the collections have not been used in studies that require better details of the samples.

FUTURE STRATEGIES

1. Address the conservation of dwindling but potentially useful genetic resources of barley before degradation reaches a critical level.
2. Target native varieties in future breeding strategies for barley improvement.
3. Use participatory breeding programmes that fully include farmers' criteria, thus maximizing the conservation of traditional landraces and knowledge of farming practices.
4. Build strong linkages between formal and informal breeding sectors through breeder–farmer collaboration.
5. Regenerate and form a core collection, including additional descriptor data. Accessions should be complemented with new collections to reasonably accommodate and represent the existing *Hordeum* gene pool. This will enable comprehensive characterization and evaluation of the range of trait variability and the identification of novel traits from cultivated barley.
6. Strengthen the documentation system with advanced information technology, such as Geographical Information Systems (GIS) and DNA marker technology. These will be of particular significance in localizing the spatial and genomic distribution of genetic resources. Certainly, this would help plant collectors search for specific sites where specific genes might be found. Subsequently, linkages with stakeholders should be strengthened to crucially improve the linkage between the conservation and the utilization of Ethiopia's genetic resources.

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Advances and experiences in barley landrace improvement in Ethiopia

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INTRODUCTION

Landraces form the major genetic resources of cultivated barley in Ethiopia. The diversity in soils, climate, altitude and topography, together with geographical isolation for long periods, are considered the main factors influencing the large diversity in Ethiopian barley (Harlan, 1968). Social factors (social values as criteria for selection, diversified uses, and association between barley types and uses) have also play an important part in the diversification. Thus, the morphological, biochemical and molecular groups in Ethiopian barley are the result of accumulated long-term mutations, hybridization, gene recombination and natural and human selection in heterogeneous environments.

Barley production in Ethiopia predominantly uses little or no fertilizers, pesticides or herbicides. However, early breeding programmes focused mainly on introductions and evaluations of exotic materials under optimum management conditions (Hailu Gebre and Fekadu Alemayehu, 1991). Hence, there has been little use of the various locally adapted landraces in the national breeding programme. As a result, adoption of released food barley lines was rather poor because the farmers' landraces performed equally well or better than the new cultivars under traditional management practices. Moreover, early studies on Ethiopian barley focused more on morphology, ecology, diversity, evolution, genetics and taxonomy (Zemede Asfaw, 1996). Interest then shifted towards using Ethiopian barley germplasm in the breeding programme. This effort has identified genotypes with better yield and desirable agronomic characters compared with the original landraces (Berhane Lakew *et al.*, 1997). The scope of research on barley landraces was also advanced from the morphological to the molecular and biochemical levels, and thus knowledge of Ethiopian barley landraces has increased in the past 10–15 years. This paper presents advances in barley landrace characterization, evaluation, and utilization since 1993.

PROGRESS IN VARIABILITY STUDIES ON LANDRACE BARLEY AND THE IMPLICATIONS FOR IMPROVEMENT

Phenotypic variability in barley landraces

Although there is ample information on morphological variability of Ethiopian barley landraces, many studies concentrated on random samples and failed to assess variability of landraces within specific localities in terms of economically important traits that pave the way for further evaluation and utilization. An experiment conducted to estimate the level of morphological variability and genetic distances within and among 44 barley landraces from North Shewa, Oromia and Amhara Regions (Ankober–Mezezo, Kimbibit, Degem, Kuyu, Girar Jarso and Wuchale) indicated that landraces from Degem, Wuchale, Girar Jarso and Kuyu were highly diverse (Alemayehu Assefa and Labuschagne, 2004). Diversity for spike type at Ankober–Mezezo, a typical high altitude area (>3000 masl), was very low. Within landraces, the variability for kernel colour was generally low except for landraces from Kuyu, but it was very high between landraces. Analysis of variance for quantitative characters revealed that differences among landraces were highly significant for all characters except for landraces from Ankober–Mezezo.

The six-row and irregular barley types had comparable spike lengths of 3–10 cm and 5–10 cm, respectively, with a mean of nearly 7 cm. The six-row types retained on average 45 seeds per spike, compared with 21 for two-rowed and 24 seeds for irregular types. Similarly, grain yields per spike for the six-row, irregular and two-row types were on average 2.19, 1.83 and 1.18 g, respectively. Accordingly, localities with the highest frequency of six-row genotypes (Kimbibit, Ankober–Mezezo and Girar Jarso) showed the highest number of seeds (>40 seeds per spike) and Wuchale—with the highest frequency of two-row genotypes—had <30 seeds per spike. The intermediate spike or irregular types, predominantly found in Debre Libanos and Degem, had a number of seeds per spike intermediate between the two and six-row types. Results suggested significant differentiation among localities, largely due to the number of seeds per spike and grain yield per spike, but not for days to maturity, plant height or spike length (Table 1). The Duncan's multiple range test for locality means indicated that number of seeds per spike and grain yield per spike of landraces from Ankober–Mezezo, Kimbibit, Girar Jarso and Debre Libanos were significantly ($P≤0.01$) different from other localities. If such significant phenotypic differences for quantitative characters within and among

TABLE 1

Means and statistical significance for the different quantitative characters of barley landraces from the Ethiopian central highlands.

Locality	DHE	DMA	PLH	SPL	NS/SP	GY/SP
Kimbibit	71	106	74	7.2	42 a	2.11 a
Ankober–Mezezo	74	104	74	7.5	44 a	2.27 a
Girar Jarso	73	104	70	7.4	38 ab	1.91 ab
Debre Libanos	70	103	76	7.6	38 ab	1.95 ab
Degem	74	101	70	7.6	29 c	1.61 b
Kuyu	71	106	74	7.9	37 abc	1.86 ab
Wuchale	70	102	73	7.6	30 bc	1.60 b
Welmera	81*	108	74	8.2	15 d	0.87 c

NOTES: DHE = days to heading; DMA = days to maturity; PLH = plant height (cm); SPL = spike length (cm); NS/SP = number of seeds per spike; GY/SP = grain yield per spike (g). * = only Welmera significantly ($P≤0.05$) differed from other localities for DHE. Means followed by the same letter in a column are not significantly different at $P≤0.05$.

TABLE 2

Range, mean and statistical significance for the different characters of barley landraces from the Ethiopian central highlands

Trait	Range	Mean ± SE	Mean square	CV (%)
Days to heading	62–94	81 ± 0.26	165.55**	12.7
Days to maturity	119–143	124 ± 0.37	546.12	18.1
Plant height (cm)	80–110	100 ± 0.40	182.36***	10.0
Spike length (cm)	4.2–9.3	6.9 ± 0.07	9.12***	21.7
NS/SP	29–69	55 ± 0.48	411.99***	21.8
GY/SP (g)	1.6–3.6	2.5 ± 0.03	1.45***	23.7
NH/m^2	205–489	341 ± 5.85	32433.67***	28.2
GY (g/plot)	289–622	44.6 ± 10.64	35946.92***	26.8
TGW (g)	31–52	40 ± 0.35	111.59***	18.6
Biomass (g/plot)	240–2140	1199 ± 18.29	148298.36***	21.1
HI	0.28–0.68	0.47 ± 0.00	0.006***	7.9

NOTES: NS/SP = number of seeds per spike; GY/SP = grain yield per spike; NH/m^2 = Number of heads per square metre; GY = Grain yield; TGW = 1000-grain weight; HI = Harvest Index; ** $P<0.01$; *** $P<0.001$.

landraces are assumed to be largely due to genetic effects, improvement can be achieved by selection within or among landraces. However, accurate scoring of flowering and maturity is difficult, in part because all plants in a plot do not flower or reach maturity at the same time for several factors (Rasmusson, Mclean and Tew, 1979). Hence, it is difficult to conclude that such large variation for quantitative characters within landraces is absolutely genetic.

Variability studies within farmers' dominant cultivars from central Ethiopia ('Magie', 'Kessele', 'Tikur Gebs', 'Netch Gebs', 'Feres Gama', 'Feleme', 'Haddo', 'Baleme', 'Tolese', 'Bukura', 'Key Gebs', 'Key Ferke' and 'Demoye'), based on quantitative morphological characters and Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) of seed storage proteins, revealed very high variability for quantitative characters (Table 2). However, this variation was primarily between, not within, cultivars (Alemayehu Assefa, 2003). Cluster analyses clearly showed that lines within cultivars were grouped together (data not shown), revealing closer genetic relationships in lines within rather than between farmers' cultivars.

A similar phenotypic diversity study was conducted on nine landrace populations (major farmers' varieties) consisting of 144 samples in 1998 at Holetta and Sheno for variation of 12 morphological and yield-related characters (seven qualitative and five quantitative). The nine landrace populations exhibited large variations for the five quantitative characters (Table 3). There was greater variation for the number of effective tillers per plant, followed by number of seeds per spike and plant height. There was significant variation between testing sites for the five quantitative traits. The range in days to heading was 57–102 days at Holetta and 70–106 days at Sheno. The landrace populations at Holetta took 98–144 days to mature, whereas at Sheno they took 122–168 days. The range in plant height between landrace populations was 52.0–113.0 cm at Holetta and 54.6–114.8 cm at Sheno. The range in number of tillers per plant was 3–24 at Holetta and 3–12

TABLE 3

Range, mean, standard error and coefficient of variation (CV) for five characters of farmers' nine major varieties tested at Sheno, Ethiopia, 1998

Farmer variety	N	Days to heading			Days to maturity			Plant height (cm)			Tillers per plant			Number of seed per spike		
		Range	Mean± SE	CV (%)	Range	Mean±SE	CV (%)	Range	Mean ± SE	CV (%)	Range	Mean ± SE	CV (%)	Range	Mean ± SE	CV (%)
Baleme	12	95–103	100 ± 0.70	2.40	150–167	160±1.56	4.1	84–95.4	91.3±1.07	4.1	5–11	8±0.44	19.9	25–48	30 ± 1.82	21.3
Tolese	12	92–106	101 ± 1.05	3.60	139–168	157±2.06	8.4	82.7–115	93.3±2.27	8.4	5–9	7±0.40	19.9	44–71	54 ± 1.85	11.8
Magie	15	81–98	86 ± 1.24	5.60	133–155	142±1.45	8.5	68.9–94.9	75.6± 1.65	8.5	5–9	7±0.31	17.9	35–54	47 ± 1.58	13.1
Kesele	24	80–92	86 ± 0.89	5.10	129–147	140±0.84	6.2	74.1–93.9	84.5±1.07	6.2	3–10	7±0.28	20.9	47–67	57 ± 0.87	7.4
Ehilzer	14	76–85	80 ± 0.73	3.40	122–137	133±0.97	3.1	67.8–76.2	72.3±0.59	3.1	6–11	9±0.34	16.2	44–55	47 ± 0.81	6.5
White Saesa	5	76–77	76 ± 0.20	0.59	128–133	130±0.79	5.4	62.1–71.9	67.5±1.62	5.4	8–10	9±0.27	7.2	23–26	25 ± 0.63	5.6
Semereta	25	70–83	74 ± 0.66	4.40	123–135	130±0.65	6.1	72.0–88.6	80.9±0.98	6.1	7–11	8±0.25	15.2	22–45	26 ± 1.08	20.5
Belga	18	75–84	78 ± 0.52	2.80	123–141	131±1.06	5.7	54.6–80.4	72.3±0.96	5.7	6–12	8±0.37	18.7	25–44	31 ± 1.26	16.9
Tsebel Gebs	19	71–100	75 ± 1.56	9.10	123–149	131±1.59	6.3	65.6–85.0	76.1±1.10	6.3	6–11	9±0.29	15.0	18–43	26 ± 1.15	22.9
Overall	144	70–106	83 ± 0.82	11.90	122–168	138±0.93	10.9	54.6–114.8	79.8±0.73	10.9	3–12	8±0.13	19.8	18–71	39 ± 1.14	35.4

TABLE 4

Estimates of diversity (H') for each of the nine farmer varieties by character and mean diversity, Holetta, Ethiopia in 1998

Farmer variety	Region	Glume and glume awn length	Row No.	Spike density	Kernel covering	Kernel colour	Fertility of basal floret	Spike length	H' ± SE
Baleme	W. Shewa	0.34	0.82	0.73	0.00	0.57	0.33	0.43	0.46 ± 0.10
Tolese	N.W. Shewa	0.12	0.37	0.81	0.00	0.36	0.99	0.46	0.44 ± 0.13
Magie	N. Shewa	0.37	0.64	0.81	0.00	0.39	0.47	0.55	0.46 ± 0.09
Kesele	N. Shewa	0.41	0.45	0.61	0.00	0.41	0.37	0.52	0.40 ± 0.07
Ehilzer	N. Wollo	0.42	0.57	0.25	0.00	0.39	0.05	0.52	0.31 ± 0.08
White Saesa	Tigray	0.06	0.00	0.64	0.00	0.34	0.14	0.33	0.22 ± 0.09
Semereta	W. Gojam	0.47	0.27	0.68	0.00	0.63	0.05	0.36	0.35 ± 0.10
Belga	N. Gonder	0.36	0.55	0.78	0.00	0.58	0.05	0.64	0.42 ± 0.11
Tsebel Gebs	S. Gonder	0.43	0.3	0.54	0.00	0.38	0.05	0.09	0.26 ± 0.08
Total		0.43	0.80	0.76	0.00	0.75	0.37	0.50	0.52 ± 0.10

at Sheno. There was a wide variation in number of seeds per spike, with a range of 12–54 in the landrace populations at Holetta, and 18–71 at Sheno. Fekadu Alemayu and Parlevliet (1997) studied variation of six quantitative characters in 18 Ethiopian barley landraces, and reported similar results. The difference in variation for the above quantitative characters at the two testing sites could be associated with site agroclimatic variation. Landrace populations from high altitude areas (Sheno) have longer vegetative and reproductive phases than those from Holetta, which affects the number of seeds per spike.

Estimates of diversity index in barley landraces

The normalized estimates of diversity (H') for individual characters and for each of the nine landrace populations are shown in Table 4. The relative contribution of each of the seven qualitative characters for H' varied. Polymorphism was high for kernel row type (H' = 0.80), spike density (H' = 0.76) and kernel colour (H' = 0.75); and relatively low for glume and glume awn length (H' = 0.43) and fertility of basal florets (H' = 0.37). All the landrace populations used were monomorphic for kernel covering. Mulugeta Negassa (1985) and Engels and Hawkes (1991) also reported high variation for row number and kernel colour, and low variation for kernel covering. The majority of variation was due to differences among characters and there were few differences among landrace populations, possibly due to small sample sizes. The average phenotypic diversity indices for landrace populations obtained from northern regions (Tigray, H' = 0.22; N. Wollo, H' = 0.31; and S. Gonder, H' = 0.26) were lower than those of the central regions (W. and N. Shewa zones, H' = 0.46). This might be explained by greater natural selection in northern Ethiopia, which is frequently affected by drought, and these landraces tend to be uniform. However, this has to be confirmed by taking more samples and considering more characters. Though the overall diversity index of the barley landrace populations used in this study showed an intermediate value due to the small sample sizes, this study supports the hypothesis that Ethiopia is still an important centre of barley diversity. This diversity indicates the presence of important genes potentially useful for future improvement of landraces. Further studies are needed to complement the morphological diversity result with biochemical markers to describe and systematically characterize the major landraces in current use. In addition, such study would help characterize landrace populations with identical names but growing in different environments and production systems, which might help avoid duplication of materials in selection and improvement of landrace populations.

In another study, van Leur and Hailu Gebre (2003) evaluated 13 farmer varieties for simple agronomic traits, as well as for resistance to scald (Table 5); the varieties were collected from different areas, with 5–24 samples per variety. The different samples of one farmer's variety are referred to as of 'farm origin'. Diversity levels for each trait differed between varieties, e.g. 'Magie' was highly variable in its reaction to scald infection, but not for heading date, while the opposite was found for varieties 'Semereta' and 'Tolose'. Only two varieties, 'Tsebel' from Gonder

TABLE 5
Performance of 13 Ethiopian farmers' barley varieties for three traits, Holetta Research Centre, 1996

Variety	N	Days to heading		Days to maturity		Scald (%)[a]	
		Mean	Range	Mean	Range	Mean	Range
				Wollo Province			
Lemisene	5	68	63–71**[b]	121	120–125	35	25–48***
Tegadine	5	70	67–72*	122	120–125***	33	25–39*
Nechita	3	73	70–79***	123	120–129	27	4–39***
Enat Gebs	16	78	72–82**	129	125–129	14	5–36***
Ehilzer	12	69	67–70	118	115–120**	30	29–32
				Gonder and Gojam Provinces			
Semereta	24	63	56–68***	109	107–113	49	44–54
Tsebel	19	58	56–60	106	106–107	54	50–56
Belga	18	65	62–69	108	107–115**	52	45–56
Abate Gebs	9	80	75–84***	129	129	19	6–35***
Awra Gebs	3	77	58–88***	118	106–129***	20	3–53***
				Shewa Province			
Baleme	14	85	82–88	129	129–129	8	1–14
Tolese	12	84	78–89***	129	129–129	3	0–11
Magie	15	71	70–77*	120	114–129***	18	5–33***

NOTES: a = averaged over three readings; b = differences between farm-origins within a variety are significant at $P<0.05$ (*), $P<0.01$ (**) and $P<0.001$ (***).

and 'Baleme' from Shewa, did not show a significant difference between farm origin samples for at least one trait. Only a few traits of direct importance to a breeding programme were measured. Despite the large variation for measured traits within the farmer varieties, the varieties showed coherence, and even closely related varieties from the same region differed from each other. For example, three early varieties from the Gojam–Gonder region differed significantly in heading date, although all three were susceptible to scald. It is suggested that grouping Ethiopian barley germplasm accessions according to their traditional names will provide a better explanation for diversity between and within accessions. Similarly, breeding programmes could concentrate on improving those varieties most appreciated by farmers.

VARIABILITY IN BARLEY LANDRACES FOR STORAGE PROTEINS

SDS-PAGE of seed storage proteins was carried out for each landrace to estimate the level of variation within each of the 44 landraces (Alemayehu Assefa, 2003). The genetic relationship between landraces was investigated, based on electrophoretic banding patterns pooled from each landrace. SDS-PAGE revealed from very litle to high variation, both within and among landraces. Although variability within some was comparable with that among landraces, genetic divergence between was greater than for landraces. The range of mean genetic distance within landraces was 0.353–0.678, and between landraces 0.235–0.881. Variability within most farmers' cultivars was generally lower than within accessions. The range in mean genetic distances between landraces within localities was lower (0.462 ±0.11, to 0.615 ±0.10) than between different localities (0.405 ±0.05, to 0.758 ±0.06). There was no association between measures of variability based on morphological descriptors and SDS-PAGE data. Landraces, genetically variable and also with desirable agronomic features, have been identified from which pure lines can be selected and evaluated in future. Future crossing programmes between genetically distant landraces can be envisaged following evaluation of pure lines from landraces with desirable agronomic features (Figure 1).

Variability studies within farmers' dominant cultivars from central Ethiopia based on SDS-PAGE of seed storage proteins also corroborated results from quantitative data discussed earlier (Table 3). The overall genetic distance among lines for all landraces had a range of 0.000–0.943 with a mean of 0.574 ±0.13, while distances from pair-wise comparisons of lines within most of the farmers' cultivars did not exceed 0.666, except between some lines within Kessele that had dissimilarity up to 0.781 (Alemayehu Assefa, 2003). Moreover, mean genetic distance within farmers' cultivars was very low, with a range of 0.094–0.444, except for 'Kessele' and 'Key Ferke' with means of 0.587 and 0.519, respectively. Lines from 'Magie' and 'Netch Gebs' had genetic similarity (i.e. genetic distance = 0) in 60% of pair-wise comparisons, indicating their relative genetic uniformity compared with the others. Earlier investigation of hordein diversity (He) in 12 farmer cultivars, using ACID-PAGE, based on two loci, indicated He values in the range of 0.05 for 'Temeje' to 0.55 for 'Aruso 2'. 'Magie' and 'Netch Gebs 2' had very low He values, 0.12 and 0.38, respectively (Berhane Lakew, 1996) (Table 6). These results are supported by those of Alemayehu Assefa (2003). The association between the 12 landraces is shown in a dendrogram (Figure 2). Groups identified by the phenotypic diversity analysis were partially supported by the hordein analysis, and landrace 'Semereta 1' and 'Semereta 2' clustered in the same group, while 'Temeje' was distinctly separate from other landraces.

FIGURE 1
Frequency (%) distribution of genetic distance values among barley landraces from pair-wise comparisons resulting from SDS-PAGE of seed storage proteins

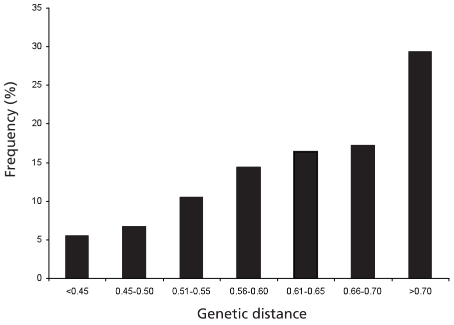
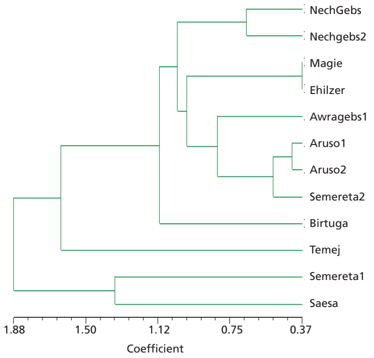


TABLE 6
Hordein diversity based on two loci of 12 landraces collected from different parts of Ethiopia

Farmers' cultivars	Sample size (n)	Ap	He
Netch Gebs 1	58	5.0	0.46
Semereta 1	60	3.0	0.31
Magie	60	2.5	0.12
Temeje	60	2.0	0.05
Netch Gebs 2	60	2.0	0.38
Awra Gebs	60	3.5	0.51
Aruso 1	60	4.5	0.50
Aruso 2	58	3.0	0.55
Ehilzer	60	3.0	0.31
Birtuga	58	3.5	0.43
Semereta 2	58	3.5	0.44
Saesa	60	2.5	0.11
Mean	–	3.2	0.35
Range	–	2.0–4.5	0.11–0.55

Notes: Ap = mean number of alleles per polymorphic locus; He = genetic diversity.

FIGURE 2
Dendrogram (average linkage) of genetic similarity among 12 landraces.



IMPLICATIONS FOR IMPROVEMENT OF BARLEY LANDRACES

The information from morphological, SDS-PAGE and ACID-PAGE studies can help in identifying selections for region-specific crossings among adapted landraces. The first step in utilization would be to dissolve landraces that are visually superior, and genetically heterogeneous as revealed by SDS-PAGE, into their components, by descent from single spikes, followed by evaluation of field performance to isolate the best lines. The subsequent step would be to identify parental lines with desirable agronomic traits from evaluation data, and to make crosses among distantly related parents. Such an approach will aid in predicting progeny performance and in estimating the degree of heterosis in the progeny of some parental combinations. Divergence for morphological traits *per se* may not reflect the true genetic distance between landraces. Hence, selection of parents for crossing should be supplemented with data from variability in hordein banding patterns to get the expected progeny variance. Since morphological traits greatly influence the attitude and preferences of farmers for a particular cultivar, their inclusion as selection criteria of crossing parents will incorporate traits of farmer interest. Careful evaluation and selection from very large samples within some farmer cultivars is required to make slight improvements in agronomic characters. However, progress through selection for yield and yield components within most of the farmer cultivars from this particular environment is unlikely.

GENETIC RELATIONSHIPS IN LANDRACES OF BARLEY

Five amplified fragment length polymorphism (AFLP) primer combinations were analysed to study the genetic relationships of 19 landraces (14 farmer cultivars and 5 accessions) where the farmer cultivars were those uniquely adapted to North Shewa, Ethiopia. Mean genetic distance between all materials tested was 0.567, with values ranging from 0.317 between accessions 1609 and 3391-15, to 0.745 between ‘Feres Gama’ and ‘Clipper’, a malting barley variety used as a check (Alemayehu Assefa, Labuschagne and Vilogen, 2007). Mean genetic distance between farmer cultivars in particular ranged from 0.372 to 0.728, with a mean of 0.545. Of the values in this range, 31% were ≤ 0.500 while 69% of the pair-wise comparisons had genetic distance values ≥ 0.600, demonstrating the presence of sufficient variation between the farmer cultivars. Among the farmer cultivars, ‘Demoye’ versus ‘Netch Gebs’, and ‘Netch Ferke’ versus ‘Key Ferke’, were the closest genetically, while ‘Feres Gama’ and ‘Netch Ferke’ were distantly related. It is interesting to see that all accessions from the same locality appeared in the same subgroup.

RESPONSE OF LANDRACES TO HIGH MOISTURE STRESS

Study on variability among farmers' barley cultivars (Alemayehu Assefa and Labuschagne, 2007) in response to waterlogging stress also revealed that differences were noticed in P concentration and uptake between the tolerant ('Magie') and susceptible ('Feres Gama') landraces. A difference in N concentration of the shoots between the tolerant and susceptible landraces was also observed, though not comparable to that observed for P.

TABLE 7

Passport data of the 30 landrace populations used for selection in 1989–1997

No.	Accession no.	Region	District	Elevation (masl)	Selected as bulk in
1	1633	Shewa	Angolela	2780	Sheno
2	1639	Shewa	Timbaro	2540	Sheno
3	1641	Shewa	Angacha	2410	Bekoji
4	1642	Shewa	Konteb	2570	Sheno
5	1644	Shewa	Konteb	2720	Holetta
6	1647	Shewa	Konteb	2800	Holetta
7	1659	Shewa	Kewet	2815	Holetta
8	1667	Shewa	Mama Midir	3000	Holetta
9	1671	Shewa	Kewet	3000	Holetta
10	1674	Arsi	Tiyo	2600	Bekoji
11	1721	Arsi	Tiyo	2500	Holetta
12	1726	Arsi	Gedeb	2580	Bekoji
13	1745	Shewa	Ambo Akababi	2720	Holetta
14	3285	Bale	Goba	2480	Holetta
15	3289	Bale	Adaba	2640	Sheno
16	3291	Bale	Adaba	2640	Holetta
17	3305	Arsi	Kofele	2570	Holetta
18	3333	Arsi	Guna	3000	Holetta
19	3336	Arsi	Guna	2915	Bekoji
20	3357	Arsi	Sude	2680	Holetta
21	3366	Arsi	Sude	2520	Holetta
22	3378	Arsi	Robi	2450	Holetta
23	3390	Arsi	Limu & Bilbil	2605	Holetta
24	3391	Shewa	Kimbebit	2920	Sheno
25	3410	Shewa	Sululta	2660	Holetta
26	3414	Shewa	Sululta	2670	Holetta
27	3426	Shewa	Ambo Akababi	2680	Bekoji
28	3447	Shewa	Dendi	2960	Holetta
29	3476	Gojam	Banja	2580	Holetta
30	3477	Gojam	Banja	2580	Holetta

ADVANCES IN BARLEY LANDRACE IMPROVEMENT

Since barley landraces are adapted to their specific growing environments, evaluation and selection targeted to exploit this specificity has gradually gained momentum, with many varieties with specific and wider adaptation released by national and regional centres. The first multidisciplinary concerted effort in landrace improvement in Ethiopia commenced in 1988, with 180 landrace populations retrieved from IBC. The populations were tested at three locations, namely Holetta, Sheno and Bekoji, using an unreplicated design and systematic checks with and without application of fertilizers (Berhane Lakew *et al.*, 1997). Based on reactions to diseases and pests and on agronomic evaluation on unfertilized plots, 60 populations were selected (Tables 7 and 10): 40 from Holetta, 10 from Sheno and 10 from Bekoji. Pure lines were extracted from each of the 60 selected populations by collecting 20 individual heads from each, giving a total of 1200 lines. The evaluation of the 1200 landrace-lines started in 1989 and continued until 1997, with a progressive reduction in the number of lines. There were two consecutive cycles of selection and three years of yield testing of the selected entries.

TABLE 8

Mean grain yield (kg/ha) in five locations of eight landrace lines, one mixture, three improved checks and the local landrace(1) during 1991–1993(2)

Material	Adet	Holetta	Sheno	Bekoji	Asasa	Mean
3357-10	2659	1080	3538	2116	3702	2619
3336-20	2810	1476	5050*(4)	2594	4236*	3193
3357-13	2864	1275	3711	2223	3685	2752
3336-03	2686	1179	4021	2086	3746	2744
3390-05	2300	1221	5208*	2485	3804	3004
3410-15	1877	1780	4153	1821	3588	2644
3410-09	1976	1788	3770	1758	3566	2571
3390-08	2358	1010	3883	1719	3843*	2562
3291-15	2159	1117	4794	2346	4034*	2890
Mixture(3)	2515	1663	4857	2264	3703	3001
Ardu-12-60B	2303	1291	5306*	2379	3589	2974
HB 42	2456	1450	4223	2270	4500*	2980
HB 100	2389	1593	4121	1816	4003*	2784
Local landrace	2410	1353	3993	2221	3102	2616
LSD (p<0.05)	704	654	984	704	671	–

NOTES: (1) The local landrace was different in each location. (2) Only two years in Sheno (1991 and 1992) and in Adet (1992 and 1993). (3) A mixture of two lines (3336-20 and 3390-05). (4) * indicates lines significantly different from the local landrace (*P*<0.05).

TABLE 9

Grain yield of three landrace-lines and the local landrace in five locations during 2–5 years of testing

Material	Location					
	Adet	Holetta	Sheno	Bekoji	Asasa	Mean
3336-20	2610	2163	4583**	2941*	4235**	3306**
3390-05	2300	1805	4630**	2474	3804	2982*
3291-15	2158	1796	4367*	2555	4034*	3003*
Local landrace	2409	1624	3552	2173	3102	2572
LSD (*P*<0.05)	479	706	638	625	746	330
LSD (*P*<0.01)	880	990	917	876	1129	443

NOTES: * = *P*<0.05; ** = *P*<0.01

The results of nine landrace-lines and one mixture selected from the first two cycles of selections, based on their yield potential, desirable agronomic characters and disease and insect resistance are shown in Table 8. The lines were extracted and advanced from the first 30 landrace populations. The nine landrace-lines, three improved checks and a local check were tested at five locations for three consecutive years. The four landrace-lines (3336-20, 3390-05, 3390-08 and 3291-15) significantly outyielded the local landraces, the first two in Asasa and Sheno, the third and the fourth only in Asasa. The four lines were significantly different from the best improved check, with the exception of 3390-05, which was significantly outyielded by HB 42 at Asasa. Only three of the four lines had a better average grain yield than the local check. The grain yield of these lines across the entire set of testing sites and years was compared with the local landrace (Table 9), which was a local check present in all trials, although different in each location. Line 3336-20 was superior to local landraces in all locations, based on consistently good performance, agronomic characters and adaptation. Line 3336-20 was released as 'Shege' for high altitude areas of Shewa and Arsi, and for similar ecologies.

TABLE 10
Passport data of the second 30 landrace populations used for the selection work in 1989–1997

No.	Accession no.	Region	Woreda	Elevation (masl)	Selected as bulk in
1	3232	Gojam	Banja	2460	Holetta
2	3284	Bale	Ginir	2480	Holetta
3	3371	Arsi	Sude	2500	Holetta
4	50	Arsi	Tiyo	2790	Holetta
5	1621	Shewa	Baso-na-Worena	2800	Holetta
6	1622	Shewa	Baso-na-Worena	2800	Sheno
7	3302	Arsi	Kofele	2640	Holetta
8	3304	Arsi	Kofele	2570	Holetta
9	3381	Arsi	Digelu-na-Ticho	2630	Holetta
10	3479	Gojam	Banja	2650	Holetta
11	1651	Shewa	Baso-na-Worena	2940	Holetta
12	1706	Arsi	Limu-na-Bilbila	2870	Holetta
13	1791	Shewa	Kewet	3000	Holetta
14	3295	Bale	Adaba	2450	Bekoji
15	3334	Arsi	Guna	3000	Bekoji
16	3296	Arsi	Kofele	2550	Sheno
17	3520	Gojam	Huletij-enese	2670	Sheno
18	3321	Arsi	Guna	3000	Sheno
19	3324	Arsi	Guna	2830	Sheno
20	3337	Arsi	Guna	2915	Sheno
21	1829	Shewa	Ambo	2430	Bekoji
22	3293	Bale	Adaba	2830	Bekoji
23	3385	Arsi	Digelu-na-Ticho	2535	Bekoji
24	1694	Arsi	Robi	2430	Holetta
25	1725	Arsi	Gedeb	2575	Holetta
26	1806	Shewa	Nono	2500	Holetta
27	3297	Arsi	Kofele	2630	Holetta
28	3353	Arsi	Sude	2580	Holetta
29	3369	Arsi	Sude	2520	Holetta
30	3379	Arsi	Digelu-na-Ticho	2535	Holetta

A set of 11 landrace lines promoted from the second set of 30 landrace populations (Table 10) were evaluated at six locations, with and without fertilizer. The lines were compared with two improved checks and a local check, the latter being different at each location. Mean grain yield, agronomic and disease data for the landrace lines were summarized (Tables 11 and 12). The results indicated that all lines had a positive response to fertilizer. However, some landrace lines, such as 3369-19, 3293-06 and 3369 (bulk), gave reasonable yields under non-fertilized conditions. Thus, these three lines, together with 3293-2, were promoted to on-farm cultivar trials. To this end, Researcher Managed and Farmer Implemented (RMFI) and Farmer Managed and Farmer Implemented (FMFI) food barley cultivar trials were conducted at Walmera and Degem in 1997–1999 with the participation of farmers (Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002; Fekadu Alemayehu, Berhane Lakew and Berhanu Bekele, 2002). The objective of the experiment was to evaluate and select acceptable food barley cultivars with the full involvement of farmers.

Mean grain yield and some agronomic trait performances of varieties tested in RMFI at both Walmera and Degem are presented in Table 13. Varietal differences for grain yield were significant at Walmera. Lines 3369 (bulk), 3293-2, 3369-19, 3293-6 and the local check had grain yields significantly higher than the standard

TABLE 11

Mean grain yield, agronomic and disease data of barley landrace lines tested at Bekoji, Asasa, Adet, Sheno and Ambo in 1994–1996, without fertilizer

Acc. No.	DH	DM	PH (cm)	SC (0–9)	NB (0–9)	SB (0–9)	LR (%)	HLW (kg/ ha)	TGW (g)	Yield (kg/ ha)	BM (t/ha)
3369 (bulk)	96	139	98	0.2	0.9	0.3	28	49.7	36.4	1931	1.2
3369-17	97	136	97	0.2	1.0	0.3	28	48.0	34.8	1840	1.2
3369-13	97	140	98	0.2	1.1	0.4	26	45.5	38	1849	1.3
3369-19	96	139	95	0.2	0.8	0.2	25	46.6	36.7	1907	1.2
3369-15	95	136	96	0.2	1.1	0.2	30	45.5	35.2	1789	1.1
3293-2	93	135	82	0.3	1.2	0.7	19	50.5	35.7	1822	1.1
3293-6	93	133	80	0.2	1.1	0.7	15	47.7	33.5	1918	1.0
3369-18	96	136	97	0.2	0.9	0.2	28	52.0	34.9	1819	1.2
3379-03	95	131	86	0.2	1.3	0.3	35	43.4	36.7	1388	1.0
3379-09	96	137	78	0.4	1.3	0.6	17	46.1	36.8	1736	0.8
3297-6	97	134	84	0.4	1.0	0.4	22	41.6	35.7	1858	1.1
Ardu- 12-60B	95	135	82	0.2	1.1	0.5	19	42.5	33.1	1639	0.9
HB 42	100	142	89	0.2	1.0	0.3	18	44.0	44	1675	1.1
Local check	93	131	90	0.9	1.3	0.4	31	44.0	36.2	1663	1.1
Mean	96	136	89	0.3	1.0	0.4	24	46.2	36.3	1774	1.1

NOTES: Acc. No. = Accession number; DH = days to heading; DM = days to maturity; PH = plant height (cm); SC = Scald (on a scale of 0–9); NB = Net blotch (on a scale of 0–9); SB = Spot blotch (on a scale of 0–9); LR = Leaf rust (%); HLW = hectolitre weight (kg/hL); TGW = 1000-grain weight (g); BM = biomass yield (t/ha)

TABLE 12

Mean grain yield, agronomic, and disease data of barley landrace-lines tested at Bekoji, Asasa, Adet, Sheno and Ambo in 1994–1996 with fertilizer

Acc. no.	DH	DM	PH (cm)	SC (0–9)	NB (0–9)	SB (0–9)	LR (%)	HLW (kg/ hL)	TGW (g)	Yield (kg/ ha)	BM (t/ ha)
3369 (bulk)	89	133	111	1.0	2.7	0.8	37.8	55.2	36.8	2558	1.8
3369-17	90	134	112	0.9	2.8	0.9	36.2	54.8	35.8	2505	1.8
3369-13	91	134	112	1.0	2.7	1.0	38.2	55.3	37.9	2557	1.8
3369-19	90	133	110	1.3	2.8	0.8	31.8	55.7	36.7	2618	1.8
3369-15	91	134	110	1.2	3.0	0.7	38.6	55.2	36.6	2519	1.9
3293-2	92	132	97	1.2	3.0	1.4	16.2	53.4	36.0	2654	1.4
3293-6	91	134	96	1.3	3.3	1.3	16.4	52.4	36.0	2597	1.3
3369-18	89	133	111	1.3	2.9	0.6	40.8	55.1	36.5	2618	1.8
3379-03	95	134	105	1.2	2.9	1.0	43.9	55.2	39.9	2188	1.7
3379-09	93	136	95	1.4	3.0	1.4	17.4	53.8	37.6	2494	1.4
3297-6	93	135	99	1.2	2.8	1.1	23.8	53.7	38.9	2566	1.3
Ardu-12-60B	92	135	100	1.1	3.0	1.0	25.8	55.2	37.1	2352	1.1
HB 42	95	140	103	1.0	2.4	1.0	19.3	55.1	45.4	2525	1.3
Local check	84	126	104	2.8	3.1	0.9	44.9	55.1	37.6	2385	1.5
Mean	91	134	105	1.3	2.9	1.4	30.8	54.7	37.8	2510	1.6

NOTES: Acc. No. = Accession number; DH = days to heading; DM = days to maturity; PH = plant height (cm); SC = Scald (on a scale of 0–9); NB = Net blotch (on a scale of 0–9); SB = Spot blotch (on a scale of 0–9); LR = Leaf rust (%); HLW = hectolitre weight (kg/hL); TGW = 1000-grain weight (g); BM = biomass yield (t/ha)

TABLE 13

Mean grain yield and agronomic characters of landrace lines in an on-farm trial with 41/46 N/P_2O_5 (F1) and without fertilizer (F0) at Walmera and Degem in 1997/1998.

Line	F0						F1				
	DH	DM	PH	TGW	BY	GY	DH	DM	TGW	BY	GY
					Walmera						
3369 (bulk)	83	124	103	46.0	48.9	15.5	78	120	41.6	91.1	23.7*
3293-2	83	124	81	44.0	36.7	10.9	78	120	43.6	68.9	20.7*
3369-19	83	123	103	45.6	46.7	16.4	78	119	41.6	88.9	19.7*
3293-06	90	125	65	24.0	18.9	9.7	78	121	42.8	73.3	25.2*
HB 379	82	124	83	45.2	35.5	10.1	77	120	44.0	57.8	18.9
Shege	83	124	77	43.6	45.5	13.8	77	120	40.0	44.4	24.6*
HB 42	87	130	80	50.4	33.3	13.2	81	125	50.0	51.1	16.2
Local Check	83	124	94	45.2	46.7	13.8	77	120	39.6	51.1	23.7
Mean	84	125	86	42.9	39.0	12.9	78	121	42.9	65.8	21.6
SE						0.7					0.7
LSD (*P*<0.05)						3.4					3.4
CV (%)						19.9					19.9
					Degem						
3369 (bulk)	65	147	101	37.6	32.2	6.6	62	141	40.6	46.7	16.2
3293-2	68	146	88	42.4	38.9	10.8	65	144	42.4	67.8	20.1
3369-19	65	147	101	42.0	32.2	11.7	62	143	37.6	52.2	11.8
3293-06	64	146	87	39.8	36.7	12.0	65	141	41.2	54.4	25.0
HB 379	66	147	100	39.0	35.5	10.4	62	141	42.0	53.3	21.9
Shege	66	146	97	41.8	56.7	14.6	69	141	42.2	61.1	24.0
HB 42	67	147	100	48.0	10.0	10.8	63	145	49.0	42.2	18.6
Local Check	64	140	95	40.7	28.9	9.3	62	140	43.2	48.9	13.0
Mean	66	146	96	41.4	37.6	10.8	64	142	42.3	53.7	18.8
SE						1.1					1.1
LSD (*P*<0.05)						NS					NS
CV (%)						39.5					39.5

NOTES: * = significantly higher than the value of the standard check (HB 42); NS = not significant; DH = days to heading; DM = days to maturity; PH = plant height (cm); TGW = 1000-grain weight (g); BY = biological yield (q/ha); GY = grain yield (q/ha).

check (HB 42) under fertilized conditions. Although there were no significant differences among varieties for grain yield under fertilized conditions, line 3369-19 gave higher grain yields than both checks. At Degem, there were no significant differences for grain yield among varieties. Nevertheless, line 3369-19 was released

The data for on-farm verification of food barley varieties tested in FMFI are shown in Tables 14 and 15. At Degem in both years, all improved varieties, including the local check, gave superior yields at all three sites under both high and low fertilizer conditions. In the 1998 crop season, the candidate variety, 3293-6, gave the highest yield, out-yielding the local cultivar and the standard check, respectively, by 40.9% and 12.6% with high fertilizer and by 44.4% and 10.6% under low fertilizer levels. Across sites and cultivars, grain yield increased by 26.7% due to increased use of fertilizer. In the 1999 crop season, the improved variety, 3369-19, gave the highest yield, out-yielding the local cultivar

TABLE 14
Mean grain yields (kg/ha) from the on-farm barley production-package verification trials at three sites in Degem, 1998–1999

Line	1998			1999			Across years		
	HM	LM	Increase	HM	LM	Increase	HM	LM	Increase
3369-19	2737	2100	30.3%	1619	1162	39.3%	2178	1631	33.5%
3293-6	3237	2580	25.5%	1540	1313	17.3%	2389	1947	22.7%
Shage	2874	2332	23.2%	1409	1007	39.9%	2142	1670	28.3%
Local	2298	1804	27.4%	1220	862	41.5%	1759	1333	32.0%
Mean	2787	2200	26.7%	1447	1086	33.2%	2117	1643	28.8%

NOTES: HM = High management; LM = Low management.

TABLE 15
Mean grain yields (kg/ha) from the on-farm barley production-package verification trial grown at three sites in Wolemera, 1999

Line	Management		Increase (%)
	High input	Farmer input	
3369-19	2002	1813	10.4
3293-6	1943	1365	42.3
Shage	1913	1619	18.2
Local	1384	1518	–8.8
Mean	1811	1579	14.7

and the standard check respectively by 32.7% and 14.9% at high fertilizer and by 34.8% and 15.4% at low fertilizer levels. Across sites and cultivars, grain yield increased by 32.2% due to increased use of fertilizer. Considering the results of both years, grain yield increased by 28.8% due to increased use of fertilizer. Similarly, at Walmera, all improved varieties performed better than the local check with increased use of fertilizer. The improved variety, 3369-19, gave the highest yield, out-yielding the local and the standard checks by 5.6% and 45.9%, respectively. Under farmer management, however, the improved variety 3293-6 performed poorly and the local check gave better grain yield. Across sites and varieties, grain yield increased by 14.7% due to improved management. Generally, the on-farm cultivar trials have progressed towards releasing the on-station technology development and variety selection work to help satisfy the diverse needs of small-scale farmers.

In all, eight improved landrace selections were released through this programme. Two of the landrace selections, 3336-20 (‘Shege’) and 3369-19 (‘Dimtu’) were released by HARC; the remaining six landrace selections were released by other barley research centres, although originally selected and advanced by HARC (Table 16). In general, this landrace evaluation programme confirmed that some individual genotypes within Ethiopian barley landraces have better yields and a more desirable expression of agronomic characters than the original landraces (Berhane Lakew *et al.*, 1997). Although ‘Shege’ was released nationally, its adaptation was restricted to certain environments and necessitated decentralized landrace evaluation and selection. Since 1993, 20 varieties have been released using such decentralized landrace improvement programmes (Table 16).

The results of this first systematic use of barley landraces justify the development of routine methodology to exploit the large collection of barley landraces available in IBC for barley improvement programmes. Usually, the samples available in the institute are bulks, i.e. a random sample of the genotypes originally present at a given collection site. The bulks should be first multiplied and then tested on a minimum of three contrasting sites. The best bulks should then be purified by extracting pure lines to be yield tested under farmers' field conditions, not only for grain yield but also for disease and insect resistance. Resulting superior pure lines can be used in three ways. First, they can be released as cultivars to achieve short-term yield increases. Second, they can be tested in mixtures to achieve higher yields combined with yield stability. Third, they can be used in a crossing programme as recipients of useful genes that might not be present in the adapted populations. This approach allows tapping fully the adapted genetic background of landraces and to add only those few genes that can improve them. Despite the release of many varieties, the utilization aspect is being questioned. There have been many pre-extension demonstration and popularization efforts, but there were no further scaling-up efforts. Moreover, farmers have different, locally adapted landraces, and obtaining seed of these improved varieties is not a priority. Hence, despite good acceptance of the varieties, their dissemination is restricted to the informal seed exchange system. Moreover, improvement efforts have still concentrated on optimum input conditions with no major shift from the past research endeavours that have been affecting adoption of improved varieties. Hence, landrace improvement targeted to the low input conditions that reflect the dominant barley production practices needs to be emphasized.

TABLE 16

Food barley varieties released from the landrace evaluation programme by national and regional research centres since 1993

No	Variety	Pedigree	Year of release	Releasing centre	Developed by
1	Agegnehu	218950-08	2007	Sirinka	Sirinka
2	Guta	3260-18	2007	Sinana	Sinana
3	Gabula	231222/MS	2007	Awassa	Awassa
4	Yedogit	BI95 IN198	2005	Sirinka	Sirinka
5	Dafo	(Aruso42) 4 (Sn99G)	2005	Sinana	Sinana
6	Biftu	Shasho#22GO-1(Sn98B)	2005	Sinana	Sinana
7	Shire	3297-06	2005	Kulumsa	Holetta
8	Dinsho	Wadago-4	2004	Sinana	Sinna
9	Estayish	218963-4	2004	Sirinka	Sirinka
10	Trit	215235-2	2004	Sirinka	Sirinka
11	Mulu	3371-03	2004	Adet	Holetta
12	Setegn	3369-17	2004	Adet	Holetta
13	Harbu	(Aruso Bale#10-1)	2004	Sinana	Sinana
14	Baso	4731-7	2004	Debre Berhan	Debre Berhan
15	Mezezo	4748-16	2004	Debre Berhan	Debre Berhan
16	Shedho	3381-01	2003	Sirinka	Holetta
17	Dimtu	3369-19	2001	Holetta	Holetta
18	Misrach	Kulumsa1/88	1998	Debre Berhan	Holetta
19	Abay	3357-10	1998	Adet	Holetta
20	Shege	3336-20	1995	Holetta	Holetta

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Response of barley landraces to low-moisture stress in a low-rainfall environment

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INTRODUCTION

Drought is one of the major production constraints that reduce crop yields in water-limited areas, where many of the world's poorest farmers live (Nguyen, Babu and Blum, 1997). This is a serious problem in arid and semi-arid regions, and in places where total precipitation is high but unevenly distributed through the growing season. As the world population continues to grow and water resources for crop production decline, development of drought-tolerant cultivars and water-use-efficient crops is a global concern. In the low-rainfall areas (<250 mm annual precipitation) of the Middle East (Acevedo *et al.*, 1991) and in most highlands of Ethiopia above 2700 masl, barley is traditionally the dominant crop.

Many famines have been reported in Ethiopia since the sixteenth century, of which 20 have received world attention (Menyonga, Taye Bezuneh and Anthony Youdeowei, 1986). These have occurred due to partial or total crop failures, caused by rainfall shortages in many parts of the country. In addition, recent reports indicate that about five million people in Ethiopia experience chronic food insecurity and ten million are vulnerable to food shortages every year. Before the 1980s, drought was most protracted in the northern and eastern regions of Ethiopia. However, the number of drought-affected areas has dramatically increased and now includes the most productive regions in the west and south.

Barley is the fifth most important crop in Ethiopia after teff, maize, wheat and sorghum. It is believed to have been cultivated in Ethiopia as early as 3000 BC (CSA, 2003). It is cultivated in a wide range of environments, from high altitude areas (>3000 masl) to low-rainfall environments, including the Rift Valley. A long history of cultivation, together with wide agro-ecological and cultural diversity in the country, has resulted in a large number of landraces of the crop, which can adapt to different environmental conditions. Among the important traits that could exist in the landraces are earliness, high nutritional quality, disease and pest tolerance, tolerance to drought and other forms of abiotic stress, and characters useful for low input agriculture.

The Institute of Biodiversity Conservation (IBC) has a collection approaching 16 000 barley landraces conserved in cold storage. Despite the availability of

TABLE 1

Origin of the 75 barley landraces collected from different parts of Ethiopia

Accession No.	Seed Colour	Province	Awraja	Woreda	Altitude (masl)
3538	Black & white	Arsi	Ticho	Robi	2415
232520	Brown	Arsi	Ticho	Amigna	2420
218994	White	Arsi	Chilalo	Sire	2390
218974	White	Arsi	Chilalo	Limu & Bilbilo	2740
218959	White	Arsi	Chilalo	Tiyo	2270
232447	Brown	Arsi	Chilalo	Tiyo	2200
230648	Black & white	Bale	Mendeyo	Agarfa	2320
230607	White	Bale	Mendeyo	Sinana	2330
217076	Brown & white	Bale			2810
230228	White	Eritrea	Akale Guzay	Dekemehare	1850
225205	White	Eritrea	Hamasen	Semen Hamasen	2270
230171	White	Eritrea	Hamasen	Semen Hamasen	1950
3608	Black	Gamogofa	Gardula	Gardula	1500
233036	White	Gamogofa	Gardula	Kemba	2580
233030	White	Gamogofa	Gardula	Banke	2030
202646	Black	Gamogofa	Gamo	Chencha	1790
64168	Black & white	Gamogofa			2960
236142	Black & white	Gamogofa		Chencha	2870
3532	White	Gojam	Mota	Hult Ij Inese	2600
4422	White	Gojam	Kola Dega Damot	Dega Damot	2430
3471	Black	Gojam	Kola Dega Damot	Dega Damot	1920
4427	Black & white	Gojam	Kola Dega Damot	Dega Damot	2450
4372	Black & white	Gojam	Kola Dega Damot	Dembecha	2220
3506	Black	Gojam	Kola Dega Damot	Dembecha	2100
3684	Black	Gojam	Debre Markos	Machkel	2030
4380	Black & white	Gojam	Agewe Midir	Banja	2540
3520	White	Gojam	Mota	Hulet Ij Inese	2670
Check(3514)	Black & white	Gojam	Mota	Hulet Ij Inese	2470
64195	Black	Gojam	—	—	2107
4145	Black	Gonder	Debre Tabor	Iste	2330
4164	Black & white	Gonder	Debre Tabor	Iste	2330
4173	White	Gonder	Debre Tabor	Iste	2230
4028	Black	Gonder	Gaynt	Lay Gaynt	3010
4190	Black & white	Gonder	Gaynt	Tach Gaynt	2400
3758	Black	Gonder	Chilga	Chilga	1972
206471	Black & white	Gonder	Wegera	Dabat	—
3720	Black & white	Gonder	Wegera	Dabat	2880
235739	White	Gonder	Wegera	Dabat	2600
4048	White	Gonder	Gaynt	Tach Gaynt	2400
3754	Black	Gonder	Gonder	—	2070
230505	White	Harargie	Harer Zuria	Jarso	2480
230506	White	Harargie	Harer Zuria	Jarso	2530
230507	White	Harargie	Harer Zuria	Jarso	2480
4281	Black & white	Harargie	Webera	Deder	2320
219174	Black & white	Harargie	Webera	Deder	2450
219130	Black & white	Harargie	Chercher & Adal Garra	Chiro	2500
232601	White	Harargie	Chercher & Adal Garra	Chiro	2090
230517	White	Harargie	Garamuleta	Grawa	2430
3612	Black & white	Kefa	Jimma	Afeta	1810

TABLE 1
Cont'd

Accession No.	Seed Colour	Province	Awraja	Woreda	Altitude (masl)
1672	Black & white	Shewa	Yerer and Kereyu	Shenkora	2390
237806	White	Shewa	Jibat & Mecha	Ambo	2360
1762	Black	Shewa	Jibat & Mecha	Jeldu	2900
1766	Black	Shewa	Jibat & Mecha	Jeldu	2730
3447	Black & white	Shewa	Jibat & Mecha	Dendi	2960
235096	White	Shewa	Menz & Gishe		3600
219589	Black & white	Shewa	Menagesha	Sululta	2560
1821	White	Shewa	Selale	Girar Jarso	2705
1785	Black & white	Shewa	Kembata & Hadiya	Konteb	2780
212943	Black	Shewa	Kembata & Hadiya	Konteb	2620
4732	Black & white	Shewa	Tegulet & Bulga	Ankober	3290
236404	White	Shewa		Gejo	2890
64006	Black & white	Shewa			3250
236147	White	Sidamo	Gedi-O	Fiseha Genet	2240
233053	Black & white	Sidamo	Gedi-O	Wenago	1850
238353	White	Tigray	Adwa	May Kental	1970
234308	White	Tigray	Adwa	Bizen	2130
237361	Black & white	Tigray	Agame	Hulet Belesa	2100
234301	Black & white	Tigray	Agame	—	2510
237365	White	Tigray	Axum	Axum	2150
4521	Black	Wellega	Horo Guduru	Haro Amuru	2700
4537	White	Wellega	Horo Guduru	Haro Amuru	2300
4495	Black	Wellega	Horo Guduru	Abay Chomen	2560
4556	Brown	Wellega	Leka	Diga	2240
4265	Black & white	Wollo	Were Himeno	Legambo	3330
236222	White	Wollo	Lasta	—	3270

many plant genetic resources, limited information means that plant breeders are not making adequate use of them to generate useful cultivars. Evaluation of barley landraces for morphological and disease resistance traits carried out by Endeshaw Bekele (1983, 1984), Mulugeta Negassa (1985) and Zemede Asfaw (1988, 1989) revealed regional differentiation in trait expression. However, there is no information on drought tolerance traits of Ethiopian barley landraces. This paper reports on the results of a trial carried out in 2004 to identify plant traits associated with high yield in a low-rainfall, semi-arid environment at Dera, in the Rift Valley of Ethiopia.

MATERIALS AND METHODS

A total of 583 landraces of barley collected from different parts of the country, whose ecologies varied in altitude, rainfall, temperature and soil type, were evaluated for drought tolerance at Dera, in the Rift Valley of Ethiopia, in the 2004 cropping season. The passport data of the drought-tolerant landraces is shown in Table 1. Dera has an altitude of 1500 masl, average annual rainfall of 400 mm, and is representative of the major drought-prone areas of the country, where recurrent drought with erratic rainfall is common.

TABLE 2

Number of rainy days, amount of rainfall received, and daily minimum and maximum temperature ranges during the cropping months at Dera

Month	Rainy days of the month	Rainfall (mm) and rainy days		Temperature range (°C)	
		Minimum	Maximum	Minimum	Maximum
July	2, 3, 5, 9, 13, 15, 19, 22, 30, 31	1 [15 July]	50 [13 July]	1–5	25–31
August	2, 4–9, 11, 12, 18, 19, 22, 24, 28, 29	1.5 [6 Aug]	25 [11 Aug]	4–7	18–25
September	1, 4, 5, 12–20	0.5 [20 Sep]	16 [18 Sep]	5–15	25–30

Each landrace was planted in a single plot of two rows 2 m long, with spacing of 20 cm between plants and 40 cm between plots. A combination of urea and DAP fertilizers was applied at planting. Of the landraces planted, only 75 survived the drought of 2004 and produced yield (Table 2). Data were collected for early plant growth vigour (GV), early ground cover (GC), number of days to ear emergence (DEE) and days to maturity (DM), number of matured tillers per plant (NT), grain yield per plot in grams (GY) and 1000-grain weight (TGW) on the drought-surviving landraces. At the 5–6 leaf-stage, plant growth vigour was scored visually on a 1–5 scale, where 1 = poor vigour and 5 = very good vigour; and ground cover was scored on a 1–10 scale, where 1 = 10% and 10 = 100% covering of the plot. The traits were recorded three times on each landrace at two-week intervals as described by Ceccarelli, Acevedo and Grando (1991). The daily precipitation and maximum and minimum temperatures of the site in July, August, and September 2004 were also recorded. Based on the means of the traits studied, the Pearson's correlation coefficients among the traits, the clustering of the landraces using the average linkage method, and principal components (PC) analyses were performed using SAS software. The data were standardized before computing clusters and PC analysis.

RESULTS AND DISCUSSION

Meteorological data

Daily rainfall and minimum and maximum temperatures data for July, August and September 2004 were obtained from the meteorological records of the Dera subcentre. There were 37 rainy days and a total rainfall of 300 mm received during the cropping months, of which 148.3 mm fell in July, 86.6 mm in August and 66.0 mm in September. The rainfall was erratic in distribution and decreased from July to September. The daily minimum temperature was lowest at 1°C in July and highest at 15°C in September. The maximum daily temperature was lowest at 18°C in August and highest at 30°C in September (Table 2).

Mean performances of traits

The drought-surviving landraces had different mean performances for the traits studied (Table 3). Number of days to 50% ear emergence were 36–59 (average 53 days); days to maturity were 78–102 (average 94 days); number of matured tillers per plant were 2–10 (average 5.4); grain yield was 14.4–310 (average 96.8 g per plot); and 1000-grain weight was 27.1–49.5 (average 40.6 g). However, the standard check had better early growth vigour and ground cover and higher tiller

TABLE 3

Means of traits of barley landraces tested for drought tolerance at Dera

Accession No.	GV	GC	DEE	DM	NT	GY	TGW
3538	3.3	74.2	44.0	83.0	10.0	310.0	48.3
232520	2.4	58.0	59.0	102.0	5.0	61.0	46.3
218994	1.8	50.3	50.0	87.0	7.0	78.1	42.6
218974	1.5	43.2	52.0	90.0	5.0	32.2	42.5
218959	1.9	57.0	53.0	90.0	4.0	89.9	43.2
232447	2.0	55.0	58.0	102.0	5.0	60.4	40.5
230648	2.5	58.0	59.0	102.0	4.0	78.1	45.8
230607	1.6	54.0	59.0	102.0	6.0	48.5	39.2
217076	1.9	51.2	49.0	87.0	4.0	47.2	42.6
230228	1.4	49.3	50.0	87.0	5.0	51.9	41.2
225205	1.9	54.0	56.0	102.0	5.0	106.7	37.5
230171	2.2	55.0	58.0	102.0	5.0	66.7	39.9
3608	2.2	60.0	54.0	90.0	5.0	161.7	43.2
233036	2.2	58.0	59.0	102.0	4.0	63.4	29.3
233030	1.5	41.0	59.0	102.0	3.0	39.4	32.0
202646	—	55.0	55.0	90.0	4.0	120.5	44.3
64168	2.2	58.0	54.0	90.0	4.0	125.7	38.0
236142	2.0	51.0	58.0	102.0	6.0	77.2	35.2
3532	3.1	75.5	36.0	78.0	8.0	261.5	40.5
4422	3.0	73.5	42.0	78.0	9.0	255.6	44.0
3471	1.1	32.0	54.0	90.0	4.0	27.7	43.2
4427	2.1	53.2	47.0	87.0	5.0	160.5	41.8
4372	2.8	65.0	43.0	80.0	6.0	171.0	47.3
3506	2.3	66.0	44.0	83.0	5.0	162.5	47.8
3684	2.5	60.1	45.0	85.0	7.0	193.1	45.6
4380	1.5	51.0	53.0	90.0	5.0	62.8	35.1
3520	2.3	59.0	59.0	102.0	5.0	58.7	38.7
Check	3.5	81.2	36.0	78.0	8.0	268.8	43.4
64195	1.1	29.0	56.0	100.0	7.0	14.4	39.3
4145	2.5	71.0	43.0	80.0	7.0	132.9	44.5
4164	2.6	63.2	45.0	85.0	8.0	194.2	42.3
4173	1.4	41.0	59.0	102.0	5.0	35.1	27.1
3754	2.6	66.3	45.0	85.0	8.0	118.1	43.2
4028	3.1	72.1	44.0	83.0	6.0	252.9	45.3
4190	2.0	49.5	50.0	87.0	5.0	84.7	43.5
3758	1.8	59.4	45.0	85.0	5.0	75.5	47.6
206471	1.6	46.7	52.0	90.0	4.0	52.1	43.2
3720	2.2	62.0	56.0	100.0	6.0	147.8	36.3
235739	1.9	45.0	59.0	102.0	5.0	45.0	36.5
4048	2.0	56.0	56.0	100.0	6.0	115.3	36.8
219130	2.8	66.0	57.0	102.0	6.0	203.7	49.5
230505	1.9	48.5	50.0	87.0	7.0	111.7	40.4
230506	2.6	61.0	59.0	102.0	4.0	96.2	37.2
230507	1.8	54.0	59.0	102.0	6.0	49.6	39.2
4281	2.7	66.0	54.0	90.0	6.0	207.5	43.6
219174	2.5	61.0	58.0	102.0	6.0	149.4	37.4
232601	1.8	39.0	57.0	102.0	5.0	39.0	35.0
230517	2.4	59.0	59.0	102.0	3.0	73.4	37.5
3612	1.8	52.0	55.0	90.0	5.0	100.1	41.7

TABLE 3
Cont'd

Accession No.	GV	GC	DEE	DM	NT	GY	TGW
1672	2.2	55.3	47.0	87.0	6.0	80.8	41.2
237806	1.6	46.5	51.0	90.0	3.0	51.1	49.1
1762	1.8	48.5	52.0	90.0	4.0	48.7	41.8
1766	1.6	50.0	54.0	90.0	3.0	67.9	42.6
3447	1.9	41.0	57.0	102.0	6.0	45.8	41.0
235096	1.2	39.0	58.0	102.0	6.0	31.5	37.4
219589	1.7	55.0	53.0	90.0	5.0	71.5	42.3
1821	2.5	66.0	53.0	90.0	7.0	170.0	41.5
1785	1.3	42.0	54.0	90.0	6.0	40.3	43.8
212943	2.0	55.0	58.0	102.0	7.0	100.2	31.8
4732	1.1	41.0	54.0	90.0	4.0	46.1	42.5
236404	1.6	32.0	58.0	102.0	6.0	28.1	41.0
64006	2.1	60.0	59.0	102.0	5.0	85.5	41.8
236147	1.9	52.0	59.0	102.0	6.0	45.3	38.0
233053	2.0	55.0	59.0	102.0	3.0	56.1	40.9
238353	1.5	29.0	58.0	102.0	5.0	20.0	29.5
234308	1.9	52.0	59.0	102.0	5.0	52.3	40.0
237361	2.1	60.0	58.0	102.0	5.0	142.5	32.5
234301	2.1	41.0	57.0	102.0	6.0	45.8	39.5
237365	1.7	38.0	59.0	102.0	5.0	28.3	34.4
4521	1.8	47.3	50.0	90.0	2.0	48.3	40.2
4537	1.6	51.0	54.0	90.0	4.0	62.9	42.0
4495	1.4	45.6	52.0	90.0	3.0	63.4	43.4
4556	1.9	54.0	54.0	90.0	5.0	116.4	43.4
4265	2.3	56.0	54.0	90.0	6.0	133.4	38.0
236222	1.9	53.0	59.0	102.0	6.0	46.1	38.5
Range	1.1–3.5	29–81.2	36–59	78–102	2–106	14.4–310	27.1–49.5
Mean	2.03	53.75	53.37	93.79	5.36	96.90	40.59
SD	0.516	10.735	5.793	7.910	1.467	66.815	4.561

NOTES: GV = early growth vigour; GC = early ground cover; DEE = number of days to ear emergence; DM = number of days to maturity; NT = number of matured tillers per plant; GY = grain yield (g); TGW = 1000-grain weight (g)

number (eight matured tillers per plant) than other landraces; additionally, it was the earliest to heading (36 days) and maturity (78 days). Only one landrace (accession 3538, a collection from Arsi) surpassed the standard check in number of tillers that reached maturity, grain yield per plot, and 1000-grain weight. Three landraces (accessions 4028, 4422 and 3532) had grain yield potential close to the check, with 3532 having the same heading and maturity time as the check. Eleven landraces (accessions 4422, 4145, 4372, 3506, 3538, 4028, 3758, 3684, 237806, 232520 and 230648) had better 1000-grain weight (44.0–49.1 g) than the standard check (43.4 g) (See Table 3).

Trait correlation

The strong positive correlation between grain yield and different traits helps to identify traits that can be used for indirect selection of high yielding cultivars. Yield is a complex trait, controlled by many genes (i.e. polygenic) and usually has low heritability. Hence, simple traits that have high genetic correlation with yield and high heritability could be used to select indirectly for yield. Correlation analysis showed that grain yield had a strong positive correlation (r = 0.59–0.84) with early growth vigour, early ground cover and number of matured tillers per plant (Table 4). However, grain yield was strongly negatively correlated with number of days to ear emergence and maturity (r = 0.53 and 0.58, respectively). Early growth vigour and ground cover were strongly positively correlated (r = 0.75) with each other and with number of tillers (r = -0.51 and -0.43, respectively). The other important trait, 1000-grain weight, had weak positive correlation with early growth vigour, early ground cover and grain yield (r = 0.24, 0.37 and 0.38, respectively). In contrast, it had strong negative correlation with number of days to flowering and maturity (r = -0.53 and -0.58, respectively) and non-significant correlation with number of matured tillers per plant.

TABLE 4

Pearson's correlation coefficient for seven traits of 75 barley landraces tested for drought tolerance at Dera in the 2004 season

	GV	GC	DEE	DM	NT	GY	TGW
GV	1.00	0.80**	–0.46**	–0.29*	0.51**	0.76**	0.24*
GC		1.000	–0.54**	–0.45**	0.43**	0.84**	0.37**
DEE			1.000	0.93**	–0.45**	–0.65**	–0.53**
DM				1.000	–0.30*	–0.56**	–0.59**
NT					1.000	0.59**	0.13
GY						1.000	0.38**
TKW							1.000

Notes: * significant at *P*<0.05; ** significant at *P*<0.01; GV = early growth vigour; GC = early ground cover; DEE = number of days to ear emergence; DM = number of days to maturity; NT = number of matured tillers per plant; GY = grain yield (g); TGW = 1000-grain weight (g).

Cluster analysis

Cluster analysis grouped the 75 landraces into three distinct groups (Table 5). The first cluster (CL1) consisted of 63 landraces, the second (CL2) of one landrace (a collection from Gamo Gofa) and the third (CL3) of 12 landraces (mostly from Gojam and Gonder). There was no definite clustering pattern of the landraces based on their geography of collection, except for the collections of Gojam and Gonder, that tended to be grouped into CL3 with one landrace from Arsi and one other from Hararge (Table 5). Only landraces from Arsi, Gojam and Gonder were grouped in CL1 and CL3. The majority of collections from different parts of the country grouped in CL1, indicating their similarities regardless of the area of collection.

The landraces in CL1 were characterized by high number of days to flowering and maturity; intermediate early growth vigour, ground cover and number of tillers that reached heading; and

TABLE 5

Clustering patterns of 75 barley landraces evaluated for drought tolerance at Dera in 2004

Origin	No. of accessions	No. of accessions in each cluster		
		CL1	CL2	CL3
Arsi	6	5	—	1
Bale	3	3	—	—
Eritrea	3	3	—	—
Gamo Gofa	6	5	1	—
Gojam	11	5	—	6
Gonder	11	7	—	4
Harargie	8	7	—	1
Kefa	1	1	—	—
Shewa	13	13	—	—
Sidamo	2	2	—	—
Tigray	5	5	—	—
Wellega	4	4	—	—
Wollo	2	2	—	—
Total	75	63	1	12

low grain yield and 1000-grain weight (data not shown). The landrace in CL2 was characterized by intermediate early ground cover, number of days to flowering and maturity, grain yield and 1000-grain weight; and low early growth vigour and number of tillers that reached heading. The landraces in CL3 were characterized by high early growth vigour, early ground cover, number of tillers, grain yield and 1000-grain weight; and low number of days to flowering and maturity. The landraces in CL3 are the most important in low rainfall areas as they have early maturity, with high grain yield and 1000-grain weight (Table 5).

Principal component analysis

Principal component analysis showed that the first principal component (PC1) explained 59% of the total variation of the traits in landraces, PC2 explained 19%, and PC3 10% (Table 6); thus, PC1, PC2 and PC3 together explained 89%. PC1 represented all traits, indicating that all contributed equally to variation in the landraces; this PC contrasted early growth vigour, early ground cover, number of tillers that headed, grain yield and 1000-grain weight with days to ear emergence and days to maturity. PC2 also represented all the traits and contrasted 1000-grain weight with the other traits. PC3 represented number of tillers and contrasted this with the other traits.

DISCUSSION

About 70% of the land mass of Ethiopia is prone to low rainfall, and genetic improvement for grain yield of different crops under this constraint has been very slow. In this study at the Dera sub-centre, there was very little or no precipitation for 17 days after the first rain in July, for 15 days after 19 August 2004, and no rain after 20 September 2004. Shortage and uneven distribution of rainfall at the centre, sandy loam soils and high maximum temperature, especially towards the end of the growing season, created a progressively severe intermittent and terminal drought that damaged most barley landraces at booting and grain-filling stages.

TABLE 6

The eigenvalues and eigenvectors of the correlation matrix for seven traits of 75 barley landraces tested for drought tolerance at Dera in 2004

Principal component	Eigenvalue	Eigenvector						
		GV	GC	DTF	DTM	NT	GY	TGW
1	4.15 (59%)	0.38	0.41	–0.42	–0.38	0.31	0.44	0.28
2	1.29 (19%)	0.43	0.26	0.33	0.49	0.33	0.21	–0.49
3	0.69 (10%)	0.27	0.40	0.27	0.20	–0.70	0.06	0.39
4	0.47 (7%)	–0.02	–0.15	0.30	0.32	0.51	–0.09	0.72
5	0.22 (3%)	–0.73	0.38	0.27	–0.02	0.06	0.49	–0.03
6	0.13 (1%)	0.14	–0.66	0.07	0.06	–0.19	0.71	0.04
7	0.04 (0.6%)	0.20	–0.05	0.69	–0.68	0.08	–0.08	–0.05

NOTES: Eigenvalues are the variances of the principal components and the values in parentheses are the percentage of total variance explained by the particular principal component. The eigenvectors give the coefficients of the standardized variables. GV = early growth vigour; GC = early ground cover; DTF = number of days to flower; DTM = number of days to maturity; NT = number of headed tillers; GY = grain yield (g); TGW = 1000-grain weight (g).

These harsh conditions contributed to identification of traits associated with high yield in a low-rainfall environment.

For the landraces that survived the drought there was strong negative correlation between number of days to ear emergence and maturity, and grain yield. Therefore, early heading and maturing (i.e. drought escape) were the major elements in drought tolerance for the 75 barley landraces at the site, followed by early growth vigour, early ground cover and number of heading tillers. All landraces that survived the drought and produced yield were those that matured before the terminal drought appeared. The landraces that gave grain showed great diversity in the traits that contributed to higher yield in the low-rainfall environment.

CONCLUSION

In the low-rainfall environment of the Mediterranean climatic region, traits useful to evaluate barley genotypes for drought tolerance and high yield are: growth vigour, days to 50% ear emergence, maturity date, harvest index, peduncle length, plant height and straw yield (Acevedo *et al.*, 1991; van Oosterom and Acevedo, 1992). However, there is great variability for these traits in indigenous barley landraces (Acevedo *et al.*, 1991). The physiological reasons why these traits should be associated with high yield in low rainfall environments were well established in physiological studies (Brown *et al*., 1987; Cooper *et al*., 1987).

For many years, it has been observed that even intermittent low-water stress at critical stages (the major phenomenon in the growing season for most crops in the low and medium altitude agro-ecologies of Ethiopia) can considerably reduce yield or lead to failure of the cereal crops that provide the major carbohydrate staples. Terminal drought at the grain-filling stage is also very common in most crops in the Rift Valley, and in the semi-arid and arid areas of the north and east of the country. Therefore, drought tolerance should be a major goal in barley breeding programmes in the drought-affected areas of Ethiopia. In this particular experiment, some barley landraces performed well and produced yield under low rainfall conditions at Dera, indicating the importance of evaluating more of the barley landraces present at IBC to identify potential drought-tolerant lines, and for those genes to be incorporated into popular varieties. However, improvement of drought tolerance is a very difficult task (Altinkut *et al.,* 2001). Complex physiological responses to drought, various environmental factors, and their interactions, have slowed the development of improved cultivars for drought-prone environments. Unpredictability of drought conditions in the field and the diversity of tolerance strategies developed by plants further complicate efforts to understand drought tolerance (Teulat *et al.,* 1997). An extensive study of the quantitative trait loci (QTLs) controlling the genetic variation has led to new breeding methodologies using molecular marker-assisted selection (MAS). Therefore evaluation of landraces of barley for genetic traits that are likely indicators of tolerance to drought under different environmental conditions in Ethiopia has to be focused to better understand drought tolerance in the Ethiopian barley gene pool. To facilitate further study of the Ethiopian barley collections, the following activities are proposed: (1) characterization and purification of the mixed collections; (2) evaluation of the landrace collections in drought-prone and ideal environments; (3) study of the traits that have strong correlation with high yield in drought-prone and ideal environments; (4) calculation of correlations between residual yield and drought susceptibility indices; and (5) continuous study of the QTLs controlling the drought-tolerance traits in drought-tolerant barley with the help of molecular markers to assist in understanding the genetic bases.

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Response of exotic barley germplasm to low-moisture stressed environments

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INTRODUCTION

Barley is an important crop in Ethiopian cereal production and in food security (Berhanu Bekele, Fekadu Alemayehu and Berhane Lakew, 2005). Barley is currently the fifth most important cereal crop, covering over one million hectares of land (CSA, 2007). It is grown both in *Meher* (June–October) and *Belg* (February–May) seasons. *Meher* production in the country is categorized into early, intermediate and late production systems. The contribution of the early production system is estimated to be 25% of total barley production. Although barley is considered a highland crop, it is also among the major cereal crops grown in the low rainfall areas of the country, which are part of the early production system. In such areas, the availability and distribution of rainfall during crop growing seasons is the major factor limiting yield. Early ear emergence is the most important feature of barley adaptation to the low moisture areas and is common in Ethiopian landraces from these areas. Thus, the farmers in drought-prone areas grow their own landraces that are well adapted to their environments, but with poor yielding ability. Hence, it was considered essential that barley productivity in low moisture areas be improved to increase the contribution of this system to overall barley grain production.

A critical shortage of improved barley varieties adapted to low-moisture stress conditions is a major problem and hence farmers are forced to grow low yielding genotypes. The germplasm sources for the improvement of barley have been landraces, exotic germplasm, and genetic variability created locally through hybridization. However, for the most part, it has been difficult to obtain genotypes from landraces that could perform better under low-moisture stress conditions. Therefore, the breeding programme has relied mostly on germplasm introduced from exotic sources, particularly from the International Centre for Agricultural Research in the Dry Areas (ICARDA). To date, >1700 genotypes from ICARDA have been evaluated in low moisture conditions and a number of genotypes and lines with the desired characteristics have been identified. Some of these genotypes are now at different stages of variety development and several varieties have been released. This paper describes the genotype-by-environment (G×E) analysis of some of these promising genotypes.

MATERIALS AND METHODS

Two sets of experiments were conducted at three locations in Arsi (Dera and Asasa) and West Arsi (Arsi Negele). Experiment 1 was carried out in 10 environments, with nine genotypes introduced from ICARDA and one local variety, 'Aruso'. The experiment was a randomized complete block design (RCBD) with three replications. Data were available for years 2001–2004 for all locations except Arsi Negele in 2001 and Dera in 2002. Experiment 2 was carried out in nine environments (location × year combinations) with 16 genotypes from ICARDA and local variety 'Aruso'. The experiment was a RCBD with four replications, with data available for 2004–2006. The descriptions of environments for Experiments 1 and 2 are given in Tables 1 and 2, respectively. For both experiments, the plot sizes were 3 m^2 (six rows with 20-cm spacing and 2.5 m long). The central four rows were harvested from each plot to determine grain yield and 1000-grain weight. Then yield was adjusted to 12.5% moisture and converted to t/ha. Additional data on days to heading and maturity, hectolitre weight, and plant height were also recorded.

TABLE 1

Description of the environments (location × year combinations) for Experiment 1

Label	Site	Area	Year	Rainfall (mm) received			
				June	Sept.	Oct.	June–Oct.
A	E1	Asasa	2001	73.8	53.9	0.0	445.5
B	E2	Dera	2001	85.9	88.8	17.2	664.9
C	E3	Asasa	2002	38.0	34.7	8.8	329.8
D	E4	Arsi Negele	2002	82.6	54.6	10.7	451.0
E	E5	Asasa	2003	61.2	95.0	6.7	330.5
F	E6	Dera	2003	54.7	108.9	0.0	425.2
G	E7	Arsi Negele	2003	87.5	85.4	13.0	358.9
H	E8	Asasa	2004	73.4	30.7	5.3	328.0
I	E9	Dera	2004	22.2	58.8	40.5	356.5
J	E10	Arsi Negele	2004	132.3	213.0	82.9	712.5

TABLE 2

Description of the environments (location × year combinations) for Experiment 2

Label	Site	Area	Year	Rainfall (mm) received		
				June	Sept.	June–Oct.
1	E1	Asasa	2004	73.4	95.0	328.0
2	E2	Dera	2004	22.2	58.8	356.5
3	E3	Arsi Negele	2004	132.3	213.0	712.5
4	E4	Asasa	2005	92.7	30.7	344.3
5	E5	Dera	2005	100.7	108.7	417.9
6	E6	Arsi Negele	2005	136.6	175.5	514.9
7	E7	Asasa	2006	89.0	85.4	444.0
8	E8	Dera	2006	49.7	82.5	408.9
9	E9	Arsi Negele	2006	114.0	124.0	510.5

Combined analysis of variance (ANOVA) for yield was done after testing for homogeneity of variance. Further analyses were done for parameters such as the stability parameters of Eberhart and Russell (1966) and stability variance (sh-σ^2) of Shukla (1972). Additive Main Effects and Multiplicative Interactions (AMMI) analysis was also done. Using SPSS v13.0 for Windows software, correlation coefficients were estimated for Interaction Principal Component Axes (IPCA) 1 and mean yield of genotypes with days to heading, days to maturity, 1000-grain weight, hectolitre weight and plant height. Similarly, correlation coefficients were determined for IPCA1 and mean yield for environments with rainfall data.

RESULTS AND DISCUSSION

Experiment 1

The three effects of genotypic, environmental and genotype ×

environment (G×E) interaction were highly significant ($P<0.01$) in the combined ANOVA (Table 3); these three effects were highly significant ($P<0.001$) in AMMI analysis also. This indicated variability in performance among genotypes and the differential response of genotypes to the varying environments. Thus, it is important to further study G×E interaction to identify stable and high yielding genotypes.

Entries #3, #2 and #4 were high yielding genotypes (4.32, 4.09 and 4.08 t/ha, respectively; Table 4). However, G×E interaction could hamper selection of consistently high yielding genotypes based on mean yield *per se* (Kang and Magari, 1996). Stability variance revealed the importance of genotypes in Entries #5, #6 and #2 (sh-σ^2 = 0.14, 0.15 and 0.18, respectively). Entry #2 possessed both stability and better yield performance. Entry #3 (sh-σ^2 = 1.14) was relatively less stable, yet it was an important genotype based on mean yield.

A stable genotype should have slope (b) and s_d^2 not significantly different from 1 and 0, respectively (Eberhart and Russell, 1966). If this combines with high mean yield, that genotype could be considered suitable for wider cultivation. Thus Entry #2 had non-significant b (1.08) and s_d^2 (0.01) with high mean yield (4.09 t/ha), indicating stability and better yield performance. Entry #9 was also among the most stable genotypes with b (0.94) and s_d^2 (0.04), but with the lowest mean yield (3.28 t/ha).

In AMMI analysis, only three IPCAs were highly significant ($P<0.001$) and contributed about 86% of the G×E interaction (Tables 3 and 5). The first IPCA alone contributed 49.4% of the interaction effect. Entries #6, #2 and #1 (IPCA1 = -0.026, -0.032 and 0.056, respectively) were the genotypes that contributed little to G×E interaction (Table 4). The bi-plot also indicated relatively high stability of these genotypes (Figure 1), which were located near the x-axis in the bi-plot. Entry #2 was also associated with significantly higher grain yield (4.09 t/ha) compared with the grand mean (3.76 t/ha), while the other two entries gave average yield. The local variety ‘Aruso’ and Entry #3 (IPCA1 = 1.384 and –0.811, respectively) contributed more to the G×E interactions. In general, Entry #2 was identified as an adaptable genotype and was released in 2006 with the name ‘Bentu’.

Among the environments, three (F, J, and G) had small IPCA1 scores (IPCA1 = 0.055, –0.065 and –0.086, respectively) and hence contributed little to total G×E interaction (Table 6). The rain in F (Dera in 2003), G (Arsi Negele in 2003) and J (Arsi Negele in 2004) was distributed evenly during the growing season and is the most probable reason

TABLE 3

Combined ANOVA and AMMI analyses for Experiment 1

Sources of variation	DF	MS
Combined Analysis		
Genotypes (G)	9	3.57**
Environment (E)	9	58.07**
G×E	81	0.62**
Error	180	0.15
AMMI Analysis		
Total	299	
Environments	9	58.1***
Replications	20	0.21
Genotypes	9	3.57***
G×E	81	0.62***
IPCA1	17	1.46***
IPCA2	15	0.71***
IPCA3	13	0.59***
IPCA Residuals	36	0.194
Residual	180	0.15

Grand Mean = 3.76 CV = 10.35 R^2 = 0.96

NOTES: *, **, and *** indicate $P<0.05$, 0.01 and 0.001, respectively. DF = degrees of freedom; MS = mean square

TABLE 4
Stability parameters for the 10 genotypes tested in Experiment 1

Entry	Label	Genotype	Mean yield (t/ha)	sh-σ^2	IPCA1 Score	S_{d2}	b
1	a	EMBSN 37/96-1-1-1	3.65	0.26	0.059	0.05	0.96
2	b	EMBSN 5th 2/95-3-3-3	4.09	0.18	–0.032	0.01	1.08
3	c	EMBSN 5th 36/95-8-8-4	4.32	1.14	–0.811	0.15**	1.28*
4	d	EMBSN 5th 46/95-9-9-5	4.08	0.60	–0.360	0.12**	1.12
5	e	EMBSN 28/96-17-17-7	3.87	0.14	0.148	0.01	0.94
6	f	EMBSN 22/96-24-24-9	3.87	0.15	–0.026	0.02	1.00
7	g	EMBSN 1/96-41-41-13	3.52	0.51	–0.228	0.12**	1.04
8	h	EMBSN 43/96-42-42-14	3.63	0.56	–0.268	0.09**	1.15
9	i	EMBSN 9/96-43-43-15	3.28	0.27	0.136	0.04	0.94
10	j	Local check	3.31	2.37	1.384	0.14**	0.50*
		Mean	3.76				
		LSD ($P<0.05$)	0.20				

NOTES: * and ** indicate $P<0.05$ and 0.01, respectively.

TABLE 5
Contribution of each IPCA to the G×E interaction for Experiment 1

IPCA Axis	Eigen value	G×E explained (%)	Cumulative (%)
1	8.247	49.4	49.4
2	3.547	21.3	70.7
3	2.563	15.4	86.1
Other IPCAs	2.326	13.9	100

TABLE 6
IPCA1 scores and mean grain yields for environments

Label	Environment	Year	IPCA1 scores	Mean yield (t/ha)
A	Asasa	2001	–0.699	4.5
B	Dera	2001	0.333	2.3
C	Asasa	2002	1.122	1.7
D	Arsi Negele	2002	–0.447	4.4
E	Asasa	2003	–0.123	4.8
F	Dera	2003	0.055	3.5
G	Arsi Negele	2003	–0.086	4.7
H	Asasa	2004	–0.670	5.4
I	Dera	2004	0.580	1.7
J	Arsi Negele	2004	–0.065	4.7

for small IPCA1 values for these environments. Conversely, three environments (all Asasa; C in 2002, H in 2004 and A in 2001) contributed greatly to total G×E interaction. In the three environments, rainfall in September was relatively low (Table 1), indicating a high frequency of terminal crop growth stage moisture stress at Asasa. Environments F and G were located near the x-axis while A, C and H were far from the x-axis on the bi-plot (Figure 1). Only rainfall in September was significantly correlated with absolute value of IPCA1 score for environments (r = –0.716**; Table 7). Environments F, J and G (small contributors to G×E) received much rain in September, while C, H and A (large contributors to G×E) received little rain in this month (Tables 1 and 6). June rainfall was the most important in determining yield (r = 0.605*), while the correlation between rainfall in September and mean yield was non-significant (r = 0.222). Hence, June and September rainfall was particularly critical for barley production in low moisture areas, determining early seedling growth and grain filling. Total growing-season rainfall, however, was not important in explaining either differences in mean yields or G×E interactions.

Mean yield for genotypes was negatively correlated with 1000-grain weight (r = -0.579*) (Table 7). This negative correlation was primarily due to the composition of the genotypes, with both six-row and two-row types included in the study. Two-row types are usually associated with heavy kernels but low yield; and the opposite is generally true for six-row types. The absolute value of genotypic IPCA1 was in particular positively correlated with days to heading, days to maturity and 1000-grain weight (r = 0.741**, 0.723** and 0.747**, respectively). Earliness is an important factor for adaptation to low-moisture areas (Ashley, 1999). This study also indicated the importance of earliness in genotypes in determining G×E interaction.

FIGURE 1

AMMI bi-plot (x-axis = mean grain yield and y-axis = IPCA1 for genotypes and environments). Genotypes are plotted a–j, and environments plotted A–J. Genotype g and environment J in place of others with similar means are not shown

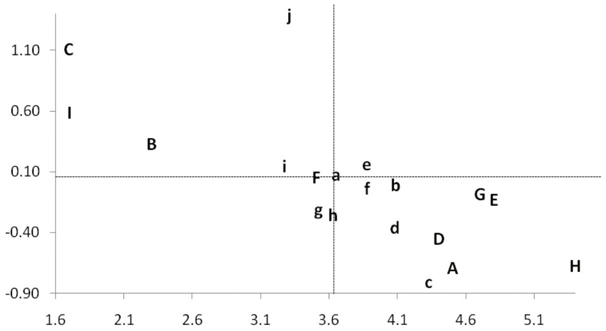


TABLE 7

Correlation of mean yield and IPCA1 with environmental and genetic factors

Variable type	Variable name	Mean yield	IPCA1
Experiment 1			
Environmental	Rainfall (June)	0.605*	–0.515
Environmental	Rainfall (September)	0.222	–0.716**
Environmental	Rainfall (June–October)	0.018	–0.382
Genetic	Days to heading	–0.400	0.741**
Genetic	Days to maturity	–0.051	0.723**
Genetic	Hectolitre weight	–0.513	0.070
Genetic	1000-grain weight	–0.579*	0.747**
Experiment 2			
Environmental	Rainfall (June)	0.539	0.097
Environmental	Rainfall (September)	0.291	0.062
Environmental	Rainfall (June–October)	0.295	–0.303
Genetic	Days to heading	–0.468	–0.014
Genetic	Days to maturity	0.346	–0.051
Genetic	Plant height	–0.634*	–0.315
Genetic	1000-grain weight	–0.527*	–0.519*

NOTE: * and ** indicate $P<0.05$ and 0.01, respectively; environmental mean yield and IPCA1 are correlated with rainfall data, while genotypic mean yield and IPCA1 are correlated with genetic factors.

Experiment 2

The combined ANOVA indicated highly significant ($P<0.01$) genotype, environment and G×E effects (Table 8), with AMMI analysis showing similar results. The significance of genotypic effect is an indication of performance difference among genotypes. For instance, Entry #13 was the highest yielding of the tested genotypes with 4.41 t/ha, while local check ‘Aruso’ was the lowest yielding, with 3.31 t/ha (Table 9). In addition to Entry #13, five genotypes (Entries #9, #7, #11, #4 and #6) gave mean yields >4.0 t/ha. Since G×E was significant, it is difficult to recommend genotypes based on mean yield *per se*; rather it is important to examine stability of performance of genotypes over environments.

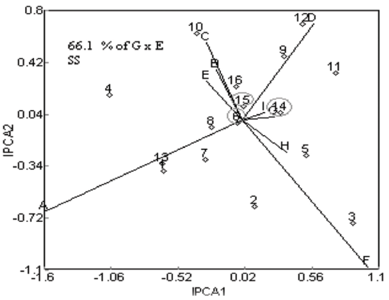
In AMMI analysis, the first three interaction principal component axes (IPCAs) were highly significant (Table 8) and accounted for 81.6% of the G×E interaction. IPCA2 captured about 66% of the G×E interaction (Figure 2). Based on the first

TABLE 8
Combined ANOVA and AMMI analyses in Experiment 2

Source	DF	MS
Combined Analysis		
Genotypes (G)	8	127.1**
Environments (E)	15	5.5**
G×E	120	1.3**
Error	405	0.5
AMMI Analysis		
Total	299	
Environments	9	127.1***
Replications	27	2.3
Genotypes	15	5.5***
G×E	120	1.3***
IPCA1	22	3.4***
IPCA2	20	1.5***
IPCA3	18	1.3***
IPCA Residuals	60	0.5
Residual	405	0.5
Grand Mean = 3.72	CV = 18.67	R2 = 0.87

NOTES: *, **, and *** indicate $P<0.05$, 0.01 and 0.001, respectively. DF = degrees of freedom; MS = mean square

FIGURE 2
IPCA1 by ICPA2 biplot for genotypes and environments



IPCA, Entries #15, #16, #6 and #2 were among those that contributed little to G×E (Table 9); of these, only Entry #6 was one of the high yielding genotypes discussed above. The IPCA1 by IPCA2 bi-plot indicated little contribution of Entries # 6, #15, # 8 and #14 (Figure 2). Environments labelled as G–I (Asasa, Dera and Arsi Negele, respectively, all in 2006,) also contributed little to G×E interaction (Figure 2). According to sh-σ^2, Entries #15, #6, #14 and #16 (0.150, 0.294, 0.427 and 0.691, respectively) were the most stable of the genotypes tested (Table 9). Entry #6 was among the six top yielding genotypes, with mean yield of 4.03 t/ha. The deviations from regression (s_d^2) values of seven genotypes (Entries #1, #3, #4 and #10–#13) were significantly different from 0, i.e. their response could not be described. Conversely, Entries #6, #7 and #9 (b = 1.058, 0.918 and 0.992, respectively) were the most stable genotypes, with high mean yields (4.03, 4.10 and 4.13 t/ha, respectively). Entry #6 was the most stable genotype using the stability parameters of Eberhart and Russell (1966) and Shukla (1992) for cultivation over a range of environments in the low-moisture areas under study.

Both mean yield and IPCA1 for genotype were negatively correlated (–0.527* and –0.519*, respectively) with 1000-grain weight (Table 7). Similarly, plant height was negatively correlated with mean yield (–0.634*). In this study, the 1000-grain weight and plant height were important in explaining both genotypic variation and the G×E interaction.

CONCLUSION

From the first set of experiments of 2001–2006, Entry #2 was released as 'Bentu' for its stable and better yield performance in the low-moisture areas. Similarly, Entries #6, # 7 and #9 were identified as stable and high yielding among the 16 genotypes evaluated in 2004–2006. These genotypes were expected to be released in the near future to improve productivity in the low-moisture areas of Ethiopia. The study also indicated the importance of rainfall in June and September to barley production in the low-moisture areas, as they affect early seedling growth and grain filling, respectively. Moreover, earliness in heading and maturity were also crucial for the adaptation of barley to such conditions.

TABLE 9

Stability parameters for the 10 genotypes tested in Experiment 2

Entry	Genotype	Yield (t/ha)	Sh- σ^2	S_d^2	b	IPCA1
1	EMBSN 36/94	3.51	1.362	2.546*	1.001	–0.611
2	EMBSN 7/96	3.97	1.102	1.972	0.913	0.095
3	7th EMBSN 28/98	6.56	3.326	5.736**	1.125	0.900
4	EMBSN 37/96	4.03	2.991	5.252**	1.096	–1.088
5	7th EMBSN 14/98	3.53	1.073	1.609	1.165	0.514
6	7th EMBSN 18/98	4.03	0.294	0.625	1.058	–0.050
7	7th EMBSN 19/98	4.10	0.950	1.718	0.918	–0.299
8	7th EMBSN 20/98	3.21	0.877	1.147	0.814	–0.254
9	26th IBON 83/98	4.13	0.850	1.649	0.992	0.306
10	7th EMBSN 31/98	3.83	1.374	2.567*	0.996	–0.369
11	7th EMBSN 44/98	4.04	1.555	2.877**	1.022	0.728
12	7th EMBSN 45/98	3.48	1.625	2.365*	0.799	0.483
13	7th EMBSN 48/98	4.41	2.232	2.929**	1.268	–0.657
14	7th EMBSN 8/98	3.23	0.427	0.797	1.084	0.310
15	7th EMBSN 41/98	3.39	0.150	0.345	0.929	0.003
16	local check	3.13	0.691	0.868	0.822	–0.011
	Mean	3.72				
	LSD (*P*<0.05)	0.32				

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Achievements of food barley breeding research in North Shewa in the Amhara Region

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INTRODUCTION

Barley is a crop of temperate climates and thrives best where seasons are cool and moderately dry. It grows best on a well-drained fertile loam or light clay soil (Derr, 1911; Carleton, 1916; Harlan, 1925). In Ethiopia, it is predominantly grown at altitudes of up to 3000 masl, where few other crops can be grown. In the highlands of North Shewa, food barley is a dependable source of food. Although there is immense genetic variability in Ethiopian barley landraces, productivity is still very low due to various yield-limiting factors. Barley breeders have been screening a great volume of breeding material against the existing yield-limiting factors in high-potential barley production areas in North Shewa of the Amhara Region.

In eastern parts of the Amhara region, including North Shewa, *Belg* (February–May) production of crops is common. The *Belg* season is characterized by low and erratic rainfall; nevertheless, farmers rely on *Belg* rain to grow crops such as barley. The *Belg* barley production is constrained by more biotic and abiotic factors than the *Meher* (June–October) barley system. The interaction of these factors complicates the identification of the main effects of each stress and hinders the acquisition of clear information on germplasm potential. The complexity of genotype-by-environment interaction forces breeders to use various germplasm sources to examine many of them against the existing yield-limiting factors, including both concomitant and intermittent drought. Divergence analysis has to be performed on such germplasm to identify the diverse genotypes. Clustering using D^2 statistics is useful in this matter because genotypes clustered together are less divergent than those that fall into different clusters.

To develop varieties suited to the *Belg* environment, research efforts have been made to exploit landrace variability. This had been done during the *Belg* season at Ankober for food barley landraces. This paper presents the results of the past 10 years of research on barley to develop varieties for potential areas and for the *Belg* season.

TABLE 1
Effect of handmade broadbeds and furrows on grain yield and other agronomic traits of barley in comparison with flat seedbeds at Fajji in 1999

Trait	Field form		Decrease (%)
	Broadbed and furrow	Flat seedbeds	
Plant height (cm)	68.83	59.69	13.28
Leaf chlorosis	2.14	2.56	-16.58
Biomass yield (kg/ha)	2244.44	1461.11	34.90
Grain yield (kg/ha)	914.53	574.52	37.18
1000-grain weight (g)	41.24	37.78	8.40

Notes: Broadbeds and furrows were prepared manually.

FOOD BARLEY BREEDING AGAINST STRESSES IN HIGH POTENTIAL AREAS

Barley variety development for waterlogging tolerance

It is important to note that barley production during the main rain season is not restricted to well drained soil. There are many instances where farmers produce barley on poorly drained soil. An experiment at Fajji in 1999 convincingly showed that barley grown on poorly drained soil inevitably suffered significant yield penalties. When excess water was drained by handmade broadbeds and furrows, leaf chlorosis from waterlogging was reduced by 17%, implying that yield loss attributable to waterlogging would be inevitable. Waterlogging stress reduced plant height, biomass, grain yield and 1000-grain weight by 13, 35, 37 and 8.4%, respectively (Table 1). Under waterlogging stress conditions, the average grain yield of relatively waterlogging-tolerant barley cultivars decreased by 33%, while the average grain yield of their susceptible counterparts decreased by 94%, compared with their respective yields when drained or relatively free of waterlogging stress (Table 2). Though it is not advisable to produce barley without adequate drainage, growing relatively waterlogging-tolerant barley cultivars gave a 69% grain yield advantage over susceptible cultivars under waterlogging stress conditions (Table 3).

TABLE 2
Mean grain yield and susceptibility index of tested barley cultivars with and without waterlogging stress in North Shewa

Line	Mean grain yield (g/plot)		Susceptibility index	Classification
	Broadbed and furrow	Flat seedbeds		
1791-02	893.875	679.875	0.644	Tolerant
Feres Gama	1273.975	1041.375	0.491	Tolerant
Feleme	964.375	692.500	0.758	Tolerant
3391-15	835.625	560.500	0.886	Tolerant
Mean	991.963	743.563	0.674	
Kessele-16	918.500	514.250	1.184	Susceptible
Netch Gebs	1258.625	638.750	1.325	Susceptible
Bukura	790.250	450.375	1.157	Susceptible
Magie	783.375	407.625	1.290	Susceptible
Keyeferkie	512.125	185.412	1.716	Susceptible
Mean	852.575	439.282	1.304	
Grand mean	2244.44	1461.11		

Notes: Broadbeds and furrows were prepared manually.

Study of the relative tolerance of barley landraces to waterlogging revealed that the grain yield reduction in lines and cultivars 1791-02, 'Feres Gama', 'Feleme' and 3391-15 were not as great as in 'Netch Gebs', 'Magie', 'Bukura', Kessele-16 and 'Keyferkie' (Table 2). A waterlogging stress susceptibility index (S_w) was calculated as

$$S_w = [(1 - YD)/YP]/D,$$

where YD = grain yield under waterlogging stress and YP = yield under non-stressed condition. The stress intensity (D) was calculated as

$$D = (1 - XD)/XP,$$

where XD and XP are mean yields of all varieties under stressed and unstressed conditions, respectively (Reddy and Kidane Giorgis, 1993). By definition, those cultivars with $S_w<1$ are classified as tolerant to waterlogging, while their counterparts with $S_w>1$ are susceptible to waterlogging. For 1791-02, 'Feres Gama', 'Feleme' and 3391-15 there was $S_w<1$, while for 'Netch Gebs', 'Magie', 'Bukura', 'Kessele-16' and 'Keyferkie' $S_w>1$, signifying that the former and latter groups were respectively relatively tolerant and susceptible to waterlogging stress (Table 2). The mechanism, heritability and other environmental factors that are suspected as affecting the waterlogging tolerance must be further investigated if an efficient and progressive strategy to utilize these cultivars is to be developed.

Adaptation ranges of barley landraces to growing conditions

An experiment aimed at studying the differential response and adaptation of nine barley landraces to different production conditions was carried out at Ankober and Mush for two seasons, 1999/2000 and 2000/2001. Analysis of variance showed that both fertilizer and food barley cultivars showed significant difference at each location. First order interaction effects, including fertilizer × location and fertilizer × cultivar effects, were significant ($P<0.05$), implying different fertilizer response and cultivar performance at both the locations. At Ankober, the full rate of fertilizer gave about 10% grain yield advantage over unfertilized plots; at Mush, the respective grain yield advantage was 17%. Without soil fertilization, the mean grain yield at Ankober exceeded that of Mush by 51%, whereas when the full fertilizer rate was used, the grain yield at Ankober exceeded Mush by 42%. The results clearly demonstrated differential performance of barley landraces at these locations (Table 3).

The large Euclidean distance ($D^2 = 3123.49$) between grain yield from Ankober and Mush under full rates of fertilizer application indicated the level of variability between the two locations. Moreover, without fertilizer application, the value ($D^2 = 3356.98$) between grain yields from Ankober and Mush was sufficiently large to indicate the variability of the two locations. At Ankober, the greater ($D^2 = 2140.82$) difference between grain yield from fertilized and unfertilized plots indicates the differential response of barley cultivars under these fertilizer levels. This hypothesis was confirmed by the relatively large value ($D^2 = 1728.53$) between grain yield from

TABLE 3

Mean grain yield (kg/ha) of barley genotypes tested with two N and P fertilizer levels combined over two years (1999/2000 and 2000/2001) at Ankober and Mush

Line	Ankober		Mush	
	0/0 (kg/ha)	41/46 (kg/ha)	0/0 (kg/ha)	41/46 (kg/ha)
Tikur Gebs	3232.25	3843.25	1914.00	2620.75
Kessele-16	3012.33	3715.92	1829.25	2567.33
Feres Gama	2365.83	3429.00	2196.25	2560.67
Keyeferkie	3052.50	2494.05	1287.83	2057.72
Netch Gebs	2624.58	3400.00	1963.08	2148.18
Bukura	3218.11	3046.75	1666.25	2050.42
Feleme	2444.25	3549.75	2180.33	2234.92
HB 42	2837.25	2653.92	1935.83	2559.58
Magie	3743.25	3121.83	2620.33	1817.75
Mean	2947.82	3250.49	1954.79	2290.81
CV (%)	11.62	18.06	4.21	3.92

fertilized and unfertilized plots at Mush (Table 4).

TABLE 4
Euclidean distances between mean grain yield of fertilized and unfertilized plots at Ankober and Mush

Location	Fertilizer level (kg/ha)	Grain yield (kg/ha)			
		Ankober		Mush	
Ankober	0/0 N/P_2O_5	0.000	2140.82	3356.98	2649.23
	41/46 N/P_2O_5		0.000	4107.21	3123.49
Mush	0/0 N/P_2O_5			0.000	1728.53
	41/46 N/P_2O_5				0.000

TABLE 5
Mean grain yield (kg/ha) and susceptibility indices (S) of nine food barley cultivars tested with and without fertilizer, combined over Ankober and Mush in 1999/2000 and 2000/2001

Line	0/0 N/P_2O_5 (kg/ha)	41/46 N/P_2O_5 (kg/ha)	S
Tikur Gebs	2573.13	3232.00	1.48
Kessele-16	2420.79	3141.63	1.66
Feres Gama	2675.13	2994.83	0.77
Keyeferkie	1826.83	2275.73	1.43
Netch Gebs	2507.79	2774.38	0.69
Bukura	2145.72	2548.58	1.15
Feleme	2650.35	2892.33	0.61
HB 42	2312.29	2606.75	0.82
Magie	2386.56	2469.79	0.24
Mean	2388.73	2770.67	1.00

The differential response of food barley cultivars to varying levels of soil fertilization was investigated by calculating the stress susceptibility index (S) as described by Reddy and Kidane Giorgis (1993). Fertilizer S was calculated as

$$S = [(1 – YD)/YP]/D,$$

where YD = grain yield under no fertilizer, YP = yield under with the application full rate of fertilizer; and the stress intensity D was calculated as

$$D = (1 – XD)/XP,$$

where XD and XP are mean yield of all varieties under no fertilizer and mean yield with the full rate of fertilizer, respectively. Accordingly, those barley cultivars with $S<1$ at Ankober were characterized by $S>1$ at Mush, reflecting the differential response of barley cultivars to the different growing conditions prevailing at each location. Combined over two locations and years, for instance, landraces 'Keyferkie', 'Bukura', 'Kessele-16' and 'Tikur Gebs' had $S>1$, implying that these varieties responded to fertilizer levels differently. However, for 'Magie', 'Feleme', 'Netch Gebs' and 'Feres Gama', $S<1$, indicating that they showed similar responses under fertilized and unfertilized conditions (Table 5). There were greater broad sense heritabilities and genetic advances under fertilized compared with unfertilized conditions in both years at both locations (Table 6), showing the differential expression of grain yield under contrasting levels of soil fertilization. It is worth noting that greater broad sense heritabilities and genetic advances were

TABLE 6
Broad sense heritabilities and genetic advances for fertilized and unfertilized plots at Ankober and Mush over two seasons

	Broad sense heritability		Genetic advance	
	Ankober	Mush	Ankober	Mush
1999/2000				
Grain yield with 0/0 kg/ha N/P_2O_5	0.01	0.51	0.01	0.82
Grain yield with 41/46 kg/ha N/P_2O_5	0.46	0.82	0.85	0.91
2000/2001				
Grain yield with 0/0 kg/ha N/P_2O_5	0.07	0.15	0.06	0.17
Grain yield with 41/46 kg/ha N/P_2O_5	0.12	0.34	0.23	0.29

TABLE 7
Mean dry matter accumulation and other agronomic traits of early and late maturing barley varieties tested at Sheno in 1998

Variety or line	Days to heading	Days to maturity	Plant height (cm)	Grain yield (kg/ha)	Dry matter accumulation (mg/day)	Grain filling period (days)
Kulumsa1/88	76.70	132.00	103.70	2033.80	9.500	55.30
Magie	76.30	120.00	97.00	1658.30	9.400	43.70
3381-07	77.30	124.00	102.30	2075.80	9.500	46.70
1791-02	81.70	128.00	95.70	1704.20	8.300	46.30
Mean of early varieties	78.00	126.00	99.68	1868.03	9.175	48.00
HB-42	90.30	148.70	106.70	2216.20	9.100	58.30
3304-16	90.70	148.70	107.00	2102.50	8.600	58.00
ARDU-12-60B	85.00	138.00	106.30	1985.00	7.800	53.00
Shege (3336-20)	88.70	146.00	106.70	1919.80	7.300	57.30
Mean of late varieties	88.68	145.35	106.68	2055.88	8.20	56.65
CV (%)	4.42	7.37	11.14	18.23	14.17	13.84
LSD (P<0.05)	6.453	17.518	NS	NS	NS	NS

NOTES: NS = not significant

recorded at Mush than at Ankober, signifying differential expression of grain yield at the two locations.

Generally, since barley landraces responded differentially to different levels of fertilizer and other growing environment factors, future varietal development should consider that, given such variation, whether breeding research programmes for wider adaptability of barley can be viable and succeed. In this regard, studying the genetic and molecular mechanisms of such differential response is necessary to facilitate marker-assisted selection for specific-environment adaptation, and to pyramid genes encoding for adaptation potentials at low and high input levels or different management conditions.

Study of barley physiology

A study of the grain-filling period was performed on food barley varieties of contrasting maturity groups. The results demonstrated that early maturing varieties had greater dry matter accumulation per day. The mean dry matter accumulation of early maturing varieties was 9.175, with a range of 8.3–9.5 mg/day, while their late maturing counterparts accumulated on average about 8.2 mg/day, with a range of 7.3–9.1 mg/day (Table 7). Although grain yields within and between maturity groups were not significantly different, the early maturing groups tended to have lower grain yields than the late maturing. The late maturing group had about 10% grain yield advantage over early maturing (Table 7). The result clearly indicated that the faster dry matter accumulation in the early maturity group was compensated by slower dry matter accumulation over a prolonged grain-filling period in the late maturing groups. This observation was confirmed by the negative correlation between daily dry matter accumulation and grain yield. If the validity of this finding is confirmed under a range of climatic conditions, the genetic and molecular mechanisms of fast dry matter accumulation and longer grain filling periods should

TABLE 8
Intercluster Euclidean distance (D^2)

Cluster	1	2	3	4	5	6	7	8	9	10
1	0	736.073	392.343	1582.267	1067.031	1353.667	1971.783	1800.822	571.364	905.749
2		0	343.807	846.235	330.981	617.618	1235.774	1064.799	164.802	169.696
3			0	1189.997	674.777	961.401	1579.518	1408.551	179.233	513.492
4				0	515.276	228.642	389.559	218.577	1011.005	676.579
5					0	286.646	904.825	733.847	495.735	161.316
6						0	618.198	447.216	782.377	447.949
7							0	170.986	1400.553	1066.131
8								0	1229.576	895.151
9									0	334.429
10										0
n	1	23	5	13	41	29	5	12	17	35

NOTES: n refers to the number of barley genotypes in each cluster.

TABLE 9
Means of grain yield and other agronomic traits of barley genotypes in each cluster

Trait	Cluster number										Kesselie
	1	2	3	4	5	6	7	8	9	10	
Days to heading	84	90	91	95	90	93	98	97	88	91	92
Days to maturity	122	127	128	129	127	129	129	129	127	128	129
Plant height (cm)	71	71	69	61	69	66	52	56	76	72	66
TGW (g)	44.8	37.8	39	36.1	37.9	37.1	33.2	33.9	40.1	38.9	38
Grain yield (kg/ha)	2634	1898	2242	1052	1567	1280	662	833	2063	1728	1359

NOTES: 'Kesselie' is an Ankober local genotype. TGW = 1000-grain weight.

be investigated to develop recombinant inbred lines or varieties that carry these traits in combination to improve productivity of food barley.

FOOD BARLEY BREEDING AGAINST STRESSES IN BELG PRODUCTION AREAS

Variability in food barley landraces

The results revealed ample variability among the 181 genotypes in this trial. Hierarchical cluster analyses based on days to heading, days to maturity, plant height, 1000-grain weight and grain yield resulted in 10 clusters, which differed significantly ($P<0.05$) one from another. The most lines were concentrated in Cluster 5, with fewest in Cluster 1. Clusters 2, 6 and 10 contained 23, 29 and 35 genotypes, respectively (Table 8). The greatest intercluster distances were between Clusters 1 and 8; 1 and 7; 3 and 7; 3 and 8; 7 and 9; 8 and 9; 7 and 10; 2 and 8; 1 and 4; 1 and 6; 1 and 5; and 2 and 7. The minimum intercluster distances were between Clusters 5 and 10; 2 and 10; 2 and 9; 7 and 8; and 4 and 8. There were moderate intercluster distances among the remaining cluster pairs. Clusters 1, 2, 3, 5 and 9 were characterized by high 1000-grain weight and high grain yield, whereas Clusters 4, 7 and 8 were characterized by short plant height, more days to heading, very low 1000-grain weight, and low grain yield (Table 9). Cluster 1 had 297% and 216% grain yield advantage over Clusters 7 and 8, respectively, while Cluster 3 had 238% and 169% grain yield advantage over Clusters 7 and 8. In addition, Cluster 9 out-yielded Clusters 7 and 8 by 127% and 147%, correspondingly. Similarly, Cluster 1 had 1000-grain weight 35% and 32% greater than Clusters 7 and 8, respectively, while Cluster 3 had 1000-grain weight greater by 17% and 15% over Clusters 7 and 8. Likewise, Cluster 9 demonstrated a 21% and 18.1% increment in 1000-grain weight over Clusters 7 and 8, respectively. Compared to the Ankober local variety 'Kesselie', Cluster 1 improved grain yield and 1000-grain weight by 94% and 18%, respectively; Cluster 3 improved the same traits by 65% and 2.5%; and Cluster 9 by 52% and 5.45%.

Generally, genotypes in Clusters 1, 2, 3 and 9 had high 1000-grain weights and grain yields. Simultaneous selection for these traits should advance varietal development in food barley. Furthermore, food barley improvement programmes should exploit the potential merit of these clusters.

Varieties released

With the objective of improving the productivity of barley landraces, there was an extensive collection and evaluation of food barley landraces in *Belg* barley growing areas for two years, 1995–1996. Subsequently, promising cultivars were advanced to regional variety trials at three locations (Ankober, Asagrit and Mezezo) for two years (2001–2002). Subsequently, two food barley varieties (4731-7 and 4748-16) suitable for *Belg* season growth were released in 2004 as 'Basso' and 'Mezezo', respectively. These are the only official varieties available for *Belg* production in North Shewa areas. These varieties gave about 13% and 11% grain yield advantage, respectively, over the standard 'Misrach', which was released for *Meher* season growth. These varieties have been multiplied, demonstrated and popularized in *Belg* barley-growing areas of North Shewa.

GAPS AND CHALLENGES

Despite the long history of barley research and production in Ethiopia, there are still many topics needing to be addressed.

- Desirable gene sources of drought and disease resistance that do not affect yield negatively need to be identified.
- Mega-environment analysis of areas growing *Belg* barley is not well documented.
- Despite extensive screening nurseries for aphid resistance, selected cultivars with resistance have neither been released for production nor crossed with already available high-yielding and susceptible cultivars for the introgression of the desirable gene(s).
- Potential parents as sources of resistant genes for various biotic and abiotic stresses have not been documented.
- The seed production system for improved food barley varieties is poor.
- There is a lack of food barley varieties responsive to low or high inputs.
- The genetics and molecular basis of important yield components under varying environmental conditions have not been characterized.

FUTURE RESEARCH DIRECTION

Future barley research should consider both specific and wide adaptation for stress breeding (e.g. for frost and drought tolerance, and aphid and disease resistance) to sustainably supply desirable recombinant inbred lines, which subsequently could be released as commercial varieties. This effort must be supplemented with molecular marker assisted selection if barley research is to be more viable and to progress systematically.

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Opportunities and challenges in malt barley research and production in North Shewa of the Amhara Region

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INTRODUCTION

It seems only natural that barley, one of the first grains used by humans (Wendorf *et al.*, 1979), is the major grain used in various alcoholic beverages, which have become part of social customs and economic endeavour. Barley is the primary cereal used in the production of malt. Historically, this may have resulted from its greater availability compared with other cereals, but there are several other sound reasons for its use. Although wheat and rye also produce α- and β-amylase, which together are more efficient than either alone in hydrolyzing starch, only barley has tightly cemented lemma and palea (Burger and Laberge, 1985). These structures protect the embryo during grain handling as well as the coleoptiles during malting, resulting in more uniform germination. In addition, the lemma and palea, or hulls, serve as an aid for filtering the brewing mash (Burger and Laberge, 1985).

Malting barley is malted for the preparation of lager, pilsner and other beers. Currently, the major Ethiopian users of malt are the domestic breweries. Their annual demand has not so far been met by the local malt supply, and consequently the breweries have long been dependent on heavy importation. While there is immense potential for producing malt barley in Ethiopia, its production is restricted to a few areas, most importantly the Arsi–Bale area. This had led to shortages of malt supply for the ever-growing local breweries. This has necessitated the expansion of malt barley production to other potential areas, including the Amhara region. This paper reports on analyses of opportunities and challenges for malting barley research and production in North Shewa, based on a two-year malting variety adaptation trial.

MATERIALS AND METHODS

Four nationally released malting barley varieties, ‘Beka’, ‘Holker’, HB 52 and HB 120, were tested at Ankober during the 2004–05 and 2005–06 cropping seasons on farmers’ fields. A randomized complete block design with three replications was used. Fertilizer was applied at rates of 21/23, 41/46 and 62/69 kg/ha N/

P_2O_5 using di-ammonium phosphate (DAP) and urea as fertilizer sources. Data on agronomic characters were recorded and grain yield per plot was measured. Harvested seeds of each variety were analysed for important malt quality traits in the seed quality laboratory at HARC.

TABLE 1

Mean grain yield and other agronomic traits of malting barley varieties tested at Ankober in 2004/2005

Variety	DH	DM	PH	TGW	GY
Beka	112	192	93	38.256	2900.889
Holker	105	186	80	38.622	3443.000
HB 52	109	189	85	40.267	3122.889
HB 120	110	191	91	38.067	3151.389
Mean	109	189	87	38.828	3154.542
CV (%)	1.35	0.80	5.82	10.93	12.45
LSD (*P*<0.05)	1.466	1.499	5.038	NS	NS

NOTES: DH = days to heading; DM = days to maturity; PH = plant height (cm); TGW = 1000-grain weight (g); GY = grain yield (kg/ha).

TABLE 2

Mean grain yield and other agronomic traits of malting barley varieties tested at Ankober in 2005/2006

Variety	DH	DM	PH	TGW	GY
Holker	100	171	90	46.10	4842.789
HB 52	104	172	100	42.45	4087.589
HB 120	99	172	105	41.24	4144.467
Mean	101	172	100	42.52	4250.013
CV (%)	7.06	1.02	4.42	2.39	11.13
LSD (*P*<0.05)	NS	NS	4.379	0.483	468.153

NOTES: DH = days to heading; DM = days to maturity; PH = plant height (cm); TGW = 1000-grain weight (g); GY = grain yield (kg/ha).

TABLE 3

Mean grain yield and other agronomic traits of malting barley varieties tested at Ankober, combined over two seasons (2004/2005 and 2005/2006)

Variety	DH	DM	PH	TGW	GY
Beka	107	182	98	39.31	3422.04
Holker	103	178	85	42.35	4133.89
HB 52	106	181	93	41.37	3605.23
HB 120	105	181	98	39.65	3647.92
Mean	105.68	181.18	93.72	40.675	3702.277
CV (%)	4.91	0.91	5.09	7.59	11.74
LSD (*P*<0.05)	3.493	1.105	3.209	2.079	292.681

NOTES: DH = days to heading; DM = days to maturity; PH = plant height (cm); TGW = 1000-grain weight (g); GY = grain yield (kg/ha).

RESULTS AND DISCUSSION

In 2004, all malting varieties tested performed very well. Although not significantly different from other varieties, 'Holker' gave the highest grain yield, suggesting that the study area has potential for malting barley production (Table 1), significantly ($P<0.01$) outyielding all other malt barley varieties in this experiment, with up to 800 kg/ha grain yield advantage over 'Beka' (Table 2). Combined over two years, 'Holker' significantly outyielded all tested varieties, with 700 and 500 kg/ha grain yield advantage over 'Beka' and HB 120, respectively (Table 3). The variety × year interaction was not significant, indicating that malting barley can be produced without yield fluctuation risk in the study area. Additionally, fertilizer main effects were not significant in each and combined over years, suggesting the study area had sufficient fertility to produce malting barley. This is likely since farmers in the study areas have long experience in using well-rotted manure for crop production. Furthermore, combined over two years, fertilizer × variety interaction was not significant for grain yield, suggesting that varietal responses to fertilizer application were similar.

Malting quality analysis of grain samples from 2004 revealed that varieties 'Beka', 'Holker', HB 52 and HB 120 gave commercially acceptable malting quality traits under Ankober conditions; however, 'Holker' and HB 52 tended to have the best malting quality traits. Fertilizer level did not alter the malting quality traits of any variety (Table 3).

TABLE 4

Mean malting quality traits of malting barley varieties tested at Ankober in 2004

Variety	N/P_2O_5 (kg/ha)	Germination after 72 h (%)	Protein content (%)	Sieving test (%) 2.8 mm	2.5 mm	2.8 mm+2.5 mm
Beka	21/23	95.00	9.200	48.00	44.10	92.00
	41/46	97.00	9.800	45.60	45.40	91.00
	62/69	96.00	10.00	46.50	46.20	92.70
Holker	21/23	100.0	9.100	74.00	21.60	95.60
	41/46	100.0	9.200	68.90	26.40	95.30
	62/69	98.00	8.900	68.90	27.00	95.90
HB 52	21/23	96.00	9.500	68.70	27.10	95.80
	41/46	97.00	10.20	35.00	30.30	95.30
	62/69	96.00	8.800	65.00	29.90	94.90
HB 120	21/23	97.00	9.000	58.10	36.00	94.10
	41/46	100.00	9.400	59.40	36.60	96.00
	62/69	98.00	9.400	63.80	32.10	95.90
Mean		97.50	9.37	58.49	33.55	94.54

NOTES: The sieving test is used to measures the plumpness of kernels in a normal sorting sieve system. There are three sieves with holes of 2.8, 2.5 and 2.2 mm diameter. Samples with more than 90% passing the 2.5 and 2.8 mm screens are acceptable for malting.

Quality analysis results confirm that the malt barley varieties have maintained their quality traits within the acceptable range for malting purpose (Table 4). All the results demonstrated that these varieties could be produced at both small and commercial scales.

GAPS AND CHALLENGES

- Despite the pressing need to increase malt barley production in Ethiopia, the genetics and quantitative trail loci (QTLs) mapping and QTL × environment interaction effects on expression of α- and β-amylases in Ethiopian malt barley varieties are unknown.
- The nitrogen use efficiency and effects of disease and insect pests on malting qualities have not been well documented.
- Breeding and management for disease resistance or tolerance have not been reported.
- The nature and patterns of genotype × environment interaction effects on malting quality traits are not quantified. The lack of this information is a gap in malting barley research.
- The Ethiopian malting barley varieties are two-row types, and are locally thought to yield less than local six-row food barley varieties. Consequently, farmers are reluctant to be involved in malt barley production. Therefore, the lack of six-row malting barley varieties is a gap in malting barley research.

FUTURE RESEARCH DIRECTIONS

- Identifying the best parent for crossing.

- Recombinant Inbred Lines should be developed to be used for molecular marker assaying and QTL mapping for the major malting quality traits within Ethiopian varieties. The expressions of malting quality QTLs may not be stable, so the QTLs identified need to be studied for the pattern and nature of the additive, epistatic and QTL × environment interaction effects on expression of malting quality traits. The results will enable identification of stable and widely or specifically adaptive QTLs. At the same time, breeding for resistance and resistance management options needs strengthening to sustain a quality malt supply for local demand.

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Achievements of food barley breeding research in Arsi Highlands

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BREEDING FOOD AND MALT BARLEY FOR POTENTIAL AREAS

The highlands of Arsi are among major barley producing areas in Ethiopia. The National Barley Research Project at Holetta Agricultural Research Centre (HARC) in collaboration with other research centres has released several varieties (Table 1). Kulumsa Research Centre (KRC) has been an important collaborator with the National Barley Research Project because of its strategic location. Before 1998, KRC was only involved in testing nationally proposed trials. Since 1998, the Barley Improvement Section of KRC has initiated barley trials for specific adaptation in the Arsi Zone.

TABLE 1
Varieties released for the Mid and highlands area by HARC in collaboration with KRC since 1995

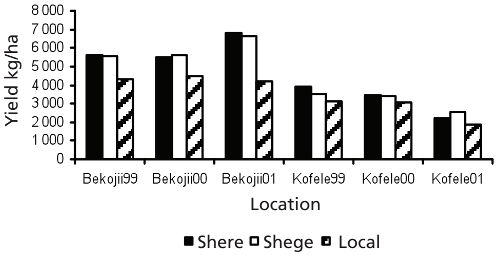
Variety	Type	Year of release	Grain yield (t/ha) On station	Grain yield (t/ha) On farm	TGW	Protein (%)
Shege	Food	1995	2.1–5.1	2.6–3.4	39.0	–
Dimtu	Food	2001	2.3–4.0	1.5–2.2	42.0	–
EH 1700	Food	2006	4.0–5.9	3.0–4.0	47.6	–
HB 52	Malt	2000	2.4–4.7	2.4–2.8	46.0	9.7
HB 1533	Malt	2004	2.4–3.8	2.3–2.8	42.0	10.6
Miscal-21	Malt	2006	2.9–3.7	2.5–3.3	48.4	11.4

NOTES: TGW = 1000-grain weight (g).

For specific adaptation at Bekoji and Koffele, seven genotypes were selected from national trials and landraces during the 1991–1996 seasons (KRC Progress Reports 1992, 1993, 1994, 1995, 1996). Among the tested entries, 3297-06 was comparable in grain yield to 'Shege' (Figure 1), has disease and lodging resistance (Table 2), and was released as 'Shere' for specific adoption in 2005, after testing at a range of sites in Arsi.

At present, 48 malt barley and 44 food barley genotypes are at different stages of evaluation by KRC for the highland areas. Some parameters of the promising malt barley genotypes are presented in Table 3.

FIGURE 1
Mean grain yield of 'Shere', 'Shege' and local variety over three years at Bekoji and Koffele



BREEDING FOOD BARLEY FOR LOW-MOISTURE STRESS AREAS

In Ethiopia, barley is usually considered a highland crop; however, it is also

TABLE 2

Some agronomic and disease parameters of cvs 'Shere' and 'Shege', and a local variety

Variety	Days to maturity	Scald (0–9)	Net blotch (0–9)	Plant height (cm)	Lodging (%)	TGW
Shere (3297-06)	126	1.2	2.8	99.1	9	38.4
Standard check (Shege)	124	1.9	3.5	115.5	17	42.8
Local variety	128	2.1	3.5	116.7	20	41.1

NOTES: Scald and Net blotch assessed on 0–9 scales where 0 = absent and 9 = 100% severity; TGW = 1000-grain weight (g).

TABLE 3

Promising malt barley genotypes compared with released varieties HB 52 and HB 1533 at three locations

Name	Location	DM	PH	LOD	SC	NB	LR	GY	TGW	PC
EH1293/F2-18B-11-1-14-19	Bekoji	162	103	1	1	0	0	6.1	53.4	11.6
	Meraro	149	112	0	4	0	0	4.4	51.9	12.3
	Koffele	160	112	1	3	0	0	6.5	44.1	11.6
HB 52	Bekoji	163	112	1	1	0	10 MS	4.3	46.8	10.9
	Meraro	164	113	0	1	5	20 MS	2.7	43.7	12.1
	Koffele	149	110	0	3	5	20 MS	4.1	45.3	11.2
HB 1533	Bekoji	159	93	1	1	0	20 MS	3.5	43.3	12.0
	Meraro	153	105	0	2	0	25 MS	4.0	43.7	12.0
	Koffele	155	112	0	2	0	25 MS	5.1	40.6	11.5

NOTES: DM = Days to maturity; PH = Plant height (cm); LOD = Lodging (%); SC = Scald (0–9 scale); NB = Net blotch (0–9 scale); LR = Leaf rust (severity score in % and type of disease reaction; MS = Moderately Susceptible); TGW = 1000-grain weight (g); GY = Grain yield (t/ha); PC = Protein content (%).

among the major cereal crops grown in the low-moisture areas. In such areas, the availability and distribution of rainfall during the growing season is the major factor limiting yield. The most important factor in barley adaptation to the low-moisture areas is early ear emergence, and is common in Ethiopian landraces from low-moisture areas. Thus, the farmers in drought-prone areas grow their own landraces that are well adapted to the local environment, but with poor yielding ability. Variety development for low-moisture areas began in Arsi using landraces in 1998. Most landraces tested were inferior in yield to the local variety (KRC, 1998). After this initial effort, the breeding programme evaluated introduced genotypes from the International Center for Agricultural Research in the Dry Areas (ICARDA). In 1998–2006, >1700 introductions were evaluated for low-moisture areas, and nine genotypes were selected and included in regional trials from 2002 to 2004 at Dera, Asasa and Arsi Negele. As a result of these trials, two varieties, 'Bentu' and 'Desta', were released in

FIGURE 2

Grain yield of 'Bentu' and 'Desta' along with 'Aruso' (local variety)

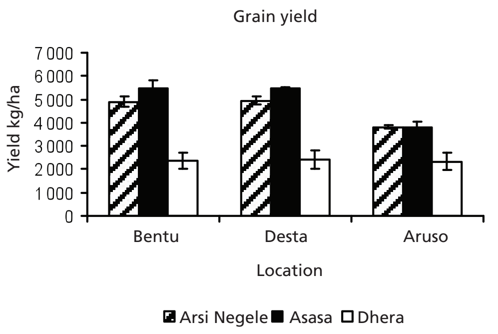


TABLE 4

Means for different agronomic and disease traits of 'Bentu', 'Desta' and 'Aruso' for 2003–2005

Agronomic and disease traits	2003			2004			2005		
	Bentu	Desta	Aruso	Bentu	Desta	Aruso	Bentu	Desta	Aruso
Days to heading	51	53	57	49	56	58	49	52	50
Days to maturity	80	86	86	83	88	90	81	89	87
Plant height (cm)	75	67	94	71	61	82	67	59	87
Lodging (%)	4	9	36	12	16	19	0	0	61
Scald (0–9 scale)	0	0	0	0	0	1	0	0	1
Net blotch (0–9 scale)	1	1	1	2	2	2	2	2	2
1000-grain weight (g)	35.2	38.2	44.3	30.2	33.1	42.5	31.2	37.2	43.3

2006. Both had much greater grain yields than the local variety 'Aruso' (Table 4). 'Aruso' is a two-row barley while 'Bentu' and 'Desta' are six-row, and thus the 1000-grain weight of 'Aruso' was higher than the new varieties (Table 4). Generally, six-row barleys have higher grain yields, but lower 1000-grain weight, compared with two-row barleys (Table 5).

TABLE 5

Comparison of grain yield and 1000-grain weight of two-row and six-row barley genotypes

Row Type	No. of entries	1000-grain weight (g)	Grain yield (kg/ha)
Two-row	14	43.6	3426.5
Six-row	25	36.0	3915.5
Difference		**	**

NOTES: ** significant at $P<0.01$

Early maturity is also an important parameter when breeding for low-moisture areas, and ensures an escape mechanism from moisture shortage during the grain filling period. 'Bentu' was earlier to maturity than 'Aruso' by nearly a week, while 'Desta' was comparable to 'Aruso' (Table 4).

At the time of writing, there are 254 lines at different stages of testing for low-moisture areas and several of these genotypes are promising. Some of the promising genotypes at the advanced stage of testing are shown in Table 6.

GENETIC DIVERSITY IN BARLEY

Theses by Tesfahun Alemu (2001) and Sintayehu Debebe (2003) contributed some basic information that supports the breeding effort. Genetic diversity and character association studies by Tesfahun Alemu (2001) at Asasa clustered 100 lines into

TABLE 6

Agronomic traits of promising lines for three sites in low-moisture areas (2003–2005)

Genotype	Grain yield (t/ha)			1000-grain weight (g)			Days to maturity	Plant height (cm)	Row type
	Asasa	Dera	Arsi Negele	Asasa	Dera	Arsi Negele			
EMBSN 7/96	4.7	2.6	4.6	34.2	37.0	40.3	95	66	6
EMBSN 37/96	4.9	2.7	4.5	34.8	32.9	37.2	88	58	6
7th EMBSN 18/98	4.8	2.6	4.6	33.4	36.5	39.8	99	71	6
7th EMBSN 19/98	5.2	3.0	4.3	36.4	36.8	39.4	93	72	6
26th IBON 83/98	4.4	3.1	4.8	34.4	38.0	41.2	98	69	6
7th EMBSN 31/98	4.4	2.7	4.6	41.0	41.6	43.0	94	69	2
7th EMBSN 48/98	5.6	2.6	5.8	37.0	36.9	44.3	93	64	6
Aruso (local control)	3.7	2.2	3.6	39.9	44.2	44.3	93	80	2

TABLE 7

Performance of the two varieties released in 2006

Variety	KPS	SSP	TGW	SL	GY	Data source	Released by
Bentu	53.1	3.8	31.5	6.6	2.4	Tesfahun Alemu (2001)	KRC in 2006
EH 1700/F7-B1-63	45.0	4.0	42.4	7.5	6.0	Sintayehu Debebe (2003)	HARC in 2006

NOTES: KPS = kernels per spike; SSP = spikes per plant; TGW = 1000-grain weight (g); SL = Spike length; GY = Grain yield (t/ha).

TABLE 8

Agronomic information generated at two locations in Arsi

Characters	Asasa in 2000				Bekoji in 2002			
	Range	Mean ± SE	h^2_B	GA (5%)	Range	Mean ± SE	h^2_B	GA (5%)
Days to heading	57–97	74.4 ± 3.2	92.4	12.4	88–110	97 ± 1.9	77.8	9.2
Days to maturity	81–136	116.8 ± 3.2	70.9	8.6	129–152	142 ± 1.2	76.3	7.5
Plant height (cm)	73–125	100.6 ± 3.5	89.8	20.3	72–106	91.7 ± 2.7	73.5	16.1
No. of spikes per plant	3.1–12.3	6.6 ± 0.9	54.4	1.4	3–5	3.8 ± 0.5	10.6	0.2
No. of kernels per spike	17.4–68.8	39.3 ± 2.8	95.9	27.2	22–65	46.6 ± 2.7	83.8	23.1
Spike length	5.5–10.4	7.5 ± 0.4	78.9	1.3	5.6–9.3	7.3 ± 0.3	58.4	1.0
1000-grain weight (g)	18–60	37.6 ± 2.4	91.4	15.7	28.9–59.6	41.4 ± 1.0	92.0	13.0
Hectolitre weight (kg)	37–64.8	56.6 ± 1.4	91.2	8.8	54.0–65.7	61.2 ± 0.7	61.4	2.9
Biomass (g/plot)	1020–4270	2380 ± 320	52.3	500.0	1779–3642	2628 ± 150	56.6	556.5
Grain yield (g/plot)	252.8–816.9	514.1 ± 57	62.4	119.5	632–1453	1090 ± 63	64.1	278.8
HI (%)	9.5–43.5	22 ± 3	75.0	7.0	30.7–53.9	41.8 ± 1.4	77.5	9.3
Source of data	Tesfahun Alemu, 2001				Sintayehu Debebe, 2003			

NOTES: h^2_B = Broad sense heritability; GA = Genetic advance at 5% selection intensity; plot size = 2 m^2; HI = Harvest Index.

three groups, with some exotic and landrace lines in the same cluster. Hence, it was concluded that geographic distance does not always guarantee genetic distance between genotypes. Moreover, Tesfahun Alemu suggested crossing the best entries from different clusters to produce high yielding segregants. 'Bentu' was among the 24 entries that combined the best expression of most characters considered in that study (Table 7).

Sintayehu Debebe (2003) examined 64 genotypes for genetic variability and character association at Bekoji in 2002. The material was drawn from different national trials. The genotypes of high biomass production, harvest index (HI), and number of kernels per spike were important in selecting for improved grain yield under the highland conditions of Bekoji. EH 1700/F7-B1-63, which was released by HARC in 2006, was among the best entries included in this study (Table 7). For both Tesfahun Alemu (2001) and Sintayehu Debebe (2003), high heritability values were estimated for number of kernels per spike and 1000-grain weight (Table 8).

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Achievements in food barley breeding research in the early production systems of northwest Ethiopia

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is a dependable crop in the mid-altitudes and is grown as a sole crop in the highland areas of north¬west Ethiopia. It is grown in diverse environments at an altitude range of 1500–3500 masl, but predominantly at 2000–3500 masl (Berhane Lakew, Hailu Gebre and Fekadu Alemayehu, 1996). Administrative zones such as East and West Gojam, North and South Gonder, and Awi are the major producers of barley, producing about 55% of the total production of the region. In Ethiopia, barley is the fifth most important cereal crop after teff, wheat, maize and sorghum in total production.The total area of barley in the Amhara region is about 370 000 ha with total production of 390 000 t and productivity of 1.1 t/ha, which is below the national average of 1.2 t/ha (CSA, 2005).

Barley production systems in north¬west Ethiopia are early, late and residual-moisture based. The early and late production systems are the most common in the main season (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998). Early maturing varieties fit the early barley production system, being ready for harvest in August–September when other crops are still green. Thus, development and promotion of such varieties has been the major target for this production system. In the past, research efforts were made to develop improved barley varieties that fit the early production system. As a result of these efforts, the Adet Agricultural Research Centre (AARC) released the cultivars ‘Abay’ (Accession 3357-10), ‘Setegn’ (Accession 3371-03) and ‘Tila’ (EMBSN 14/98), which have a grain yield advantage over local and standard checks, are early maturing, possess moderate field resistance to major foliar diseases, and show wide adaptability.

This paper summarizes major achievements in variety development for the early-barley production system, and assesses the yield potential and stability of the different varieties.

MATERIALS AND METHODS

Multi-location trials were carried out during the 1996–1998, 1999–2001 and 2003–2005 main cropping seasons using cultivars ‘Abay’, ‘Setegn’ and ‘Tila’,

TABLE 1
Altitude, rainfall, soil type and location of testing sites

Site	Altitude (masl)	Total rainfall (mm)	Soil type	Location	
				Latitude	Longitude
Adet	2240	1332	Nitosol	11°16′ N	37°29′ E
Burie	2600	1623	Nitosol	10°42.7′ N	37°5.6′ E
Debre Tabor	2630	1379	Luvisol	11°49′ N	38°9′ E
Motta	2470	1013	Nitosol	11°20′ N	37°88′ E

Sources: Tsige Genet, 2002; Yihenew Selassie, 2004.

respectively. The locations were Adet, Debre Tabor, Motta and Burie, which represent early maturing barley growing areas of north¬west Ethiopia (Table 1).

Fifteen promising genotypes, local checks and the best standard check were used in each trial. The genotypes were selected from national variety trials and lines derived from biodiversity collections based on yield potential, agronomic traits and disease resistance or tolerance. The trials were laid out in randomized complete blocks with three replications. Each experimental plot had six rows spaced 20 cm apart. The plot areas were 3 m2 (1.2 m × 2.5 m). A distance of 1.5 m was maintained between replications in all environments. Planting dates varied from May at Adet to June at Motta. The fertilizer rate was 41 kg/ha N and 46 kg/ha P2O5. The seeding rate was 85 kg/ha. The first weeding was done 35 days after emergence and the second 30 days later. Neither herbicides nor insecticides were applied during experiments.

Data on grain yield, agronomic traits and disease reaction were taken from each plot. Days to heading were recorded when each plot reached 50% of head emergence and maturity when 75% of heads attained physiological maturity. The days were calculated from the date of sowing. Plant height (cm) was taken at full maturity from five randomly selected plants of the central four rows, measured from ground level to the top of the plant. Responses of varieties to major diseases were recorded between flowering and maturity; blotches (spot and net), scald and leaf rust were recorded on 0–100% scales (0% was none; 100% was severe). Yield data were recorded on clean, dried samples and plot yields adjusted to 12.5% moisture level. Adjusted yield data were converted to kg/ha. The 1000-grain weights were recorded. Hectolitre weight of every sample was determined in a standard hectolitre measure. Good performance of a genotype was evaluated on major parameters: a maturity period that fits the early production system; high grain yield in this period; intermediate height; stiff straw; widely adaptable over environments; and resistant to scald, blotches and leaf rust.

RESULTS AND DISCUSSION

Accession 3357-10 was selected from the 1996–1998 multi-location trial and released as ‘Abay’. In research fields, ‘Abay’ had a mean grain yield of 2500–3000 kg/ha and 1500–1800 kg/ha in farmers’ fields. ‘Abay’ is a six-row type, with long spikes and high 1000-grain weight, which contributed to its high yield potential. It also has white kernel colour and plant height of 95–103 cm. It can be harvested after 98–112 days and has moderate resistance to scald and blotch (economically important diseases in the area). ‘Abay’ has been used for production in the targeted environments and as a parent in subsequent breeding.

TABLE 2

Mean grain yield and other important agronomic traits of early-maturing food barley varieties (1999–2001)

Genotype	DH	DM	PH	TGW	HLW	GY
EMBSN 5TH 33/96	68	104 c	67	32.2	32.4	1930 def
EMBSN 5TH 35/96	70	106 bc	62	32.5	32.38	1840 ef
EMBSN 5TH 31/96	68	104 c	61	32.9	32.38	1630 f
EMBSN 5TH 30/96	67	105 c	61	35.1	32.38	1880 ef
EMBSN 5TH 19/95	71	108 bc	69	30.5	32.38	1940 def
EMBSN 5TH 36/94	69	106 bc	65	34.2	32.38	1760 f
EMBSN 5TH 6/96	69	105 c	63	34.3	34.5	1900 ef
EMBSN 5TH 36/96	67	104 c	64	32.3	32.4	1980 def
3371-03	73	107 bc	99	42.4	42.8	2640 ab
3284-04	69	107 bc	101	37.6	38.2	2320 bcd
3381-10	76	110 b	85	38.1	38.3	2910 a
PGRC/E 874	73	105 c	92	38.7	38.9	2210 cde
PGRC/E 64	73	106 bc	90	44.6	45.3	2420 bc
3357-10 (Standard check)	82	116 a	96	34.2	34.1	2330 bcd
Local check	65	105 c	91	41.6	41.6	2000 def
Mean	70	106	78	36.1	36.3	2110
CV (%)		5.21				24.9

NOTES: DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); HLW = Hectolitre weight (kg/hL); GY = Grain yield (kg/ha). Values in a column followed by same letter are not statistically different.

Accession 3371-03 was selected from the 1999–2001 multi-location trial and released as ‘Setegn’; it has mean grain yield of 1630–2910 kg/ha. ‘Setegn’ and 3381-10 (a sister line of ‘Sheho’ released by Sirinka Agricultural Research Centre in 2003) were top performers, while ‘Abay’, PGRC/E 64, Accession 3284-04 and PGRC/E 874 were intermediate yielding genotypes. There were highly significant maturity differences among the genotypes tested. ‘Setegn’ matured early (100–109 days) compared with standard checks: ‘Abay’ (105–113 days) and Accession 3381-10 (104–111 days). The local check was the earliest to mature (93–101 days) but had the lowest grain yield (800–1400 kg/ha) (Table 2).

The combined analysis of variance (ANOVA) for grain yield indicated highly significant ($P<0.01$) variation across genotypes, and genotype × location and genotype × year × location interactions. Thus, genotype performance varied throughout the testing years and locations. Stability analysis was carried out using the model of Eberhart and Russell (1966) as it was difficult to identify superior genotypes by main effects only. According to Eberhart and Russell (1966), the sum of squares due to environments and genotype × environment interaction are partitioned into environments (linear), genotype × environment (linear), and deviation from regression. The genotype performance across environments is generally expressed as three parameters: mean yield, the regression coefficient (b), and the deviations from regression (sd2). A stable genotype should have high mean yield, $b = 1$, and $sd2 \sim 0$ (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966).

In the present study (Table 3), apart from Accession 3381-10 and EMBSN 5TH 31/96, all tested genotypes had b not significantly different from unity and

TABLE 3

Estimates of stability and adaptability parameters of grain yield (kg/ha) for 15 genotypes tested on 12 sites

Genotypes	X	b	s_d^2
EMBSN 5th 33/96	19.3	0.90	–2.8
EMBSN 5th 35/96	18.4	0.82	1.2
EMBSN 5th 31/96	16.3	0.65*	–8.7
EMBSN 5th 30/96	18.8	0.91	–5.4
EMBSN 5th 19/95	19.5	1.12	–1.0
EMBSN 5th 36/94	17.6	0.98	–5.9
EMBSN 5th 6/96	19.0	0.96	–1.6
EMBSN 5th 36/96	19.8	0.99	–3.9
3371-03	26.3	0.94	–0.5
3284-04	23.2	1.17	–2.7
3381-10	29.1	1.56**	23.5**
PGRC/E 874	22.1	1.09	–2.6
PGRC/E 64	24.2	1.00	4.7
Abay	23.3	1.16	3.4
Local check	20.0	0.77	12.4*

NOTES: X = Mean grain yield (kg/ha); b = regression slope; sd2 = deviation from regression; * & ** = significant at P<0.05 and P<0.01 from either b and sd2, respectively.

Accession 3381-10 was the only variety with sd2 significantly different from 0. This genotype was sensitive to changes in environment and tended to have high yields in favourable environments. 'Setegn' had grain yield of 2640 kg/ha, b ~ 1, and smallest sd2, thus indicating stable grain yield across environments; since b < 1, it also had considerable yield in low-input environments. Alamnie Atanawu, Settie Agmas and Tadesse Dessalegn (2004) had similar results. However, EMBSN 5th 31/96 had b significantly less than unity, which shows that this genotype had above average stability and was insensitive to changes in environment. Improved environment or agronomic practices will not increase grain yield in such varieties.

EMBSN 14/98 was selected from the 2003–2005 multi-location trial and released as 'Tila'. The mean grain yield of environments averaged over genotypes was 3112 and 1993 kg/ha in 1995 at Adet and Motta, respectively (Table 4). The highest mean grain yield was for genotype IBON 41/95 (3113.0 kg/ha) and the lowest EMBSN 52/98 (1004.65 kg/ha). The mean grain yield over all the genotypes and environments was 2720 kg/ha. EMBSN 14/98 outperformed all the genotypes at most environments. The top performing genotypes were Arar/Lignee 527, Valeriana S'/Aga, F2(S×S) 40/95, IBON 56/95, with mean grain yields of 2898, 2859, 3115 and 3033 kg/ha, respectively. There were variations between genotypes in days to heading and maturity. This difference was due to heritable variation among genotypes. Early maturing varieties like PGRC/E 219051, PGRC/E 218981, PGRC/E 218966, EMBSN 25/98 and EMBSN 14/98 fit the early system well. Since early maturing varieties complete their life cycle in a shorter period, they have an advantage over the late maturing varieties in environments where rain begins late and ends early and are compatible with this type of agro-ecology.

The ANOVA of AMMI model showed highly significant differences (P<0.01) among locations; years; genotypes; genotype × location, genotype × year, and genotype × year × location interactions; and IPCA1 and 2 axes. The percentage of genotype × environment interaction explained was higher for principal component analysis axis 1 (PCA1), followed by PCA2. The remaining genotype × environment interaction was explained by the rest of PCA axes, which were not significant. Regardless of the positive or negative signs, genotypes with large scores have high interactions (i.e. unstable), whereas genotypes with small IPCA scores close to zero have small interactions and are stable (Zobel, Wright and Guach, 1988). Among the genotypes tested, IBON 41/95 showed the highest PCA1 score (28.3), indicating that it was sensitive to changes in environments or it

TABLE 4

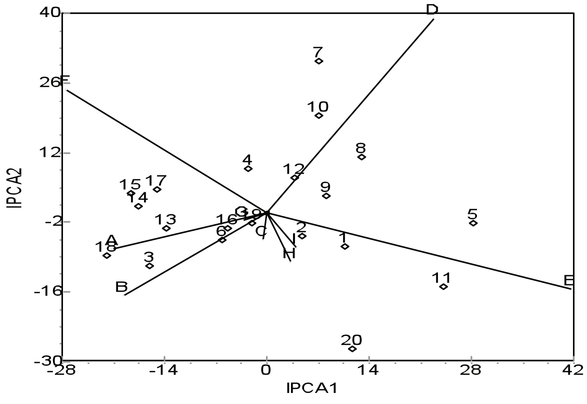
Mean grain yield and other important agronomic traits of early-maturing food barley varieties (2003–2005)

Genotype	DH	DM	PH	HLW	TGW	GY	Disease score SC	BL	LR
EMBSN 14/98	63	104	66.0	58.6	31.4	3076	12	21	2
EMBSN 15/98	67	107	79.8	56.9	33.4	2762	19	18	1
EMBSN 25/98	65	103	102.1	60.4	42.0	2703	67	4	3
EMBSN 44/98	68	110	80.5	55.0	33.2	2661	34	20	0
EMBSN 41/98	81	119	90.5	55.7	40.0	2835	11	20	0
EMBSN 52/98	65	103	104.7	61.5	36.7	2333	36	15	0
Arar/Lignee 527	74	114	89.2	57.8	41.1	2898	20	28	0
Valeriana S/Aga	84	121	105.0	57.9	40.7	2898	21	27	1
F2(S×S) 40/95	76	117	82.7	55.7	30.2	2475	28	16	0
Cebada 31/94	84	120	106.5	57.9	38.7	2859	18	27	2
IBON 41/95	74	109	72.0	56.0	30.4	3115	15	21	0
IBON 56/95	70	108	78.3	57.5	30.8	3033	7	22	0
PGRC/E 218966	64	102	99.5	58.3	37.8	2499	67	6	0
PGRC/E 218981	64	102	93.8	55.5	30.9	2457	65	5	2
PGRC/E 232217	71	106	99.9	53.1	32.4	2372	58	5	0
PGRC/E 219051	66	102	96.1	58.1	40.3	2791	66	3	0
PGRC/E 230628	64	103	130.0	57.5	38.0	2640	61	4	0
PGRC/E 230625	63	103	100.3	57.6	33.6	2632	50	7	5
Abay (Acc no. 3357-10)	76	113	99.4	55.6	34.6	2672	16	21	3
Local check	63	104	95.4	58.2	41.4	2688	52	12	1
Mean	70.1	108.6	93.6	57.2	35.9	2720			
CV (%)	3.46	3.5	50.09	3.54	8.71	17.24			
LSD (*P*<0.05)	1.30	2.03	25.09	1.09	1.67	251.00			

Notes: DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); HLW = hectolitre weight (kg/hL); GY = Grain yield (kg/ha); BL = Blotches severity score (%); SC = Scald severity score (%); and LR = Leaf rust severity score (%).

FIGURE 1

Biplot of PCA1 against PCA2 of 20 genotypes grown at nine sites



Designation of accessions by number: 1 = EMBSN 14/98; 2 = EMBSN 15/98; 3 = EMBSN 25/98; 4 = EMBSN 44/98; 5 = EMBSN 41/98; 6 = EMBSN 52/98; 7 = Arar/Lignee 527; 8 = Valeriana S/Aga; 9 = F_2(S×S) 40/95; 10 = Cebada 31/94; 11 = IBON 41/95; 12 = IBON 56/95; 13 = PGRC/E 218966; 14 = PGRC/E 218981; 15 = PGRC/E 232217; 16 = PGRC/E 219051; 17 = PGRC/E 230628; 18 = PGRC/E 230625; 19 = Abay; and 20 = local check. Designation of locations by letter: A = Adet in 2003; B = Adet in 2004; C = Adet in 2005; D = Debre Tabor in 2003; E = Debre Tabor in 2003; F = Motta in 2002; G = Motta in 2004; H = Motta in 2005; I = Burie in 2004; and J = Burie in 2005.

was adaptable to only some environments. It was plotted along with high potential environments that shared opposite signs of PCA score (negative) (Figure 1). These sites were Adet in 1994, 1995 and 1996, and had high environmental means. This implies that the variety gave high yields provided that it was grown in areas with high potential and good agronomic practices. In contrast, the standard check showed the lowest PCA scores, indicating that it was the most stable. 'Tila' (EMBSN 14/98) was plotted near the origin (i.e. small PCA1 and PCA2 scores), showing stable grain yield performance across the tested locations and years.

CONCLUSIONS

In summary, the released varieties 'Abay' in 1997, 'Setegn' in 2003, and 'Tila' in 2006, were early in maturity (98–101 days), had high grain yield (3000–3500 kg/ha), and were moderately resistant to major foliar diseases. Early maturing varieties allow food barley producers to use the land for double cropping, break the seasonal food shortages farmers face when most of crops are still too green for harvest, and escape yield losses from late commencement and early termination of rain. 'Setegn' and 'Abay' are tall plants that will be benefit farmers as a livestock feed source and as roof thatching. 'Setegn' and 'Tila' were relatively stable and high yielding compared with the other genotypes tested. 'Setegn' is also an input-insensitive variety and able to yield in low input environments. Furthermore, these varieties are moderately resistant to diseases, including scald and blotches. With these advantages, the varieties were released for large-scale production by the National Variety Release Standing Committee. The released varieties are crucial to boost production and productivity in the early barley production system of north¬west Ethiopia and in similar agro-ecologies.

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Achievements of food barley breeding research for low-moisture stressed environments of northeast Ethiopia

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INTRODUCTION

Barley is an important cereal crop grown by subsistence farmers on small-scale farms. Among the major cereals, barley ranks fifth in area, productivity and total production in Ethiopia as a whole, but it is the sole crop in the highlands of Wollo. Although barley is grown in areas at 1800–3000 masl, it is predominantly grown at 2000–3000 masl, which is traditionally known as *Dega.* It has a number of attributes that make it desirable to resource-poor farmers: it is a dependable source of food, as it is grown in different seasons and production systems, and it does well in marginal areas of low soil fertility. Barley is also a low-input crop requiring relatively low investment. In addition to its grain, barley straw is also useful, as it is a good source of livestock feed during the dry season when there is an acute shortage of good quality fodder. In general, barley is the most desirable crop in the highlands where there is no alternative crop, but this dependence on a single crop implies risk. Despite barley's importance as a source of food for poor farmers, there are limited improved high yielding varieties that could perform well in low-moisture stressed areas. The present report concentrates on the development of varieties that performed better in low-moisture stressed areas.

MATERIALS AND METHODS

All the four sets of experiments were planted in a randomized complete block design with three replications, at three locations in three consecutive years (Table 1). The plot sizes were 3 m^2 with a net harvestable area of 2 m^2. The seed rate was 85 kg/ha and fertilizer rate was 41/46 kg/ha N/P_2O_5 for all locations and cropping seasons. Planting was done from late June to early July, at the onset of the main rainy season. Other cultural practices were based on previous agronomic recommendations. Data were recorded on days to heading, days to maturity, plant height, 1000-grain weight, disease resistance or tolerance, and yield. Seed yield (kg/ha) was used for statistical analysis. The MSTAT-C computer program

TABLE 1
Altitude, rainfall and soils of the experimental sites

Location	Altitude (masl)	Mean annual rainfall (mm)	Soil		
			Texture	Colour	pH
Kone	2800	1054	Lithosol	Red	6.5
Geregera	2650	1104	Lithosol	Brown	6.0

TABLE 2
Combined analysis of barley varieties over locations and years at Kone, Geregera and Akesta from 1998–2000

Genotype	DM	PH	TGW	GY
3296-15	148	78	45.5	2095.8
219017	133	79	42.9	1955.7
218955	133	71	41.8	1925.5
218950	134	77	42.9	2098.2
218957	133	79	42.7	1998.5
218998	131	82	41.0	2188.1
215275	128	79	42.2	1370.3
219016	133	78	42.2	2016.1
219048	134	75	43.5	2111.2
218959	135	80	43.4	2205.4
3381-10	133	75	44.1	2295.5
3381-01	134	77	44.3	2516.2
3371-03	130	87	43.9	2059.3
Demyie	149	86	51.1	2270.6
HB 42	154	90	45.3	2021.1
Ehilzer	132	74	41.0	1832.5
Mean	135.9	79.2	43.6	2060.0
L × Y	**	**	**	**
L × V	**	**	**	*
Y × V	*	**	NS	**
L × Y × V	**	NS	**	NS
CV (%)	5.58	11.5	9.3	28.17

NOTES: 3381-01 was released as 'Shedho'; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha); * = significant at P<0.05; ** = significant at P<0.01; NS = Not significant; L = Location; V = Variety; Y = Year.

TABLE 3
Summary of major disease scores for genotypes tested in regional variety trials

Genotype	Scald	Leaf rust	Genotype	Scald	Leaf rust
3296-15	2	1	219048	3	2
219017	4	3	218959	2	2
218955	3	2	3381-10	2	2
218950	4	2	3381-01	1	2
218957	2	2	3371-03	3	3
218998	2	3	Demyie	1	2
215275	4	3	HB 42	2	3
219016	2	2	Ehilzer	4	3

NOTES: Scoring system of 1–5 scales for both scald and leaf rust, where 1 = little or no damage, and 5 = the greatest damage.

was used to compute the combined and individual analyses of data over years and locations.

Cropping season rainfall and soil type are presented in Table 1 for two of the locations. Rainfall distribution was generally erratic and uneven; it often started late and finished earlier than average. Nearly 90% of annual rainfall was received in July–August, creating temporary waterlogged conditions; the other months were dry, starting from the crop flowering stage. In general, rainfall was variable with uneven distribution during the growing season.

RESULTS AND DISCUSSION

Set I – Evaluation of promising landrace lines

The combined analysis over location and year (data for 1998–2000) showed non-significant differences for grain yield and plant height, but not for days to maturity and 1000-grain weight (Table 2). Genotypes 3381-01, 3381-10 and 'Demyie' had higher yields than other genotypes, and 3381-01 and 'Demyie' also had good tolerance to scald and leaf rust diseases (Table 3). Genotypes 3381-01, 3381-10 and 'Demyie' were proposed for release in 2001, with 3381-01 released as 'Shedho'. Yield of 'Shedho' (2516.2 kg/ha) was 37.3% greater than the local variety 'Ehilzer' (1832.5 kg/ha) and 24.5% greater the standard check, HB 42 (2021.1 kg/ha), and had good nutritional value (Table 4). Currently, 'Shedho' is used by many farmers in Meket and Wadla Woredas, where moisture stress is common.

TABLE 4

Nutritional value of 'Shedho' compared with the standard and local checks on a percentage of dry weight basis (Analyses performed by IBCR laboratory)

Variety	Protein	Fat	Crude fibre	Mineral ash	Carbohydrate	Moisture
Shedho (3381-01)	8.08	2.07	5.53	2.37	77.11	10.37
HB 42 (Standard check)	8.3	1.91	6.16	2.68	76.41	10.7
Ehilzer (Local check)	8.38	1.83	6.46	3.02	75.87	10.9

Set II – Evaluation of early maturing lines

For the individual year and combined analyses of variance, there were significant differences among the varieties. In the 2001 cropping season, days to heading, days to maturity, plant height and grain yield were significantly different over locations; however, plant height and 1000-grain weight were not significantly different. Yields from the whole experiment of 2001 were poor due to low rainfall, although, under these poor conditions, genotypes 218963-4 and 215235-2 performed better than the others (Table 5). In the 2002 cropping season, genotypes 215235-2, Ehilzer and EMBSN 9/96 gave the highest yields. All parameters except plant height showed significant differences in combined analysis over locations (Table 6). In general, 218963-4 and 215235-2 had better performance over years and locations than did the other genotypes (Table 7). Therefore, these two genotypes were considered

TABLE 5

Mean grain yield and agronomic data of barley genotypes combined over locations at Geregera, Kone and Estayish in 2001

Genotype	DH	DM	PH	GY	TGW
EMBSN 35/96	81	132	60	1125.2	31.1
EMBSN 33/96	77	131	63	1466.6	32.6
EMBSN 26/96	77	132	61	1276.0	31.4
EMBSN 21/96	78	130	54	1177.1	31.4
EMBSN 39/96	78	132	57	1358.7	33.1
EMBSN 44/96	80	134	62	1085.2	33.4
EMBSN 1/96	77	131	57	1211.0	31.1
EMBSN 9/96	78	136	65	975.7	34.7
EMBSN 18/96	77	133	61	1407.3	31.4
EMBSN 3/96	78	132	61	1355.1	32.0
EMBSN 5/96	78	133	62	1216.6	33.2
EMBSN 31/96	79	130	61	1233.0	30.7
218963-4	84	135	70	1894.9	36.2
215235-2	85	136	77	2440.5	38.6
HB 42	94	148	86	1703.8	38.9
Ehilzer	82	134	64	1515.6	35.2
Mean	80.257	133.569	63.833	1336.30	33.43
L × V	**	**	NS	**	NS
V	**	**	**	**	**
CV (%)	2.94	2.08	13.27	18.96	8.72

NOTES: * = significant at $P<0.05$; ** = significant at $P<0.01$; NS = Not significant; L = Location; V = Variety; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha).

TABLE 6

Mean grain yield and other agronomic traits of barley genotypes over locations (Geregera, Kone and Estayish) in 2002

Genotype	DH	DM	PH	GY	TGW
EMBSN 35/96	72	125	64.3	2218.7	31.6
EMBSN 33/96	71	123	61.9	2141.7	32.0
EMBSN 26/96	70	123	63.0	2084.3	31.2
EMBSN 21/96	69	123	54.9	2550.5	29.7
EMBSN 39/96	71	123	66.1	2168.4	33.2
EMBSN 44/96	73	122	64.6	2212.9	31.5
EMBSN 1/96	69	123	58.4	2358.5	29.0
EMBSN 9/96	70	127	78.1	2758.6	33.6
EMBSN 18/96	71	124	58.0	2093.5	29.5
EMBSN 3/96	70	122	60.9	2215.8	30.4
EMBSN 5/96	71	123	63.9	2166.3	33.1
EMBSN 31/96	71	124	65.0	2032.8	30.1
218963-4	78	129	77.1	2571.3	36.0
215235-2	78	128	77.7	2898.0	34.6
HB 42	84	134	78.8	2344.5	35.9
Ehilzer	73	126	80.7	2850.6	34.3
Mean	72.507	124.965	67.646	2354.15	32.240
L × V	**	*	NS	**	**
V	**	**	**	**	**
CV (%)	2.52	2.44	11.05	16.34	7.23

NOTES: * = significant at $P<0.05$; ** = significant at $P<0.01$; NS = Not significant; L = Location; V = Variety; DH = Days to heading;DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha).

suitable for moisture-stressed barley growing areas of Wollo, and possibly for other areas with similar environments.

Set III – Evaluation of mixed barley germplasm for low-moisture areas

Despite unfavourable conditions in the 2001 cropping season, genotypes BIT 94 N 1092 and 3296-15 had good yields compared with other genotypes (Table 8). In 2002, genotypes BI 95 IN 198 and BIT 94 N 1092 gave the highest yield (Table 9). In 2003, the analysis combined over locations showed that the standard check ‘Shedho’ had higher yields than the other genotypes (Table 10). Year and location combined analysis showed significant differences for days to heading, plant height, 1000-grain weight and biomass, but not for days to maturity and grain yield. Genotypes BI 95 IN 198 and BIT 94 N 1092 gave higher yields than the other genotypes tested (Table 11). Therefore, after evaluating these two genotypes, the seed release committee released genotype BI 95 IN 198 as ‘Yedogit’. The earliness of this variety (heading within 67–70 days) also increases its tolerance to frost that usually occurs around mid-October.

Set IV – Adaptation trial of released food barley varieties

Three varieties were tested for their adaptability in comparison with the local check variety. All parameters showed non-significant differences, except for

TABLE 7

Mean grain yield and agronomic data of barley genotypes over locations (Geregera, Kone and Estayish) and years (2001 and 2002)

Genotype	DH	DM	PH	GY	TGW
EMBSN 35/96	76	128	62	1671.9	31.4
EMBSN 33/96	74	127	63	1804.1	32.3
EMBSN 26/96	73	127	62	1680.2	31.3
EMBSN 21/96	74	127	55	1863.8	30.6
EMBSN 39/96	75	128	61	1763.6	33.2
EMBSN 44/96	76	128	63	1649.0	32.4
EMBSN 1/96	73	127	58	1784.8	30.0
EMBSN 9/96	74	131	72	1867.1	34.1
EMBSN 18/96	74	128	59	1750.4	30.5
EMBSN 3/96	74	127	61	1785.4	31.2
EMBSN 5/96	75	128	63	1691.4	33.1
EMBSN 31/96	75	127	63	1632.9	30.4
218963-4	81	132	74	2233.1	36.1
215235-2	81	132	77	2669.2	34.6
HB 42	89	141	87	2024.2	37.4
Ehilzer	77	130	72	2183.06	34.7
Mean	76.382	129.267	65.740	1878.04	32.836
L × Y	**	**	**	**	**
Y × V	NS	**	*	**	
L × Y × V	**	**	NS	**	**
CV (%)	2.77	2.26	12.15	17.60	8.04

Notes: * = significant at $P<0.05$; ** = significant at $P<0.01$; NS = Not significant; L = Location; V = Variety; Y = Year; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha).

TABLE 8

Combined analysis over locations (Geregera, Kone and Estayish) for mean days to heading, days to maturity, plant height, grain yield, 1000-grain weight and biomass (g/plot) for 2001

Genotype	DH	DM	PH	GY	TGW	Biomass
BI 95 IN 454	79.000	136.222	59.778	1348.611	35.600	722.222
BI 95 IN 586	76.556	132.000	65.778	1523.333	37.267	855.556
BI 95 IN 198	75.778	135.556	63.111	1742.056	35.778	877.778
BIT 94 N 1092	81.111	135.222	71.222	1875.222	34.067	1033.333
BOLW 94 40	76.000	140.333	69.111	1720.778	37.500	988.889
BOLW 94 47	81.000	134.778	65.444	1335.556	29.911	844.444
BOLW 94 74	86.222	132.444	64.222	1018.167	37.789	788.889
BOLW 94 87	79.333	129.889	55.444	1113.889	32.256	688.889
4839-9	82.333	137.556	79.556	1592.056	37.711	1000.000
4837-16	81.444	134.444	88.222	1681.333	37.667	1016.667
4744-13	82.111	136.111	79.222	1538.944	35.156	977.778
4744-4	82.000	135.444	83.000	1674.778	36.511	1033.333
4748-17	83.111	137.111	81.222	1720.833	39.300	933.333
3296-15	84.111	141.333	74.889	1924.278	37.411	1061.111
Shedho	88.222	151.333	82.333	1651.500	40.056	1222.222
Ehilzer	81.778	134.778	71.000	1757.167	36.456	933.333
Mean	81.257	136.535	72.097	1576.156	36.277	936.111
CV (%)	4.96	3.05	8.43	26.02	5.72	25.21
L × V	**	**	NS	NS	**	NS

Notes: ** = significant at $P<0.01$; NS = Not significant; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha); L = Location; V = Variety.

TABLE 9

Combined analysis over locations (Geregera, Kone and Estayish) for days to heading, days to maturity, plant height, grain yield, 1000-grain weight and biomass (g/plot) for 2002

Genotype	DH	DM	PH	GY	TGW	Biomass
BI 95 IN 454	71	133	67	2476	37	1156
BI 95 IN 586	69	129	76	2177	37	1174
BI 95 IN 198	67	131	73	3477	37	1489
BIT 94 N 1092	73	126	84	2973	33	1594
BOLW 94 40	70	121	76	2324	35	1161
BOLW 94 47	65	127	77	2319	29	1325
BOLW 94 74	68	124	79	2564	35	1394
BOLW 94 87	70	125	57	1859	34	1133
4839-9	74	130	93	2342	36	1422
4837-16	76	124	100	2403	34	1411
4744-13	76	131	97	2536	34	1478
4744-4	77	124	96	2470	34	1500
4748-17	75	135	95	2471	34	1444
3296-15	78	132	85	2433	35	1484
Shedho	79	138	88	2199	36	1424
Ehilzer	74	127	87	2571	33	1383
Mean	72.722	128.521	83.229	2474.733	34.544	1373.396
CV (%)	3.30	7.36	7.20	19.05	6.89	17.58
L × V	NS	NS	*	NS	**	NS

Notes: ** = significant at $P<0.01$; NS = Not significant; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha); L = Location; V = Variety.

TABLE 10

Combined analysis over locations (Estayish, Kone and Geregera) for days to heading, days to maturity, plant height, grain yield, 1000-grain weight and biomass (g/plot) for 2003

Genotype	DH	DM	PH	GY	TGW	Biomass
BI 95 IN 454	72	135	61.7	2475.8	40.9	1164
BI 95 IN 586	70	133	73.0	2321.5	41.1	1078
BI 95 IN 198	70	136	63.3	2732.3	39.9	1155
BIT 94 N 1092	79	132	72.0	2622.8	34.6	1111
BOLW 94 40	72	132	67.4	2378.4	40.5	1111
BOLW 94 47	68	129	71.6	2135.7	32.5	1077
BOLW 94 74	73	128	69.6	2403.3	37.2	1033
BOLW 94 87	71	128	50.8	1939.6	35.9	911
4839-9	78	133	88.2	2636.6	38.7	1267
4837-16	79	131	90.7	2518.7	40.7	1244
4744-13	79	135	84.9	2405.5	36.1	1175
4744-4	81	129	89.1	2392.2	38.5	1219
4748-17	78	134	92.2	2261.8	38.2	1441
3296-15	81	137	81.7	2144.3	40.0	1147
Shedho	79	133	80.0	2988.8	37.4	1397
Ehilzer	79	131	81.4	2349.4	36.8	1341
Mean	75.757	132.333	76.051	2419.169	38.07	1179.569
CV (%)	3.13	3.09	12.22	22.71	5.72	19.66
L × V	NS	**	NS	NS	**	**

Notes: ** = significant at $P<0.01$; NS = Not significant; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha); L = Location; V = Variety.

TABLE 11

Combined analysis over locations (Estayish, Kone and Geregera) and years (2001, 2002 and 2003) for days to heading, days to maturity, plant height, grain yield, 1000-grain weight and biomass (g/plot)

Genotype	DH	DM	PH	GY	TGW	Biomass
BI 95 IN 454	74.185	134.815	62.763	2100.19	37.804	1003.70
BI 95 IN 586	71.593	131.407	71.659	1993.83	38.489	1035.93
BI 95 IN 198	70.815	134.296	66.585	2650.51	37.430	1174.07
BIT 94 N 1092	77.815	130.926	75.852	2490.46	34.026	1246.29
BOLW 94 40	72.815	131.259	70.719	2141.09	37.570	1087.04
BOLW 94 47	71.333	130.259	71.363	1930.04	30.367	1082.41
BOLW 94 74	75.889	128.111	71.030	1995.29	36.789	1072.22
BOLW 94 87	73.741	127.704	54.541	1604.43	33.956	911.11
4839-9	78.296	133.481	86.985	2190.09	37.448	1229.63
4837-16	78.852	130.000	92.993	2201.06	37.452	1224.07
4744-13	79.259	133.889	86.896	2160.13	35.189	1229.63
4744-4	80.037	129.593	89.526	2178.96	36.407	1262.96
4748-17	78.926	135.259	89.474	2124.83	37.119	1255.56
3296-15	81.074	136.852	80.637	2167.33	37.459	1248.29
Shedho	82.111	140.704	83.422	2279.78	37.700	1360.00
Ehilzer	78.519	130.852	79.570	2226.13	35.552	1179.63
Mean	76.579	132.463	77.126	2152.14	36.297	1162.66
CV (%)	3.96	4.84	9.45	22.49	6.10	21.67
V	**	**	**	**	**	**
L	**	**	**	**	**	**
L × V	**	NS	NS	**	**	NS
L × Y	*	NS	**	**	**	**
V × Y	**	**	NS	**	**	NS
L × V × Y	**	NS	*	NS	**	**

NOTES: * = significant at $P<0.05$; ** = significant at $P<0.01$; NS = Not significant; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); TGW = 1000-grain weight (g); GY = Grain yield (kg/ha); L = Location; V = Variety; Y = Year.

TABLE 12

Yield of 'Yedogit' (BI 95 IN 198) in comparison with the standard and local checks

Variety	Grain yield (kg/ha)	Yield advantage over the local check (%)	Yield advantage over the standard check (%)
Yedogit	2650.5	+19	+16
Shedho	2279.8	–	–
Ehilzer	2226.1	–	–

days to maturity and to heading. However, farmers selected 'Misrach' due to its earliness and yield (Table 13).

GAPS AND CHALLENGES

- The region has an unfavourable environment.
- The mandated working area of Sirinka Agricultural Research Centre is repeatedly affected by drought and has poor soil fertility. Under these conditions, there is a problem of inconsistent data and sometimes no yield.

TABLE 13

Means of days to heading, days to maturity, plant height, grain yield and 1000-grain weight data from participatory evaluation of released barley varieties at Delanta in 2002

Variety	DH	DM	PH	GY	TGW
Misrach	66	118	85	3300.0	37.7
Shege	92	132	70	3374.9	39.0
Abay	84	127	88	3174.9	37.1
Local check	60	106	96	2600.0	37.1
Mean	75.417	120.750	84.583	3112.467	37.750
CV (%)	6.49	2.01	13.75	22.30	6.86
LSD ($P<0.05$)	9.782	4.848	NS	NS	NS

NOTES: NS = Not significant; DH = Days to heading; DM = Days to maturity; PH = Plant height (cm); GY = Grain yield (kg/ha); TGW = 1000-grain weight (g).

- There is a lack of exotic material (accessions) suited to moisture stressed and poor soil conditions.
- There is a lack of material for malting barley research.
- There is a lack of skilled labour familiar with this unfavourable environment.

FUTURE RESEARCH DIRECTIONS

- Scaling up the released food barley varieties for barley-growing areas of Wollo.
- Developing malting barley varieties.
- Developing drought-tolerant food barley varieties.
- Developing varieties with resistance or tolerance to scald and blotches.

Achievements of food barley breeding research in Southern Nations, Nationalities and Peoples' Region

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ACHIEVEMENTS

The major breeding activities in the region focus on the selection of barley genotypes for target environments. For this purpose, breeding materials were obtained from both the Institute of Biodiversity Conservation (IBC) and the national barley research programme at Holetta Agricultural Research Centre (HARC). A second important activity is collaborative research with the national barley research project at HARC.

In general, the objective of breeding research has been to replace the farmers' landraces with improved, better yielding material. Yield trials were conducted in 2000–2002 at three locations, and one line was provisionally released that had yielded better than local checks, standard checks and all other materials in the trials (Table 1).

The candidate variety (Table 1) had yield advantages over standard and local checks of 62.5% and 31.8%, respectively. It had greater yields than the standard check in all seven environments (2000–2002 at Kokate and Hosanna, and 2002 at

TABLE 1

Mean yield and other agronomic traits of provisionally released material in comparison with standard and local checks (2000-2002)

Genotype	Average yield (kg/ha)				Agronomic trait		
	Kokate	Hosanna	Hagere Selam	Mean	DM	PH	TGW
ACC 231222/MS	2085.4	2983.1	1331.0	2362.34	96	99.5	45.0
HB 42	1325.0	1947.7	358.24	1454.04	111	95.3	41.6
Local check	1868.5	2118.0	584.60	1792.04	99	94.4	38.8
Location mean	1818.5	2444.1	1134.10				

NOTES: The yield trial was conducted for one year only; Mean is the overall average yield at two locations (Kokate and Hosanna); DM = days to maturity; PH = plant height (cm); TGW = 1000-grain weight (g).

TABLE 2
Grain yield of barley lines in regional trials in 2003 and 2004 at Bule, Fereze and Hosanna.

Genotype	2003			2004			Mean (kg/ha)	Disease score	
	Bule	Fereze	Hosanna	Bule	Fereze	Hosanna		Leaf rust	Blotch (%)
NBSN43198	2371	2160	4045	2757	1591	3961	2864	0	72.0
NBSN44198	2061	1556	2546	2591	1062	3859	2279	1.7	24.0
NBSN50198	2644	1340	3286	2608	818	3330	2338	0	23.6
NBSN45198	2636	2025	3576	3044	1174	3767	2704	1.7	48.0
NBSN46198	2477	1160	2871	2561	1816	3060	2323	1.7	71.6
NBSN50198	2550	1227	2821	2175	1304	3053	2188	0	23.6
NBSN48198	2036	1116	2942	2411	1007	3255	2128	0	23.6
Local check	2486	1257	3215	2288	2224	2329	2295	1.7	73.6
Mean	2408	1480	3163	2554	1375	3327	2385		

Hagere Selam). The material was early maturing, thus suited to areas with a short rainy season, and was relatively large seeded.

Additional yield trials were conducted from 2003–2004 at three locations (Bule, Fereze and Hosanna) using eight food barley lines (Table 2). In this experiment, the mean yields of lines NBSN43198 and NBSN45198 were greater than the grand mean, while all other lines yielded less.

RESPONSE OF EXOTIC GERMPLASM TO EXTERNAL INPUTS

The influence of fertilizer on the yields of food barley lines was tested in 1998 at two locations (Hosanna and Hagere Selam) using nine lines. The fertilizers levels were 41 kg/ha N plus 20 kg/ha P. The application of fertilizer at Hosanna gave a remarkable yield advantage (Table 3). Hence, lines tested at Hosanna required the recommended fertilizer rate. However, the application of fertilizers at Hagere Selam gave lower yields than from plots without fertilizers for most lines tested. Lines IBON 09/92 and IBON 17/92 responded to fertilizer application at Hosanna but not at Hagere Selam. Line IBON 24/92 gave a better yield at both locations without fertilizers, indicating good performance of this variety in a low-input environment, and that it may be beneficial for those farmers who cannot apply fertilizer. In general, the response of test materials to fertilizer varied according to variety and location, indicating the need for site- and genotype-specific recommendations, which can be a challenge for improvement programmes.

TABLE 3
Effect of application of 41 kg/ha N plus 20 kg/ha P on grain yield (kg/ha) of food barley at Hosanna and Hagere Selam

Genotype	Hosanna		Hagere Selam	
	F+	F–	F+	F–
IBON 64/92	2733.14	1241.50	1672.44	1085.80
IBON 09/92	2288.99	614.50	1760.86	2233.42
IBON 17/92	1740.67	784.25	2198.96	860.31
IBON 24/92	787.88	1240.75	776.35	2032.65
IBON 94/91	1641.99	856.25	779.28	2371.53
Line 1108	2387.92	1174.75	1592.13	2335.92
Line 937	1809.83	660.00	1712.75	1081.65
HB 42	3083.18	383.50	1228.42	1742.02
Local	3253.87	520.50	3493.77	3660.41
Mean	2191.94	830.66	1690.55	1936.86

NOTES: F+ = with fertilizer; F- = without fertilizer.

Agronomy and soils

Potentials and limitations of acid soils in the highlands of Ethiopia: a review

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INTRODUCTION

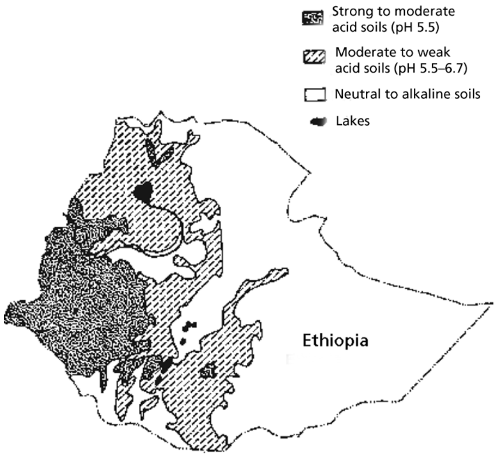
Principal soil-related constraints in the management of crops include nutrient deficiencies and imbalances, deterioration in soil structure (leading to surface crusting and compaction), loss of soil organic matter, accelerated soil erosion and degradation, coupled with lack of incentives and policies to adopt improved and ecologically friendly technologies (Thomas, 1995).

Due to the wide variability in climate, physiographic conditions, soil types and associated vegetation and farming systems, almost all types of soil degradation are occurring in Ethiopia, at an alarming rate, although there are marked differences in magnitude. The most important soil chemical degradation is fertility decline, in the form of excessive nutrient exhaustion followed by salinization and acidification. This aspect of soil chemical degradation is the most serious problem in the majority of the cultivated soils of Ethiopia, seriously affecting crop yields and agricultural productivity. As a result of this degradation, the national average yield of cereal crops is no more than 1 t/ha, even in the productive highlands of the country. This is aggravated by intensive land use and high population pressure.

The main nutrients that become depleted and therefore seriously limit soil productivity are nitrogen and phosphorus. The relatively weathered red soils are limited more by a lack of phosphorus, whereas black and less well drained soils are limited more by nitrogen. Nationwide fertilizer trials with cereals have indicated that more than 50% of the soils are highly responsive to the addition of nitrogen, 25% to phosphorus and a very few to potassium. In addition, the nutrient status of most soils is decreasing. Between 70% and 75% of the agricultural soils of the highland plateau area of Ethiopia are deficient in phosphorus (Duffera and Robarge, 1999).

The solubility and availability of important nutrients to plants is closely related to the pH of the soil (Somani, 1996). Soil pH affects the availability of plant nutrients. The effects of high acidity in a soil cause a shortage of available Ca, P and Mo on the one hand, and an excess of soluble Al, Mn and other metallic ions on the other. In soil pH 6–7, P fixation is low and its availability to plants is higher. Toxicity and deficiency of Fe and Mn may be avoided if the soil reaction is held within a soil pH range of 6–7; this pH range seems to promote a ready availability of plant nutrients (Somani, 1996).

FIGURE 1
Distribution of acid soils in Ethiopia



SOURCE: Schlede, 1989.

Soil degradation with respect to soil acidity is mainly an inherent problem due to the weathering stage of the soil as opposed to problems caused by humans. However, sub-soil acidity as a result of the removal of surface soils by erosion is most common in warm, humid areas where soils are disturbed by humans. Soil surveys of Ethiopia show that the soils of large areas of western and southwestern Ethiopia are acidic, with pH values below 5.5 (Schlede, 1989) (Figure 1). The extent of acid soils is estimated to be 30% of the land area, and those that are highly acidic (with a pH of <5.5) are estimated to be 13% of the total land area. A recent study on the two important plant growth limiting nutrients—nitrogen and phosphorus—shows that acid soils dominate most of the southern and southwestern parts of Ethiopia and generally have low P content. Soils in the south and southwestern parts, including Sidamo, Illubabor and Keffa, have high N and low P contents (Hailu Regassa, 1998).

Crops differ in their susceptibility to soil acidity. The pH of soils for best crop yields is considered to be between 6.5 and 7.0. A summary of the crop relationship to soil reaction is given in Table 1. Cotton, alfalfa, oats and cabbage do not tolerate acid soils and are considered to be suitable for neutral soils with a pH range of 7–8. Wheat, barley, maize, clover and beans grow well on neutral to mildly acid soils with a pH of 6–7. Crops that are tolerant to acid soils include millet, sorghum, sweet potato, potato, tomato, flax, tea, rye, carrot and lupin.

TABLE 1
Crop relationship to soil reaction (pH)

Crop	Optimum pH for growth	Crop	Optimum pH for growth
Alfalfa	7.0–8.0	Sugar beet	5.8–7.0
Cotton	7.0–8.0	Millet	5.5–7.5
Oat	7.0–8.0	Sorghum	5.5–7.5
Cabbage	6.0–6.5	Sweet potato	4.5–6.5
Wheat	6.0–7.0	Potato	4.5–6.5
Barley	6.0–7.0	Tomato	5.5–7.5
Maize	6.0–7.2	Deciduous fruits	6.5–7.5
Clover	6.0–7.0	Mango	5.0–6.0
Faba bean	6.0–8.0	Papaya	6.0–6.5
Field pea	6.0–7.0	Avocado	5.0–8.0
Chickpea	7.0–8.0	Pineapple	4.5–6.5
Lentil	6.5–8.0	Flax	5.0–7.0
Soybean	6.2–7.0	Tea	4.0–6.0
Beans	5.5–8.0	Carrot	5.5–7.0
Onion	5.8–6.5	Rye	5.0–7.5
Sugar cane	5.0–8.5	Lupin	4.5–6.0

SOURCES: IFA, 1992; Somani, 1996.

Increased soil acidity may lead to reduced yields, poor plant vigour, uneven pasture and crop growth, poor nodulation of legumes, stunted root growth, persistence of acid-tolerant weeds (e.g. *Geranium*), increased incidence of diseases and abnormal leaf colour. The planting of tolerant species allows production to continue on the acidic soils but does not change the acidity. In many soils, the best results are obtained from the combined use of tolerance and lime. Whereas many plants can tolerate pH ranges of 5.2–7.8, most plants grow best in mineral soils when soil pH is between 6.0 and 7.0 (Marschner, 1995; Somani, 1996).

Of the main cereal crops, barley is the most sensitive and responsive to an acidic environment. With continuous cropping, soil pH can decrease (increase in acidity) because of various factors, including crop removal, leaching of basic cations, application of ammonia-based nitrogen fertilizers, and organic matter decomposition. Adding lime or other materials can raise the soil pH to the ideal range for crop production, create an environment for the healthy functioning of microbes, and increase levels of calcium or magnesium ions.

LIMESTONE OR DOLOMITE AS CALCIUM SOURCE

Liming material can be found in Ethiopia within three main geological categories: Proterozoic, Mesozoic and Cenozoic. The largest sources of limestone are located in the eastern part of the country, although there are extensive and thick Mesozoic limestone and gypsum sequences in the Blue Nile River area in central Ethiopia. Proterozoic limestone and dolomite deposits in western and southwestern Ethiopia have considerable potential, as they are located close to the acid soils. Dolomitic limestones and marbles have been reported from many places in western Ethiopia, including Daletti, near Mendi (Abera, 1994). Agronomic experiments were successfully carried out by the Institute of Agricultural Research (IAR) using limestone on acid soils of the Nejo area, which is close to Mendi, Wellega.

Proterozoic liming materials

Proterozoic marbles occur in northern Ethiopia (Tigray), and also in the western (Gojam, Wellega, Illubabor, Kaffa), southern (Omo, Sidamo) and eastern (Hararge) parts of the country. Accounts of these resources are provided by Schlede (1989). A general observation is that these resources occur in areas where strong to moderately acid soils (pH <5.5) are dominant. Schlede (1989) stated that the marble deposits are well distributed over the area of acid soils that require liming materials to improve soil productivity.

Mesozoic liming materials

Mesozoic limestone, dolomitic and marble deposits in western and northern Ethiopia occur in Tigray, in the Danakil Alps and in the Blue Nile (Abbay) valley. They also outcrop over large areas on the Somali plateau. Smaller outcrops of Mesozoic liming materials occur in the central plateau area near Ambo town, in the Didessa valley. Smaller deposits occur in the Kella area, which is south of Addis Ababa. The Jurassic Antalo Group, which has sequences of limestone, dolomites and marl, occur in the Blue Nile (Abbay) valley and the Mekelle area (Tigray). In the Mekelle area, the Antalo limestone is about 750 m thick (Kazmin, 1972). In general, the Mesozoic limestone, dolomite and marl resources are located distant to areas with strong to moderate acid soils (pH <5.5).

Cenozoic liming materials

Cenozoic calcareous sediments occur in three areas of Ethiopia: in eastern Ogaden, in the Danakil Depression and in the lower Omo valley. The limestone resources from the east of the country are too far from the acid soils of western and southwestern Ethiopia to be of economic interest.

PARENT MATERIALS AND INHERENT FERTILITY

The inherent fertility of Ethiopian soils developed under varied parent materials and climate, and varies depending on the origin and composition of the materials. For instance, soils developed from sandstones give rise to poor sandy soils, whereas the inherent soil fertility developed over basic parent materials is relatively high (Asnakew Woldeab *et al.*, 1990). In alluvium plains, alluvium will be rich and fertile if it originates from relatively young materials, and less fertile if it originates from highly weathered surfaces. In general, Ethiopian soils are low in available N and P. The pH values in the majority of soils are in the range of 4.5 to 6.5. However, in the lowland areas with less rainfall, the pH is always more than 8. As a rule, soils found in high-altitude areas are acidic in reaction, poor in exchangeable cations and low in base saturation (Asnakew Woldeab *et al*., 1990) (Table 2).

SOIL ACIDITY IN ETHIOPIA

Soil acidity and associated low nutrient availability is one of the constraints to barley production on the acidic soils, mainly Nitisols or Oxisols, of Ethiopian highlands. Acid soils occur widely in Ethiopian highlands, where the rainfall intensity is high and crop cultivation has occurred for many years (Desta Beyene, 1987; Schlede, 1989; Taye Bekele and Höfner, 1993). The fertility status of these soils is very low in terms of reserves of nutrients available to plants, due to removal of nutrients in the harvested products and losses through erosion and leaching. The pH of the soils is less than 5.5 and, as a result, yields of barley (as well as other crops grown in the highlands) are very low compared with other barley growing soils of the country. In addition to the lack of proper cultural practices, the low

TABLE 2
Analytical data for some typical topsoils in Ethiopia

Parent material	Soil type	pH	OM (%)	N (%)	P (ppm)	meq/100 g soil				Clay (%)	Silt (%)
						Na	K	Ca	Mg		
Trachy-basalt and pyroclastic	Chromic Luvisol	5.5	3.8	0.22	3.6	0.6	1.7	11.8	2.6	38	45
Olivine basalt and pyroclastic	Eutric Nitosol	5.4	2.3	0.17	3.5	0.02	1.6	9.1	4.1	66	28
Weathered basalt	Pellic vertisol	6.8	2.3	0.14	9.9	0.6	2.7	40.0	9.0	64	24
Colluvium alluvium	Pellic vertisol, Sodic Phase	8.2	2.3	0.10	2.2	5.5	1.7	36.5	6.8	49	25
Volcanic ash	Haplic Phaeozem	6.5	2.6	0.23	11.9	0.8	1.5	20.0	8.3	23	41

NOTES: OM = organic matter; P determined by Olsen method.
SOURCE: Asnakew Woldeab *et al.*, 1990.

barley yields could be attributed mainly to the deficiency of nutrients and low soil pH (Taye Bekele and Höfner, 1993).

The main crops raised by farmers on acidic soils are barley, wheat, teff, rapeseed, faba bean and field pea (Table 3). Barley is one of the most important cereal crops widely grown by small-scale farmers under rainfed conditions in Ethiopia. It ranks third next to teff and wheat in mid-altitude and first in high-altitude areas in terms of area coverage (82 6778 ha) and production (CSA, 2004), covering 13% of the total area under cereals. The national average yield is low, with a mean of about 1.0 t/ha (CSA, 2004) due to poor soil fertility (Asnakew Woldeab *et al.*, 1990). This is true particularly for N and P nutrients due to continuous cropping of cereals and the low level of fertilizer usage (Hailu Beyene, Muwangi and Werkneh Negatu, 1991; Amsal Tarekegne, Hailu Gebre and Francis, 1997).

The clay mineralogy, pH, presence of oxides and hydroxides of Fe and Al and content of amorphous materials seem to be the dominant factors affecting P sorption. In the case of the highly weathered soils of Chenca, Nedjo and Indibr—where the dominant minerals are Gibbsite, Goethite, Kaolinite and desilicated amorphous materials—P sorption is high to very high. High sorption of phosphate by amorphous materials, and presence of oxides and hydroxides of iron and aluminium, have been reported by several investigators. The mechanism of phosphate adsorption is considered to be mainly through replacement of hydroxyl ions on crystal lattices, and hydrated iron and aluminium by phosphate ions (Velayuthan, 1980).

Phosphorus sorption capacity increases with increasing acidity, i.e. decreasing pH value. The lowest amount of P sorbed is by the soil from Melkassa, which is the least weathered (with a pH value of 7.8). The highest P sorption is by the soil from Chencha, which has a pH of 4.5, and which has the highest content of gibbsite, goethite and amorphous materials (Table 3).

The reddish-brown soils of the Ethiopian highlands are highly deficient in phosphorus. Results from fertilizer trials have shown that yields could be doubled, in some cases tripled, with P application (Taye Bekele and Höfner, 1993). However, the high costs of high grade, water-soluble P fertilizers, coupled with the high fixing capacities of these soils for P, present agronomic and economic constraints to crop production (Sahlemedhin Sertsu and Ahmed Ali, 1983). For

TABLE 3
Amount of P sorbed by some Ethiopian soils at the standard solution P of 0.2 ppm

Soil origin	P sorbed (mg/g)	Sorbed P (kg/ha)	pH	Fe_2O_3 (%)	Exch. Al (meq/100 g)	Amorphous material (%)	Gibbsite and Goethite (%)
Chencha	1200	2400	4.5	11.7	0.4	51	10
Nedjo	950	1900	4.4	16.1	6.16	32	12
Indibir	800	1600	4.8	11.7	1.69	61	0
Melko	600	1200	5.2	15.8	0.37	ND	ND
Bako	400	900	6.6	14.4	0.02	41	5
Melkassa	150	300	7.8	0.2	Tr	ND	ND

NOTES: ND = not determined; Tr = trace. SOURCE: Sahlemedhin Sertsu and Ahmed Ali, 1983.

TABLE 4

Initial soil chemical properties of the experimental field of Holetta Agricultural Research Centre, 2001–2003

Field No.	pH 1:1 (H_2O)	P (ppm)	N (%)	OC (%)	meq/100 g soil				
					Na	K	Ca	Mg	CEC
Rep I	4.2	5.6	0.19	1.56	0.11	1.66	2.76	2.31	23.44
Rep II	4.3	5.0	0.16	1.48	0.14	1.25	2.73	2.36	28.98
Rep III	4.4	5.0	0.17	1.52	0.07	1.28	2.75	2.20	27.94
Rep IV	4.4	4.2	0.18	1.52	0.08	1.14	2.74	1.48	26.04
Mean	4.3	4.95	0.17	1.52	0.10	1.33	2.74	2.09	26.60

NOTES: P determined by Olsen method; CEC = cation-exchange capacity; OC = organic carbon.
SOURCE: Getachew Agegnehu and Taye Bekele, 2005b.

TABLE 5

Chemical characteristics of soils of two sites in Walmera area, 2003–2004.

Soil type	pH 1:1 (H_2O)	N (%)	(mg/kg)			meq/100 g soil				
			P	NH^{4+}-N	NO^3-N	Na	K	Ca	Mg	CEC
Nitisol/Dila	5.04	0.20	21.26	37.68	21.75	0.15	2.03	12.52	3.29	25.75
	5.09	0.18	18.17	39.85	19.65	0.01	2.13	9.24	2.24	23.97
	5.24	0.24	17.93	27.74	23.68	0.01	2.20	12.76	2.63	29.80
Mean	5.12	0.21	19.12	35.09	21.69	0.06	2.12	11.51	2.72	26.51
Nitiosol/Dimile	4.46	0.20	8.40	39.46	9.83	0.01	1.41	8.95	1.76	20.78
	4.62	0.16	10.80	17.26	5.63	0.01	1.82	8.82	1.58	20.35
	4.51	0.17	10.00	34.28	13.58	0.02	1.64	6.85	1.38	19.51
Mean	4.53	0.18	9.73	30.33	9.68	0.01	1.62	8.21	1.57	20.21

NOTES: CEC = cation-exchange capacity. SOURCE: Getachew Agegnehu and Taye Bekele, 2005a.

instance, soil analytical results have indicated that most of the soils in the Walmera area are low in pH and deficient in available P. Thus, the amount of available P in the soil is, by and large, insufficient to meet the requirements of barley production. Soil analytical results were found to be suboptimal for the production of crops. As presented in Tables 4 and 5, the soil pH, available P and exchangeable cations were found to be far below the optimum. In most cases, soils with pH values less than 5.5 are deficient in Ca and/or Mg, and also P (Marschner, 1995).

MANAGEMENT OF ACID SOILS

Lime application

Adding lime or other materials can raise soil pH to the ideal range for crop production, create an environment for the healthy functioning of microbes, and increase the levels of calcium or magnesium ions. Lime neutralizes both the active acidity and some of the reserve acidity. As active acidity is neutralized by lime, reserve acidity is released into the soil solution, maintaining the active acidity or the pH. The ability of a soil to resist changes in pH is called buffering capacity and is largely due to the reserve acidity. More lime is required to neutralize acidity in a highly buffered soil than in a less-buffered soil. Monitoring pH changes over time is an important management tool. By comparing past and present soil tests, it is possible to see whether or not the soil acidity is increasing over time and whether or not management methods need to be altered to prevent this trend from continuing.

The effect of lime on barley grain yield was studied at Bedi (Welmera Woreda, West Shewa) from 1978 to 1981.The major crop grown on the Bedi plateau is barley. Yields of this crop in this area are generally low, less than 500 kg/ha. The soils at the Bedi site are typical of an extensive plain, where about 50% of the arable land is left in bare fallow each year and 50% is put to barley (Desta Beyene, 1987). The findings of Desta Beyene (1987) showed that the application of lime markedly increased the yield of barley (Table 6). The application of limestone (3 t/ha) was adequate to maintain barley grain yields of 1500 kg/ha or higher. However, the residual effect of liming on grain yield was minimal.

TABLE 6

Effects of different rates of lime applied once (1978) and twice (1978 and 1979) on grain yield (kg/ha) of barley, 1978–1981

Lime rate (t/ha)	Harvest year						
	1978	1979		1980		1981	
	L10	L10	L11	L10	L11	L10	L11
0	1125	1390	1272	1172	1182	1292	1398
1.5	1245	1339	1410	1019	1217	1259	1360
3.0	1407	1523	1639	1593	2062	1523	1800
4.5	723	1585	1650	1697	1688	1677	1571
SE±	36	60	86	107	95	44	63

NOTES: L10 = lime applied in 1978; L11 = lime applied in 1978 and 1979. SOURCE: Desta Beyene, 1987.

Responses to applied lime will occur at rates ranging from 0.5 t/ha to 4 t/ha. Normal application rates of lime of 1–2 t/ha on a soil of pH 4.8 can raise the soil pH by 0.6–1.0 pH units. This pH will gradually decline over the next 10 years. Applying lime at 3–4 t/ha can raise the pH from 4.8 to 6.3. This pH gradually declines over a 12-year period, but the liming effect may still be present after this. Lime can be applied at any time of the year; best results are achieved if it is incorporated. Lime quality is best described by fineness (particle size) and neutralizing value. The finer the lime, the higher the neutralizing value. How effective the lime is at increasing on-farm production depends on the starting pH of the soil, the level of aluminium or manganese, or both, in the soil, the production system being used, the fineness of the lime and its neutralizing value, and the amount of rainfall received since lime application.

The most common liming materials are calcitic or dolomitic agricultural limestone. These are natural products made by finely grinding natural limestone. As natural limestone is relatively insoluble in water, agricultural limestone must be very finely ground so it can be thoroughly mixed with the soil and allowed to react with the acidity of the soil. Calcitic limestone is mostly calcium carbonate ($CaCO_3$). Dolomitic limestone contains a mixture of calcium and magnesium carbonates. Either will neutralize soil acidity, but Dolomitic limestone also provides magnesium. The two main factors that affect the value of limestone for soil application are neutralizing value and particle size. Neutralizing value is the amount of acid a given quantity of limestone will neutralize when it is totally dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate. A limestone that will neutralize 90% as much acid as pure calcium carbonate is said to have a neutralizing value of 90. In general, the higher the

TABLE 7

Chemical properties of soils in the experimental field of HARC after harvesting, 2001–2003

Fertilizer regime		pH 1:1 (H_2O)	N (%)	P (ppm)	OC (%)	Minerals (meq/100 g soil)				
FYM (t/ha)	P (kg/ha)					Na	K	Ca	Mg	CEC
0	0	4.5	0.09	4.2	1.28	Tr	1.25	4.77	0.83	18.76
0	13	4.6	0.13	4.4	1.29	0.03	1.33	5.35	0.99	18.84
0	26	4.7	0.12	5.2	1.29	0.03	1.33	5.62	1.10	19.08
0	39	4.6	0.13	5.2	1.30	0.03	1.35	5.59	1.22	19.22
0	52	4.6	0.14	5.4	1.29	0.03	1.34	5.75	1.15	19.14
4	0	4.7	0.14	4.6	1.32	0.04	1.37	5.89	1.25	20.54
4	13	4.7	0.15	5.4	1.36	0.04	1.37	5.96	1.26	20.12
4	26	4.7	0.14	5.4	1.36	0.04	1.42	6.31	1.29	20.74
4	39	4.8	0.14	5.6	1.36	0.05	1.41	6.72	1.38	21.24
4	52	4.8	0.15	6.4	1.36	0.06	1.40	6.38	1.47	21.38
8	0	4.6	0.15	5.2	1.40	0.06	1.44	7.19	1.60	21.26
8	13	4.9	0.15	6.0	1.48	0.13	1.45	7.29	1.69	22.38
8	26	4.7	0.14	6.4	1.44	0.15	1.47	7.57	2.56	24.28
8	39	4.8	0.16	6.0	1.44	0.38	1.48	9.61	2.51	23.50
8	52	4.9	0.15	6.4	1.44	0.21	1.50	9.18	2.11	25.64
Mean		4.84	0.14	5.45	1.36	0.09	1.39	6.61	1.50	21.08

NOTES: CEC = cation exchange capacity; P determined by Olsen method; FYM = farmyard manure; OC = organic carbon; Tr = Trace. SOURCE: Getachew Agegnehu and Taye Bekele, 2005b.

calcium and magnesium content of a limestone, the higher the neutralizing value. The second factor that affects the value of limestone as a neutralizer of acidity is the particle size. Limestone rock has much less surface area to react with acid soil than finely powdered limestone and hence it neutralizes acidity much more slowly—so slowly that it is of little value.

Remediation of the acidic situation in Walmera nitosol was carried out by comparing the use of farmyard manure and chemical P source separately and in combination. The analysis of soil samples collected after harvesting indicated that there were raised pH levels and nutrient concentrations on plots treated with both farmyard manure and P fertilizer compared to sole application of either farmyard manure or P fertilizer (Table 7). The lowest pH and nutrient content were observed in soils that were not treated with farmyard manure. According to Sharma, Verma and Gupta (1990), the use of animal manure might have made the soil more porous and pulverized, allowing better root growth and development, thereby resulting in higher root cation exchange capacity. Sanchez (1976) has also indicated that the application of manure directly influences the availability of native or applied phosphorus.

CONCLUSION

Soil acidity problems are increasing in the highland areas of Ethiopia. These problems result from continuous cropping and use of acidifying fertilizers. Soil acidity may be reduced by applying lime, but distance from the lime source can make this a costly option. The rate of soil acidification may be reduced through management. Matching applied nitrogen and sulphur with crop needs may reduce input costs while reducing acidification. Other practices involve choosing less-acidifying fertilizers or improving application timing. Such practices may increase input and management costs. When considering changes, these costs need to be weighed against an eventual reduction in the cost of lime application.

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Research achievements in barley cultural practices in Ethiopia

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the main cereal crops produced in the Ethiopian highlands. It grows in the range of 1500–3500 masl, but is predominantly grown between altitudes of 2000 and 3000 masl (Hailu Gebre and van Leur, 1996). Barley ranks fourth in worldwide production of all cereals (FAO, 2004). In Ethiopia, barley is ranked fifth of all cereals, based on area of production, but third based on yield per unit area (CSA, 2004). Although barley is the most important cereal crop in Ethiopia, the national yield has remained low at below 1.3 t/ha (CSA, 2004), whereas the potential yield goes up to 6 t/ha on experimental plots (Berhane Lakew, Hailu Gebre and Fekadu Alemayehu, 1996). Several abiotic and biotic factors have contributed to this low productivity, such as poor crop management practices; the use of low-yielding cultivars; the limited availability of the very few improved cultivars released; weeds, insects and diseases; and the inherently low yield potential of the prevalent local varieties (Asfaw Negassa *et al.*, 1997; Berhane Lakew, Hailu Gebre and Fekadu Alemayehu, 1996; Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998; Woldeyesus Sinebo and Chilot Yirga, 2002). This low productivity is mainly due to traditional methods of production and poor soil fertility. The limited agronomic studies in the region have shown the importance of improved cultural practices for maximizing yield. Various investigations have therefore been carried out by research centres to mitigate the barley production problems. The purpose of this paper is to review research finding and to identify gaps, challenges and future research directions in relation to improving cultural practices for the production of barley in Ethiopia.

TABLE 1

Effects of hand weeding and nitrogen and phosphorus rates on plant height and grain yield of barley at Shambo

Hand weeding and N kg/ha	P_2O_5 kg/ha applied					
	Plant height (cm)			Grain yield (kg/ha)		
	0	20.5	41	0	20.5	41
0/0	92	79	85	860	773	796
0/23	76	88	91	746	1095	928
0/46	88	80	90	899	976	1223
1/0	75	76	78	715	894	1097
1/23	83	89	87	1677	1142	1392
1/46	77	88	91	986	1420	1293
2/0	76	78	78	927	1337	1177
2/23	71	83	82	760	1305	1100
2/46	76	79	78	1190	924	1057
	LSD ($P<0.05$)					
Hand weeding (A)		5.06			93	
Nitrogen rate (B)		NS			93	
Phosphorus rate (C)		NS			93	
A × B		NS			8.77	
A × C		NS			NS	
B × C		NS			NS	
A × B × C		NS			15.19	
CV (%)		19.93			28	

NOTE: First and second hand-weeding at 25–30 and 55–60 days after planting, respectively. NS = not significant at 5% probability level. SOURCE: Anon., 1998–2000.

MAJOR RESEARCH FINDINGS

Interaction of weeding and nutrient application

Trials to study the interactive effects of hand weeding and rates of nitrogen and phosphorus application on barley were conducted at Shambo for 3 years. Hand weeding significantly ($P<0.05$) affected plant height and grain yield (Table 1). The combination of hand weeding and application of nitrogen and phosphorus significantly affected grain yield. This indicates the importance of the three cultural practices for yield increment in barley. However, the highest grain yield (1677 kg/ha) was obtained with hand weeding and with applications of 23 kg/ha of N (Table 1).

Weed control using herbicides

Herbicides were evaluated for the control of *Gommanee* (*Raphanus raphanistrum*) on barley at Shambo. Effective control of the target weed was achieved by applying Dicopur PPD (mixture of Dicopur pp 600 SL (Mecoprop) + Dicopur 720 SL (2,4-D)); Dicopur pp 600 SL (Mecoprop), Brittox, and Dicopur 720 SL (2,4-D) (Table 2). The most common and predominant weeds at the experimental site other than *R. raphanistrum*, were *Polygonum nepalense*, *Guizotia scabra*, *Spergula arvensis* and *Plantago lanceolata*, which are known as Booqee, Cuqii (Tuufoo), Birbirsa and Qorxobbii, respectively, in the local language (Afaan Oromoo). The mean grain yield varied from 849 kg/ha for the no-weeding treatment to 1411 kg/ha for the plots

TABLE 2

Effect of post-emergence herbicides on general and individual weed control score in percentage and grain yield of barley in 1997.

Treatment	General weed control score	Individual weed control score					Grain yield (kg/ha)
		R.r.	P.n.	S.a.	G.s.	Others	
Unweeded check	0.00 f	0.00 c	0.00 d	0.00 b	0.00 c	0.00 c	955
Other weeds weeded	50.00 e	0.00 c	86.67 c	87.67 a	91.67 a	85.00 a	1034
Raphanus weeded	71.67 d	96.33 ab	0.00 d	0.00 b	0.00 c	0.00 c	1255
Weeded check	94.33 a	98.00 a	94.67 ab	92.67 a	95.33 a	91.33 a	1638
Dicopur 720 SL (2,4-D)	85.83 ab	97.50 a	94.67 ab	85.83 a	95.83 a	79.97 ab	1399
Dicopur pp 600SL (Mecoprop)	93.00 a	100.00 a	95.00 ab	91.67 a	95.17 a	87.00 a	1387
Dicopur PPD	92.17 ab	100.00 a	98.83 a	95.50 a	92.50 a	78.9 ab	1429
Brittox	75.83 cd	100.00 a	89.17 c	89.17 a	68.33 b	67.20 b	1497
Granstar	82.50 bc	86.50 b	91.67 bc	92.50 a	90.83 ab	81.10 a	1385
Terbutryn + Sulfonylurea	90.83 ab	99.20 a	97.50 a	95.00 a	89.67 a	81.70 a	678
Mean	73.3	77.75	74.8	72.00	70.9	65.2	1266
CV (%)	7.24	7.73	3.93	10.64	11.8	11.00	8.7
LSD ($P<0.05$)	9.106	10.32	5.048	13.15	14.35	12.31	NS

NOTES: G.s. = *Guizotia scabra*; P.n. = *Polygonum nepalense*; R.r. = *Raphanus raphanistrum;* S.a. = *Spergula arvensis*; Others = other broad leaf and grass weeds; NS = not significant; Dicopur PPD = Dicopur720SL+Dicopur pp 600SL. Means followed by the same letter do not differ significantly at 5% probability level according to Duncan's multiple range test (DMRT).
SOURCE: Daba Feyisa and Tolera Abera, 2006.

TABLE 3

Effect of post-emergence herbicides on weed populations and the resulting agronomic performance of barley in 1998

Treatments	General weed control	Individual weed control score						Plant height (cm)	Spike length (cm)	Grain yield kg/ha
		R.r.	P.n.	G.s.	S.a.	P.l.	Other			
Unweeded check	0.00	0.0	0.00	0.00	0.00	0.00	0.00	89	6	742
Other weeds weeded	47	0.0	90	92	85	88	84	88	6.53	993
Raphanus weeded	58	98	0.0	0.00	0.00	0.00	0.0	95	7.75	1253
Weeded check	89	96	93	93	83	88	82	91	7.95	1076
Dicopur 720 SL (24-D)	78	95	88	95	83	90	52	91	7.10	1019
Dicopur pp 600 SL (Mecoprop)	80	97	82	77	82	88	66	89	7.10	1142
Dicopur PPD	87	97	92	95	92	93	73	90	7.82	1392
Brittox	83	98	88	92	88	93	67	87	7.33	1137
Granstar	67	80	87	78	85	77	49	84	6.75	825
Terbutryn + Sulfonylurea	79	93	88	90	83	87	63	89	7.25	1628
Mean	67	75	71	71	69	71	54	89	7.17	1120
CV (%)	5.67	3.3	6.7	5.3	5.3	6.7	14.94	5.5	7.65	6.53
LSD ($P<0.05$)	6.5	4.2	8.1	6.5	6.2	8.1	13.73	8.43	0.94	NS

NOTES: Means followed by the same letter do not differ significantly at 5% probability level according to DMRT. G.s. = *Guizotia scabra*; P.n. = *Polygonum nepalense*; R.r. = *Raphanus raphanistrum*; S.a. = *Spergula arvensis*; P.l. = *Plantago lanceolata*; Other = other broad leaf and grass weeds; NS = not significant; Dicopur PPD = Dicopur720SL+Dicopur pp 600SL.
SOURCE: Daba Feyisa and Tolera Abera, 2006.

treated with the ready tank mixture (Dicopur PP 600 SL (Mecoprop) + Dicopur PP 720 SL (2.4-D)) (Tables 2 and 3). Higher mean grain yield was obtained in 1997 than in 1998. This could be attributed to the irregular rainfall that occurred prior to crop maturity in 1998. All of the applied herbicides showed no toxic effect on the crop.

Mean grain yield loss due to all weeds together (other than *R. raphanistrum*) was 7.59%, but with *R. raphanistrum* alone was 25.28%, and all weeds together with *R. raphanistrum* was 37.47% compared to weeded check (Table 3).

Effects of seed rate and weeding frequency on yield and yield components of barley

A study carried out at Sinana on the effects of seed rate and weeding frequency on the grain yield of food barley was conducted for 4 years (1992–1995). The results indicated that the grain yield and yield components of food barley were significantly affected by seed rate and weeding frequency (Table 4), although weed competition was found to depend on the amount and distribution of rainfall. Generally, a seed rate of 100 kg/ha for row planting and 100–125 kg/ha for broadcasting, supplemented by one hand weeding at 20–25 days after crop emergence, gave significantly higher grain yields in the Sinana area (Table 4).

Relative importance of yield-limiting factors on the yield of food barley

This study was conducted in northwest Ethiopia at five test locations (Table 5). The results indicated that the improved barley variety was inferior to the local ones, with a grain yield reduction of 56% at Huleteju-Enebssie and 19% at Dabat. This is because most of the local varieties at the test locations were high yielders when they received the full package of improved management practices. However, at Farta, the improved variety gave a 12% yield advantage over the local varieties (Table 5). Application of fertilizer significantly increased grain yield, with a yield advantage of 285% at Farta, 97% at Huleteju-Enebssie, 134% at Dabat, 105% at Laie-Gaient and 93% at Yilmana-Denssa (Table 5). Differences in grain yield due to weeding, fungicide and insecticide sprays were less pronounced at both locations. In general, the difference in grain yield due to fertilizer application was higher than the differences as a result of improved versus local variety; weeded versus unweeded; and sprayed versus unsprayed plots. Therefore, fertilizer was relatively more limiting than the other factors for food barley production at the test locations (Table 5).

TABLE 4

Effect of seed rate and weeding frequency on grain yield of food barley during the 1992–1995 Meher seasons, Sinana

Treatment	Grain yield (kg/ha)				
	1992	1993	1994	1995	Mean
Seed rate (kg/ha)					
75 kg/ha	1956	1029	2357	1012	1607
100 kg/ha	2299	1287	2499	1287	1868
125 kg/ha	2269	1428	2645	1338	1951
150 kg/ha	2495	1414	2543	1514	2029
175 kg/ha	2419	1538	2686	1457	2068
LSD (*P*<0.05)	249	202	NS	278	
Weeding frequency					
No weeding	2249	1186	2299	1153	1722
One hand weeding	2310	1489	2683	1408	1973
Two hand weedings	2304	1461	2686	1403	1964
LSD (*P*<0.05)	NS	227	301	175	
CV (%)	13.2	19.3	10.2	16	

NOTES: NS = not significant.

Interactions of tillage and weed control on yield and yield components of barley

The study was performed around Holetta and the results obtained indicated that ploughing × weed control interactions, for all measured parameters, were not statistically significant ($P=0.05$). At Sademo, all measured growth parameters were not affected significantly by ploughing frequencies, whereas 1000-grain weight and control of *Polygonum nepalense* were significant at Rob Gebeya ($P<0.05$) (Table 6). Increasing the frequency of ploughing failed to reduce weed infestation. The weed population was significantly reduced by herbicide treatments at both locations. Terbutryn (2.0 kg/ha) was particularly effective in controlling *Polygonum nepalense*, *Galium spurium*, *Spergula arvensis* and *Anagalis arvensis*. *Guizotra scabra* and *Galium spurium* proved to be difficult weeds to control at Rob Gebeya, where all herbicide treatments showed reduced activity against the two species. Ploughing twice at widely spaced time intervals—between the onset of rainfall in mid-March and the beginning of the main rainy season in mid-June—seemed to be adequate for optimum yields of barley. More effective control of major weed species was achieved by herbicide treatment compared with hand-weeding plots.

TABLE 5

Main effects of yield-limiting factors on grain yield (kg/ha) of food barley

Factor	Test locations				
	Farta	Huleteju-Enebssie	Dabat	Laie-Gaient	Yilmana-Denssa
Variety 1 (V1)	1662	1395	1231	NA	NA
Variety 2 (V2)	1865	613	998	NA	NA
Main effect	+203	–782	–233	NA	NA
Percentage change	+12	–56	–19	NA	NA
Fertilizer 1 (F1)	1189	414	666	776	952
Fertilizer 2 (F2)	2338	1593	1562	1593	1833
Main effect	+1149	+1179	+896	+817	+881
Percentage change	+97	+285	+135	+105	+93
Weeding 1 (W1)	1713	NS	1114	1204	1415
Weeding 2 (W2)	1814	NS	1114	1164	1370
Main effect	NS	NS	NS	–40	–45
Percentage change	NS	NS	NS	–3	–3
Fungicide 1 (Fc1)	NA	NA	NA	1105	1261
Fungicide 2 (Fc2)	NA	NA	NA	1263	1522
Main effect	NA	NA	NA	+158	+261
Percentage change	NA	NA	NA	+14	+21
Insecticide 1 (I1)	NA	NA	NA	NA	1418
Insecticide 2 (I2)	NA	NA	NA	NA	1367
Main effect	NA	NA	NA	NA	–51
Percentage change	NA	NA	NA	NA	–4

NOTES: V1 = local variety; V2 = improved variety; F1 = unfertilized; F2 = fertilized; W1 = unweeded; W2 = weeded; Fc1 = unsprayed; Fc2 = sprayed with fungicide; I1 = unsprayed; I2 = sprayed with insecticide; NA = not available; NS = not significant.
SOURCE: Minale Liben and Alemayehu Assefa, 1998.

TABLE 6

Effect of ploughing frequency on grain yield and other agronomic characteristics of barley in Welmera Woreda

Ploughing frequency	Seed yield (kg/ha)		Plant height (cm)		Stand count (No. per m^2)	
	Sademo	Rob Gebeya	Sademo	Rob Gebeya	Sademo	Rob Gebeya
Four times	2210	1320	121.1	130.6	294	272
Three times	2590	1500	123.5	132.2	272	249
Two times	2550	1400	120.6	127.7	280	239
LSD ($P<0.05$)	NS	NS	NS	NS	NS	NS

NOTES: NS = not significant. SOURCE: Anon., 1995–2001.

Participatory evaluation of production packages

Trials of production of on-farm food barley varieties using different packages of management practices was conducted in 1998 and 1999 at Degem (N. Shewa) and Welmera (W. Shewa). The results obtained at Welmera indicated that improved landrace lines outyielded the local and standard checks by 44.6% and 3.6%, respectively, under improved management, and by 19.4% and 11.9% under farmer management, respectively (Table 7). At Degem, in both years, the improved landrace lines, including the checks, gave satisfactory grain yields (Table 8). Across years, the improved landrace lines 3369-19 and 3293-06 gave a yield advantage of 28.2% and 22.1%, respectively, due to improved management practices (Table 8). Overall, improved management increased the yield by 28.4% at Degem and 14.7% at Welmera. At Degem in the 1999 cropping season, the improved landrace line 3293-06 gave the highest yield, outyielding the local check by 32% and the standard by 9.4% under improved management, and by 69% and 31%, respectively, under farmer management practices. Similarly, the landrace line 3369-19 outyielded the local check by 19% under improved and 43% under farmer management practices.

TABLE 7

Mean grain yield and standard deviation of the two promising food barley genotypes compared with the checks, at Welmera, 1999

Genotype	Mean grain yield (kg/ha)	SD	Percentage increase over	
			Local check	Standard check
Improved management practices				
3369-19	2000	2.3	44.7	3.6
3293-06	1930	4.6	39.7	1.1
Shege	1910	0.7		
Local check	1380	3.1		
Local management practices				
3369-19	1810	2.3	19.4	11.9
3293-06	1370	1.3	(10.1)	(15.7)
Shege	1620	1.7		
Local check	1520	1.2		

NOTES: Figures in parenthesis show decrements. SOURCE: Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002.

Interactions of weeding and fertilizer application on yield and yield components of barley

The study was conducted at Holetta between 1987 and 1988. Application of new production technologies (fertilizers and hand weeding) improved the grain yield of barley by 1639 and 1328 kg/ha in 1987 and 1988, respectively. Straw yield was increased by 1384 kg/ha in 1988, and the plant stand increased by 217 and 46 plants in 1987 and 1988, respectively. Plant height was increased in 1987 and maturity was delayed with the use of the higher-level factor combination (Table 9). Fertilizer × weed control interaction was significant for date of heading in both seasons (Table 9). In both seasons, weeding delayed the date of heading by 8 days for line Ahor 880/61 without fertilizer and advanced heading by 2–4 days with fertilizer application. Cultivar 'Baleme' showed no response, except in 1987, when weeding delayed heading by 5 days without fertilizer. Cultivar × fertilizer × seed dressing interaction was significant for grain yield and plant height in 1987 and for

TABLE 8

Mean grain yield (kg/ha) from on-farm barley production package evaluation trial grown at three sites at Degem, 1998–1999

Genotype	1998			1999			Across years		
	IM	FM	% increase	IM	FM	% increase	IM	FM	% increase
3369-19	2737	2100	30.3	1925	1537	25.24	2331	1819	28.15
3293-06	3237	2580	25.5	2138	1822	17.34	2688	2201	22.13
Shege	2874	2332	23.2	1955	1390	40.65	2415	1861	29.77
Local	2298	1787	28.6	1620	1076	50.56	1959	1432	36.80
Mean	2787	2200	26.9	1910	1456	31.18	2348	1828	28.45

NOTES: FM = farmer management; IM = improved management.
SOURCE: Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002.

1000-grain weight in 1988. Seed dressing increased grain yield for both cultivars under both fertilizer levels.

TABLE 9

Fertilizer × weeding interaction effects on grain yield and days to heading and maturity of food barley at Holetta in 1987 and 1988

Fertilizer	1987		1988	
	No weeding	One hand weeding	No weeding	One hand weeding
	Grain yield (kg/ha)			
No fertilizer	895	754	1472	1623
With fertilizer	2089	2836	2314	2708
	SD=78.3		SD=38.8	
	Days to Heading			
No fertilizer	96	102	97	101
With fertilizer	83	83	87	85
	Days to Maturity			
No fertilizer	131	137		
With fertilizer	126	124		
	SD=1.7			

Source: Amsal Tarekegne, Hailu Gebre and Francis, 1997.

On-farm evaluation of fertilizer and weeding methods

In an on-farm evaluation of fertilizer and weed control methods in 2001 on barley in the highlands of Wollo, a non-significant ($P>0.05$) difference was obtained for grain and biomass yield when fertilizer was applied (Table 10). In 2002, fertilizer application had a significant ($P<0.05$) effect on grain yield (Table 10). The increase in grain yield with fertilizer application in 2002 could be due to the significant ($P<0.05$) increase in spikes per unit area and grains per spike with fertilizer application. Fertilizer application significantly increased grain and biomass yields, which amounted to a 78% increase over the control. In 2001, hand weeding at 25–30 days after emergence (DAE) + 45–55 DAE gave the greatest significant ($P<0.05$) grain and aboveground biomass yield (Table 11). In 2002, the difference in grain yield between the treatments was not significant. Increase in grain yield could be due to the increase in spikes per unit area and grains per spike with hand weeding at 25–30 + 45–55 DAE.

TABLE 10

Effect of fertilizer on barley yield and yield components, phenological data and weed biomass in 2001 and 2002, and the combined data

Fertilizer	GY	Biomass	Spikes per m^2	Grains per spike	PH	DH	DM	Weed biomass (g/m^2)
2001								
Zero fertilizer	1956	2909	72	20	41	85	129	55
50 kg/ha Urea + 100 kg/ha DAP	3519	5144	102	23	55	77	124	68
LSD ($P<0.05$)	NS	NS	NS	NS	*	*	*	NS
2002								
Zero fertilizer	815	10981	149	26	54	89	131	23
50 kg/ha Urea + 100 kg/ha DAP	1417	19732	185	34	66	77	122	34
LSD ($P<0.05$)	*	**	**	**	***	***	***	NS
Combined over years								
Zero fertilizer	1385	6945	110	23	47.6	87	130	39
50 kg/ha Urea + 100 kg/ha DAP	2468	12438	144	29	60.7	77	123	51
LSD ($P<0.05$)	***	*	*	*	**	**	**	NS

Notes: *, ** & *** indicate a significant difference at 5%, 1% and 0.1% significance level, respectively; NS = non-significant difference; DAP = di-ammonium phosphate; GY = grain yield (kg/ha); Biomass = biomass yield (kg/ha); PH = plant height (cm); DH = days to heading; DM = days to maturity.

TABLE 11

Effect of weed control methods on barley yield and yield components, phenological data and weed biomass (g/m²) in 2001 and 2002, and the combined data

Weed control methods	GY	Biomass	Spikes per m²	Grains per spike	PH	DH	DM	Weed biomass
				2001				
HW at 25–30 DAE	2843 ab	4173 ab	89	22	48.5	80	128	54 b
HW at 25–30 DAE + 45–55 DAE	3405 a	4897 a	92	24	48.9	80	128	53 b
HW at 60–80 DAE	2535 ab	3758 ab	79	20	46.3	81	131	30 b
2,4-D	2166 b	3278 b	87	21	48.1	81	121	110 a
LSD ($P<0.05$)	1143	1613	NS	NS	NS	NS	NS	35
				2002				
HW at 20–25 DAE	1188	17930	171	33	63	83	126	22 b
HW at 25–30 DAE + 45–55 DAE	1202	14962	171	29	61	83	128	9 b
HW at 60–80 DAE	1141	14714	155	30	59	83	126	11 b
2,4-D	932	13820	172	29	58	83	125	70 a
LSD ($P<0.05$)	NS	NS	NS	NS	NS	NS	NS	42.5
				Combined over years				
HW at 25–30 DAE	1879	11051	130	27	56	82	127	38 b
HW at 25–30 DAE + 45–55 DAE	2160	9930	131	27	56	82	128	31 b
HW at 60–80 DAE	1705	9236	117	25	53	82	129	21 b
2,4-D	1440	8549	129	25	53	82	123	90 a
LSD ($P<0.05$)	NS	NS	NS	NS	NS	NS	NS	39

NOTES: DAE = days after emergence; HW = hand weeding; NS = not significant; GY = grain yield (kg/ha); Biomass = biomass yield (kg/ha); PH = plant height (cm); DH = days to heading; DM = days to maturity.

Application of fertilizer could improve the productivity of barley at Delanta. The practice of early hand weeding and mid-season hand weeding has given better grain yield compared with farmer practice. Application of fertilizer and early weeding recommendation (hand weeding at 30–35 days after planting) improved the productivity of barley in Delanta Woreda.

Effect of tillage and precursor crops on barley

A study on the tillage requirements of barley, as affected by break crops, was conducted from 1995 to 2000 on-station and on-farm at Sheno, using broadbed and furrow drainage methods. The grain yield of barley tended to decrease with the increase in tillage frequencies (Table 12). Ploughing four times gave the lowest grain yield, which was significantly different ($P<0.05\%$) from the highest yielding treatment when ploughing occurred only once (Table 12). Ploughing once, twice or three times gave no significant grain yield difference ($P<0.05\%$). Compared with barley-barley rotation, when barley was planted after flax and faba bean, the grain yield of barley increased by about 133% and 66%, respectively, when ploughed once; 116% and 122%, respectively, when ploughed twice; 116% and 77%, respectively, when ploughed three times; and 107% and 81%, respectively, when ploughed four times (Table 12).

TABLE 12

Effect of precursor crops and tillage frequency on grain yield (kg/ha) of barley at Sheno on-station combined with the three rotation cycles, 1995–2000

Precursor crop (P)	Tillage frequency (T)				
	T1	T2	T3	T4	P mean
Barley	324.3	267.3	284.5	277.8	288.5 c
Faba bean	539.5	594.1	504.0	503.0	535.2 ab
Linseed	754.8	578.3	614.7	574.4	630.6 a
Oat	370.7	429.3	373.3	376.7	387.5 bc
T mean	497.3 a	467.3 ab	444.1 ab	433.0 b	
LSD ($P<0.05$)			T means = 59.4		
			P means = 186.7		
			T × P = 119.4		
CV (%) = 20.8					

NOTES: T1 = ploughing once (June at sowing); T2 = ploughing twice (March, and June at sowing); T3 = ploughing three times (March, April and June at sowing); T4 = ploughing four times (March, April, May and June at sowing). SOURCE: Anon., 1995–2001.

Based on the on-station results, verification of selected treatments was executed on farmers' fields at two locations, Chacha and Kotu, in 2003 and 2004 for one rotation cycle on fixed plots. In both locations, the effect of treatments on grain and biomass yield was not statistically significant (Table 13). The lowest yielding treatment (barley grown after barley with one ploughing) gave a grain yield of about 1057 kg/ha at Chacha and 505 kg/ha at Kotu (Table 13). The control—barley grown after barley with three ploughings—gave a grain yield of about 1427 kg/ha at Chacha and 551 kg/ha at Kotu. This indicates that barley monoculture tends to be productive at higher tillage frequencies. The highest yielding treatments—barley grown after linseed with one ploughing at Chacha and barley grown after faba bean with one ploughing at Kotu—gave grain yields of 2154 and 628 kg/ha, respectively (Table 13).

The productivity of barley at Kotu was generally very low. The soil type of the site was a vertisol; barley is relatively very sensitive to waterlogging on vertisols, even with the provision of a broadbed and furrows to drain excess soil water. This low productivity of barley was also observed at the on-station trial of 1995–2000, due to the pellic vertisols (Tables 12 and 13). In general, break crops such as faba bean and linseed are very important for increasing productivity and for reducing the tillage frequency requirements for growing barley. Farmers' assessments of the verification trials also indicated that ploughing twice is the optimum for yield and it is the minimum requirement for broadbed and furrow preparation in waterlogging-prone soils.

TABLE 13

Barley grain yield as affected by precursor crops and tillage frequency on farmers' fields, 2004

Treatment	Grain yield (kg/ha)	
	Chaha	Kotoo
Barley after barley, ploughed once	1057	505
Barley after barley, ploughed three times	1427	551
Barley after faba bean, ploughed once	1744	628
Barley after linseed, ploughed once	2154	564
Mean	1596	562
CV (%)	46.8	34.6
LSD ($P<0.05$)	NS	NS

NOTES: NS = not significant. SOURCE: Anon., 2003–2005.

TABLE 14

Percentage relative grain yield of barley as calculated against the lowest yielding treatment for two rotation cycles, 1998–2001

N/P (kg/ha) applied on the test crop	Precursor crops			Mean
	Barley	Field pea	Faba bean	
0/0	100	204	173	159
18/20	146	251	230	209
41/20	161	265	257	228
64/20	208	281	290	260
Mean	154	250	237	

NOTES: Yield averaged over three sites, two fertilizer levels (0/0 and 18/20 kg/ha N/P applied to grow precursor crops) and two replications per site for two rotation cycles.
SOURCE: Anon., 1995–2001.

Integration effect of fertilizer and precursor crops on barley

On pellic vertisols

A barley-based crop rotation trial was conducted on pellic vertisols at Sheno from 1995 to 2000, with the objective of determining the fertilizer requirements of barley. The treatments comprised linseed-barley, wheat-barley, oats-barley, faba beans-barley and barley-barley sequences for three rotation cycles grown on broad-beds and furrows to drain excess water. Applications were made of 0/0, 18/20 and 41/20 kg/ha N/P to each preceding crop and the test barley crop. Results of three rotation cycles indicated that the mean grain yield of barley following linseed, and barley following faba bean without fertilizer, gave about 23% and 22%, respectively, more grain than barley monoculture produced with the application of 18/20 kg/ha N/P. Thus, these break crops could help small-scale farmers to save 18/20 kg/ha N/P in the form of di-ammonium phosphate (DAP). The grain yield of barley in monoculture with the application of 41/20 kg/ha N/P was about 75% and 78% of the respective yield obtained from barley following linseed and barley following faba bean with an application of 18/20 kg/ha N/P. This indicates that the grain yield of barley monoculture with an application of 41/20 kg/ha N/P was lower than the yield of barley following linseed or faba bean with an application of 18/20 kg/ha N/P, which saved 23 kg N/ha in the form of urea.

On well-drained brown soils

In areas where frost hazard is low in hill-sheltered and well-drained areas between Debre Berhan and Tarimaber with an altitude range of 2700–3100 masl, farmers rotate barley with either faba bean or field pea. Farmers usually rate field pea better than faba bean as a break crop. Therefore, an experiment was conducted from 1998 to 2001 using fixed plots on three sites representing adequate, medium and low soil fertility status according to farmers' classification. Precursor crops received 0/0 and 18/20 kg/ha N/P, whereas the test crop barley was grown on 0/0, 18/20, 41/20 and 64/20 kg/ha N/P. This was performed for two rotation cycles. The fertilizer levels applied on the precursor crops had no statistically significant effect on the grain yield of the test crop barley. The lowest and the highest grain yields of the test crop barley were 563 and 1633 kg/ha, respectively, which were obtained from the respective treatments of unfertilized test crop on barley precursor and the test crop fertilized with 64/20 kg/ha N/P on the faba bean precursor. Percentage relative grain yields of barley, as calculated against the lowest yielding treatment, are presented in Table 14. The grain yield of the test crop barley from the application of 64/20 kg/ha N/P on the barley precursor was almost as high as the unfertilized control on the field pea precursor, with a difference of only 4%. The grain yield of the test crop barley obtained from the application of 64/20 kg/ha N/P on the barley precursor was lower by 43% and 22% than the yield obtained with the application of 18/20 kg/ha N/P on field pea and faba bean precursors, respectively. From this comparison, it can safely be suggested that these two precursor crops could help farmers to save at least 46 kg N/ha in the form of urea.

Chiflik (short fallow period)

In waterlogged areas from Sheno to Angolela, which has an altitude range of 2740–2920 masl, a fallow period of 10–15 years followed by soil burning (locally known as guie) was the traditional practice for alleviating waterlogging and soil fertility problems. However, this long fallow period has been reduced to 3 to 5 years due to a shortage of farmland as a result of the ever-increasing human population. Guie has become less productive with only a short period of fallowing, and hence farmers turned to the so-called chiflik. Chiflik is the practice of maintaining soil fertility by fallowing the land for 1–2 years depending on the availability of the land, followed by ploughing it twice, in September and October, while the soil is moist. This chiflik land is used to produce barley or wheat for 2–3 consecutive years before being left to fallow for the next chiflik cycle. This is the dominant practice in these areas because, on such waterlogging-prone plain lands, the production of legumes is limited by frost in addition to waterlogging. Therefore, an on-farm experiment was conducted in 1997 and 1998 in these areas to quantify the contribution of chiflik to improving soil fertility, thereby potentially reducing the fertilizer requirements of barley produced by the broad-bed and furrow drainage method.

Results have shown that about 97% of the barley grain yield obtained by the application of 82/40 kg/ha N/P on non-chiflik land was achieved with the application of 20/10 kg/ha N/P on chiflik land in which the difference was only 3% (Table 15). This means that about 62/30 kg/ha N/P in the form of urea and DAP was saved by using chiflik land. About 88% of the grain yield of barley obtained by the application of 41/20 kg/ha N/P on non-chiflik land was produced on chiflik land without fertilizer. In this comparison, the difference is only 12%. Thus, about 50 kg urea and 100 kg DAP fertilizer per hectare can be saved on chiflik land when barley is produced without fertilizer, with only a 12% yield loss. However, it does not mean that chiflik is economically viable taking into account the yield loss during fallowing. However, the results of this experiment help value the practice of chiflik and take it as a priority research agenda for future work to find ways

TABLE 15

Grain yield (kg/ha) of barley, as affected by NP fertilizer and chiflik, 1997–1998

N/P levels (kg/ha)	Grain yield average of six sites		
	Chiflik	Non-chiflik	Mean
0/0	1278	790	1034
20/10	1862	1008	1435
41/20	2230	1451	1841
82/40	2920	1913	2417
Mean	2073	1291	

NOTES: Non-chifilik sites are considered those sites with cereal monoculture for at least two consecutive years, with ploughing practiced in March and April, when the soil is moist. SOURCE: Anon., 1995–2001.

and means for optimization with regards to sustaining soil fertility, productivity and production in the face of the ever-increasing human population.

Although barley was highly responsive to N/P fertilizer levels higher than 41/20 kg/ha N/P, it was difficult to recommend higher rates as farmers were using different landraces, some of which could be very liable to lodging and, in most cases, farmers were not weeding barley fields. Only very few farmers apply fertilizer for barley production, regardless of strong promotion of the practice through the extension system. Apart from higher rates, it would be a rewarding dose if farmers adopt the application of 41/20 kg/ha N/P under such circumstances.

Evaluation of drainage methods for barley production

On-farm comparison of soil drainage methods for barley production was conducted for three consecutive years (1996, 1997 and 1998) to compare one improved drainage method with three indigenous methods, namely (i) ridge and furrowing (RF) of Alaltu areas; (ii) hand-made broadbeds and furrowing (HBBF) of Enewarie areas; (iii) open drainage furrowing (ODF) at 3-m intervals of Angolela and Kotu areas; and (iv) improved drainage methods (broadbeds and furrowing made using the broadbed and furrow maker (BBM)).

Due to continuous rainfall from the *Belg* to *Meher* seasons in 1996, farmers rejected the BBM methods as it was heavy for the pair of oxen under the wet soil conditions. HBBF gave significantly ($P<0.01$) higher grain and straw yields than that of 3-m interval ODF. HBBF increased the grain and straw yield by 103% and 96% over ODF, and by 42% and 34% over RF, respectively (Table 16). The rainfall of the 1997 *Meher* season was relatively light, and one farmer out of five was willing to test the BBM. Soil drainage methods did not show statistically significant differences in barley grain yields. However, hand-made BBM gave the highest yields, and improved grain yield by 21% over the 3 m interval ODF. In the 1998 cropping season, the grain yield obtained from HBBF was significantly higher than that of the 3 m interval ODF. The combined result indicated that the effectiveness of drainage methods varied with the rainfall across years. In years of high rainfall, handmade BBF significantly outyielded the ridge and furrow drainage method (Table 16). However, in years of light rainfall (as in 1997 and 1998), the effects of RF and HBBF on productivity of barley were comparable (Table 16). Farmers also believe that HBBF facilitates weeding, even though weeding barley fields is not a common practice in the area. In conclusion, it is advisable to use HBBF for barley production in areas prone to waterlogging.

TABLE 16
Grain yield of barley, as affected by different drainage methods in areas prone to waterlogging between Kotu and Angolela

Drainage methods	Grain yield (kg/ha)	
	1996	1997
Open drainage furrows at 3-m intervals	224 c	1959
Ridge and furrow	320 b	2011
Hand-made broadbed and furrows	455 a	2364
Broadbed and furrow made by BBM	Rejected by farmers	1934
Probability level	0.05	0.05
CV (%)	20.5	NS

NOTES: BBM = broadbed and furrow maker; Grain yield in 1996 was very low due to damage by chafer grub at emergence.

Effect of sowing dates and seed rate on yield of barley

A study on sowing date and seed rate for local barley was carried out at Fereze (2800 masl) in Guraghe Zone in 2003. The results indicated that the highest yield (2559 kg/ha) was obtained when barley was planted in the first week of July followed by the second week of July. In delaying the planting date beyond the first week of July, significant yield reduction was observed (Table 17). Seed rates showed a non-significant difference in the grain yield of barley (Table 17). Therefore, the use of 100 kg/ha of barley seed is sufficient at Fereze and nearby areas.

TABLE 17
Grain yield of barley as affected by sowing date and seed rate

Sowing date	Seed rate (kg/ha)				
	100	125	150	175	Mean
6 July	2264	2597	2597	2777	2559 a
16 July	2664	1500	1722	1819	1826 b
26 July	1139	1528	1264	1528	1364 b
5 August	527	639	833	694	674 c
Mean	1549	1566	1604	1705	

NOTES: Means followed by the same letter are not significantly different.

GAPS AND CHALLENGES

1. Soil fertility problems are the main constraints on barley production.
2. Waterlogging can be a problem, mainly during seasons with heavy rain, and even on well drained soils.
3. Uneven distribution, onset and cession of rainfall causes intermittent and terminal low-moisture stress.
4. Lack of appropriate agronomic practices for malting barley and for recently released food barley varieties.
5. Lack of drought-tolerant genotypes of barley based on physiological traits.
6. Not enough information on the effect of break crops and tillage frequency in relation to soil types, soil moisture conservation, weed emergence patterns, soil physico-chemical properties, productivity and profitability.
7. Lack of a concerted effort to disseminate knowledge of soil drainage methods to their specific sites, such as 3-m interval ODF for sloping lands, and the HBBF method for flat lands.
8. Little research on cultural practices targeting high-input barley production systems to increase productivity and production, to catch up with an ever-increasing human population.

FUTURE RESEARCH DIRECTIONS

1. Develop an alternative cropping system for barley production that incorporates legumes.
2. Develop production packages for malt barley production around the Debre Berhan area.
3. Develop appropriate seed rates and tillage practices for better quality and yield of different food and malt barley varieties for different agro-ecologies.
4. Identify, in collaboration with breeders, drought-tolerant barley genotypes based on physiological traits.
5. Focus future research work on the gaps identified above, such that holistic information can be generated through a multidisciplinary approach.

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Research achievements in barley cropping systems in Ethiopia

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INTRODUCTION

Although barley is one of the most important grain crops in Ethiopia, its productivity is low due to several factors. Of these, the major ones are poor soil fertility, use of low-yielding cultivars, poor agronomic practices, diseases (scald, net blotch, spot blotch, rusts and smuts) and pests (Russian wheat aphid and barley shoot fly) (Berhane Lakew, Hailu Gebre and Fekadu Alemayehu, 1996; Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998; Woldeyesus Sinebo and Chilot Yirga, 2002). Barley is the fifth major crop in Ethiopia, after maize, teff, wheat and sorghum. It is preferred by subsistence farmers because of its early maturity and ability to grow better on marginal farms than other cereals, as well as its suitability for growing during the *Belg* season—the short rainy season from March to May, and the main rainy season, *Meher*, from June to September.

In a high-yielding environment where moisture is non-limiting, yield constraints such as inappropriate cultivar choice, poor seed quality, poor weed control, low soil macronutrient and micronutrient levels, poor seedbed preparation and stand establishment, inappropriate seeding date or rate, wide row spacing and inappropriate crop protection technology are the most commonly reported agronomic constraints (Bolton, 1979, and Singh, 1988, cited in Amsal Tarekegne, Hailu Gebre and Francis, 1997). Natural constraints to agricultural production in northwest Shewa specifically include unreliable rainfall, waterlogging, frost, dry wind and poor soil fertility (Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002).

Traditionally, barley is cultivated with no or little external inputs (such as fertilizer, or chemical application to control major barley diseases, pests and weeds). Moreover, it is cultivated on eroded, low-moisture stressed hillsides. Hence, its productivity at a national level is very low, at about 1 t/ha. To solve this problem, different cropping system trials have been conducted on barley by several agricultural research centres since 1993. This paper reviews previous research results on barley cropping systems in the central highlands of Ethiopia since 1993.

TABLE 1

Effects of mixed cropping of barley and faba bean on grain yields of component crops, barley yield equivalent, and partial and total land equivalent ratios (LERs) at Holetta, Ethiopia

Treatment (Mix proportion %)	Grain yield (kg/ha)			Partial and total LER values		
	Barley	Faba bean	Total	Barley	Faba bean	Total
Sole barley	2396a	–	2396	1.00 a	–	1.00 c
Sole faba bean	–	2521 a	2521	–	1.00 a	1.00 c
Barley/faba bean (100:12.5)	2237 ab	312 e	2549	0.93 b	0.12 e	1.05b c
Barley/faba bean (100:25)	2036 bc	576 d	2612	0.85 c	0.23 d	1.08 b
Barley/faba bean (100:37.5)	2042 bc	945 c	2987	0.85 c	0.38 c	1.23 a
Barley/faba bean (100:50)	1831 cd	1023 c	2854	0.76 d	0.41 c	1.17 a
Barley/faba bean (100:62.5)	1762 d	1203 b	2965	0.73 d	0.48 b	1.21 a
LSD ($P<0.05$)	271.1	178.4		0.12	0.07	0.13

SOURCE: Getachew Agegnehu, Amare Getaneh and Woldeyesus Sinebo, 2006.

CROPPING SYSTEMS

Barley/faba bean mixed cropping

Mixed cropping of barley (*Hordeum vulgare* L.) with faba bean (*Vicia faba* L.) was compared with sole cropping for three growing seasons (2001–2003) at the Holetta Agricultural Research Centre. The treatments were sole barley (125 kg/ha), sole faba bean (200 kg/ha) and an additive series of 12.5, 25, 37.5, 50 and 62.5% of the sole seed rate of faba bean mixed with the full barley seed rate. Results showed that total yield and total land equivalent ratios (LERs) of mixtures exceeded those of sole crops, especially when the faba bean seed rate in the mixture was increased to 75 kg/ha (37.5%) or more (Table 1). The highest total yield and land equivalent ratio (LER) were obtained when faba bean was mixed at a rate of 37.5% with the full seed rate of barley.

The mean values of LER, ranging from 1.05 to 1.23, were obtained from different mixed proportions of barley and faba bean (Table 1). This means that the sole culture of each crop requires 5–23% more land than the mixed crop to produce equal yields, indicating greater land use efficiency from intercrops compared with sole crops. Similar results were reported for mixed cultures of pea and barley (Jensen, 1996), field bean and wheat (Hauggaard-Nielsen and Jensen, 2001), and maize and faba bean (Li *et al.*, 1999).

Barley/wheat mixed cropping

Two pot and two field experiments were conducted on mixed cropping of barley (*Hordeum vulgare*) and wheat (*Triticum durum*) to study yield, water use and water-use efficiency, competition levels and stability. Grain and biomass yield increased with increasing irrigation water levels (from a 78–80% deficit to a 25–30% deficit in soil available water) and with increasing planting densities (88 to 354 plants per m^2) in a pot experiment. This in turn resulted in increased water use and better water use efficiency. The increased grain and biomass yield, water use and water use efficiency for grain yield with increasing irrigation was also confirmed in the field experiment, which had 168 and 238 mm as the lowest and highest irrigation water levels, respectively. Grain and biomass yield, and their water use efficiency in the mixtures, mainly increased with increasing ratio of the higher-yielding component. Barley was consistently higher yielding in biomass in the early stages, whereas wheat was usually higher yielding in biomass towards the reproductive stage in both pot and field experiments.

Mixtures had higher water use efficiency than either of the sole crops in pot and field experiments, mainly due to the higher grain and biomass yield than the low-yielding sole crops, and due to lower water use than the sole crops with higher water use. Sole wheat was the highest in water use both in the pot experiment and in one of the field experiments, mostly by virtue of its late maturity. Pot and field experiments consistently showed that yield advantage and land use efficiency of mixed cropping of barley and wheat increased with decreasing irrigation water levels. Mixed cropping had no advantage at optimum and near-optimum moisture levels. These experiments also proved that barley was more competitive in the early stages, whereas wheat dominated towards the reproductive stage.

Intraspecific competition was greater than interspecific competition for barley at all harvesting stages (tillering, heading and maturity) under all irrigation water levels in a pot experiment. This was also true for wheat, except that its intraspecific competition was less than interspecific competition at the tillering stage. Intra- and interspecific competition decreased with increasing irrigation water levels, but increased with increasing planting densities. The stability analyses showed that the mixture of 50% barley and 50% wheat was more stable than sole barley or sole wheat across eight environments; these environments were created by applying different irrigation water levels at the growth stages of barley and wheat in the pot experiment.

FOOD AND FORAGE LEGUMES/BARLEY DOUBLE CROPPING SYSTEM

Double cropping in barley system

A cropping system experiment was conducted in 2005–2006 in Degem Woreda in North Shewa Zone to investigate the possibility of double cropping and the effects of precursor crops on the growth and yield of *Belg* barley in the area, which is left fallow during the main rainy season. Immediately after harvesting the *Belg* barley in June, faba bean (*Vicia faba* line CS20DK), vetch (*Vicia villosa* line 8235) or a vetch-oat (*Avena fatua*) mixture (75 kg vetch and 25 kg oat per ha) as the forage crop were planted in the main cropping season. A fallow plot was left as a treatment to imitate the farmer practice in the area.

Results showed that optimal growth and yields of both grain and forage legumes were obtained in the main growing season (Table 2). The highest grain and straw yields of barley were achieved from sowing barley after vetch and faba bean. Sowing barley after faba bean, vetch and the oat-vetch mixture increased yields of barley by 40%, 41% and 9%, respectively, compared with the yields of barley from the

TABLE 2

Food and forage legumes/barley double cropping system in Degem Woreda, North Shewa, 2005–2006

Precursor crops	Oven dry weight§ (kg/ha)	Barley yield (kg/ha)	
		Grain	Straw
Faba bean	2000	1154a	2476ab
Vetch	2800	1158a	2711a
Oat+vetch	2300	897b	2188b
Fallow	–	822b	2112b
LSD (*P*<0.05)	–	160.1	410.2
CV (%)	–	19.0	20.7

NOTES: § = Food+forage legumes. SOURCE: HARC, 2006.

fallow plots. Similarly, straw yields of barley were increased by 17%, 28% and 4%, respectively, compared with the fallow plots. From the results of this preliminary study, double cropping of fallow fields is shown in the main season not only to increase yield and farm income but also to enhance the productivity of land due to the planting of leguminous crops.

TABLE 3
Productivity of double cropping systems at Ankober, 1999–2001

Treatment	Grain yield (kg/ha) of barley in different years					
	Meher season			*Belg* season		
	1999	2000	Mean	2000	2001	Mean
1	3595	1178	2387	1067	398	733 (Barley)
2	3319	1347	2333	293	303	298 (Field pea)
3	3061	1251	2156	254	306	280 (Field pea)

NOTES: For explanation of treatments, see text. SOURCE: DBARC, 2005.

Double cropping systems of barley with barley versus barley with field pea were compared under different soil fertility management practices at Ankober. The results are presented in Table 3. The barley grain yield in the double cropping system of barley in the *Meher* and *Belg* seasons with the application of 41/20 kg/ha N/P in both seasons (treatment 1) declined markedly compared with the yield in the *Meher* season of 1999.This shows that double cropping systems with barley monoculture, even with the application of 41/20 kg/ha N/Pin both seasons, could not be agronomically sustainable. Production of barley in the *Meher* season and field pea in the *Belg* season, with the application of 18/20 kg/ha N/P only during the *Meher* season on barley (treatment 2), gave comparable barley grain yields with those of treatment 1 in the *Meher* season. The grain yields of barley in the *Meher* season during 2000 in treatment 2 are higher than those of treatment 1, showing that treatment 2 is agronomically more sustainable. The same is true for treatment 3 (double cropping of barley in the *Meher* season and field pea in the *Belg* season without fertilizer application in both seasons). The major problem in treatments 2 and 3 is the low yield of field pea, which was severely infected by powdery mildew. Therefore, higher-yielding field pea varieties, and those that are tolerant to powdery mildew, are required to proceed with treatments 2 and 3. In addition to field pea, the introduction of high-value legume crops, such as lentil, may help treatments 2 and 3 be successful and maintain higher productivity of the double cropping systems in higher altitude areas such as Ankober.

Crop rotation in barley systems

A long-term cropping sequence experiment conducted at Kulumsa and Bekoji from 1984 to 1991 in the Arsi region of Ethiopia indicated that the cropping sequence had an impact on barley grain yield at Bekoji during only one of the five seasons in which it was assessed (i.e. 1989) (Table 4). In each of the other seasons, continuous barley produced the lowest grain yield, except for the 1991 barley plots, which followed wheat; however, none of these differences were significant despite mean grain yields ranging from 1990 to 4404 kg/ha with associated CVs ranging from 10.3% to 23.8%.

Averaged across all of the available data for the Bekoji trial, barley in the first and second years after either faba bean or rapeseed outperformed continuous barley by 37% and 17%, respectively (Table 5). The cropping sequence ×

TABLE 4

Yield of crops included in the barley-based cropping sequence trial at Bekoji (1984–1991)

Treatment	Cropping sequence and yield (kg/ha) of each crop in sequence							
	1984	1985	1986	1987	1988	1989	1990	1991
1	Fb 1 029	Ba 4 294 a	O/V 10 520	Ba NA	R NA	Ba 3 560 a	Fb 3 238	Ba 2 121 a
2	O/V 11 678	Ba 4 453 a	R 854	Ba NA	Fb NA	Ba 3 698 a	W 2 990	Ba 1 766 a
3	R 1 750	Ba 4 581 a	Fb 2 280	Ba NA	Fb NA	Ba 3 698 a	W 2 990	Ba 2 378 a
4	Fb 1 144	Ba 4 220 a	Ba 3 526 a	O/V NA	Ba 2 366 a	Ba 2 544 bc	Fb 3 186	Ba 2 285 a
5	O/V 9 025	Ba 4 525 a	Ba 3 151 a	R NA	Ba 2 482 a	Ba 2 112 d	W 2 233	Ba 1 132 a
6	R 1 688	Ba 4 559 a	Ba 3 515 a	Fb NA	Ba 2 633 a	Ba 2 140 cd	R 1 459	Ba 2 234 a
7	Ba 3 237	Ba 4 195 a	Ba 3 258 a	Ba NA	Ba 2 139 a	Ba 1 703 c	Ba 1 106	Ba 2 016 a
Barley mean yield (kg/ha)	3 237	4 404	3 362	NA	2 405	2 647	1 106	1 990
LSD (*P*<0.05)	NA	NS	NS	NA	NS	407	NA	NS
Effect on barley yield:								
Sequence	NA	NS	NS	NA	NS	***	NA	NS
Fertilizer	NS	***	*	NA	NS	***	NS	***
Interaction	NA	NS	*P*<0.10	NA	NS	NS	NA	NS

NOTES: Ba = barley; Fb = faba bean; O/V = oat/*Vicia* mixture; R = rapeseed; W = wheat; NA = not available; NS = not significant. Means within each year (column) followed by the same letter are not significantly different at the 5% level of the LSD test. * & *** indicate a significant difference at 5% and 0.1% significance level, respectively.

SOURCE: Amanuel Gorfu *et al.*, 1994.

fertilizer interaction was marginally significant ($P<0.10$) only in the 1986 season (Table 4). The differential interaction among cropping sequences was as follows: the highest N level increased the yield of continuous barley by 67.2%, whereas the highest N level decreased barley yield by 4.7% in the second crop of barley after faba bean. This interaction was detected in 1986 despite the absence of significance of cropping sequence in 1985 or 1986, or for interaction in 1985.

Barley response to N fertilizer followed a similar pattern to wheat in that the response was lower in

TABLE 5

Relative grain yield response following faba bean and rapeseed break crops at Kulumsa and Bekoji

	Kulumsa (wheat)	Bekoji (barley)
1st year after faba bean	128.6	137.8
2nd year after faba bean	124.6	117.0
1st year after rapeseed	125.2	137.1
2nd year after rapeseed	99.2	116.0
Continuous cereal	100(1)	100(2)

NOTES: (1) and (2) are index yields, 2447 and 2662 kg/ha, respectively.

SOURCE: Amanuel Gorfu *et al.*, 1994.

TABLE 6

Grain yield response to N fertilizer in specific cropping sequences at Kulumsa and Bekoji

Kulumsa			Bekoji		
Wheat after	Year 1	Year 2	Barley after	Year 1	Year 2
Faba bean	+10.5%	+43.7%	Faba bean	+11.4%	+32.0%
Rapeseed	+28.5%	+76.0%	Rapeseed	+28.1%	+21.8%
Oat/*Vicia* or barley	+28.1%	+53.0%	Oat/*Vicia* or barley	+55.6%	+44.8%
Wheat	+56.5%	NA	Barley	+31.4%	NA
Continuous wheat	+36.2%	NA	Continuous wheat	+53.5%	NA
Mean response	+30.8%		Mean response	+29.6%	

NOTES: N applied: 60 and 55 kg/ha at Kulumsa and Bekoji, respectively. NA = not available.

SOURCE: Amanuel Gorfu *et al.*, 1994

the first barley crop following faba bean than in any other combination (Table 6). The second year response increased for faba bean, but not for the other cropping sequences. The magnitude of the N response of first-year barley sown after either oat or wheat may have been exaggerated by the visually apparent (but statistically non-significant) suppression of barley vigour following the wheat break crop of 1990 (Table 4). Continuous barley exhibited a dramatic fertilizer response of 53.5%.

TABLE 7
Productivity of the Meher season barley, as affected by break crops on drained brown soils of three sites in 1998–2001

Preceding break crop	Grain yield of barley (kg/ha)			
	Bakelo (fertile soil)	Keyit (medium)	Laymush (low)	Mean
Barley	1273	1020	305	866
Field pea	1856	1743	629	1409
Faba bean	1546	1802	662	1337
Mean	1559	1522	532	

NOTES: Yield averaged over two replications and two rotation cycles at each site. SOURCE: DBARC, 2005.

A barley-based crop rotation trial was also conducted on pellic vertisols at Sheno from 1995 to 2000. The treatments comprised linseed-barley, wheat-barley, oat-barley, faba bean-barley and barley-barley sequences for three rotation cycles grown on broadbed and furrows to drain excess water and with the application of 18–20 kg/ha of N-P fertilizer to each preceding crop and the barley test crop.

Growing barley after linseed, faba bean and wheat increased the grain yield of barley by about 100%, 93% and 63%, respectively, over the control (barley monoculture). Barley grown after oats produced about 4% less yield than that obtained from barley monoculture. From this experiment, it seems that linseed, a non-legume crop, is an important break crop in areas where root-rot diseases associated with soils prone to waterlogging, such as pellic vertisols, cause yield loss, as linseed is not a host to most diseases that commonly attack cereals. However, this experiment lacked important disease data.

In areas where frost hazard is low, in hill-sheltered and well-drained areas between Debre Berhan and Tarimaber, with an altitude range of 2700–3100 masl, farmers rotate barley with either faba bean or field pea. Farmers usually rate field pea better than faba bean as a break crop. Therefore, an experiment was conducted in 1998–2001 at Bakelo, Keyit and Laymush, representing adequate, medium and low soil fertility status, respectively, according to farmers' classification. Field pea increased the grain yield of barley by about 46%, 71% and 106% over the respective barley monoculture at Bakelo, Keyit and Laymush; the respective increments attributable to faba bean break crop were 21%, 77% and 117% (Table 7). It can be seen that field pea contributed far more at Bakelo, indicating adequate soil fertility status.

GAPS AND CHALLENGES

1. Generally, the barley production systems in the highlands of Ethiopia are low input and depend solely on landraces. Most landraces are tall and liable to lodge in a high-input production system. This limits the scope of increasing productivity to satisfy the demands of an ever-increasing human population. However, these landraces are chosen by small-scale farmers as they are less demanding in terms of fertile land, and are more competitive with weeds.

2. The agro-ecological variation over short distances creates demands for specific technologies. At the same time, researchers are inherently unenthusiastic about multidisciplinary integrated research approaches. This problem is exacerbated by the promotion career structure that has been established in the agricultural research system of Ethiopia, which discourages co-authorship. However, most crop management research gaps in barley, as indicated below, require a multidisciplinary integrated approach.
3. Barley is produced in areas of higher altitude on a sharply undulating topography that has been cultivated for a long time and that is severely eroded. Hence, soil fertility problems are the main barley production constraint.
4. Waterlogging problems, mainly during seasons with heavy rainfall conditions, occur even on well drained soils.
5. Many of the past crop management research work has been fragmented and concentrated on the effect of management practices on yield, neglecting interactions with soil biological and physico-chemical properties, which may contribute to crop input requirements and yields.
6. There is not enough information on the relative contribution of break crops in reducing disease build up, and the contribution of break crops in improving soil physico-chemical properties and overall system productivity and profitability.
7. There is very meagre information on intercropping research with barley.
8. There is a lack of information on compatible crop species and/or varieties for double cropping with barley so as to improve system productivity and profitability in areas receiving dependable *Belg* and *Meher* season rainfall.
9. There is a lack of early maturing, disease-tolerant and relatively higher-yielding legume crops, such as field pea, for double cropping with barley in high-altitude areas such as Ankober.
10. There is unreliable rainfall distribution, with variable onset and cessation before crop maturity, hence terminal low-moisture stress.
11. There is minimal use of improved landraces or improved barley varieties.

FUTURE RESEARCH DIRECTIONS

1. Future research work on agronomic management practices for barley should focus on the gaps identified above so that information can be generated through a multidisciplinary approach.
2. In the more marginal higher areas, where barley is the main crop grown, the fallowing system was a means of maintaining the fertility status of the soil. However, population pressure has forced farmers to reduce the fallow period and barley is grown after barley on eroded hillsides. Hence, looking for an alternative cropping system is important. To this end, efforts should be made to try the adaptation of legume crops for rotation and mixed cropping with barley and to diversify the cropping system.
3. There is the potential for producing malting barley in this region, which is more profitable to farmers. Hence, focusing research activities towards

finding optimal production packages (Variety + Agronomy) suitable for this region is important.

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Research achievements in soil fertility management in relation to barley in Ethiopia

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INTRODUCTION

In the highlands of Ethiopia, particularly the uplands and hillsides, soils become shallow and stony as a result of severe soil erosion and nutrient depletion (Asmare Yallew *et al.*, 1998a, b; Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002). As much farmland is now not used for production, farmers also recognize poor soil fertility as a factor constraining barley yield. Soil fertility is the most limiting factor for barley production in the highlands of Ethiopia (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998; Woldeyesus Sinebo and Chilot Yirga, 2002). Due to the undulating nature of the land in these areas, soil washes down the slope every year. In barley-growing areas, particularly at higher altitudes that are not suitable for the production of other crops, farmers use a fallow system to adjust the fertility of their farm. However, population pressure has forced farmers to reduce the number of years that land is left fallow and to convert grazing lands into crop production fields, resulting in increased erosion that creates impoverished soils. Chemical fertilizer usage by the resource-poor subsistence farmers in Ethiopia is insignificant and inadequate. However, fertilizer is applied to such farmland in the form of di-ammonium phosphate, mainly at rates of 9/10 to 18/20 kg/ha N/P, which are suboptimal rates for barley production (Chilot Yirga, Berhane Lakew and Fekadu Alemayehu, 2002). Application of P fertilizer increases N use efficiency and thus mines soil N when N is in short supply (Woldeyesus Sinebo, Chilot Yirga and Rezene Fisehaye, 2002). Traditionally, barley is cultivated with no or little external inputs such as fertilizer or agro-chemical application. Moreover, it is cultivated on eroded, moisture-stressed hillsides. Hence its productivity at a national level is very low, about 1.0 t/ha. Nevertheless, in a cropping system where large quantities of nutrients are exported in harvested products, it is unlikely that a sustainable and high yield would be obtained without nutrient replenishment. This paper reviews previous research results on soil fertility management with barley in the highlands of Ethiopia.

RESPONSE TO N AND P FERTILIZERS IN BARLEY IN CENTRAL ETHIOPIA

The results of fertilizer trials conducted in 1987 and 1988 at Holetta indicated that fertilizer had a significant effect on grain and straw yields, 1000-grain weight, plant height, and days to heading and maturity in both seasons. Application of fertilizer almost doubled grain yield (from 824 kg/ha to 1639 kg/ha in 1987) and straw yield increased by 72% (from 2609 kg/ha to 4485 kg/ha in 1988) (Table 1). The use of fertilizer significantly increased the plant stand count and plant height, and significantly delayed the date of heading and maturity.

Fertilizer trials were conducted on three locally common soil types, namely dila, dimile and kosi, using both improved and local barley cultivars. Results indicated that the effect of fertilizer on grain yield was highly significant on all three soil types. The application of nitrogen and phosphorus fertilizers at the rates of 41/20, 64/20 and 73/30 kg/ha N/P increased the grain yield of barley by 37%, 58% and 73%, respectively, compared with the farmers' check (9/10 kg/ha N/P) on dila soil. The corresponding yield increments for dimile soil were 44%, 77% and 69%, respectively (Table 2). Similarly, the application of 9/10, 18/20 and 41/20 kg/ha N/P increased the barley grain yield by 43%, 64% and 94%, respectively, compared with the unfertilized check on kosi soil (Table 3). Regarding varieties used, grain

TABLE 1

Main effects and significant differences of fertilizer on barley grain yield and some yield components at Holetta, 1987 and 1988

N/P fertilizer (kg/ha)	Grain yield (kg/ha) 1987	Grain yield (kg/ha) 1988	Straw yield (kg/ha) 1988	1000-grain weight (g) 1987	1000-grain weight (g) 1988	Plant height (cm) 1987	Plant height (cm) 1988
0/0	824	1547	2609	42.4	45.8	91	96
57/25	2463**	2511**	4485**	44.2**	47.0**	110**	108**
Mean	1643.5	2029	3547	43.3	46.4	100.5	102
CV (%)	13	12	15	4	3	5	6

NOTES: ** = Significant at the 1% level of probability; SOURCE: Amsal Tarekegne, Hailu Gebre and Francis, 1997.

TABLE 2

Average effects of variety and fertilizer on grain and biomass yields (kg/ha) of two barley varieties for two soil types in Welmera

	Dila Soil type		Dimile Soil type	
	Biomass yield	Grain yield	Biomass yield	Grain yield
Variety				
Baleme	4737	1307	3275	996
HB 42	4294	1336	2691	832
Fertilizer regime (kg/ha N/P)				
9/10	3191	960	2231	653
18/20	3902	1162	2470	715
41/20	4583	1310	2990	941
64/20	5172	1515	3675	1155
73/30	5731	1660	3549	1105

SOURCE: Woldeyesus Sinebo, Chilot Yirga and Rezene Fisehaye, 2002.

yields were about 1.0 and 0.83 t/ha for 'Baleme' and HB 42, respectively, on dimile soil, but about 1.3 t/ha on dila for both varieties (Table 2). When data were combined for the two soil types, dila and dimile, the effects of soil type, soil type by variety interaction and fertilizer were significant. As expected, the dila soil type was superior to dimile (Table 2). Similarly, Taye Bekele *et al.* (1996) and Woldeyesus Sinebo (2005) reported that the yield of barley increased following N/P fertilizer application at many locations.

TABLE 3

Effect of fertilizer on biomass and grain yields of barley on kosi soil at Welmera

N/P (kg/ha)	Biomass yield (kg/ha)	Grain yield (kg/ha)
0/0	2546	843
9/10	3407	1209
18/20	3870	1384
41/20	4602	1639
R-mean square	1317449	187552
R-squared	0.46	0.48
CV (%)	31.83	34.13

SOURCE: Woldeyesus Sinebo, Chilot Yirga and Rezene Fisehaye, 2002.

An on-farm trial was carried out to assess the effect of N and P application levels in barley after various precursor crops at different locations in West and North Shewa. It was found that N application has a highly significant effect on barley grain yield after fallow and barley rotation at Annokere in West Shewa, but no significant effect after barley rotation at Gendesheno in North Shewa. The maximum rate of N applied increased barley grain yield by 120% compared with the control plots at Annokere (Table 4). In general, the barley grain yield increased linearly with an increase in N levels.

At Menagesha, however, a significant effect was observed after barley and faba bean rotations, but no significant effect was obtained after fallow rotation. At Tatek no significant effect was obtained as a result of N application after fallow rotation. However, a significant effect was obtained after teff rotation. The highest N rate gave a 35% increase in barley grain yield (Table 4). Similarly, the

TABLE 4

Effects of N and P on barley grain yield (kg/ha) after fallow, barley, teff and faba bean rotations

	Annokere		Gendesheno	Menagesha			Tatek		Rob Gebeya
	After fallow	After barley	After barley	After barley	After fallow	After FB	After fallow	After teff	After FB
					N fertilizer (kg/ha)				
0	1118	795	2151	518	2047	1768	501	1244	884
23	1657	1146	2522	639	2086	2205	812	1607	1019
46	2259	1422	2786	726	2144	1854	858	1686	1403
69	2457	1702	2552	859	2238	2396	994	1838	1255
P	0.000	0.000	NS	0.099	NS	0.022	NS	0.074	0.086
					P fertilizer (kg/ha)				
0	1670	724	2062	367	1547	1429	605	1260	1004
10	1830	1337	2619	680	2308	1976	982	1564	1197
20	1898	1483	2745	832	2182	2374	787	1858	1429
30	2093	1521	2585	862	2480	2444	790	1693	931
P	NS	0.000	NS	0.006	0.003	0.001	NS	0.073	NS
N × P	NS	0.013	NS	NS	0.064	NS	NS	NS	NS
CV (%)	17.1	15.1	24.6	37.5	19.7	19.6	48.6	26.6	35.4

NOTES: *P* = probability level; FB = faba bean; NS = not significant.

SOURCE: Woldeyesus Sinebo (unpublished work).

application of P had a significant effect after barley rotation, in which a 110% increase in barley grain yield was recorded as a result of application of the maximum rate of P compared with the control at Annokere, but not after fallow and barley rotations at Gendesheno. A highly significant effect on grain yield was observed after barley, fallow, faba bean and teff rotations at Tatek and Robgebeya, where a 71% yield increase was obtained from the highest P rate after faba bean rotation (Table 4).

TABLE 5

Effects of N/P fertilizer on barley grain yield (kg/ha) in West and North Shewa

Farm	0/0 N/P (kg/ha)	41/20 N/P (kg/ha)	CV (%)
Tikur Inchinii District			
Merga	939	1298*	28.1
Tamiru	1324	1706*	24.3
Chalchissa	1515	2095*	31.7
Degem District			
Nigussie	3268	4188**	19.0
Legesse	1293	2325***	32.4
Geleta	1803	2198*	19.5

NOTES: *, ** & *** = Significant at 5%, 1% and 0.1% probability levels, respectively.
SOURCE: Woldeyesus Sinebo, 2005.

On-farm fertilizer trials were conducted at Tikur Inchini and Degem. Grain yield differences were observed between farmers who had and who had not used fertilizer. At Tikur Inchini, the yield variability due to unaccounted-for differences among the three farms with or without fertilizer was greater than the degree of response due to fertilizer application on any one farm (Table 5). At Degem, the grain yield among farms varied between 1.3 and 3.3 t/ha without fertilizer and between 2.3 and 4.2 t/ha with fertilizer application, in each case giving rise to a maximum yield difference of 2 t/ha among farms. However, the maximum response to fertilizer application at this location was only about 1 t/ha. Trials on the response of barley to the application of fertilizer in fallow and barley, teff or faba-bean-grown fields were carried out in Degem (North Shewa), Menagesha, Rob Gebeya and Tatek (West Shewa). There were significant differences in grain yield of barley grown with and without fertilizer application on barley, teff and faba-bean-cropped fields. Except at a farm in Anokere, barley grown on fallowed fields did not respond to fertilizer application (Table 6).

TABLE 6

Nitrogen fertilizer effects on barley grain yield (kg/ha) in West and North Shewa

Location and Farm	Precursor crop	Low N	High N	CV (%)
Degem/Annokere				
Fekadu	Barley	795	1702***	15.1
Geleta	Fallow	1118	2457***	17.0
Degem/Gendesheno				
Eyaleke	Barley	2151	2786	24.6
Menagesha				
Teshome	Barley	518	859*	37.5
Abebe	Faba bean	1768	2396**	19.6
Abebe	Fallow	2047	2238	19.7
Rob Gebeya				
Gadissa	Teff	1244	1838*	26.6
Guta	Faba bean	884	1403*	35.4
Tatek				
Tsige	Fallow	501	994	48.6

NOTES: *, ** & *** = Significant at 5%, 1% and 0.1% probability levels, respectively, SOURCE: Woldeyesus Sinebo, Chilot Yirga and Rezene Fisehaye, 2002.

EFFECTS OF DIFFERENT SOURCES OF PHOSPHORUS FERTILIZER

An experiment was conducted on different sources and rates of phosphate fertilizer at Holetta in the 1988 and 1989 cropping seasons on fields with different histories. The results indicated that, on continuously cropped fields, all sources of P except Ethiopian Rock Phosphate (ERP) were effective in increasing P uptake, straw and seed yields of barley (Table 7). In contrast, on newly cleared fields, no significant differences were observed between the different sources of P on barley.

The positive effects of bone meal on crop development, particularly at the highest level

TABLE 7
Direct effect of P sources and rates on barley yield and P uptake at Holetta, on continuously cropped and newly cleared fields

		Continuously cropped soils			Newly cleared soil	
P fertilizer source	P rate (kg/ha)	Seed yield (t/ha)	Straw yield (t/ha)	P uptake (kg/ha)	Seed yield (t/ha)	Straw yield (t/ha)
Control	0	2.80	5.40	6.4	4.01	11.30
Bone meal	26.4	3.22	6.50	8.7	4.64	14.40
	52.8	3.73	8.00	12.0	4.59	14.10
	105.6	4.23	7.90	13.1	4.52	14.60
Basic slag	26.4	3.58	7.90	13.1	4.57	13.20
	52.8	4.38	8.60	16.1	5.58	15.30
	105.6	4.86	10.6	20.0	4.28	14.10
Gafsa rock Phosphate (GRP)	26.4	3.64	6.20	11.0	4.22	13.20
	52.8	3.98	8.40	16.1	4.49	13.40
	105.6	4.47	9.40	15.9	3.79	13.10
Triple super-phosphate (TSP)	26.4	3.64	6.20	11.0	4.14	12.60
	52.8	3.79	9.80	20.5	4.57	13.80
	105.6	4.99	10.6	24.1	4.96	16.50
Ethiopian rock phosphate (ERP)	26.4	2.34	4.90	5.6	NA	NA
	52.8	1.64	4.80	6.8	NA	NA
	105.6	1.47	3.40	4.8	NA	NA
TSP + GRP mixture (1:4)	26.4	NA	NA	NA	4.65	13.30
	52.8	NA	NA	NA	4.46	13.30
	105.6	NA	NA	NA	4.32	14.50
LSD (*P*<0.05)		0.26	0.90	3.3	NS	NS

Notes: NA = not applicable; NS = not significant. Source: Taye Bekele and Höfner, 1993.

of application, might have been partly due to admixture of blood meal, which is rich in nitrogen. On continuously cropped fields, unlike the other P sources, increasing the rate of ERP had a negative effect on barley yield. The addition of 26.4, 52.8 and 105.6 kg/ha P gave a grain yield decrease of 16%, 41% and 47%, respectively, below the control. Similar trends were observed for straw and P uptake. The residual effects of the various P fertilizers were evaluated by comparing seed yield responses. On the newly cleared fields at Holetta, there was no residual effect from P sources, whereas all fertilizers except ERP at 26.4 and 52.8 levels were better than the control on continuously cropped fields (Table 7).

SPLIT APPLICATION OF NITROGEN FERTILIZER

The blanket fertilizer recommendation of 41/20 kg/ha N/P was not used by farmers for barley production in the waterlogging-prone areas (2740–2920 masl) of Sheno and Angolela. The ever-increasing price of fertilizer was felt to be the probable factor that caused farmers to produce barley without fertilizer. In these waterlogging-prone and high rainfall areas, it was also expected that the applied nitrogen fertilizer might have been lost through leaching, wash-off and denitrification. Therefore, looking for ways that could improve the productivity of the blanket recommendation, thereby reducing the requirement for higher levels of NP fertilizer application, was thought to be an option. Thus, an on-farm experiment comprising unfertilized check; application of 20/10 kg/ha N/P at sowing; 20/10 kg/ha N/P split at sowing and at tillering; 41/20 kg/ha N/P at sowing; 41/20 kg/ha N/P split at sowing and tillering; 82/40 kg/ha N/P at sowing; and 82/40 kg/ha N/P split at sowing and tillering were compared for three consecutive years (1996–1998) under improved soil drainage conditions. Splitting was performed only for N fertilizer.

The results of the 3 years were consistent. Split and basal application did not show statistically significant yield differences. The same was true for interaction effects. However, the grain yield of barley increased with increasing levels of N+P. Similar trends were also observed for straw yields. Although there were no statistically significant yield differences between split and basal applications of N fertilizer, split application is important to save some N fertilizer for whenever barley fails at the early vegetative stage due to waterlogging, or aphid or barley shoot fly infestation. Aphid and barley shoot fly infestations are usually sporadic, but they are devastating when they occur.

RESPONSE TO N AND P FERTILIZERS IN BARLEY IN WESTERN ETHIOPIA

The yield response of barley to N and P application rates was determined for 2 years (2003–2004) in the Arjo, Gedo and Shambo highlands of Ethiopia. Results of the combined analysis of variance over 2 years showed that the mean grain yield of barley was not significantly affected by N and P, nor by N×P interactions at Arjo, in which the application of 10/30 kg/ha N/P resulted in the highest mean grain yield of barley.

At Gedo, the grain yield of barley was significantly affected by N application, but not by P or N×P interactions. The application of 10 kg/ha N resulted in a better grain yield (2469 kg/ha) than the control and other N rates (Table 8). Nevertheless, the combined application of N and P at a rate of 10/30 kg/ha resulted in the highest yield (Table 9).

At Shambo, the grain yield of barley was significantly ($P<0.05$) affected by P application but not by N or N×P interactions (Table 8). The application of 20/30 kg/ha N/P doubled the barley grain yield compared with the unfertilized

TABLE 8

Response of barley grain yield (kg/ha) to N and P rate at Arjo, Gedo and Shambo, 2003–2004

Application rate N (kg/ha)	Arjo	Gedo	Shambo	Application rate P (kg/ha)	Arjo	Gedo	Shambo
0	2143	2297 b	1692	0	2122	2270	1264 c
10	2148	2469 a	1764	15	2172	2424	1744 b
20	2104	2426 ab	1867	30	2066	2451	2063 a
30	2049	2284 b	1902	45	2085	2331	2155 a
LSD ($P<0.05$)	NS	150	NS	LSD ($P<0.05$)	NS	NS	195
				CV (%)	12.3	11.0	18.7

NOTES: Means within a column followed by the same letter are not significantly different at $P=0.05$. NS = not significant. SOURCE: BARC, 2006.

plots; this application rate is the recommended rate for barley production at Shambo (Table 9).

SOIL FERTILITY MANAGEMENT IN NORTHWEST ETHIOPIA

Barley is one of the most important cereal crops in Ethiopia; it is mainly grown by small-scale farmers in mid- and high-altitude areas of northwest Ethiopia. It is predominantly grown between an altitude of 2000 and 3000 masl (Asmare Yallew *et al.*, 1998a). It has a number of attributes that makes it attractive to resource-poor farmers. Despite its importance, productivity at farm level has remained low, even lower than the national average (1 t/ha) (Asmare Yallew *et al.*, 1998a, b). This low productivity is mainly due to traditional methods of production and poor soil fertility. The limited agronomic studies in the region have shown the importance of improved practices for maximizing yield.

TABLE 9
Interaction effects of N and P fertilizers on barley grain yield (kg/ha) at Arjo, Gedo and Shambo, 2003–2004

Fertilizer application (kg/ha N/P)	Arjo	Gedo	Shambo
0/0	2107	2160	1113
0/15	2263	2401	1614
0/30	2163	2390	2043
0/45	2040	2236	2000
10/0	2189	2524	1199
10/15	2074	2445	1882
10/30	2312	2612	1967
100/45	2019	2296	2009
20/0	2144	2147	1279
20/15	2319	2468	1808
20/30	1858	2547	2213
20/45	2210	2543	2170
30/0	2049	2249	1465
30/15	2031	2382	1670
30/30	2045	2254	2030
30/45	2070	2251	2442
LSD (*P*<0.05)	NS	NS	NS

NOTES: NS = not significant. SOURCE: BARC, 2006.

RESPONSE TO N AND P FERTILIZERS IN BARLEY IN NORTHWEST ETHIOPIA

Considerable research has been carried out to determine the economic optimum nitrogen and phosphorus fertilizer rate on local food barley cultivars in major barley-growing areas of northwest Ethiopia. In the main cropping seasons of 1996 and 1997, factorial combinations of four levels of nitrogen fertilizer (0, 23, 46 and 69 kg/ha N) and four levels of phosphorus fertilizer (0, 10, 20 and 30 kg/ha P) were evaluated on early-maturing local food barley cultivars at Farta and Huleteju-Enebssie, and at Laie-Gaient Woreda. In 2000 and 2001, nitrogen fertilizer at the rates of 0, 32, 64 and 92 kg/ha, with the same P rates, were tested on late-maturing local food barley cultivars. Similarly, from 2000 to 2002, eight selected combinations of nitrogen and phosphorus fertilizers at rates of 0/0, 46/10, 46/20, 46/30, 69/10, 69/20, 69/30 and 92/30 kg/ha N/P were evaluated at Estie (South Gonder), Chillga, Wogera (North Gonder), Enarg-Enawga, Machakel, Gozamen, Debay-Tilatgin (East Gojam) and Banja (Awi Zone).

In all the studies carried out, progressive increases in barley grain yields were recorded with increased levels of N/P fertilizer rates. At Farta, the grain yield increased from 678 to 1617 kg/ha in response to N and from 1011 to 1271 kg/ha in response to P applications, and at Huleteju-Enebssie the grain yield increased from 714 to 1401 kg/ha due to N application and from 865 to 1286 kg/ha due to P application (Table 10). However, the economic optimum yield of 1669 kg/ha was obtained from the combined application of 69/10 kg/ha N/P at Farta. At Huleteju-Enebssie, the optimum grain yield of 1293 kg/ha was obtained from

TABLE 10

Effect of N and P fertilizer on grain yield (kg/ha) of food barley at Huleteju-Enebssie and Farta

P level (kg/ha)	Huleteju-Enebssie					Farta				
	N level (kg/ha)					N level (kg/ha)				
	0	23	46	69	Mean	0	23	46	69	Mean
0	662	792	967	1038	865	591	830	1254	1370	1011
10	588	1019	1292	1407	1077	668	947	1306	1669	1154
20	772	1186	1451	1543	1238	745	1102	1517	1702	1267
30	833	1163	1532	1616	1286	707	1185	1491	1699	1271
Mean	714	1040	1310	1401		678	1016	1392	1617	
LSD (*P*<0.05)			N means =142					N means = 232		
			P means = 81					P means = 150		
			N × P = 142					N × P = NS		

NOTES: NS = not significant. SOURCE: Minale Liben *et al.*, 2001.

TABLE 11

Effect of N and P fertilizer rates on grain yield (kg/ha) of food barley in the Laie-Gaient area

P level (kg/ha)	N level (kg/ha)				
	0	32	64	92	Mean
0	1223	1426	1644	1846	1535
10	1191	1421	1911	2177	1675
20	1245	1588	1826	2470	1782
30	1323	1640	2255	2258	1869
Mean	1246	1519	1909	2188	
LSD (*P*=0.05)		N means =163.4			
		P means =163.4			
		N × P = 326.8			
CV (%)		33.5			

SOURCE: AARC, 2001.

46/10 kg/ha N/P for early-maturing local food barley production. Similarly, at Laie-Gaient, the grain yield increased from 1246 to 2188 kg/ha in response to N and from 1535 to 1869 kg/ha in response to P applications (Table 11). In general, the highest mean grain yield of 2470 kg/ha was recorded from the combined application of 92/20 kg/ha N/P, which exhibited a yield advantage of 1247 kg/ha over the control treatment (Table 11).

With regard to the other locations, the most profitable and recommended rates for food barley production were found to be 46/20 kg/ha N/P for Enarge-Enawga, Machakel and Debay-Tilatgin; 69/30 kg/ha N/P for Gozamen and Chillga; 69/10 kg/ha N/P for Estie; and 69/20 kg/ha N/P for Wogera. However, the application of chemical fertilizers for barley production in the Banja area was found to be uneconomical. This might be due to the acidic nature of the soil; this subject needs further investigation (Table 12).

RATE AND TIME OF NITROGEN APPLICATION

An on-farm experiment was conducted in the 1995 and 1996 cropping seasons to determine the effects of fertilizer rate, time of nitrogen application and their interaction on the yield of early-maturing local food barley cultivars at Huleteju-Enebssie and Yilmana-Denssa. The treatments consisted of three fertilizer rates: F0 (0/0 kg/ha N/P); F1 (32/10 kg/ha N/P); and F2 (64/20 kg/ha N/P); and three N fertilizer application times: T1 (all nitrogen at sowing); T2 (half nitrogen at sowing and half at tillering); and T3 (all nitrogen at tillering).

Results indicated that fertilizer rate, time of application and fertilizer rate by time of application significantly affected barley grain yield. The application of

TABLE 12

Effect of N/P fertilizer application on grain yield of food barley at various locations

N/P-rate (kg/ha)	Estie	Enarg-E	Machakel	Gozamen	Debay	Banja	Chillga	Wogera	Mean
0/0	832.5	1497.0	720.3	665.2	2095.2	995	689	1738	1154
46/10	1742.0	2417.8	1424.4	1289.7	3125.4	1350	1385	2401	1892
46/20	1802.2	2589.0	1628.6	1475.2	3321.2	1425	1510	2627	2047
46/30	1840.4	2644.0	1709.9	1426.2	3207.4	1477	1521	2741	2071
69/10	1965.2	2475.6	1644.1	1343.1	3316.9	1485	1515	2840	2073
69/20	1998.0	2618.4	1706.3	1665.7	3341.2	1582	1623	3115	2206
69/30	2108.7	2848.9	1769.7	1857.0	3249.2	1549	1784	3100	2283
92/30	2152.6	2651.3	1795.3	2048.6	3510.6	1588	1730	2969	2306
LSD ($P<0.05$)	104.6	288.7	157.4	148.8	277.2	179.0	142.8	562.1	
CV (%)	13.9	19.1	18.8	15.3	14.4	21.9	20.0	31.5	

SOURCE: AARC, 2000–2002.

62/20 kg/ha N/P in the form of urea and DAP, all at sowing time, gave the highest mean grain yields of 1797 and 1635 kg/ha at Yilmana-Denssa and Huleteju-Enebssie, respectively (Table 13). The general misconception in fertilizer application on barley is that the use of mineral fertilizers merely increases crop yield. This misconception has led to either no use of mineral fertilizers or the application of lower rates for barley production. However, the application of fertilizer has a major role in increasing yield in all farmers' fields. Generally, the results of these studies show that soil fertility management can not be ignored if the productivity of barley is to be improved in semi-arid areas.

TABLE 13

Interaction effect of fertilizer rate × time of application on grain yield (kg/ha) of barley, 1995–1996

Treatment	Yilmana-Denssa	Huleteju-Enebssie
F1+T1	1494	1194
F1+T2	1303	940
F1+T3	1018	768
F2+T1	1797	1635
F2+T2	1607	1445
F2+T3	1089	966
CV (%)	10.0	12.0
F	*	*
T	*	*
F×T	*	*

NOTES: For explanation of F1, F2, F3, T1, T2 & T3, see text. * = Significant at 5% probability level. SOURCE: AARC, 1996.

EFFECT OF N AND P LEVELS ON THE GRAIN QUALITY AND YIELD OF MALTING BARLEY

An experiment was conducted on farmers' fields in Laie-Gaient Woreda in the cropping seasons of 2002 and 2003 to determine the optimum levels of N and P fertilizers for acceptable levels of grain protein in malting barley. The treatments consisted of factorial combinations of five rates of nitrogen fertilizer (0, 15, 30, 45 and 60 kg/ha N) and three rates of phosphorus fertilizer (0, 13 and 26 kg/ha P), arranged in a randomized complete block design. Results showed that grain yield responded significantly to N and P fertilization and their interaction. The highest grain yields of 1801, 1783, 1774 and 1677 kg/ha were obtained from the applications of 60/13, 60/26, 45/26 and 30/26 kg/ha N/P, respectively (Table 14). However, the analysis of malt quality indicated that application of 30/26, 60/0 and 60/26 kg/ha N/P resulted in first-grade barley, which is best suited for malt making under Laie-Gaient conditions (Table 15). Despite old data, a review by

TABLE 14

Effect of N and P fertilizers on the grain yield (kg/ha) of malt barley at Laie-Gaient

N level (kg/ha)	P level (kg/ha)			
	0	13	26	Mean
0	1081 d	1286 bcd	1323 bcd	1230
15	1166 cd	1383 bc	1349 bcd	1299
30	1189 cd	1398 bc	1774 a	1454
45	1381 bc	1525 ab	1677 a	1527
60	1518 ab	1801 a	1783 a	1700
Mean	1267	1479	1581	
LSD ($P<0.05$)		N means = 146.5		
		P means = 113.5		
		N × P = 253.8		
CV (%)		30.9		

SOURCE: AARC, 2003.

TABLE 15

Results of analysis for the selective treatments of malt barley

N/P (kg/ha)	Moisture (%)		Dry matter extract (%)		Protein (%)		1000-grain weight (g)		Conclusion
	Grade 1	Actual	Grade 1	Actual	Grade 1	Actual	Grade 1	Actual	
30/26	Max. 13	9.54	80–85	81.79	9–11	9.19	38–45	39.0	Grade 1
60/0	Max. 13	9.87	80–85	81.82	9–11	9.19	38–45	39.3	Grade 1
60/26	Max. 13	9.61	80–85	81.73	9–11	9.31	38–45	39.3	Grade 1

SOURCE: AARC, 2003.

Amsal Tarekegne *et al.* (1996) showed that the optimum level of application was 40/17 kg/ha N/P for malting barley at the Arsi Agricultural Development Enterprise.

RESPONSE TO N AND P FERTILIZER IN BARLEY IN NORTHEAST ETHIOPIA

Field experiments were carried out at Estayesh, North Wollo, during the main cropping seasons of 1996, 1997 and 1999 to determine barley response to N/P fertilizer application. The results indicated that N, P and N × P interaction showed significant effects on the grain yield of barley (Table 16). Grain yield benefits of 19%, 56% and 77% over the control were recorded, attributed to the increased rates of N fertilizer application. Similarly, the grain yield advantages of 19%, 35% and 60% over the control were obtained due to P fertilizer application. The maximum grain yield (2160 kg/ha) was obtained when the highest rates of 69/30 kg/ha N/P were applied, resulting in a grain yield benefit of 202% over the control. However, based on the results of economic analysis, 46/10 kg/ha N/P gave the best marginal rate of return (MRR) under the dry highland conditions of Wollo.

A similar experiment was conducted at Estayesh, North Wollo, during the main cropping seasons of 1997 and 1999. The results indicated that applied N influenced N and P concentrations of both grain and straw, whereas applied P had little effect on the same parameters. Application of N and P fertilizers significantly

TABLE 16

Effect of N and P application on barley grain yield (kg/ha)

Rate applied	Grain yield (kg/ha) 1996	1997	1999	Mean
		N (kg/ha)		
0	860 b	1196 c	942 c	1000 d
23	915 b	1585 b	1074 c	1191 c
46	1327 a	1838 a	1510 b	1558 b
69	1516 a	2072 a	1729 a	1772 a
Rate	**	**	**	**
		P (kg/ha)		
0	882 b	1403 b	941 b	1075 d
10	1182 a	1510 b	1132 b	1275 c
20	1198 a	1614 b	1547 a	1453 b
30	1357 a	2164 a	1635 a	1719 a
Rate	**	**	**	**
N × P	*	*	NS	*
CV (%)	20.8	17.7	19.3	19.1

NOTES: Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. * & ** = significant at 5% and 1% probability level, respectively. NS = not significant.
SOURCE: Getachew Alemu, 2001.

TABLE 17

Nitrogen uptake (kg/ha) of barley, as influenced by different rates of N and P application at Estayesh, North Wollo, Ethiopia

Fertilizer application	1997 Grain yield	Straw yield	1999 Grain yield	Straw yield
		N (kg/ha)		
0	19.09 d	23.66 b	13.18 b	7.82 b
23	25.37 c	34.91 a	16.00 b	13.19 a
46	30.68 b	32.70 a	21.71 a	15.93 a
69	39.34 a	32.94 a	25.18 a	14.08 a
F-test	**	**	**	**
		P (kg/ha)		
0	23.91 b	24.60 b	13.91 b	11.60
10	25.82 a	30.95 ab	16.41 b	11.47
20	27.07 a	35.45 a	22.51 a	15.54
30	37.68 a	33.19 a	23.25 a	12.40
F-test	**	*	**	NS
N × P	*	NS	NS	NS
CV (%)	21.7	25.0	22.5	31.4

NOTES: Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. * & ** = significant at 5% and 1% probability level, respectively. NS = not significant.
SOURCE: Getachew Alemu and Tekalign Mamo, 2003.

TABLE 18

Phosphorus uptake (kg/ha) of barley, as influenced by different rates of N and P application at Estayesh, North Wollo, Ethiopia

Fertilizer application	1997 Grain	Straw	1999 Grain	Straw
		N (kg/ha)		
0	1.78 b	3.30	1.70 c	1.01 b
23	2.55 a	4.22	2.29 c	1.47 a
46	2.71 a	3.76	3.00 b	1.66 a
69	3.04 a	3.87	3.69 a	1.50 a
F-test	**	NS	**	*
		P (kg/ha)		
0	1.94 b	2.55c	1.54 b	1.19
10	2.31 b	3.58b	2.13 b	1.37
20	2.49 b	4.05ab	3.25 a	1.52
30	3.34 a	4.96a	3.77 a	1.55
F-test	**	**	**	NS
N×P	NS	*	*	NS
CV (%)	33.5	30.7	27.1	35.7

NOTES: Means within a column followed by the same letter are not significantly different at $P \leq 0.05$. * & ** = significant at 5% and 1% probability level, respectively. CV = coefficient of variation; NS = not significant.
SOURCE: Getachew Alemu and Tekalign Mamo, 2003

increased N and P uptake in grain and straw. In general, the grain and straw N uptakes were greater in the relatively wetter season (1997) than in the drier season (1999). Application of N and P fertilizers exhibited a marked increase in grain and straw N uptake, probably as a result of their yield-enhancing effects (Table 17). Similarly to N uptake, P uptake in barley was greatly influenced by N and P application rates (Table 18).

RESPONSE TO N AND P FERTILIZERS IN BARLEY IN SOUTH ETHIOPIA

Poor soil fertility, particularly deficiency of nitrogen and phosphorus, is one of the major barley production constraints in Ethiopia, as well as in the Horn of Africa in general. In order to address the problem, fertilizer trials were conducted at different locations to determine optimum N/P fertilizer rates using an improved variety (HB 42) and local barley cultivars. The trial was conducted at Hosanna and Kokate during the main cropping seasons of 1998–2000, and at Bule during the main cropping seasons of 2004–2005. At Hosanna, the results indicated that the grain yields of both local and improved varieties of barley increased as the rate of phosphorus increased (Table 19). In contrast, application of nitrogen increased only the grain yield of the improved barley variety but not the local cultivar at Hosanna. The data showed that the highest yield was obtained from the application of 69/20 kg/ha N/P, but 23/20 kg/ha N/P can be recommended for barley production.

The results at Kokate indicated that a slight increase in yield was observed when P and N rates increased to 10 and 23 kg/ha, respectively. However, the yield advantage obtained due to the fertilizer application was not significant (Table 20). Although previous experimental results from WADU (1977) indicated that a rate of 41/20 kg/ha N/P gave better grain yields at Kokate, the current results do not support this. The current findings indicated that production of food barley is possible at Kokate without the application of NP fertilizers. At the same time, 2 years' data at Bule, in Gedeo Zone of SNNPR, showed that the grain yield of barley increased with application of NP fertilizer (Table 20). Nevertheless, the increase in yield due to the increase in N/P rates was not consistent. From these results, it can be suggested that in order to recommend an economic optimum N/P rate for barley production, the yield data should be supported by economic analysis.

A fertilizer trial was conducted on-farm in the main growing seasons of 2003 and 2004 at Fereze in Guraghe Zone. The results showed that the application of nitrogen did not have a significant effect on grain yield. In contrast, the mean grain yield consistently and significantly increased as the rate of P increased (Table 21). Hence, despite the necessity of identifying the economic optimum rate by conducting economic analysis, based on the results of this study, barley at Fereze can be produced by the application of 30–40 kg/ha P but without the application of nitrogen fertilizer.

TABLE 19

Effect of NP fertilizers on grain yield (kg/ha) of food barley varieties at Hosanna, Ethiopia

N rate (kg/ha)	Variety	P rate (kg/ha)			Mean
		0	10	20	
0	HB 42	1160	1730	2090	1660
	Local	810	1260	1340	1140
23	HB 42	1540	1590	2470	1870
	Local	750	1060	1550	1120
46	HB 42	1480	1970	2260	1900
	Local	690	1160	1360	1070
69	HB 42	1720	2150	3000	2290
	Local	740	1170	1460	1120
Mean	HB 42	1480	1860	2460	
	Local	750	1160	1430	

SOURCE: Areka Agricultural Research Centre, 2000.

TABLE 20

Grain yield (kg/ha) of barley, as affected by different NP fertilizers rates at Kokate and Bule

N rate (kg/ha)	Kokate				Bule				
	P rates (kg/ha)				P rates (kg/ha)				
	0	10	20	Mean	0	10	20	30	Mean
0	1690	1780	1700	1720	2410	2477	2739	2188	2480
23	1680	1860	1690	1740	2220	2889	2911	2744	2692
46	1440	1760	1760	1660	2455	2833	3044	2866	2822
69	1570	1650	1670	1630	2833	2667	3077	2755	2833
Mean	1606	1760	1710		2489	2775	2903	2661	

SOURCES: Areka Agricultural Research Centre, 2000; Awassa Agricultural Research Centre, 2005.

A similar experiment to that at Fereze was also conducted at Waka. The results showed that the application of phosphorus at Waka did not consistently increase the grain yields of barley cultivars, but the degree of response among cultivars varied (Table 22). The application of 10 kg/ha P gave maximum grain yield for the improved barley cultivar. The yields of both improved and local cultivars are high without the application of chemical fertilizers. Therefore, when fertilizer trials are planned, the sites to be selected should be representative and results should always be substantiated using soil analytical results, in addition to economic analysis.

TABLE 21
Effect of N and P fertilizers on grain yield (kg/ha) of improved and local food barley at Fereze

N (kg/ha)	Variety		P (kg/ha)	Variety	
	HB 42	Local		HB 42	Local
0	2473	3150	0	1367	2400
23	2282	3300	10	2041	3270
46	2491	3390	20	2503	3470
69	2640	3550	30	3013	3700
Mean	2471	3347	40	3442	3890
			Mean	2473	3346

SOURCE: Areka Agricultural Research Centre (2004)

TABLE 22
Grain yield (kg/ha) of improved and local food barley obtained at different levels of N at Waka

N (kg/ha)	Variety		P (kg/ha)	Variety	
	HB 42	Local		HB 42	Local
0	4733	3067	0	4769	3202
23	4894	3184	10	5156	3162
46	5083	3280	20	4838	3180
69	5244	3324	30	5198	3301
Mean	4988	3214	40	4981	3324
			Mean	4988	3234

SOURCE: Areka Agricultural Research Centre, 2004.

RESPONSE TO FERTILIZERS IN BARLEY IN NORTHEAST CENTRAL ETHIOPIA

Response to fertilizers in barley grown by small-scale farmers

This section summarizes the results of integrated soil fertility management trials conducted by the Debre Berhan Agricultural Research Centre. The blanket fertilizer recommendation of 41/20 kg/ha N/P has not been used by farmers for barley production in the highlands of North Shewa. The ever-increasing price of fertilizer seems to be one of the most probable factors causing farmers to produce barley without fertilizer. It was also expected that applying N fertilizer in waterlogging-prone and high rainfall areas might cause wastage through leaching, wash-off and denitrification. In contrast, manure application by small-scale farmers is a well-established practice in some areas. Most barley landraces are tall, thus suppressing weeds, but lodge easily at higher rates of fertilizer application, so these scenarios make weeding and fertilizer application less attractive to farmers. Therefore, looking for ways that can improve the productivity of the blanket recommendation, thereby reducing the requirement for higher levels of NP fertilizer, was an option in the period from 1993 to 2006.

Most farmers in the highlands of northeast Shewa apply manure, so in most cases they are productive without chemical fertilizer. However, the blanket implementation of an agricultural extension package for fertilizer application did not consider these variations in soil fertility management practices by farmers. Many failures resulted, such as incurring costs without improving yields, especially around homestead lands. Therefore, it was necessary to determine the effects of selected levels of N and P. Based on this, 0/0, 20/10 and 41/20 kg/ha N/P were tried around Debre Berhan and Tarimaber.

The results of various experiments conducted in 1996 and 1997 indicated that, unlike farmlands that had been manured 3–5 years previous, the barley response to fertilizer was high on farmlands that had never been manured (Table 23). Application of 41/20 kg/ha N/P on sites that had been manured 3–5 years previous and on sites that had never been manured, gave respective grain yield advantages of about 28% and 82% over the unfertilized control. Productivity of barley was high on sites that had been manured 3–5 years earlier. For example, the grain yield of unfertilized controls on sites manured 3–5 years before was about 45% higher than that obtained from the application of 41/20 kg/ha N/P on sites that had never been manured. In conclusion, it was suggested that no NP fertilizer application is required for barley grown in homesteads that receive manure or household wastes. Farmlands located far from homesteads are difficult to manure and hence require an application of at least 41/20 kg/ha N/P.

TABLE 23

Barley grain yield response on sites with different soil fertility management practices of farmers in areas between Debre Berhan and Tarimaber, 1996–1997

N/P level (kg/ha)	Sites manured 3–5 years previous		Sites never manured	
	Grain yield (kg/ha)	Increment over the control (%)	Grain yield (kg/ha)	Increment over the control (%)
0/0	2260	0.00	857	0.0
20/10	2491	10.22	1142	33.3
41/20	2884	27.61	1562	82.3

SOURCE: ShARC, 1997.

In general, barley production systems in the highlands of North Shewa are low input and are solely dependent on landraces. Most landraces are tall and liable to lodging in high-input production conditions; this limits the scope of increasing productivity and production to satisfy the demands of the ever-increasing human population. However, these landraces are the choice of small-scale farmers as they are less demanding in terms of land fertility and are more competitive with weeds. The prevailing agro-ecological variations within short distances in North Shewa also demand site-specific technologies.

GAPS AND CHALLENGES

1. Poor soil fertility, particularly nitrogen and phosphorus nutrient deficiency, is one of the main barley production constraints in Ethiopia.
2. Past crop management research has been fragmented and mainly concentrated on the effect of management practices on yield, neglecting the interaction with soil biological and physico-chemical properties and disease build up, all of which may affect crop input requirement and yield.
3. Production constraints are not properly identified. Hence, there is no clear information regarding variety adaptability, fertilizer requirement and response to agronomic practices.
4. Barley is produced in areas of higher altitude with undulating topography that has been cultivated for a long time and become severely eroded, and this soil quality problem is one of the main barley production constraints.
5. Soil fertility improvement for enhanced barley production has not covered all the barley growing areas of the country. According to the results of fertilizer

trials, differences exist among varieties in response to fertilizer, so different varieties could be involved during trials. There is also a need for site-specific fertilizer rate determination.

6. There is not enough information on the relative contribution of break crops in reducing fertilizer requirements and in improving soil physico-chemical properties, and their role in overall system productivity and profitability.
7. There is a lack of information on the effect of *chiflik* (a short period of fallow), a common practice in high-altitude areas of North Shewa, with regard to soil fertility improvement and its effects on soil-borne disease challenge and fertilizer requirements.
8. There is little or no information on soil fertility management and varieties for a high-input barley production system, so as to support the ever-increasing human population in the high-altitude areas where crop optiona are very limited.
9. Fertilizer recommendations focus only on inorganic source of fertilizers; no attention is given to quality aspects in relation to fertilizer application; and there is an absence of laboratory facilities to analyse crop quality parameters.

FUTURE RESEARCH DIRECTIONS

Future research on soil fertility management in barley should focus on the gaps identified, making them priority research areas. Among many, the following important topics should be considered as future research directions:

- Barley production constraints and possible solutions should be identified in the highlands of the country so as to be able to improve barley production and productivity.
- Optimum and economic N/P fertilizer rates and timing of nitrogen application should be developed for better quality and yield of malt barley.
- Both inorganic and organic sources of fertilizers should be integrated with cropping systems for sustainable barley production.
- Collaborative research work should be strengthened with national and international research organizations.
- Information available in areas of nutrient management for barley production should be scaled up into practical recommendations and extended to end users.
- In North and northwest Shewa, where barley is grown as the main crop, the fallowing system was a means of maintaining the fertility of soil. However, population pressure has forced farmers to shorten the fallow period and barley is grown after barley on eroded hillsides. Hence, looking for an alternative cropping system is important, and efforts should be made to diversify the cropping system by involving leguminous crops for rotation and mixed cropping with barley.
- There is a potential for producing malting barley, which is more profitable to farmers. Thus, focusing research activities towards finding optimal production packages suitable for malt barley production is important.

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Entomology

Research achievements in barley shoot fly in Ethiopia

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INTRODUCTION

In Ethiopia, many insect pests that attack barley have been recorded. Of these, Russian wheat aphid (RWA) and Barley shoot fly are the main ones (Adugna Haile and Kemal Ali, 1986). There are two species of barley shoot fly that occur in Ethiopia: *Delia arambourgi* Seguy, recorded from the central part of the country (Holetta) (Davidson, 1969) and *D. flavibasis* Stein, recorded from Bale (Tafa Jobie, 2003). Other field insect pests, such as the chafer grub (*Melolontha* spp.), weevil grub (*Mesoleurus* spp.) and *Epilachana* spp., are important, but affect only a few areas. This paper provides a wider overview of research findings; management options; and the challenges, gaps, opportunities and prospects with regard to research towards sustainable management of barley shoot flies in Ethiopia.

SHOOT FLIES ATTACKING BARLEY

In Ethiopia, the first record of barley shoot fly was in 1967. It was first observed at Holetta Agricultural Research Centre and the species was identified as *Delia arambourgi* Seguy (Davidson, 1969). This pest was then expected to infest three crops, barley, wheat and teff, and was considered to be a major pest of barley and a minor pest of wheat and teff (Adugna Haile and Kemal Ali, 1986). As the agro-ecology of Bale differs greatly from other parts of Ethiopia, where barley shoot fly is known to occur, and because the pest is uniquely destructive to barley in this zone (ABPHC, 1991, 1992, 1993), there has been increasing doubt as to the identity of shoot flies that attack small cereals. In addition to the previous record, two more shoot fly species, one from wheat and the other from barley, were recorded in 2003 at Sinana. Both species were identified at the Natural History Museum, UK. The species reared from wheat was identified as *D. steiniella* Emden, belonging to family Anthomyiidae, Order Diptera, and caused an infestation in the range of 56.5–74.5% on different bread wheat varieties at Sinana, Ethiopia, under field conditions and natural infestations (Tafa Jobie and Tadesse Gebremedhin, 2005). This is perhaps the first report of *D. steiniella* on wheat. Similarly, specimens of shoot fly reared from barley at Sinana were identified as *D. flavibasis* Stein, belonging to the same family (Tafa Jobie, 2003). Hence, currently there are at least two known species of shoot fly that attack barley in Ethiopia: *D. arambourgi* and

D. flavibasis. The latter commonly occurs throughout high- and mid-altitude areas of Bale. The research results reviewed here focus on the two species.

REVIEW OF RESEARCH FINDINGS ON DELIA FLAVIBASIS STEIN (DIPTERA: ANTHOMYIIDAE)

Survey of incidence and infestation level

A survey of *D. flavibasis* incidence and damage level was conducted in 2003 and 2004, during the *Bona* season in 10 barley growing districts of Bale, which represented the range of barley growing regions extending from the lowest possible altitudes in Goro and Ginir (below 1800 masl) to the highest (above 2000 masl) in the Upper Dinsho and areas bordering the Sanatti Plateau in Goba. Seven of the survey districts (Agarfa, Sinana, Goba, Gasara, Ginir, Gololcha and Goro) have a bimodal rainfall pattern; the remaining three districts (Dinsho, Adaba and Dodola) receive unimodal rainfall.

FIGURE 1

Mean percentage infestation and deadhearts caused by barley shoot fly attack in seven barley growing districts of Bale in 2003

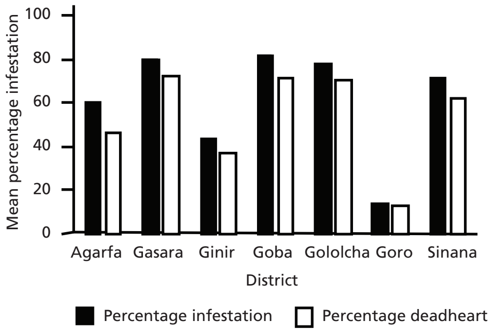
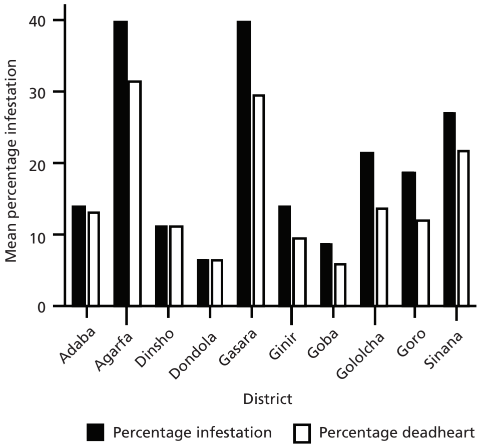


FIGURE 2

Mean percentage infestation and deadhearts caused by barley shoot fly attack in different barley-growing districts of Bale in 2004



D. flavibasis infestation was recorded in all the districts surveyed. However, the population level implied by adult and egg bioassay, as well as the degree of damage (infestation and deadhearts), varied greatly among districts. Pest incidence and damage level were lower in Dinsho, Adaba, Dodola, Ginir and Goro compared with the remaining districts (Figures 1 and 2). Hence, these districts may be used to promote the production of improved food and malt barley varieties, at least with minimum costs incurred due to barley shoot fly management. Similarly, some suitable test sites for barley research in Bale may be located within these districts.

Generally, shoot fly incidence and damage (infestation and deadhearts) appeared to be higher in 2003 than in 2004 (Figures 1 and 2) in all the districts surveyed. Malt barley was found to be more infested than food barley (Figures 3 and 4).

Barley cultivars grown in Bale

In Bale, farmers have not been adopting improved barley varieties, nor have the research and extension system been pushing them. This situation is in contrast to that of wheat, the improved varieties of which have been widely adapted by farmers. There is a valid and well-justified reason for this, namely the hyper-susceptibility of improved varieties to barley shoot fly infestation, leading to total yield loss. In the surveyed area, the production of barley is predominantly using the most popular and resistant (to barley shoot fly) cultivar, known as 'Aruso'. Other local cultivars in production, particularly in Dinsho, include 'Falibahe', 'Wadago', 'Barsadade', 'Engliz' and 'Magie'. A cultivar known as 'Aklas' (highly susceptible to barley shoot fly), the seed of which farmers exchange, was also occasionally encountered. Improved food barley varieties were not encountered at all throughout the study.

FIGURE 3

Comparison of infestation level in malt and food barleys in Sinana in 2003

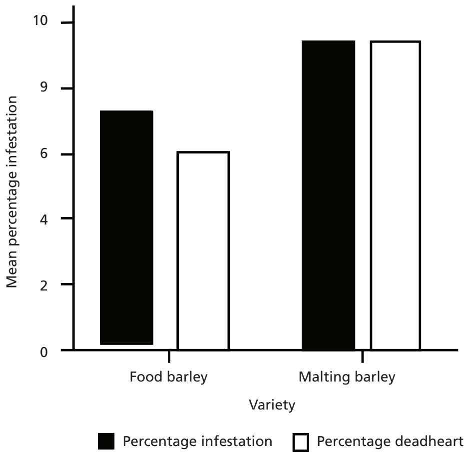
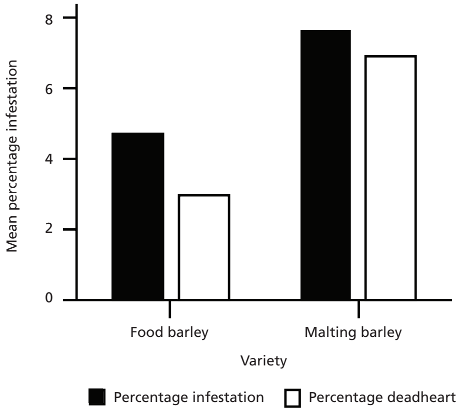


FIGURE 4

Comparison of infestation levels in malt barley and food barley in Agarfa in 2003



Improved malt barley varieties are nationally released and supposed to adapt to the agro-ecology of Bale, particularly the Sinana, Gasara and Dinsho areas; these varieties include 'Beka', 'Holker' and HB 120 (Hailu Gebere, 1997). It has been repeatedly proven, however, that these varieties, similar to many other nationally released improved varieties and other exotic germplasm, could not adapt to this ecoregion. The main reason for this is that these varieties cannot withstand infestation of barley shoot fly and, unfortunately, malt barley appears to be more susceptible than food barley to this pest (Figures 3 and 4). Many screening attempts have been made in the past to obtain malting barley varieties that could resist shoot fly attack. In 2005 alone, all 125 malt barley genotypes tested against the barley shoot fly failed. This is why not a single malt barley variety was released, whereas several food barley varieties were released from Sinana Agricultural Research Centre (SARC).

A survey in 2003 and 2004 found very few malt barley farms in the Agarfa, Sinana and Dodola districts. In Agarfa and Sinana, the variety 'Beka' has been distributed to farmers through cooperatives, but it failed due to high shoot fly infestation. In Dodola, where malt barley is collectively known as Shake, malt barley is commonly grown, covering about 50% of the area under barley. Interviews with the farmers indicated longer and more successful experience of malt barley production in this area compared with other places in Bale. This might have been due to the single rainy season in Dodola, Adaba and Dinsho, which contributes to low shoot fly infestation. Other areas that are less prone to shoot fly infestation, according to the results of the 2003 and 2004 surveys, were Ginir and Goro (lower altitudes). Such areas may be used to promote the production of improved food and malt barley varieties.

Farmers' perception of barley pests in Bale

Most of the farmers interviewed responded that they are familiar with a pest that is locally known as *Meseki* (cutworm), an insect that attacks barley seedlings. Farmers have also observed that aphids cause more serious damage under dry conditions, whereby the yield losses may be very high. Only very few farmers (in the Dodola area) know that barley shoot fly is a major pest of barley, and they believe that the pest is not so active during heavy rains and causes less damage under such conditions. Farmers generally claim that the damage caused by barley shoot fly affects barley and even wheat. However, an infestation of barley shoot fly does not actually appear to the majority of farmers as a biotic stress, as they attribute most of the damage to moisture stress, and soil and other nutrient-related factors. The reason that barley shoot fly is not familiar to most farmers relative to other pests is that the larvae responsible for the seedling damage are found burrowed deep inside the shoots, the eggs are thinly spread and located in the soil, and the adults are small and not easily visible. They are also indistinguishable in the field, by a non-professional, from other dipteran flies.

RESPONSE OF BARLEY GENOTYPES TO *D. FLAVIBASIS* INFESTATION

Two-stage consecutive screening

An experiment was conducted during two years, 2002 and 2003. In 2002, 300 landraces obtained from IBCR were screened in a non-replicated nursery. Relatively resistant genotypes were selected for further evaluation, based on infestation and tolerance (crop recovery). In the first infestation score, 10 genotypes had an infestation level of 21–40%; 38 genotypes of 41–60%; 124 genotypes of 61–80%; and 128 genotypes of 81–100%. For the terminal score, six genotypes had an infestation level below 40%; 35 genotypes in the range of 41–60%; 86 genotypes in the range of 61–80%; and the remaining 173 genotypes in the range of 81–100%. Regarding recovery growth (tolerance), the 300 genotypes could be classified as: 110 with very poor recovery growth; 36 with poor recovery growth; 72 with moderate recovery growth; 32 with moderately high recovery growth; and the remaining 50 with high recovery growth. At the same time, 15 genotypes were completely destroyed, with consequently no yield.

In 2003, 62 relatively resistant genotypes were selected out of the 300 genotypes tested in preliminary screening. For the first score, two genotypes had an infestation level below 60%; nine in the range of 61–80%; and 51 in the range of 81–100%. For the terminal score, 18 genotypes had an infestation level in the range of 41–60%, 25 genotypes in the range of 61–80%; and the remaining 19 in the range of 81–100%, with 14 genotypes exhibiting an appreciable level of tolerance.

Advanced testing

In this experiment, 18 pre-tested accessions were evaluated for their response to infestation of barley shoot fly. The results showed that all of the genotypes turned out to be highly susceptible to the infestation of *D. flavibasis*, although some showed a tolerance response. In the first score, the percentage infestation was 63–96%, whereas in the terminal score, infestation was 82–99% (Table 1). In spite of the heavy infestation, some of the genotypes, such as 'Kesele', IBDR-2, IBDR-I, Acc 229999, Acc 03 and Acc 99, showed better recovery growth and gave good yields. IBDR-2 exhibited the best level of relative tolerance to *D. flavibasis* in terms of score of recovery growth and, subsequently, gave the highest yield (followed by 'Kesele'). In contrast, four accessions were completely lost (yield=0) to the damage of *D. flavibasis*, whereas the remaining accessions gave very low yields (Table 1).

TABLE 1

Infestation, recovery growth and yields of some barley genotypes evaluated for their response to infestation of *D. flavibasis*

Genotype	Percentage infestation I	Percentage infestation II	Recovery (1–5)	Yield (kg/ha)
Kesele	63	94	2.65 ab	3.32 b
IBDR-2	77	82	3.32 a	3.58 a
Acc 3441-94	83	98	0.00 d	0.00 g
IBDR-1	79	83	1.11 bcd	0.26 b
Chare	81	91	0.27 cd	1.96 efg
Acc 216008	77	95	0.27 cd	2.96 cdef
Acc 212845-02	65	96	0.00 d	0.00 g
Acc 229999	84	85	1.93 ab	3.24 b
Acc # 03	87	98	2.00 ab	3.17 bcd
Acc 3286	78	96	1.00 bcd	2.99 cde
Acc 3192	90	93	0.00 d	0.91 fg
IBDR-3	90	98	1.00 bcd	2.84 defg
Acc 212840	81	95	1.00 bcd	3.00 cde
Acc 3314	93	99	0.00 d	0.00 g
Acc 208040-02	93	99	0.00 d	0.00 g
Acc 99	84	92	1.42 abc	3.21 bc
Acc 3296	91	97	0.00 d	0.98 efg
Acc 3782	81	93	0.27 d	2.81 efg
HB 42	96	99	1.00 bcd	2.98 cdef
SE	6.44	1.61	0.55	705.4
LSD (*P*=0.05)"	NS	NS	0.14	705.4

NOTES: Recovery means are re-transformed after square root transformation. Yield values are Log x+1-transformed. Values in a column followed by the same letter are not significantly different according to DMRT. Mean separation was made based on the untransformed data. NS = not significant.

The results of this study indicated that *D. flavibasis* is a destructive barley pest in Bale; it has a high infestation level (usually approaching 100%). The subsequent yield loss is also substantial (usually 100% for susceptible varieties). Although all of the accessions tested in this study were found to be highly susceptible to infestation, some of them manifested better levels of tolerance (recovery growth) and gave better yields, indicating that there is an appreciable degree of variation among genotypes for their response to infestation by barley shoot fly. The results also confirm that resistance to barley shoot fly is partially due to tolerance mechanisms, corroborating previous studies (Tafa Jobie, 2003). Most of the accessions that showed better recovery growth and yields appeared to have relatively lower infestation levels, suggesting that resistance is due also to reduced initial infestation.

DETERMINATION OF DEVELOPMENTAL PERIOD OF *D. FLAVIBASIS*

The developmental biology of *D. flavibasis* was studied on six barley genotypes ('Aruso', HB 42, PGRCE/E 1799, PGRCE/E 4414, PGRCE/E 4409 and PGRCE/E 4282). Egg hatching took 2.5–3.13 days; the subsequent larval development period was 4.17–5.88 days. The pupal period lasted 7.75–9 days. The overall developmental period (egg to adult) took 14.88–17.67 days. The weights of larvae, pupae and adults were 3.60–4.02, 3.00–3.63 and 2.13–3.11 mg, respectively (Tafa Jobie, 2003).

HOST PREFERENCE OF BARLEY SHOOT FLY

Cultivated grass species

This was assessed in a greenhouse, using pot culture. Some cereals widely grown in Bale (Emmer wheat, bread wheat, teff, maize and oat) were evaluated for their preference as host by barley shoot fly. The infestation in the susceptible barley variety HB 42 (control) was 100%. Emmer wheat, bread wheat and teff sustained very high infestations, whereas maize and oat were infested least. Infestation in maize did not result in deadheart formation. This shows the equal importance of the first three crop species as alternative hosts to barley shoot fly. In Bale, wheat is harvested using combine harvesters; this causes some shattering of seed, which remain in the cropped fields and germinate during the off-season following short rains. Thus, *D. flavibasis* may easily survive on volunteer crops during the off-season, consequently aggravating the incidence of the pest.

A field study was conducted in Sinana in the *Bona* season of 2006 to investigate the responses of bread, durum and emmer wheat genotypes to infestation by barley shoot fly, *D. flavibasis*,. Results generally showed that most of the genotypes in all the three crops were highly infested, and all infestations resulted in deadheart formation in durum and bread wheat. Infestation generally ranged from 20% to 90% in bread and durum wheat, and from 40% to 56% in emmer wheat. Similarly, the occurrence of deadheart in emmer wheat was 26–30%. The results of this study confirmed the results of the greenhouse trials, namely that durum, bread and emmer wheat are suitable hosts for barley shoot fly. Therefore, there is a need for management interventions to harvest yields that increase the genetic potential of these crops. Emmer wheat was relatively less infested under both pot culture and field conditions and is apparently the least preferred host compared with bread and durum wheat, as well as barley. The infestation level of barley was very high (100%) for susceptible varieties, such as 'Shege' and HB 42, under field conditions during the study period (data not shown).

Wild grass species

In addition to cereals, shoot flies may also survive on a variety of grasses in the absence of appropriate hosts (Bullock, 1965). At Sinana, elephant grass (*Pennisetum* sp.) was observed to be the main wild host of barley shoot fly, *D. flavibasis*. In similar field observations, *Snowdenia polystachya* was found to host *D. steiniella*.

An unexpected observation at Sinana was the severe infestation by *D. flavibasis* Stein of lupin, *Lupinus angustifolius*, a legume crop. This is perhaps the first report recording *D. flavibasis* on *L. angustifolius*. This observation suggests that the fly is polyphagous and may use such legumes as alternate hosts in the absence of grass species. This shows that this pest is a potential threat for the production of the crop in the southeastern ecoregion, and hence the wide introduction of lupin may further aggravate the pest situation.

SEASONAL VARIATIONS IN BARLEY SHOOT FLY INFESTATION

Infestation during the non-crop period

An experiment was conducted at SARC to test the occurrence of infestation of barley shoot fly on wheat and barley during the off-season (non-cropping period). Accordingly, five varieties each of barley and wheat were sown in February 2004 and 2005. The results indicated that, in the non-cropping period of 2004, the infestation level was 7–39% on barley and 12–19% on wheat. In 2005, infestation of barley genotypes during the off-season was 21–54% and that of wheat was 8–12%. The implication is that *D. flavibasis* appears to ensure year-round survival through normal reproduction by infestation of the main host and alternative volunteer crops and wild hosts.

Variation in infestation level between Ganna and Bona

Ten barley varieties that were resistant previously and 10 that were susceptible (reported in previous studies) were planted in the *Ganna* and *Bona* seasons of 2004 to investigate the seasonal and yearly variation pattern of the barley shoot fly population, manifested in terms of the degree of infestation. In *Ganna*, infestation was 7–14%, whereas in *Bona* the infestation was 52–100%, indicating that the pest is more favoured in the *Ganna* than the *Bona* season. This could be because there is nearly 5 months between the previous year's *Bona* and the following year's *Ganna*, when the host plant is totally absent from both *Ganna* and *Bona* (nearly 2 months). The bulk of barley is produced in the *Ganna* season. This, together with the fact that farmers grow a local resistant cultivar ('Aruso'), is probably one of the reasons why barley shoot fly is less recognized by farmers and experts compared with other insect, disease and weed pests.

MECHANISMS OF BARLEY RESISTANCE TO *D. FLAVIBASIS*

Ovipositional antixenosis

The ovipositional antixenosis in the resistance of barley to the barley shoot fly was ascertained based on the average number of eggs per plant. The average number of eggs per plant ranged from 5.6 (for 'Aruso') to 11.3 (for HB 42) (Table 2). There were no significant differences among the resistant genotypes, but the susceptible genotype had a significantly greater number of eggs per plant than all the resistant genotypes (Table 2). The fact that HB 42, compared with the resistant genotypes,

TABLE 2
Ovipositional preference of *Delia flavibasis* and tolerance of some barley accessions under field conditions

Accessions	Eggs per plant	Infestation	Deadhearts	Dead seedlings	Crop recovery (1–5)	Yield (g/plot)
PGRCE/E 1799	7.7 b	98	96	43.3 b	4.5 a	295.9 ab
PGRCE/E 4414	6.1 b	100	100	52.0 b	3.8 a	245.7 b
PGRCE/E 4409	5.9 b	96	93	55.8 b	4.0 a	296.3 ab
PGRCE/E 4282	6.8 b	97	98	62.0 b	4.3 a	272.1 ab
Arusso	5.6 b	99	99	44.8 b	4.5 a	315.0 a
HB 42	11.3 a	100	100	170 a	1.0 b	49.0 c
SE	0.7	1.1	2.0	7.8	0.4	12.9
LSD ($P<0.01$)"	2.8	NS	NS	32.3	1.5	53.6

NOTES: NS = not significant. Values in a column followed by same letter are not significantly different at $P<0.05$.

had the highest number of eggs per plant is apparently due to higher preference by barley shoot fly for oviposition, which shows that antixenosis is a component of resistance in barley against barley shoot fly (Tafa Jobie, Tadesse Gebremedhin and Sakhuja, 2004.; SARC, 2005).

Tolerance

The tolerance mechanism of resistance in barley genotypes against barley shoot fly was assessed based on number of dead seedlings due to infestation, crop recovery growth following infestation, and grain yield. In spite of the heavy infestation, the resistant genotypes gave a significantly higher yield relative to the susceptible check (Table 2). The number of dead seedlings following infestation peaked for HB 42. There were 170 dead seedlings per plot of HB 42, in contrast to 43–62 for the resistant genotypes (Table 2). The difference was statistically significant between HB 42 and the resistant genotypes, but was not significant among the resistant genotypes. For visual crop recovery growth following infestation, there was no significant variation among the resistant genotypes, but HB 42 had significantly lower recovery growth compared with the resistant genotypes (Table 2). The remarkable differences between HB 42 and the resistant genotypes for the number of dead seedlings, crop recovery growth and yield suggest that HB 42 is less tolerant compared with resistant genotypes when exposed to nearly equal levels of barley shoot fly infestation in the field. This confirms that the resistance of barley genotypes to barley shoot fly is mainly due to tolerance. A tolerance mechanism of resistance was also reported in a previous study (Tafa Jobie, 2003).

MANAGEMENT OF *D. FLAVIBASIS*

Sources of resistance

Many Ethiopian barley landraces have been reported to possess relative resistance to *D. flavibasis* (SARC, 2001; Tafa Jobie, 2003). Exotic genotypes and malt barley are, in contrast, highly susceptible to the pest. A number of improved barley varieties, including HB 42, Ardu-10-60B, ‘Shege’, ‘Beka’, ‘Holker’ and HB 120, that were released in the past for the Arsi and Bale areas (Hailu Gebere, 1997) were tested for their response to barley shoot fly infestation at SARC, and were found to be highly susceptible, with infestations of 85–100% (Amare Andargie, 1993; Tesfaye Getachew, Mulugeta Amsalu and Kassahun Tesfaye, 1997) (Table 3). As a result, the breeding and host plant screening strategy was shifted from working with exotic germplasm to the utilization of indigenous germplasm, particularly local landrace collections from Bale. Between 1994 and 2006, almost 6000 Ethiopian barley landraces were screened at Sinana for their resistance to *D. flavibasis*, and many relatively resistant genotypes were promoted to yield trials for the release of improved varieties. Improved varieties currently released from SARC include ‘Harbu’, ‘Dinsho’, ‘Dafo’ and ‘Biftu’, and are the results of this screening effort. Other examples of resistance sources are accessions PGRCE/E 1799, PGRCE/E 4414, PGRCE/E 4409 and PGRCE/E 4282, which were used for the study of resistance mechanisms (Tafa Jobie, 2003). Hence, host resistance is one of the principal components in integrated barley shoot fly management practices.

TABLE 3
Response of some nationally released barley varieties to shoot fly infestation at Sinana Agricultural Research Centre

Genotype	Days to maturity	Plant height (cm)	Infestation (%)	Grain yield (t/ha)	
				F0	F1
HB 42	160	97	95	2.00	2.80
Ardu-12-60B	155	105	95	1.90	1.80
HB 120	154	108	93	1.50	1.60
HB 100	157	97	94	2.00	2.20
Shegie	154	98	87	1.90	2.40
Beka	151	104	87	1.30	2.20
Holker	151	102	91	1.90	1.80
Arusso	128	98	25	1.80	1.70

NOTES: F0 = without fertilizer; F1 = with fertilizer. SOURCE: Tesfaye Getachew, Mulugeta Amsalu and Kassahun Tesfaye, 1997.

Chemical control

An insecticide trial conducted at SARC with imidacloprid (Gaucho), tubuconazole (Gaucho Raxil), thiamethoxam (Apronstar) and heterahabditis (Cruiser) showed that heterahabditis (at 50, 75 and 100), thiamethoxam (at 250 and 375) and imidacloprid at 250 g per 100 kg seed were effective as seed dressing against *D. flavibasis* (SARC, 2001). Imidacloprid reduced infestation and also resulted in excellent control of barley shoot fly.

Sowing date

The effect of sowing date on infestation by barley shoot fly, *D. flavibasis* Stein, was investigated in 2001, 2002 and 2003 in the *Bona* season at Sinana. Four sowing dates, using two barley genotypes (‘Aruso’ and ‘Holker’), were evaluated for their effect on infestation and yield. Infestation varied significantly among years, with the heaviest level recorded in 2003. Infestation was significantly higher in the improved variety (‘Holker’) than in the farmer variety (‘Aruso’). Significant differences were observed among the four sowing dates for two infestation scores and grain yield (Table 4). ‘Aruso’ gave a lower yield in the early sowing dates of 2001 and 2003, but had higher yields than ‘Holker’ in 2002, when there was severe

TABLE 4
Effect of sowing dates on infestation level of *D. flavibasis*

Sowing date	Percentage infestation						Yield (kg/ha)		
	2001-I$^{(1)}$	2001-II$^{(2)}$	2002-I$^{(1)}$	2002-II$^{(2)}$	2003-I$^{(1)}$	2003-II$^{(2)}$	2001	2002	2003
1st	24 b	49 b	24 b	25 b	35 b	38 c	4090 ab	2313 ab	3401 a
2nd	37 ab	33 b	21 b	16 b	49 b	60 b	4146 a	2431 a	2841 a
3rd	48 ab	45 b	74 a	71 a	96 a	91a	3305 ab	1881 ab	1752 b
4th	52 a	86 a	54 ab	78 a	92 a	97 a	2468 b	1637 b	1256 b
LSD (*P*<0.01)"	26.54	29.45	43.57	14.90	17.07	18.58	1638	782.70	1072
SE	4.46	4.95	7.32	2.50	2.87	3.12	275.19	131.47	180.12

NOTES: Means in a column followed by the same letter are not significantly different. (1) = scored 14 days after emergence; (2) = scored 21 days after emergence. SE = Standard error of the means.

low-moisture stress. It was also relatively more stable in yield over years and sowing dates. Yield of both the varieties was negatively correlated with infestation. Generally, early sowing significantly minimized infestation and resulted in higher yields than late sowing. Hence, early sowing, extending from late July to early August, and planting the resistant local cultivar ('Aruso'), could be recommended as potential components of an integrated barley shoot fly management programme for the Bale highlands.

INTEGRATED MANAGEMENT OF *D. FLAVIBASIS*

Integrated management of *D. flavibasis* was studied in three locations (Sinana on-farm, Agarfa and Gasara) in 2004–2005 to study the best integration option of seed dressing chemical, variety and sowing date. The results suggested that proper combination of early sowing, resistant varieties (such as 'Aruso') and lower rates of chemicals (half the recommended rate) could be used to reduce barley shoot fly infestation and increase yield to an appreciable level. The study showed that even resistant varieties and early sowing alone can be used to significantly reduce infestation and to attain reasonable yields.

REVIEW OF RESEARCH FINDINGS ON *DELIA ARAMBOURGI* (DIPTERA: ANTHOMYIIDAE)

Sources of resistance to *Delia arambourgi*

At Holetta between 1986 and 1995, 2200 barley lines developed from landrace accessions were evaluated for their resistance to barley shoot fly, *Delia arambourgi* Seguy. The entries were evaluated based on the percentage of deadhearts. The results showed that all the lines were susceptible to barley shoot fly. Nevertheless, 38 lines with relatively lower infestation levels were selected for further screening (HARC, 1987, 1988, 1991, 1992, 1996).

Of the 20 lines in advanced testing in 1994 and 1995, the lowest infestation was recorded with 1806-11, but this genotype gave the lowest grain yield. In contrast, of the lines that survived higher infestations in both seasons, 3321-17 gave a consistently higher yield in both treated and untreated cases. When genotypes were evaluated dressed with insecticide, the infestation level on all lines was significantly

TABLE 5

Reaction of barley lines to barley shoot fly (*Delia arambourgi* Seguy) infestation in the advanced stage trial at Holetta in the 1994 crop season

Genotype	Log transformed						Yield (q/ha)	
	MDHC		MLHC		DHE			
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
1667-01	1.6	0.2	1.5	1.9	71.0	68.0	12.71	12.38
1721-19	1.6	0.1	1.5	1.9	74.3	65.7	12.96	18
3285-08	1.7	0.3	1.4	2.0	73.3	66.3	7.38	11.5
3285-11	1.6	0.0	1.4	2.0	87.7	73.3	7.71	15.25
3305-17	1.6	0.3	1.3	1.9	96.7	83.7	6.42	14.08
3357-06	1.6	0.1	1.4	2.0	75.0	68.3	6.08	16.67
3476-09	1.6	0.2	1.4	1.9	74.7	65.0	12.71	13.79
1694-05	1.6	0.3	1.5	1.9	73.0	66.3	11.13	13.50
1694-13	1.7	0.3	1.4	1.9	75.7	67.7	8.54	8.54
1806-04	1.6	0.5	1.3	2.0	77.0	65.0	10.25	12.71
1806-06	1.6	0.3	1.4	2.1	85.0	74.0	8.46	12.17
1806-07	1.6	0.2	1.5	2.1	85.0	75.0	13.00	12.67
1806-11	1.5	0.1	1.4	2.0	73.0	66	8.33	12.25
1806-14	1.7	0.2	1.3	2.0	79.3	69.7	12.38	17.29
3321-17	1.6	0.2	1.6	1.9	71.0	63.3	16.71	17.83
3353-16	1.6	0.2	1.5	2.0	78.7	73.3	9.17	14.13
3520-02	1.5	0.3	1.4	1.9	76.0	66.3	7.25	12.63
3520-04	1.7	0.4	1.4	2.0	78.3	69.7	10.17	14.04
3520-10	1.6	0.2	1.5	2.0	72.3	67.0	13.13	14.58
3520-13	1.6	0.2	1.4	1.9	76.0	67.0	15.42	15.67
3520-16	1.7	0.3	1.5	2.0	75.3	69.7	8.96	12.33
3305-03	1.6	0.1	1.3	2.0	79.3	63.7	10.42	15.25
CV (%)	3.92	61.17	5.67	2.33	5.48	6.02	31.64	19.49
LSD ($P<0.05$)"	0.10	0.22	0.13	0.07	7.00	6.83	5.43	4.49

NOTES: MDHC = mean deadheart count; MLHC = mean live heart count; DHE = days to head emergence.

lowered (Tables 5 and 6). Of the 18 lines evaluated in 1995, 3232-07 and 3232-16 sustained lower damage and gave better yields than most other lines (Table 7).

In general, all the selected genotypes showed early seedling vigour, which might have contributed to the reduced barley shoot fly damage. However, earliness was found to be linked with low yield. For instance, line 3284-14 headed earlier (in 66 days) than all the other genotypes but gave relatively lower yields (738 kg/ha) (Table 7). Therefore, improving the yield potential of barley with the inherent characteristic of early seedling vigour might help to overcome the barley shoot fly damage.

Chemical control of *Delia arambourgi* with seed dressing insecticides

The untreated check was significantly more infested by barley shoot fly compared with the other treatments. Similarly, the pest pressure was higher on diazinon-TMTD-treated plots. The best barley shoot fly control was attained by the use of aldrin, the standard insecticide. However, the differences in the mean percentage damage were not statistically significant between the standard seed dressing

TABLE 6

Reaction of barley landrace lines to barley shoot fly (*Delia arambourg*i Seguy) in aldrin-treated and -untreated cases at Holetta in the 1995 crop season.

Accession	Seedling damage (%)		Heading date		Plant height (cm)		Yield (g/plot)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
1806-07	28	13	79	74	72	77	137	156
1806-04	28	19	77	75	73	77	79	121
1694-05	28	15	76	72	77	78	124	136
1694-13	29	15	70	67	79	78	152	150
1806-14	29	16	80	77	66	69	65	100
1721-19	29	19	73	69	73	77	151	180
1806-06	30	15	77	74	68	77	125	157
1806-11	30	16	89	87	72	74	47	75
3520-13	31	23	73	71	63	67	130	167
3321-17	32	20	72	69	82	88	171	188
3520-02	32	17	73	69	74	74	114	126
3520-10	32	19	82	76	59	65	89	137
3285-08	32	21	86	86	70	77	100	126
3520-16	33	15	73	69	73	77	97	141
3520-04	34	22	71	73	72	77	90	131
3357-06	34	21	75	71	68	72	53	94
3476-09	35	21	79	76	69	79	73	159
3353-16	35	21	77	73	77	87	102	177
3285-11	36	18	76	70	74	77	116	165
3305-17	36	19	83	80	69	78	57	93
Mean	32	18	77	74	71	76	104	139
CV (%)	13.9		1.8		5.3		16.9	
LSD (P<0.05)"	5.7		2.3		6.5		33.9	

TABLE 7

Reaction of barley landraces to barley shoot fly (*Delia arambourgi* Seguy) damage at Holetta in the 1995 crop season

Accession	MDHC	MLHC	DHE	Yield (q/ha)
2332-17	20.3	20.6	86	12.13
1622-13	20.0	27.0	91	21.63
3232-15	20.0	24.0	86	20.38
3371-01	20.0	27.6	70	9.00
3284-14	19.6	47.6	66	7.38
50-08	19.3	15.0	104	10.00
3284-02	19.3	24.3	72	9.50
3284-18	19.3	30.0	66	10.38
3284-15	19.0	28.0	71	14.38
3371-18	18.6	22.0	72	7.38
3371-17	18.6	30.0	72	7.75
3284-11	18.0	32.0	66	8.88
3284-06	17.3	19.3	71	7.38
1621-14	17.0	21.3	76	4.63
3232-07	17.0	21.6	90	20.00
3232-16	16.3	22.3	97	20.25
3284-04	15.0	26.3	71	13.88
3284-08	10.3	23.3	70	12.50

NOTES: MDHC = mean deadheart count; MLHC = mean live heart count; DHE = days to head emergence.

insecticide (aldrin)-treated plots and imidacloprid 70% WS and furathiocarb 400 CS-treated plots (Table 8). The grain yield obtained was not significantly different among the plots treated with aldrin and those treated with imidacloprid 70% WS and furathiocarb 400 CS (Table 8). Diazinon-TMTD caused phytotoxicity on the barley seedlings. The insecticide component in diazinon-TMTD is low (15% by weight), and in order to obtain 65 g a.i. to treat 100 kg of seed, 433 g product was needed. This might have been the cause for the observed seedling toxicity (HARC, 1999a). On-farm evaluation of imidacloprid and furathiocarb did not give a significant advantage over the control, despite the difference in the level of seedling damage sustained (HARC, 1999b).

TABLE 8

Effect of some seed-dressing insecticides on infestation of barley shoot fly (*Delia arambourgi* Seguy) and grain yield at Holetta

Treatment	Rate (g a.i. per 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	Untreated	77.15	94.18	88.80	30.15
CV (%)		25.96	5.73	31.64	17.87
LSD ($P<0.05$)"		10.35	3.397	21.2	13.91

NOTES: D-I = 15 days after emergence; D-II = 1 week after the D-I; D-III = 2 weeks after D-I.

INTEGRATED MANAGEMENT OF *D. ARAMBOURGI*

Manipulation of fertilizer, seed rate, sowing date and the use of seed-dressing insecticides were found to be promising in the management of *D. arambourgi*. The combined effect of these factors was studied for two years at Holetta. In the first year (1998), seedling damage due to barley shoot fly was significantly affected by the combined effect of fertilizer and insecticide ($P<0.0001$), whereas in the second year (1999) the combined effect of the two factors was found to be only marginally significant ($P<0.04$) (HARC, 1999c). However, as individual factors, both significantly affected seedling damage ($P<0.0001$) (Tables 9 and 10).

TABLE 9

Main and interaction effects of different barley shoot fly management methods on different parameters measured in 1998

Responses	Sources of variation						
	F	I	S	F×I	F×S	I×S	F×I×S
Seedling damage on D-I	NS	NS	**	NS	NS	*	NS
Seedling damage on D-II	***	***	NS	***	**	NS	NS
Seedling damage on D-III	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	***	***	***	***	***	***	***
1000-grain weight	NS	NS	NS	NS	NS	NS	NS

NOTES: F = Fertilizer; I = Insecticide; S = Seed rate; D-I = 15 days after emergence; D-II = 1 week after D-I; D-III = 2 weeks after D-I; *, ** & *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively; NS = not significant.

TABLE 10

Main and interaction effects of different barley shoot fly management methods on different parameters measured in 1999

Responses	Sources of variation						
	F	I	S	F×I	F×S	I×S	F×I×S
Seedling damage on D-I	NS	***	NS	NS	NS	NS	NS
Seedling damage on D-II	***	***	NS	*	**	NS	NS
Seedling damage on D-III	*	***	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
1000-grain weight	NS	NS	***	NS	*	*	NS

NOTES: F = Fertilizer; I = Insecticide; S = Seed rate; D-I = 15 days after emergence; D-II = 1 week after D-I; D-III = 2 weeks after D-I; *, ** & *** = Significant at 0.05, 0.01 and 0.001 probability levels, respectively; NS = not significant.

In 1998, days to heading and grain yield were significantly influenced by the combined effect of the three factors. The highest rates of insecticide and seed combined with the highest rate of fertilizer gave significantly higher yields than without fertilizer application ($P<0.0013$). These results did not repeat themselves in 1999. The effect of 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.

GAPS, CHALLENGES AND FUTURE RESEARCH DIRECTIONS

- The species composition and distribution of shoot fly on barley has not been given due attention. The recent identification of the shoot fly species in the Bale highlands is a very good addition to the knowledge of species composition of shoot fly in barley. However, comprehensive knowledge of shoot fly species composition remains a challenge.
- Developing varieties that are resistant to barley shoot fly is still a challenge and needs to be addressed.
- Obtaining alternative and affordable seed dressing insecticide is still difficult.
- Not enough research has been carried out on cultural, biological and physical control methods of barley shoot fly. Due to this, the development of an integrated control method has never been achieved.
- In the high- and mid-altitude areas of Bale, barley improvement was totally constrained by the high pressure of barley shootfly, *D. flavibasis*. Until recently, there were no improved barley varieties in the hands of farmers. Hence, farmers have been growing low-yielding local cultivars such as ‘Aruso’, Burtuji, Balticha and Senefkolo. Although some resistant food barley varieties have been released recently, the improvement of malt barley adaptable to this agro-ecology remains a great challenge.

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Biology and population dynamics of *Delia flavibasis* Stein (Diptera: Anthomyiidae) in Bale, Ethiopia

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Barley (*Hordeum vulgare* L.) is the most important staple food crop in Ethiopia. In Bale, southeast Ethiopia, it is grown during two equally important seasons that are locally called *Bona* (August to December) and *Ganna* (March to July). Barley production covers an area of 48 000 ha, which is 19% of the agronomic land in the region, ranking second after wheat (*Triticum aestivum* L.) (CSA, 2002). The actual yield of barley under subsistence farming conditions, however, is only 1.4 t/ha (CSA, 2002). Such low yields are attributed to a multitude of abiotic and biotic factors, including the damage caused by various insect pests. Barley shoot fly (*Delia* spp.) is one of the most important insect pests of barley that has been recorded in Ethiopia (Davidson, 1969; Tafa Jobie, 2003; Tafa Jobie, Tadesse Gebremedhin and Sakhuja, 2004).

Two barley shoot fly species, *Delia arambourgi* Seguy (Davidson, 1969) and *D. flavibasis* Stein (Tafa Jobie, 2003), are known to occur in Ethiopia, resulting in considerable yield losses. Both species belong to the order Diptera and family Anthomyiidae. *D. flavibasis* has only recently been reported to occur in Ethiopia (Tafa Jobie, Tadesse Gebremedhin and Sakhuja, 2004) and it has been shown to be a major pest of barley in both Ethiopia and Kenya (Macharia and Mueke, 1986; Tafa Jobie, 2003). It causes significant yield loss and is becoming an important constraint in barley-growing districts of the Bale highlands of Ethiopia, where all the improved varieties are highly susceptible to the pest (Amare Andargie, 1993; Tafa Jobie, Tadesse Gebremedhin and Sakhuja, 2004). Infestation levels of barley shoot fly in the Bale highlands frequently reach 100% on susceptible varieties such as HB 42, Ardu-10-9-60B, 'Shege', 'Beka', 'Holker' and HB 120; the Bale highlands have become a hot spot for this pest (Amare Andargie, 1993; Tafa Jobie, 2003). Because of its devastating effects, especially on improved and exotic germplasm of malt barley, the pest is considered to be a major constraint to barley cultivation. At the Sinana Agricultural Research Centre (SARC), heavy infestation usually results in the failure of several trials, particularly those with malt barley and exotic genotypes (SARC, 2004). In contrast, farmers who grow the local barley cultivar, 'Aruso', often experience low infestation of barley shoot fly in their barley fields, perhaps because the variety has co-existed with the pest for many years.

Studies have been conducted regarding the management of barley shoot fly, including cultural control, host plant resistance and chemical control (Thewodros Mesfin, 1982; Hussien, Melde and Wetzel, 1993; Berhane Lakew, Hailu Gebere and Fekadu Alemayehu, 1996; SARC, 2004). However, the contribution of these research efforts to minimize the ill effects of barley shoot fly has been very small. This is mainly due to lack of information on the biology of the pest, such as life cycle, nature of attack, and over-seasoning or diapausing, which form the basis for a sound pest management strategy. In addition, determination of the peak activity periods of *D. flavibasis* will help to obtain the maximum barley shoot fly pressure for host plant screening purposes. Furthermore, knowledge of the population incidence and abundance pattern of the pest will provide concrete information to aid in management of the pest through the adjustment of planting dates. This paper reviews the results of studies made on the fecundity, phenology and population dynamics of *D. flavibasis*.

MATERIALS AND METHODS

Biology of *D. flavibasis*

Fecundity

The fecundity of *D. flavibasis* was studied on a susceptible barley variety, 'Holker', and on two relatively resistant varieties, 'Dinsho' and 'Harbu' (SARC, 2004). Barley seedlings with deadhearts as a result of *D. flavibasis* infestation were collected from the field and kept in cages in the laboratory until the emergence of adult flies. A pair (male and female) of newly emerged flies, 24-hours old, were released into individual cages (30 × 20 × 20 cm). Newly emerged seedlings (1 week after sowing) (five seedlings per cage) growth stage 1.1 (first leaf unfolded) (Zadoks, Chang and Konzak, 1974) were assessed for oviposition. A completely randomized block design with five replications was used in the experiment. The cage had a plastic cover with plastic mesh in the middle to allow air circulation. Adults were provided with a diet prepared from glucose, brewer's yeast and distilled water at a ratio of 4:7:10, respectively (Kasana and Ali Niazee, 1994). Cages were examined twice a day to determine the pre-oviposition period, number of eggs per female and total reproductive period. Data on days to oviposition, total number of eggs per day and total reproductive period were recorded. Eggs were removed at each time of data collection.

Phenology

Egg stage

The developmental period of *D. flavibasis* was studied on the same cultivars as described above. For this study, eggs that had been freshly laid (less than 24-hours old) were collected from the field and transferred to individual seedlings in pots

(25 cm diameter) in the laboratory. A completely randomized block design with four replications was used. Twelve seedlings of each of the three varieties were raised in each pot and thinned to ten before egg inoculation. Each seedling was inoculated with two eggs of *D. flavibasis* by placing them at the base of each plant at the 1.1-growth stage (Zadoks, Chang and Konzak, 1974). This was performed using a sterile camel hairbrush (Delobel and Unnitahn, 1983; Ortega *et al.*, 1980). Fluorescent lamps were hung above the rearing pots and artificial light was supplemented to 12 hours per day during the experimental period in the laboratory. The same experiment was repeated under field conditions. A total of 80 eggs were used for each variety, both in the laboratory and in the field. In the field, the pots were housed in a screen cage (41 × 50 × 60 cm) made of a wooden frame covered with a white muslin cloth to protect from oviposition by extraneous adult flies. Seedlings were examined four times at 4-hour intervals per day to observe egg hatching. Data on the number of hours required for hatching were recorded.

Larval stage

After egg hatching, the duration of larval development was assessed on the three barley varieties in the pot experiment. A total of 56 and 52 larvae on each variety were used for the laboratory and field experiments, respectively. Observations were made four times daily until pre-pupation commenced and the number of days taken were recorded.

Pupal stage

To determine pre-pupal (last larval instar becomes inactive, stops feeding and detaches from the seedling and buries itself in the soil) and pupal developmental time, seedlings of the three barley varieties with deadhearts having a last larval instar were carefully uprooted and placed in moistened soil in a 14-cm diameter Petri dish and kept at room temperature in the laboratory (and in the screen cage in the field experiment). The purpose of adding soil to the Petri dishes was to provide the pupae with suitable conditions similar to their natural habitat (Bullock, 1965). A completely randomized block design with four replications was used. Observations were made on 48 and 40 pupae collected from each variety both in the laboratory and in the field, respectively. Each Petri dish was examined four times per day at 4-hour intervals. Records were taken on pre-pupal and pupal developmental time and pupal weight. Pupae were weighed using a WA 80 analytical electronic balance having a sensitivity of 80/0.0001 g. All pupae were weighed and carefully returned to the respective Petri dishes in the soil to determine adult emergence.

Adult stage

To determine the adult emergence period, pupae were collected from each Petri dish of each variety and kept in rearing cages (30 × 20 × 20 cm). A completely randomized block design with four replications was used. Observations were made on 36 and 28 flies on each variety both in the laboratory and in the field, respectively. Each cage was examined four times at 4-hour intervals per day until adult flies emerged. Just after emergence, adults were carefully sucked up using a siphon trap and were placed in another cage. The flies were provided with an artificial diet. Data were recorded on adult emergence and the longevity period of adult flies.

Sex ratio, wing span and body length

Deadhearts of the susceptible variety, 'Holker', were collected from the field and allowed to develop to adult stage. A total of 102 flies were used to determine the sex ratio, and 50 flies were used to determine wingspan (from the bottom tip of one wing to the bottom tip of the opposite wing) and body length (from the anterior region of the head to the posterior region of the abdomen).

Population dynamics of *Delia flavibasis*

The population incidence, abundance (density) and peak activity of *D. flavibasis* at different planting dates were tested during the experimental season (August to October, 2005). A staggered planting date (eight sequential plantings at weekly intervals) was used. The design used was a completely randomized block design with four replications. Three barley varieties (two, 'Dinsho' and 'Harbu', resistant and one susceptible, 'Holker') were sown on a plot size of 2 × 6 m with a row spacing of 0.2 m (ten rows per plot) and an inter-plot and inter-block distance of 2 m. The seed rate was 100 kg/ha, with fertilizer at 23/46 kg/ha N/P_2O_5. Data recorded per plot were number of infested plants, deadhearts, number of eggs per seedling and adult catches per sweeping net. Infestation and deadhearts were scored by counting seedlings showing damage symptoms from a total of 50 plants within a 1 m^2 quadrat 8 and 16 days after seedling emergence, respectively. Eggs were counted on 20 randomly sampled plants 8 days after sowing. Infestation was considered to be a range of symptoms, from mild and early leaf mining to deadhearts. Subsequently, data on deadhearts were recorded. Deadhearts referred to seedlings attacked by *D. flavibasis*, the central shoots of which had already dried or showed wilting (Tafa Jobie, 2003). Adult catches were carried out daily in the morning (09:30) from barley seedlings of a 30-m row length using sweeping nets, starting from seedling emergence until the crop reached growth stage 3.2 (Zadoks, Chang and Konzak, 1974). The average weekly catch of adult flies per sweeping net was collected and recorded.

Statistical analysis

Data collected on the growth and development parameters were analysed using a general linear model (PROC GLM; SAS Institute, 1999–2000). Egg counts were transformed to square root ($\sqrt{X + 0.5}$) before analysis to stabilize the variance. Whenever the F-test was found to be significant, least significant difference (LSD) was used for mean separation. The data were reported in the text and/or figures using the back-transformed values. Whenever the F-test statistics were significant, LSD was used for mean separation and comparison.

RESULTS

Biology of *D. flavibasis*

Fecundity

The eggs of *D. flavibasis* are white and elongate-ovoid in shape, resembling grains of rice. They have longitudinal ridges or strips when looked at under a microscope. As observed in the laboratory and in the field, eggs may be found to be laid singly or in groups. There were significant differences ($P<0.05$) in number of eggs oviposited between the barley varieties (Table 1). The highest number of eggs (17.9) were laid on the susceptible variety, 'Holker', and the least on 'Harbu' (12.3) and 'Dinsho' (11.5). However, no significant differences were observed between varieties in pre-ovipostion and total reproductive periods.

TABLE 1

Mean (±SE) number of eggs, pre-oviposition period and total reproductive period of *Delia flavibasis* in three barley varieties

Variety	No. of eggs per female	Pre-oviposition period (days)	Total reproductive period (days)
Dinsho	11.50 ± 2.33 b	3.53 ± 0.24	5.03 ± 0.20
Harbu	12.33 ± 2.78 b	3.50 ± 0.22	5.02 ± 0.24
Holker	17.90 ± 2.62 a	3.50 ± 0.31	5.35 ± 0.22
LSD	4.42	NS	NS

NOTES: Means in a column followed by the same letter are not significantly different at $P<0.05$. NS = not significant.

Phenology of *D. flavibasis*

Egg stage

A significant difference ($P<0.05$, DF=2, F value=5.79) was observed in the time needed for egg hatching between the varieties in the laboratory experiment (Table 2). There was a shorter interval from egg to larval stage on the variety 'Holker' than for 'Dinsho' and 'Harbu'.

Larval stage

The number of days required for the development of larvae significantly ($P<0.05$, DF=2, F value=12.18) varied between the varieties (Table 2). Larvae were quicker to enter the pre-pupal stage on the susceptible variety compared with the resistant varieties, under both laboratory and field conditions.

TABLE 2

Developmental time of *Delia flavibasis* and adult longevity on the three barley varieties (Mean ± SE) in the laboratory and field

Variety	Egg hatching (hr)	Development time in days				Pupal weight	Adult longevity
		Larval	Pre-pupal	Pupal	Total		
			Laboratory experiment				
Dinsho	74.45±4.12 a	13.14±1.81 a	1.68± 0.21 b	13.81±1.52 a	40.54± 4.01 a	3.20±0.31	8.61±2.01
Harbu	77.59 ±6.04 a	12.60±1.52 a	1.61±0.32 b	13.58±1.81 a	39.56±3.42 a	3.15±0.29	8.54±1.80
Holker	68.40±3.01 b	11.35±1.05 b	2.26±0.55 a	11.94±1.03 b	36.81±2.81 b	3.48±0.34	8.90±2.30
LSD	6.72	0.91	0.30	0.56	2.06	NS	NS
			Field experiment				
Dinsho	72.43±3.52	13.24±1.04 a	1.65±0.30	13.99±2.03 a	39.67±3.32 a	3.06±0.42	7.37±1.48
Harbu	75.81±5.21	13.20±1.92 a	1.79±0.41	13.60±1.82 a	39.62±3.04 a	3.20±0.23	7.54±1.50
Holker	77.74±5.00	12.35±0.42 b	1.82 ±0.34	11.50±0.81 b	36.21±2.40 b	3.50±0.27	8.10±2.00
LSD	NS	0.74	NS	0.63	2.83	NS	NS

NOTES: Means in a column followed by the same letter are not significantly different at $P<0.05$. NS = not significant.

Pupal stage

The number of days required for pre-pupal and pupal stages on 'Holker' was greater (2.26 days) than on 'Harbu' and 'Dinsho' under laboratory conditions (Table 2). However, in the field, significantly fewer days were required for the pupal stage on 'Holker' than on 'Harbu' and 'Dinsho'. There were no differences between varieties in pupal weight under both laboratory and field conditions. The newly formed pupa is light brown in colour and slowly changes to dark brown with age. Pupation took place in the soil within a depth of 1–3 cm among the roots. This is similar to *D. arambourgi* (Bullock, 1965). Observations under field conditions showed that, in rare cases, pupation also took place inside the basal stalk of barley seedlings. In the present study, no evidence of diapause was obtained; all larvae and pupae that were reared in the laboratory completed their cycle rapidly without interruption, indicating that *D. flavibasis* did not diapause in immature stages. Previous observations also revealed that barley planted on the experimental plots was attacked at all times of the year, including during the off-seasons (SARC, 2004).

Adult stage

Adult emergence and longevity were not affected by varieties under both laboratory and field conditions (Table 2). However, adult emergence and longevity took 7–9 days. The total developmental period (from egg to adult emergence) was significantly ($P<0.05$, DF=2, F value=14.43) shorter on the susceptible variety compared with the resistant varieties, under both laboratory and field conditions.

Sex ratio, wingspan and body length

The male to female sex ratio was 1:1.1 (n = 102; 54 females and 48 males). Fully expanded wingspan of male flies was 9.40 mm, while that of the female was 9.68 mm (Table 3). Body length of male and female flies were 5.5 mm and 5.6 mm, respectively. Male and female flies can easily be identified based on their abdominal apex. The female has a cone shaped (pointed) abdominal apex while the male has a cylindrical shaped (rounded) abdominal apex.

TABLE 3
Mean wing span and body length (mm) (Mean ± SD) of adult *Delia flavibasis*

	Male	Female	Number of flies sampled
Body length	5.51±0.61	5.63±0.60	50
Wing span	9.40±0.90	9.68±0.70	50

Fly activity

Adult *D. flavibasis* are most active during late morning (09:30–10:30) and late afternoon (16:00–17:00). Adult flies are usually found on newly ploughed moist soil and newly emerging seedlings during these periods. Preliminary observation made during the field study revealed that most of the adults trapped from barley seedlings and from newly ploughed lands are females. The females visit these areas probably to lay their eggs on barley seedlings.

The present study demonstrated the effect of barley varieties on the fecundity and phenology of *D. flavibasis*. The susceptible variety, 'Holker', is the variety that is preferred for oviposition above 'Dinsho' and 'Harbu'. This may indicate that the resistant varieties used for the study were not preferred by *D. flavibasis* for oviposition and that the fly oviposited much less than it could do on ideally suitable varieties. Tafa Jobie (2003) reported a similar trend in the egg hatching time of *D. flavibasis* on different barley varieties that had been inoculated with eggs of *D. flavibasis* under laboratory conditions. He found significant differences between the susceptible (60 hours) and resistant (78 hours) barley varieties for the time required for egg hatching. Previous studies conducted on *D. arambourgi* (Bullock, 1965) and on *D. platura* (Hill, 1987) indicated that the time taken for egg hatching was 72–96 hours. The eggs are laid in the soil close to the collar region of the seedlings. They may also be found (rarely) sticking to the seedlings. This finding is also in agreement with Bullock (1965), who studied the pattern of oviposition on *D. arambourgi*. Occasionally, *D. flavibasis* may oviposit on the undersurface of older leaves. Under normal conditions, young barley seedlings (2–3 leaf stage) are the most preferred for oviposition. However, oviposition can occur on the tillers of older plants and their leaves. On susceptible varieties, which are recurrently infested, oviposition lasts for a longer period.

Generally, fewer eggs were laid by *D. flavibasis* compared with 100 eggs per female by *D. radicum* (Hill, 1987) and about 238 eggs per female by *Atherigona soccata* (Sileshi Gudeta, 1994). This may show the differences in oviposition potential among the dipteran species. Diet is also a relevant factor that results in variation in total ovipostion. According to Jones *et al.* (1992), lack of protein at the adult stage is an important constraint to the reproductive success of many muscoid dipterans. McDonald and Borden (1996) found that elimination of protein from the diet of female *D. antiqua* often resulted in reduced sexual attraction, reproductive competency and fecundity. The diet provided for the adult *D. flavibasis* in this experiment comprised glucose, brewer's yeast and distilled water at a ratio of 4:7:10.

For *D. flavibasis*, larvae infestation commences with a mine in the first or second leaf or both, and the larva makes its way down through the tissues to the growing point. The larva is positioned head-down within the seedlings. The attack results in death of the central shoot, producing a deadheart. Following deadheart formation, the larvae may quit the shoots and mine through the leaves of the seedlings. In the field, the mined leaves collapse at their weakened bases, lying flat on the soil surface. Similar observations were reported by Davidson (1969) on *D. arambourgi* at Holetta. In contrast, Bullock (1965) observed that this type of attack by *D. arambourgi* is only occasional in Kenya. The larvae of *D. arambourgi* bore directly into the central shoot after climbing above the first leaf sheath. Field observations revealed that most of the attacked seedlings had both the first and second leaves mined. It was observed that, occasionally, a seedling may host more than one larva and the larvae may quit a seedling and bore another seedling in the vicinity. Davidson (1969) reported similar observations for *D. arambourgi*. The variations in number of days required for the larval and pupal stages of *D. flavibasis* under both laboratory and field conditions between the susceptible and resistant varieties may be attributed to the existence of antibiosis in resistant varieties. Tafa Jobie (2003) reported an antibiosis mechanism of resistance to *D. flavibasis* in different barley lines, namely PGRCE/E 1799, PGRCE/E 4414, PGRCE/E 4409 and PGRCE/E 4282; and to a lesser degree in 'Aruso'.

Delia flavibasis causes serious damage to improved malt and food barley varieties in the highlands of Bale, southeast Ethiopia. To overcome this damage, research findings, which have focused on the fecundity and phenology of barley shoot fly, are of paramount importance, especially if combined with population dynamics studies and estimated lifetable parameters acting on the population. This would help greatly to plan a management strategy for *D. flavibasis*.

Population dynamics of *Delia flavibasis*

Results obtained from trap catches indicated the presence of a varying shoot fly population density throughout the study period (Figure 1). The shoot fly population was low until late August. From late August to mid-September the population reached its peak. The shoot fly population started to decline from late September onwards.

FIGURE 1
Mean number of adult shoot fly catches per sweeping net from the three varieties

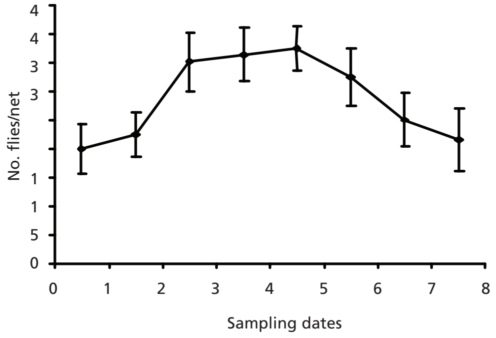
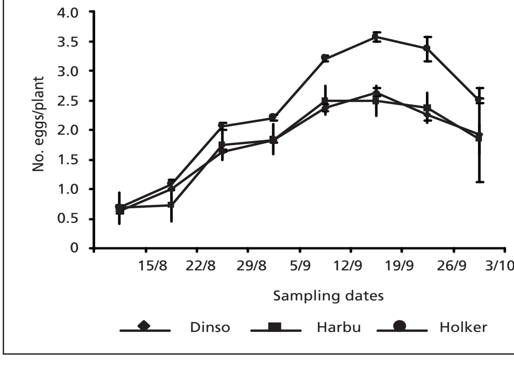


FIGURE 2
Number of eggs per seedling on the susceptible and resistant varieties



The number of eggs per plant did not exhibit significant variation between the three barley varieties for the first sowing date (Figure 2). Starting from the second sowing date, the number of eggs laid per plant steadily increased for all the test varieties. Significantly ($P<0.05$) lower numbers of eggs per seedling were laid on 'Harbu' than on 'Dinsho' and 'Holker'. However, the difference between 'Dinsho' and 'Holker' was not statistically significant for the number of eggs laid per plant during the second sowing date. The highest number of eggs per seedling was observed at the sixth sowing date for all the three varieties. Starting from the seventh sowing date, the number of eggs laid per seedling declined and non-significant variations were observed between varieties. In spite of the lower number of eggs laid per seedling compared with the previous sowing dates, a significantly ($P<0.05$) higher number of eggs was recorded on the susceptible variety, ‘Holker’, compared with the resistant varieties at the last sowing date. A higher number of eggs per seedling were laid on the susceptible variety, ‘Holker’, across all the sowing dates compared with the resistant varieties.

Shoot fly abundance, as measured by percentage infestation, exhibited significant variation between the resistant and susceptible varieties across all the sowing dates. The highest infestation percentage (100%) was recorded on the susceptible variety, ‘Holker’, from the third to the fifth sowing dates. On the resistant variety, ‘Harbu’, infestation percentage ranged from 45% for the last sowing date to 89% for the third sowing date. The percentage of infestation for ‘Dinsho’ ranged from 38% to 92% in the same order. For all sowing dates, the susceptible variety, ‘Holker’, was more infested than the resistant varieties. However, the resistant varieties were not significantly different from each other in terms of level of infestation. The resistant varieties, ‘Harbu’ and ‘Dinsho’, showed a reduction in infestation and deadheart formation at the second sowing date (Figure 3). In contrast, the percentage deadheart formation for these varieties showed a linear increment until the sixth sowing date. Starting from the sixth sowing dates and onwards, the percentage deadheart formation declined in a similar manner to percentage infestation for both the susceptible and resistant varieties (Figure 4). Deadheart formation was the least (22.5%) on ‘Harbu’ on the last sowing date and reached its peak (72%) on the third sowing date. Similarly, the lowest percentage deadheart formation (18%) was recorded on ‘Dinsho’ at the last sowing dates and the highest (71%) was recorded at the third sowing date.

The highest number of eggs per seedling were laid from late August through mid-September. The highest number of infestation and deadheart percentages were observed starting from early September to late September. In parallel with this, the highest number of flies trapped during the season were recorded in this period. The number of flies trapped affects the number of eggs laid per seedling, which determines the extent of infestation and deadheart formation.

FIGURE 3

Infestation level of barley varieties by *D. flavibasis* at different sowing dates

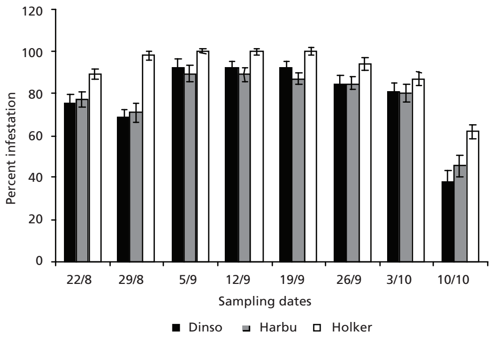


FIGURE 4

Mean number of deadhearts due to infestation by *D. flavibasis* in the three barley varieties at different sowing dates

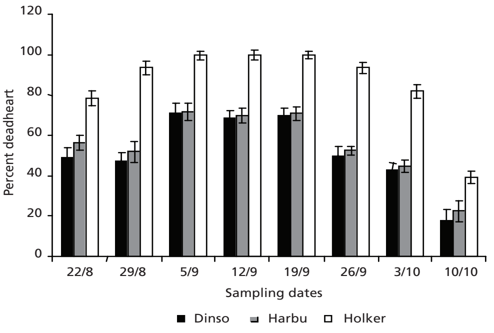


TABLE 4

Pearson correlation coefficient between relative humidity, *D. flavibasis* damage and population density during the 2005 cropping season

	Relative humidity	No. BSF/ sweep	Egg/ seedling	Deadhearts	Infestation
Relative humidity	1	0.901**	0.949**	0.985**	0.800**
No. BSF/sweep	0.901**	1	0.980**	0.983**	0.725**
Egg/seedling	0.949**	0.980**	1	0.993**	0.723*
Deadhearts	0.965**	0.983**	0.993**	1	0.770*
Infestation	0.800*	0.725*	0.723*	0.770*	1

NOTES: BSF = Barley shoot fly; * = Correlation is significant at 0.05 level; ** = Correlation is significant at 0.01 level.

Abundance and peak activity of *D. flavibasis*, expressed as percentage infestation, showed a significant ($P<0.05$) correlation (r=0.80) with relative humidity. A similar trend was observed between deadheart count and relative humidity ($P<0.01$; r=0.959). Barley shoot fly catches per sweeping net were highly correlated ($P<0.01$; r=0.977) with the number of eggs laid per seedling and with percentage deadheart count ($P<0.01$; r=0.985) and infestation ($P<0.05$; r=0.725). The two parameters (egg laying and deadheart count) that have been used to quantify the shoot fly incidence were highly significant and positively correlated ($P<0.01$; r=0.986) with each other. As can be expected, infestation percentage is significantly correlated with the percentage of deadhearts ($P<0.05$; r=0.743) (Table 4). The number of adult flies trapped per sweeping net was low during late September. However, the number of eggs laid per seedling reached its peak at this time of the season. During late September, the only barley seedling with the appropriate growth stage for oviposition by *D. flavibasis* was from the sixth sowing date; all the nearby barley seedlings had escaped damage caused by *D. flavibasis*.

The population dynamics study of *D. flavibasis*, as measured by the number of eggs laid on each variety, clearly and consistently showed preference/non-preference of barley shoot fly for oviposition on different varieties. Ovipositional non-preference (antixenosis) is the major component of resistance mechanism in sorghum against *A. soccata* (Singh and Jotwani, 1980; Sileshi Gudeta, 1994) and many other crops. Tafa Jobie, Tadesse Gebremedhin and Sakhuja (2004) reported that antixenosis is the major resistance mechanism in barley against *D. flavibasis*.

Significant variations in deadheart formation were observed between the resistant and susceptible barley varieties across all the sowing dates, indicating that the population of *D. flavibasis* may vary depending on the types of varieties (susceptible or resistant) in a particular region.

The positive correlation of percentage infestation and deadheart formation with relative humidity is probably due to the fact that the availability of humidity affects leaf surface wetness, which, in turn, may affect larval movement to the leaf base and, ultimately, deadheart formation (Raina, 1981; Nwanze *et al.*, 1992). Although significant effects of rainfall and median temperature on shoot fly population were not observed, there was a drastic decrease in the insect population, percentage infestation and deadheart formation starting from early October. This might, presumably, be due to unfavourable climatic factors (very low moisture and relative humidity), which are crucial for leaf surface wetness, as dryness reduces larval movement to the leaf base, resulting in less infestation and deadheart formation (Raina, 1981; Nwanze *et al.*, 1992; Taneja and Leuschner, 1985). Weekly catches of adult flies per sweeping net were highly correlated with relative humidity and availability of barley seedlings. Similar observations were reported on sorghum shoot fly, *A. soccata*, by Sileshi Gudeta (1994) in Ethiopia and by Ogwaro (1979) in Kenya, where fluctuations in numbers of adults were related to relative humidity. However, the abundance pattern of adult flies in this study did not correlate with temperature, which contrasted with the effect of mean temperature on sorghum shoot fly catches, as reported by Sileshi Gudeta (1994), and Delobel and Unnitahn (1983). This might reflect the insignificant daily mean temperature variation (range of temperature; 14.3–16.8°C) during the experimental season, which does not vary as much as in the highlands of Bale in the main rainy season.

When barley seedlings become older, oviposition drastically decreases. The probable explanation for the non-occurrence of oviposition on old seedlings is that when barley seedlings become older, locomotion and oviposition may become difficult for the barley shoot fly. This also hinders larval infestation due to the increased lignin content of the crop. Herbivores prefer and perform better on young than on old plants because nutritional quality decreases with phenological stage (Karban, 1990). Leite *et al.* (2005) similarly reported that white fly population dynamics were apparently determined by environmental factors and crop phenology.

Study of the population dynamics of *D. flavibasis* has practical implications. First, it enables determination of the periods of peak activity of *D. flavibasis* and to utilize this information to obtain maximum shoot fly pressure for host plant screening purposes. The main thrust of barley entomology at SARC focuses on the development of an efficient, reliable and repeatable host plant resistance screening technique. Therefore, synchronization of uniform and increased insect pressure with the most susceptible stage of crop growth is of vital importance. Second, as the barley shoot fly remains active throughout the growing season, with differences in density, adjustment of planting time was found to be the best practice to avoid heavy infestations. Results obtained from trap catches, average number of eggs per plant, infestation and deadheart percentages indicated that early planting provided enough moisture to be retained in the soil; this could be used as a means of reducing the infestation of barley shoot fly.

To find the key factors in the population dynamics of *D. flavibasis*, it is necessary to undertake studies in both seasons (main and short rainy seasons) and across years. In addition to frequent population sampling, life table analysis of the pest should also be assessed. After the development of a series of life tables, covering a wide range of conditions, it is likely that the key factor(s) responsible for population changes will be found.

Combined with this information from both biology and population dynamics, it should be possible to plan a management strategy for control of *D. flavibasis*.

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Research achievements for the Russian Wheat Aphid (*Diuraphis noxia* Mord.) on barley in Ethiopia

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INTRODUCTION

In Ethiopia, more than 38 species of insect pests have been reported to affect barley. Of these, eight are aphid species; the most important is the Russian Wheat Aphid (RWA) (*Diuraphis noxia* Mordvilko Homoptera: Aphididae) (Adugna Haile and Kemal Ali, 1985). Mokrecki first described the RWA in 1900. The aphid was confused with *Aphis cerealis* until 1914, at which point it was distinguished as *Brachycolus noxius* Mordvilko (Grossheim, 1914). It has been reported to be an indigenous aphid in southern Russia, Iran, Afghanistan and countries that border the Mediterranean (Hewitt *et al.*, 1984, cited in Webster, Baker and Porter, 1991). To date, it is found distributed in both the Old and New Worlds, mainly threatening the production of barley, followed by wheat (Robinson, 1992; Webster, Starks and Burton, 1987).

In Ethiopia, RWA was first recorded on barley in the northern parts of the country in the drought period of the early 1970s. At present, it is found in all barley growing areas of the country, with varying degrees of barley destruction (Adugna Haile and Tesema Megnasa, 1987; Bayeh Mulatu and Tadesse Gebremedhin, 1996). Barley yield loss due to RWA damage at Chacha in North Shewa was estimated to be between 50% and 60%; this occurred during years of rainfall shortage, which favours the development of the pest population (Adugna Haile and Kemal Ali, 1985).

Drought stress and aphid infestations are two factors that individually cause large yield reductions in cereal grains. Devastating yield losses when these two factors occur in succession indicate a possible synergistic interaction between aphid infestation and drought stress (Fereres *et al.*, 1988, cited in Riedell, 1989). Riedell (1989) hypothesized that a synergism would result if aphid infestation prevented the plant from successfully responding to drought stress and confirmed that RWA, in fact, causes drought-stress symptoms in leaves of infested barley plants even in the presence of ample root moisture. This may explain the catastrophic yield losses experienced by farmers in the RWA hot spots of Ethiopia when rainfall shortage has coincided with RWA infestation. As well as inducing drought-stress symptoms, the other biological effects it can have include: chloroplast breakdown caused by stylet-injected toxins; and rolling of leaves, including the flag leaves, resulting in contorted "goose neck" grain heads, which are sterile (Smith *et al.*, 1991). In Ethiopia, RWA infestation often starts at the early seedling growth stage, and as damage progresses the aphid pressure increases and the infestation may even persist after heading and result in severe crop damage or total crop failure. This is mainly the case in the *Belg* season (February to May), which has low rainfall.

The present RWA situation in Ethiopia is that the pest is abundant in certain places. Cyclical drought has been occurring over many years or erratic rainfall distribution has been noted within a growing season. The *Meher* season (June to October) is the most important season for barley production across the country. Early planting in May was abandoned by farmers in places such as the eastern parts of South Gonder, Wollo and North Shewa, due to a dry period in early June. This dry period, as mentioned earlier, favours the insect. The solution that farmers have adopted in the RWA hot spots of North Shewa is to grow early maturing varieties of barley by planting them in late June. This delayed sowing helps the crop to escape much pest damage; however, as observed, the yields decrease correspondingly (Bayeh Mulatu and Tadesse Gebremedhin, 1996). Due to the subsistence nature of the farming system in these areas, farmers have not adopted the use of insecticides. However, spraying insecticides may not be that effective against RWA due to the rolled leaves of barley, which prevent direct contact. Seed dressing formulations applied systemically to the plants could reduce or prevent early crop infestation, but the available formulations are costly to use. Seed dressing chemicals could be effective in preventing RWA infestation during the *Meher* season, as this is when the RWA infestation mainly occurs (especially during the early part of the growing season). The alternative, which requires less investment from the farmers and does not need special skill to implement, is sustainable and environmentally friendly, namely the use of RWA-resistant cultivars. Webster *et al.* (1993) suggested that an effective management strategy for the RWA in the USA is the use of a resistant cultivar. By focusing on the development of resistant strains of barley, other management methods also need to be developed in order to develop integrated management systems against RWA. This review therefore includes all the research work carried out in Ethiopia over the past 13 years or more. Such research includes some basic studies, as well as studies on host plant resistance, chemical screening, use of botanicals and natural products, and integrated control of RWA.

BASIC STUDIES

Population dynamics

The population dynamics of RWA was studied at Chacha, which is the most important area 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 over time. It then reaches a very low level, causing no significant damage when the rainfall becomes more frequent (Adugna Haile, 1984a). Similar results were obtained in North (at Estayesh) and South Wollo (at Gimba) (SiARC, 1996).

Host range

A host range survey conducted in a part of the Amhara region identified 16 cultivated and wild grass species that host the RWA (Amare Andargie and Addisu Berhan, 1998). The results of host preference studies on six grass species conducted in field and pot experiments showed that broom grass, wheat and barley were the hosts most preferred, and oat (cultivated and wild) and teff were less preferred. Similar results were obtained earlier at Holetta (Adugna Haile, 1984b; Adugna Haile and Tadesse Gebremedhin, 1989).

Yield loss assessment

Barley yield loss assessment due to RWA was conducted by superimposing on barley grown on farmers' fields in South Gonder (Melaku Wale *et al.*, 1998); at Chacha in North Shewa (Amare Andargie and Addisu Berhan, 1996); North Shewa around Degem (HARC, 1996a, 1998); Gimba in South Wollo; and Estaysh, Debresina, Hamisit and Kon in North Wollo (SiARC, 1997c). The assessments were made in the growing seasons of 1995 and 1996. Similarly, loss assessment studies were conducted in the cropping seasons of 1999 and 2000 in Tigray, around Mai-Chew and Alaje (MeARC, 1999, 2000a). From these assessments, the yield losses estimated were described (Table 1).

CONTROL MEASURES

Study on botanicals

Evaluation of some selected village-available botanicals for the control of RWA conducted by the Sirinka Research Centre in 1998 showed that spraying tobacco and fermented cow urine resulted in good pest control and there was more than a 50% grain yield advantage in barley over the untreated check (SiARC, 1998).

Cultural control (sowing date trial)

A sowing date experiment was conducted at Gimba and Gashena, in North Wollo, during the *Belg* season of 1996. Delayed planting increased aphid infestation and decreased grain and biomass yield, indicating the importance of early planting as a cultural control of RWA (Adane Tesfaye, 1998).

TABLE 1

Barley grain yield losses caused by the Russian wheat aphid 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 and 1996	86–100
North Shewa	Degem	1995 and 1996	9.6 and 68
North Wollo	Estaysh	1995 and 1996	35
	Debresina	1995 and 1996	26
	Hamisit	1995 and 1996	14
	Kon	1995 and 1996	21
South Wollo	Gimba	1995 and 1996	62
Tigray	May Chew and Alajie	1999 and 2000	9.6 and 40.30*

NOTES: * = For the two locations, respectively, over the 2 years

Effect of fertilization of barley on the population of RWA

The effect of N fertilization on the population of RWA was studied during the 1995 crop season in the highlands of Maichew. Results indicated that there was no significant variation between the different levels of fertilizers and the control. However, 100 kg/ha urea and 100 kg/ha DAP treatment combinations showed a relatively high level of aphid population (MeARC, 1997b).

HOST RESISTANCE IN BARLEY TO THE RWA

Host resistance to the RWA has a relatively longer recorded history on wheat than on barley (Du Toit, 1988). Identification of RWA resistance sources in barley was a success in the United States of America (Burton, 1989, cited in Webster, Baker and Porter, 1991.) and Mexico at the International Maize and Wheat Improvement Center (CIMMYT). CIMMYT also produced some promising lines of barley (Gilchrist, 1985, cited in Robinson, 1992). Robinson (1992), from CIMMYT, selected two resistant barley lines (S12 and S13) and both were found to have antibiosis resistance against the RWA. In the United States of America, line PI366449 (Afghanistan) was identified to have the highest level of antibiosis and reduced RWA reproduction by 50% compared with the control, Wintermalt (Webster, Baker and Porter, 1991). A study on the effect of resistance on RWA feeding was conducted on a number of barley lines; PI366450 (Afghanistan) and CI 1412 (Spain) were found to be the most resistant lines (Webster *et al.*, 1993). A plant population from the line PI366450 was found to be heterogeneous for RWA resistance, with individual plant reactions ranging from resistance to susceptibility. STARS-9301B, a six-row spring barley, which was a selection from the PI366450 plant population, was found to be uniformly resistant to the RWA. The resistance of STARS-9301B is primarily tolerance, with antibiosis as a secondary mechanism (Mornhinweg, Porter and Webster, 1995).

In Ethiopia, barley has been in production as part of a diverse ecosystem for thousands of years and its genetic diversity is very high. Engels in 1991 reported the results of a diversity analysis on barley landraces of Ethiopia, and confirmed that Ethiopia is a centre of diversity for barley and that the diversity is evenly distributed over the barley-growing areas of the country, although there is some concentration for individual characters. Therefore, although RWA has a short history in the country as a major pest, considering the diversity of the crop genetic base, evaluation of barley landraces to identify genotypes with inherent resistance against the RWA began with a mass screening programme. The screening was initiated together with the breeders and the pathologists in 1991 and completed in 1995. A total of 1200 single-head selections were made from 60 landrace populations, which were then evaluated for their resistance against RWA. The screening was carried out in two stages, described below.

First-stage screening

In the first cycle, by dividing the 1200 pure lines into two groups, mass screening was carried out. Each group was evaluated for two consecutive years under field conditions at Holetta in the off-season, using irrigation water. The lines were sown unreplicated on two rows of a ridge with the local cultivar 'Baleme' included as a susceptible check after every 60 lines. Following this, all the plots were artificially infested at about the four-leaf stage by spreading RWA-infested leaves of the susceptible local cultivar 'Baleme', which were cut into small pieces for ease of spreading. Supplemental infestation was never required in the four years of the trial. From 2 weeks after infestation, scoring of the extent of seedling leaf chlorosis and rolling was performed three times at weekly intervals, using a scoring scale of 0–9, but improved at Holetta for visually assessing entire plots (Table 2) (Webster, Straks and Burton, 1987). The recorded score data were then stored in a spreadsheet file and sorted to identify lines that showed a good level of resistance, which was determined mainly by the lower scores for the two measuring parameters for RWA damage symptoms (HARC, 1991, 1992).

TABLE 2

Scales used for the visual rating of the damage levels inflicted on the different barley lines

Scale	Damage description
0	Plants are healthy
1	Few isolated chlorotic spots and slightly folded leaves
2	Slight increase in isolated chlorotic spots and slightly folded leaves
3	Chlorotic spots larger and more numerous with slightly enfolded leaves
4	Chlorosis in about 25% of the leaves and increased level of enfolding of leaves
5	Merging of chlorotic spots with apparent streaking parallel to and on either sides of the midribs and pronounced enrolling of leaves
6	Distinct streaking parallel to and on either side of the midrib and enrolled leaves with leaf dieback symptoms from tips
7	Extensive leaf streaking and enrolled leaves with leaf dieback
8	>80% chlorotic and enrolled leaves with leaf dieback and stunted growth
9	Plants are already dead or dying

In the first stage of the screening (1991–1994), 29 lines were identified and found to have a good level of resistance to RWA damage; this was manifested by the lower scores for both parameters (leaf chlorosis and rolling) among the 1200 landrace pure line selections. However, none of the lines were immune, although it was not expected that a host plant would be immune from infestation nor killed by the pest attack. Line 3296-15 (from the 1993–1994 selection) had a better stand, despite higher mean scores for seedling leaf chlorosis 4 and leaf rolling 3, i.e. it was found to be tolerant to the RWA population of Holetta. Line 1659-07, in addition, was found at this stage of the screening to be tolerant, despite its high degree of leaf chlorosis, which was worse than occurred in the susceptible cultivar 'Baleme'. Three accessions, 3293-15, 3296-3 and 3296-13 scored 3 and 3, whereas 'Baleme' scored 6 and 5 in the first set, and 5 and 5 in the second set for leaf chlorosis and rolling, respectively (Tables 3a and 3b). As described in Table 2, lines that scored 3 and 3 for leaf chlorosis and rolling, respectively, had larger and more numerous isolated chlorotic spots without any streaking but with slightly enfolded leaves. This shows the possibility of integrating host plant resistance with biological control agents for the control of the RWA. This is because (unlike susceptible lines, which give protective cover for the infesting aphids as a result of the pronounced enrolling that their leaves show), the resistant lines expose the aphids residing on their leaves to the predators or natural enemies. Moreover, the effect of foliar-applied insecticide increases. These selected lines, as well as the good level

TABLE 3A
Barley accessions with a good level of resistance against RWA (*D. noxia* Mord.) damage (1991–1992)

Line	Mean scores (0–9)	
	Leaf chlorosis	Leaf rolling
1639-2	4	3
1642-19	4	2
1647-10	4	3
1667-4	4	3
1667-16	4	4
1667-18	4	3
1671-8	4	3
1726-17	4	3
1726-20	4	2
3285-14	4	4
3333-5	4	1
3357-4	4	1
3410-3	4	4
3379-17	4	3
Baleme	6	5

TABLE 3B
Accessions with a good level of resistance against RWA (*D. noxia* Mord.) damage (1993–1994)

Line	Mean score (0–9)	
	Leaf chlorosis	Leaf rolling
3305-12	4	3
3293-15	3	3
3296-3	3	3
3369-3	4	4
1659-7	6	4
1725-7	4	4
3379-12	4	3
1725-11	4	4
1671-6	4	3
3297-11	4	4
3296-15	4	3
3379-16	4	3
3297-12	4	3
3296-13	3	3
3379-10	4	3
Baleme	5	5

of resistance to RWA, also give the aforementioned associated benefits. Due to the promising results, these lines were further evaluated for one more year (1995) in the second stage of the screening.

Second-stage screening

In this stage of the screening, which was carried out for only one season, the 29 lines that were selected from the first cycle of the selection were further evaluated by sowing them on larger plots (2 m × 3 m, with six rows in each plot). There were three replications per line. Infestation was performed in the same way as in the first stage of the experiment. Comparison of the lines was made on the basis of percentage-infested tillers (by counting infested and healthy seedlings contained within a 50 cm length per row). The rows were taken at random in the six rows. Aphid count was carried out by randomly removing ten seedlings from each plot at a time (destructive sampling), visual assessment and scoring of the leaf chlorosis and rolling manifested by each line and the number of days taken by a line to head. Data on these parameters, except the last, were collected three times at weekly intervals. In counting the aphids, particularly in the last 2 days of data recording, only the dominant tiller was taken, with the assumption that it was the mother plant that was originally infested at the 4-leaf stage as the other tillers were infested by aphids reproduced in the mother plant. All the recorded data on the parameters considered at this stage of the screening were then analysed using SPSS/PC+ software for computation of the parameter means, analysis of variance and group mean comparison. The results obtained from both stages of screening are described below (HARC, 1996b, c, d).

The results for the 29 accessions selected are given in Table 4, with values rounded to the nearest whole number. The percentage infestation data taken on the three subsequent scoring dates were not found to be statistically significant ($P<0.05$), so they were not included in the results table. In contrast, for the parameters mentioned in Table 4, the variations were found to be significant even at $P<0.01$. Duncan's multiple range test (DMRT) showed that, for the aphid count data, the majority of the lines were grouped into one, with 1667-04 and 3285-14 hosting more aphids on the first day of scoring. Line 3357-

TABLE 4

Response of the selected barley lines to RWA (*Diuraphis noxia* Mordv.)

Line no.	Mean aphid count			Mean leaf chlorosis			Mean leaf rolling			Days to heading
	D-I	D-II	D-III	D-I	D-II	D-III	D-I	D-II	D-III	
1639-02	46 a	79 a	34 a	1 a	5d	4b	2 a	4c	4 a	87 b
1642-19	39 a	88 a	23 a	3 b	4 b	5 d	3 c	3 a	4 a	96 e
1647-10	51 a	108 a	15 a	4 d	4 a	5 c	2 a	3 a	4 b	93 c
1659-07	51 a	158 a	62 e	3 b	4b	4 b	3 c	4 c	5 c	95 d
1667-04	108 b	73 a	27 a	2 b	3 a	3 a	2 a	2 a	3 a	84 b
1667-16	55 a	106 a	43 a	3 b	4 a	4 b	2 a	3 a	4 a	85 b
1667-18	40 a	133 a	19 a	2 a	3 a	3 a	1 a	2 a	2 a	85 b
1671-06	35 a	44 a	10 a	2 a	4 a	4 b	1 a	3 a	3 a	100 i
1671-08	57 a	56 a	25 a	2 a	2 a	3 b	1 a	2 a	3 a	96 e
1725-07	43 a	60 a	28 a	3 a	3 a	4 a	2 a	2 a	3 a	99 g
1725-11	56 a	67 a	38 a	2 b	5d	3 b	2 a	4 b	4 a	103 i
1726-17	73 a	57 a	17 a	3 c	3 a	4 a	2 a	2 a	4 a	90 c
1726-20	42 a	108 a	10 a	3 c	4 a	5 b	3 c	3 a	3 a	101 i
3285-14	127 c	164 a	50 c	2 a	5 d	5 c	2 a	4 c	4 a	103 i
3293-15	26 a	56 a	18 a	1 a	3 a	2 a	1 a	2 a	3 a	97 f
3296-03	40 a	80 a	42 a	1 a	2 a	4 a	1 a	2 a	3 a	87 b
3296-13	24 a	62 a	16 a	2 a	3 a	4 b	2 a	3 a	4 a	98 g
3296-15	65 a	136 a	42 a	2 a	3 a	2 a	1 a	2 a	3 a	101 i
3297-11	36 a	109 a	46 b	3 c	5 c	5 c	3 c	4 d	4 b	98 g
3297-12	50 a	54 a	31 a	2 b	4 a	4 b	2 a	3 a	4 a	100 h
3305-12	75 a	98 a	47 b	3 b	4 a	4 b	2 a	3 a	5 b	89 c
3333-05	70 a	50 a	18 a	3 c	4 a	4 b	2 a	3 a	4 b	102 i
3357-04	90 a	197 b	54 d	2 a	4 a	5 d	2 a	4 b	4 a	74 a
3369-03	47 a	101 a	30 a	3 b	4 a	4 b	3 b	4 c	5 d	101 i
3379-10	39 a	49 a	16 a	1 a	3 a	4 b	1 a	2 a	4 a	98 g
3379-12	37 a	38 a	21 a	2 a	3 a	3 a	1 a	2 a	2 a	97 e
3379-16	56 a	72 a	37 a	1 a	3 a	4 a	1 a	3 a	4 a	101 i
3379-17	63 a	42 a	14 a	1 a	2 a	3 a	2 a	2 a	3 a	94 d
3410-03	83 a	76 a	24 a	3 c	4 a	5 c	3 c	4 b	4 a	102 i

NOTES: Values in a column followed by same letter are not significantly different at $P<0.05$, according to DMRT. D-I = 35 days after emergence; D-II = 1 week after D-I; D-III = 2 weeks after D-I.

04 had the highest infestation on day 2; on day 3, the infestation level was higher on lines 1659-07, 3285-14, 3297-11, 3305-12 and 3357-04. For the most important parameter, leaf chlorosis, there were four groups on day 1, with 15 lines scoring between 1 and 2; 8 lines scoring 2 to 3; 5 lines scoring 3; and 1 with a score of 4. On the second scoring day, the scores were 23 lines between 2 and 4; 2 lines with 4; 1 line scoring 5; and 3 lines >5. On the last scoring day there were 10 lines a score of 2 to 3; 13 lines at 3 to 4; 4 lines scoring 5; and 2 lines >5. For leaf rolling, there were 23 lines scoring 1 to 2; 1 line at 3; 5 lines >3. On the second scoring day, there were 23 lines at 2 to 3; 3 lines scoring 4; and 1 line >4. On the last day, there were 23 lines scoring 3 to 4; 4 lines 4 to 5; 1 line at 5; and 1 line >5. These results showed that lines that sustained higher levels of RWA infestation scored higher for leaf chlorosis and rolling. When the changes over the scoring days are seen, particularly the data on aphid count, 1671-06, 1762-17, 3293-15, 3296-03, 3296-13, 3379-10, 3379-12 and 3379-17 had lower aphid counts and the corresponding

scores on leaf chlorosis and rolling were also lower. However, among these lines, those that had better plant stands with a good level of tolerance to the pest, although not comparable with 3296-15, were 3379-17, 3296-3, 1671-6 and 1726-17. Line 3296-15 is very tolerant, with acceptable agronomic merits, but it hosted more aphids and sustained more damage, indicating the high level of tolerance that the line has to the pest. The other lines with aphid counts exceeding that of 3296-15 were 1659-07, 3357-04, and 3284-14. Line 1659-07 was included in the second stage of the screening, considering its seemingly good agronomic performance during the first phase of the screening, but in the second stage it was found to be more susceptible and had a relatively poor crop stand.

These results suggest that, in the Ethiopian barley gene pool, there is a possibility that lines may exist that have a good level of tolerance to the RWA population under Ethiopian conditions. This particular screening work has shown that there is variability in the reaction of landrace barley collections to RWA. For instance, lines 3296-03, 3296-13 and 3296-15, which are selections from the population 3296 from Kofele (Arsi region), reacted differently to the pest attack. Line 3296-15 had the combined advantages of a good level of tolerance to the pest attack and acceptable agronomic merits. This line should be further assessed in pest hot-spot areas.

Additional screening of barley accessions for their resistance against RWA was carried out during 1995–2000 at the Mekelle Agricultural Research Centre (MeARC) (at Mai-Chew, Alaje and Adigrat locations). The testing used 721 barley accessions from the Institute of Biodiversity Conservation (IBC) [Formerly the Plant Genetic Resource Collection of Ethiopia (PGRC/E)] and screened against RWA at Illala and Atsbi sites in Tigray using artificial infestations in 1995–1997 (MeARC, 1997a, 2000b). The results showed that 23 accessions had moderate levels of field resistance to RWA, and these were further screened at MeARC using artificial infestation. The screened accessions differed in their reaction, scored on a 1–6 scale (Calhoun *et al.*, 1991), to the insect at two defined growth stages, tillering and post-heading (Table 5). Two accessions, however, PGRC/E 1987 and 848, revealed some tolerance to the insect. These two accessions supported heavy infestations of RWA at the tillering and jointing stages, but seemed to recover at the post-heading stages. Their reaction was significantly different from the remaining accessions. Similarly, they have given the highest yields, although yield was not the important yardstick at this stage of the experiment.

In this same on-farm experiment, attempts were also made to involve farmers in the evaluation of the barley accessions, although not much emphasis was given to the criteria to be used in the process. Accordingly, in addition to those selected by the principal investigator, the farmers selected and suggested the inclusion of the following accessions in the advanced evaluation experiment that should follow: PGRC/E lines 465, 3833, 487, 3583 and 3949. None of the accessions sustained significantly lower than the local check. However, accession 2987 gave the highest grain yield, followed by accession 848.

Although screening of barley landraces for resistance to RWA was not totally terminated, most of the studies since 1998 that were carried out at Chacha by

TABLE 5
Performance of selected barley accession to Russian wheat aphid at Maichew, 1997

Accession	Damage score (1–6 scale) at various growth stages			DHE	Yield/plot (g)
	GS1	GS2	GS3		
PGRC/E 4369	2.375	3.00	5.50	79.5	898.45
Tselim	2.875	2.25	6.00	80.50	1139.10
Tsaeda	3.625	3.00	5.00	90.50	938.60
PGRC/E 465	3.625	3.00	5.50	91.50	1172.55
PGRC/E 4531	2.813	3.50	4.50	82.00	1012.00
PGRC/E 3367	3.125	3.375	5.50	87.00	1104.80
PGRC/E 1705	3.625	3.125	5.00	88.00	1162.45
PGRC/E 3374	3.875	2.625	5.50	88.00	1190.30
PGRC/E 1989	4.125	3.000	6.00	84.50	921.40
PGRC/E 3581	3.312	3.625	5.50	80.50	796.45
PGRC/E 2987	3.312	3.250	2.75	91.50	1306.80
PGRC/E 848	3.312	3.000	2.75	92.00	1158.55
PGRC/E 4371	3.437	3.750	4.50	79.50	667.20
PGRC/E 2239	3.312	4.000	5.50	80.50	894.65
PGRC/E 3049	3.563	4.000	4.75	89.00	929.00
PGRC/E 206353	3.500	4.250	5.00	82.00	1022.80
PGRC/E 206344	3.500	3.625	3.25	79.50	1178.45
PGRC/E 207553	4.500	4.000	3.50	83.00	644.40
PGRC/E 3833	3.625	2.875	5.00	92.50	1029.65
PGRC/E 487	3.875	3.875	5.00	79.50	1147.55
PGRC/E 3583	2.875	3.125	4.50	82.00	931.00
PGRC/E 207558	3.375	3.250	5.50	92.50	894.40
PGRC/E 3949	2.687	2.875	4.50	94.00	1352.20
Local check	3.813	3.375	3.50	105.50	951.40
CV (%)	12.6	16.2	12.2	7.32	19.90
LSD (*P*<0.05)"	0.9041		1.194		

NOTES: GS1 = Zadoks growth stage 20–29; GS2 = Zadoks growth stage 30–35; GS3 = Zadoks growth stage 50–60 (see Zadoks, Chang and Konzak, 1974); DHE = days from emergence to heading.

Debre Berhan Agricultural Research Centre (DBARC) were focused on the evaluation of advanced barley lines that had been developed at ICARDA. The materials from ICARDA are crosses of selected Ethiopian landraces with known RWA-resistant parent material developed in countries where the pest has a longer history. The materials had been introduced through the national barley programme. Of 29 barley lines screened during the 1999 and 2000 *Belg* seasons at Chacha, only seven lines have shown a good level of resistance (Table 6), although they were not comparable to the local and standard checks in agronomic terms (DBARC, 2003).

LOCATION OF RESISTANCE FACTOR IN RWA-RESISTANT BARLEY

To determine that 3296-15 is indeed a tolerant line, the feeding behaviour of RWA was studied using an electrical penetration graphics technique (Tjallingii, 1987) in comparison with resistant line 9301B from the USA and susceptible line 3284-11 from Ethiopia. Total phloem feeding time was significantly longer on 3296-15, indicating that it has more suitable phloem sap than the others. Although the aphids did not show a preference between the lines, the live weight of aphids

TABLE 6

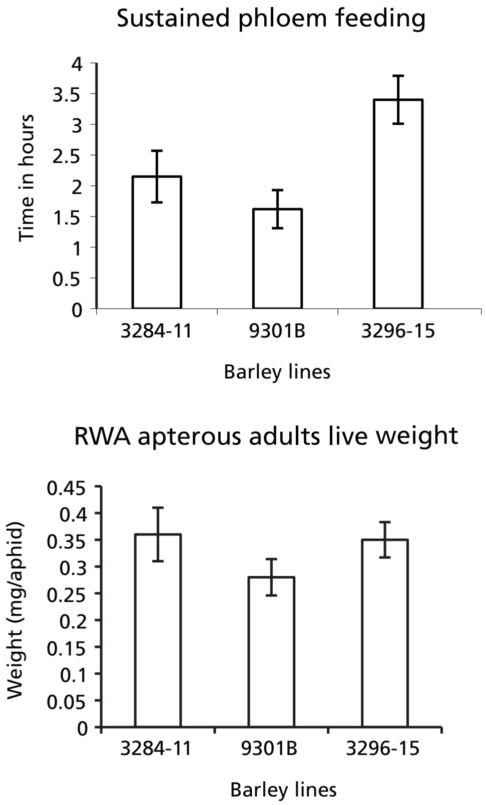
Barley lines with a good level of resistance against RWA (*D. noxia* Mord.) with local and susceptible checks in the 1999 and 2000 *Belg* seasons at Chacha

Barley line	1999 *Belg* season				
	I (%)	LC	LR	DH (%)	DTH
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
Susceptible check (3284-9)	52	6	5	24	90

NOTES: I = percentage infestation; LC = leaf chlorosis using 0–9 scale scoring; LR = leaf rolling using 0–9 scale scoring; DH = percentage deformed head; DTH = days to heading.

FIGURE 1

Mean ± SE total time lapsed in sustained phloem feeding and live weight of RWA apterous adults after being reared on three barley lines



reared on 9301B was significantly lower than on the other two lines (Figure 1). Therefore, it may be stated that 3296-15 is indeed a tolerant line (Bayeh Mulatu, 1997).

CHEMICAL CONTROL USING SEED DRESSING INSECTICIDES

Carbofuran 35% ST at five concentrations between 1 and 5%, Carbosulfan 75% and Diazinon 50% were compared as seed treatments. All controlled RWA significantly and gave significant yield advantages over the untreated control (Adugna Haile and Tadesse Gebremedhin, 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 rates of 88.2, 74, 65, and 74 g/ha a.i. In dressing the seeds, enough water was sprinkled over the seeds in polyethylene bags and shaken in order to create a wet surface for effective admixing of the insecticides with the barley seeds. All the treated seeds were then air-dried under shade.

All the treatments, including the standard and untreated checks, were planted on plots of size 3 m × 2 m in four replications. The plots were laid down in a randomized complete block design. When the seedlings reached the four-leaf stage, all the plots were artificially infested with apterous forms of RWA. This was performed by spreading RWA-infested small leaf pieces of the barley cultivar 'Baleme'. The infested leaves were taken from the aphid culture that was maintained under field conditions at Holetta. Two weeks after infestation, data on the number of infested tillers and aphids per tiller were taken at random from six 50-cm row lengths per plot, and the degree of leaf chlorosis, leaf rolling and phytotoxicity were visually scored on a whole-plot basis. The leaf chlorosis and rolling were scored three times at weekly intervals. Additional data collected were days to heading, days to maturity and grain yield. Analysis of variance was performed on the collected data and the means are reported (Tables 7a and 7b).

The results showed that, of the five seed dressing insecticides, the mean percentage infested tillers was lower over the subsequent scoring days on imidacloprid 70% WS-treated plots. However, the mean aphid count per tiller was not significantly different. However, on the second scoring day, statistically higher numbers of aphids were recorded on the untreated plots. In general, for both parameters considered in the analysis, the mean infestation level and the number of aphids counted per tiller were consistently lower on imidacloprid 70% WS-treated plots (Table 7a). However, the yield obtained was low, in general, and the yield gap between the untreated check plots and imidacloprid 70% WS-treated plots was 3.6 q/ha (Table 7b) (HARC, 1996e).

Rate determination of the seed dressing insecticide, Imidacloprid 70 WS, the most promising of the seed dressing insecticides tested at Holetta, was carried out at Chacha and Kotu in North Shewa in the 1995 and 1996 *Belg* seasons. Five rates (0.5, 1, 1.5, 2 and 2.5 g a.i per kg) were compared. The highest rate controlled aphid

TABLE 7A

Mean percentage infested tillers and aphids counted on synthetic-insecticide-dressed barley

Treatment	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	21 b	20 c	28 c	15 a	14 a	13 b
Furathiocarb 400 CS	74	24 b	20 c	25 bc	16 b	17 a	11 a
Imidacloprid 70% WS	88.2	10 a	12 a	16 a	6 a	11 a	8 a
Diazinin-TMTD	55	21 b	16 b	20 ab	8 a	9 a	6 a
Lindane-TMTD	74	24 b	16 b	19 ab	7 a	11 a	12 a
Local check		25 b	21 c	18 ab	10 a	18 b	8 a

NOTES: D-I = 35 days after emergence, D-II = 1 week after D-I, D-III = 2 weeks after D-I. Values in a column followed by the same letter are not significantly different at $P<0.05$.

TABLE 7B

Mean days to heading, plant height and grain yield of synthetic-insecticide-dressed barley

Treatment	Rate a.i. (g/ha)	DTH	PH	GY
Carbosulfan 25% ST	162.5	89 a	87 a	14.46 bc
Furathiocarb 400 CS	74	89 a	87 a	14.46 bc
Imidacloprid 70% WS	88.2	90 a	96 b	14.60 c
Diazinin-TMTD	55	92 ab	85 a	10.63 a
Lindane-TMTD	74	92 ab	86 a	14.26 b
Local check		94 b	88 b	11.00 a

NOTES: Values in a column followed by the same letter are not significantly different at $P<0.05$. DTH = days to heading; PH = plant heigh (cm); GY = grain yield (q/ha).

TABLE 8A

Results of combined analysis over location on the effect of seed dressing insecticides on RWA infestation and yield of barley at Kotu and Chacha during the 1998 *Belg* season

Insecticide	Rate (g a.i./kg seed)	Damage score (0–9 scale) at three growth stages				Yield (q/ha)	
		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	9.0
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	5.0
CV (%)		26.3	25.8	17.3	12.4	23.6	33.7
LSD ($P<0.05$)"		1.1	1.3	1.04	0.9	10.8	5.0

damage more and increased grain yield (Addisu Birhan and Tadess Gebremedhin, 1999). This study, however, did not include economic analysis. Thus, another study was conducted in the 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 a fixed rate of 0.75 g a.i. per kg seed. The minimum aphid damage and highest grain yield were obtained from Imidacloprid 70 WS, Cruiser 70 WS at a rate 0.75 g a.i. per kg and Apron star 42 WP at a rate of 5 g a.i. per kg seed (Table 8a).

The above 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 m × 10 m to assess their profitability (ShARC, 2000). It was found that, of the insecticides, Cruiser 70 WP was the most profitable and use of Cruiser 70 WP at a rate of 0.75 g a.i. per kg seed can give a net benefit of 3065 Birr/ha and a marginal rate of return of 915% over the untreated barley. The other two insecticides, Apron star 42Ds and Imidacloprid 70% WS, were found to be effective in controlling RWA, but they were not profitable because they were too expensive and the recommended rates were relatively high compared with Cruiser 70 WP. The sensitivity analysis showed that a 25% increase in the price of Cruiser 70 WP is more profitable (Marginal Rate of Return (MRR) = 736) than a 50% reduced price for both Guacho 70 WP and Apron star 42 DS (Table 8b). In other words, the price of these two insecticides must be reduced by more than

TABLE 8B

Partial budget analysis for the three insecticides and untreated local barley seed at Cheki and Chacha under irrigation, 1999

Parameter	Cruiser 70 WP	Apron Star 42 DS	Gaucho 70 WP	Untreated
Average grain yield (kg/ha)	1124	1008	1188	926
Average straw yield (kg/ha)	2777	1828	1609	1870
Gross benefit (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 labour (Birr/ha)	12	12	12	–
Price of barley seed (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 (Birr/ha) at 10% pm	3067	2042	1833	2379
Net benefit (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)		305/2442/73	380/2640/162	

Notes: TC = total cost; NB = net benefit; MRR = marginal rate of return; pm = allowed profit margin for insecticide importers. Price of the insecticides is estimated after importer profit margins of 10% and 15% are included at Addis Ababa. Prices of Cruiser 70 WP, Apron Star and Gaucho were 672, 759 and 3170 Birr/kg, respectively. Labour used to treat the seed is at the local wage rate of 6 Birr per work-day. Estimated price of local barley seed at planting is taken to be 1.75 Birr/kg. Estimated value of local barley output after harvest is 2.0 Birr/kg. Estimated value of barley straw is 0.4 Birr/kg.

80% (Table 8b) for farmers to obtain an acceptable MRR. In areas such as Chacha, where RWA is a serious and constant problem for barley production during the *Belg* and under irrigation, it was recommended that seed dressing insecticides be used. Similar results were obtained at Gimba (SiARC, 1997b).

CHEMICAL CONTROL USING SPRAY INSECTICIDE

Verification of the spray insecticide Dimethoate (Ethiothoate) 40% EC for the control of RWA on barley was conducted at Chacha and Cheki with supplemental irrigation during the *Belg* season of 2003. Two sprayings of these insecticides at a rate of 1.5 L/ha effectively controlled RWA on barley and gave a marginal net benefit of 437.95 and 446.95 Birr/ha when the price of the chemical is taken at market and company prices, respectively (DBARC, 2003).

INTEGRATED CONTROL OF RWA

Integration of different sowing dates with a one-off spraying of Pirimiphos-methyl 50% EC (1 l/ha) was studied at Gimba in 1996 and 1997 to see their combined effect in controlling RWA on barley. It was found that there is a significant interaction between sowing date and insecticide treatment. Early sown barley, after being sprayed with insecticide, suffered significantly lower damage than all the other treatment combinations. Moreover, although the difference was

TABLE 9A

Effect of sowing date and insecticide treatment on RWA infestation, yield and yield components of barley at Gimba in 1996

Treatment	Infestation (%)			Plant height (cm)	Productive tillers (%)	Yield (q/ha)	
	Tillering	Booting	Flowering			Biomass	Grain
Treated (A)	6 b	26 b	35	84 a	80	21 a	44 a
Untreated (B)	9 a	33 a	40	81 b	74	09 b	37 b
12 January (1)	5	5 d	5 d	89 a	94 a	154 b	60 a
22 January (2)	6	9 c	13 c	89 a	91 ab	160 a	56 b
01 February (3)	7	25 b	38 b	85 b	88 b	115 c	37 c
11 February (4)	11	78 a	94 a	67 c	35 c	32 d	9 d
A × 1	8 c	5	4	88	93	158	61
A × 2	6 c	9	16	90	92	160	57
A × 3	3 d	15	31	88	88	127	44
A × 4	8 c	76	88	69	47	40	13
B × 1	3 d	5	6	90	96	151	58
B × 2	7 c	10	9	88	90	59	55
B × 3	11 b	35	45	82	88	102	31
B × 4	14 a	80	99	63	23	23	5
CV (%)	60.21	47.43	7.85	5.60	14.79	18.31	19.52

NOTES: Values in a column followed by the same letter are not significantly different at $P<0.05$.

TABLE 9B

Effect of sowing date and insecticide treatment on the incidence of RWA on barley at Gimba in 1997

Treatment	Chlorosis (1–9)	Rolling (1–6) and stunting (1–9)	Infestation at (%)		
			Tillering	Booting	Flowering
Treated (A)	2.3 b	1.7 b	1.7 a	2.4 b	1.7 b
Untreated (B)	3. 63 a	2.6 a	2.7 a	4.1 a	2.8 a
January 24 (1)	4.25 a	3.25 a	3.63 a	1.84 c	2.76 b
February 3 (2)	4.63 a	3.25 a	1.58 a	2.77 b	3.80 a
February 13 (3)	1.38 b	1.13 b	1.22 b	4.17 a	1.22 c
February 22 (4)	1.50 b	1.00 b	1.22 b	4.25 a	1.22 c
A × 1	3.25 b	2.50 b	4.40	1.70 c	2.03 c
A × 2	3.00 bc	2.00 bc	1.72	2.27 bc	2.22 c
A × 3	1.50 d	1.25 c	1.22	2.92 bc	1.22 c
A × 4	1.25 d	1.00 c	1.22	2.69 bc	1.22 c
B × 1	5.25 a	4.00 a	2.86	1.99 c	3.49 b
B × 2	6.25 a	4.50 a	1.45	3.27 b	5.39 a
B × 3	1.25 d	1.00 c	1.22	5.41 a	1.22 c
B × 4	1.75 cd	1.00 c	1.22	5.81 a	1.22 c
CV (%)	25.05	27.46	45.16	18.65	27.41

NOTES: Values in a column followed by the same letter are not significantly different at $P<0.05$.

not statistically significant, the early sown barley gave the highest yield after being treated with insecticide (SiARC, 1997a) (Tables 9a and b).

In 2000 and 2002, a RWA-tolerant barley line (3296-15) was tested with dimethoate and tobacco or animal urine for the control of RWA at Gimba. The combination of variety and dimethoate with either tobacco or urine gave significantly higher grain yields than the local variety under the farmer practices.

TABLE 10

Effect of resistant or tolerant barley variety (3296-15) and seed dressing chemical on aphids at Gimba in 2001

Treatment	Leaf chlorosis (1–9 scale)		Leaf rolling	Aphid count per 5 plants		Infestation (%)			Yield (kg/ha)
	Apr 27	May 5	May 5	Booting	Flowering	Tillering	Booting	Flowering	
Chemical									
Treated (A)	1.2 b	1.0 b	1.0 b	5.7 b	0.0 b	0.0 b	1.2 b	0.0 b	1300 a
Untreated (B)	2.7 a	3.3 a	2.3 a	50.5 a	16.7 a	5.2 b	7.3 a	8.7 a	842 b
Variety									
3296-15 (1)	1.8 a	2.0 a	1.5 a	22.8 b	5.5 b	1.0 b	2.8 b	3.2 b	1322 a
Ehilzer (2)	2.0 a	2.3 a	1.8 a	33.3 a	10.7 a	4.2 a	5.7 b	5.5 a	820 b
Interaction									
A × 1	1.3 a	1.0 a	1.0 a	2.7 b	0.0 c	0.0 b	0.7 b	0.0 b	1652 a
A × 2	1.0 a	1.0 a	1.0 a	8.7 b	0.0 c	0.0 b	1.7 b	0.0 b	993 a
B2 × 1	2.3 a	3.0 a	2.0 a	43.0 a	11.0 b	2.0 b	5.00 ab	6.3 ab	949 a
B2 × 2	3.0 a	3.7 a	2.7	58.0 a	21.3 a	8.3 a	9.67 ab	11.0 ab	692 b
CV (%)	23.0	13.3	17.3	17.7	62.4	30.5	28.2	25.3	11.9

NOTES: Values in a column followed by the same letter are not significantly different at $P<0.05$.

In addition, the tolerant line was compared with the local cultivar, both dressed and undressed, with Gaucho 85% WS as seed treatment at Gimba in 2001. The tolerant line in dressed form controlled the aphid significantly better and gave significantly higher yields than all the other treatments (SiARC, 2002) (Table 10).

The use of resistant or tolerant host plants, as well as effective, economical and available seed dressings or spray formulations of insecticides, are possibilities in the management of RWA. Under small-scale farming conditions, the following are usable technologies for the management of RWA:

1. Clearing broom grass in and around barley fields is a good cultural practice for reducing damage by RWA.
2. Early planting of barley in the *Belg* season in North Wollo.
3. Promoting the use of 3296-15, a proven RWA-resistant cultivar.
4. Using Cruiser 70 WP, Furathicarb 400 CS and Imidacloprid 70 WS at rates of 75, 74 and 88.2 g per 100 kg barley seed as effective seed treatments against RWA.
5. Using Dimethoate 40% EC at a rate of 1.5 L/ha to effectively control RWA on barley.
6. Using Pirimiphos-methyl 50% EC at 1 L/ha to effectively control RWA on barley.
7. Early sowing combined with a one-off spraying of Pirimiphos-methyl 50% EC to effectively control RWA on barley.
8. Combining a tolerant line (3296-15) with dimethoate, and complementing the spraying with fermented cow urine or tobacco extract, to effectively control the RWA.

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Biotypic and genetic variability in the Russian Wheat Aphid (*Diuraphis noxia* (Mordvilko)) (Homoptera: Aphididae)

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INTRODUCTION

The Russian wheat aphid (RWA), *Diuraphis noxia* (Mordvilko), was first reported to affect cereal crops in the southern Caucasus region prior to 1900 (Poprawski *et al.*, 1992). In Ethiopia, RWA was first reported in the Atsbi and Adigrat areas of Tigray in 1972 (Adugna Haile and Tesema Megnasa, 1987). RWA prefers barley and wheat, but also feeds on grass species when the main crops mature or are not available.

RWA body length is about 2 mm and the colour varies from yellow-green to grey-green. The body of the RWA is spindle-shaped and can be distinguished from other cereal aphids by a projection above the last abdominal segment, the supracaudal process. This gives the impression, when viewed from the side, that the RWA has a forked tail (Stoetzel, 1987). The tubular body shape, well-developed wax glands and lack of well-developed cornicles indicate that the species has adapted to life in a gall-like environment (that is, in a rolled leaf (Nault and Phelan, 1984)). The RWA is probably anholocyclic in Ethiopia as there is no severe cold season that may require sexual reproduction. RWAs with an anholocyclic life cycle occur in southern Afghanistan, North America, South America, South Africa, France and Turkey (Kiriac *et al.*, 1991), whereas those with a holocyclic life cycle occur in most parts of the former USSR (Grossheim, 1914), Hungary (Basky and Jordaan, 1997) and northwest China (Zhang & Zhang, 1996).

Barley yield losses caused by RWA ranged from 41% to 79% in a previous study (Miller and Adugna Haile, 1988). Thus, in the *Belg* season, many farmers in Ethiopia have stopped growing barley. Infestations are particularly serious in the highlands. The climate there is cool and barley is sown during late April to early May. Farmers prefer the late barley varieties as they give higher yields. However, this barley type is often subject to severe RWA damage, beginning in late May. In the highlands of Ethiopia, most farmers live at a subsistence level and so they cannot afford the use of insecticides against RWA, although a number of seed dressings and sprays have been identified (IAR, 1984). Less expensive contact insecticides have not proved to be effective due to the insect's habit of secluding itself in the rolled leaves (Webster, 1990). Biological control is difficult as the efficiency of most of the existing natural enemies is low at the early stage of the crop (Adugna Haile and Tesema Megnasa, 1987). Thus, control management should mainly focus on cultural controls and host-plant resistance.

As with many cereals (Robinson, 1992), the use of resistant cultivars is an ideal management option for RWA as it avoids the use of insecticides. Furthermore, Mornhinweg, Porter and Webster (1995) observed genetic diversity for RWA resistance in barley and identified two genes (*Dnb1* and *Dnb2*) that are responsible for RWA resistance. Variation within a biotype can threaten the durability of plant resistance (Saxena and Barrion, 1987; Puterka, Burd and Burton, 1992). Biotypes develop as a result of selection from the parent population in response to exposure to resistant cultivars. According to Saxena and Barrion (1987), 50% of recognized insect biotypes on crops belong to the family Aphididae.

Biotypes were described for several important aphid species and are characterized by their ability to feed and damage resistant cultivars of a plant species (Smith, 1994). Biotypes are known for the green bug, *Schizaphis graminum*, on wheat and sorghum (Puterka and Peters, 1990); the cabbage aphid, *Brevicoryne brassicae*, on Brussels sprouts; the spotted alfalfa aphid, *Therioaphis maculata*, on alfalfa (Nielson and Lehman, 1980); the corn leaf aphid, *Rhopalosiphum maidis*, on maize; and the raspberry aphid, *Amphoraphora rubi*, on raspberry (Briggs 1965). Butts and Pakendorf (1984) noted differences in the performance of wheat varieties on United States of America and South African RWA populations. Bush, Slosser and Worrall (1989) reported varying levels of plant damage on wheat among RWA populations collected from Idaho, Oklahoma and Texas in North America, following short-duration infestations. Puterka, Burd and Burton (1992) identified and described, for the first time, biotypes of RWA among worldwide collections, based on differential responses on susceptible and resistant wheat and barley varieties. According to Basky *et al.* (2001), Hungarian and South African RWA isolates also showed biotypic differences. Shufran, Burd and Webster (1997) found no biotypic variation in 11 RWA North American isolates from host-response studies.

This review presents research assessing biotypic and genetic variation among RWA populations from Ethiopia and other countries.

BIOTYPIC STATUS OF THE RWA IN ETHIOPIA

In order to check the biotypic status of RWA populations in Ethiopia, aphid clones were collected from barley fields in Shewa, Wollo, Gonder, Adigrat and Maichew during the *Belg* season of 2002. Clonal colonies were initiated by placing a single RWA on barley seedlings inside cages. Colonies were maintained by transferring a few adults to a fresh barley seedling.

TABLE 1

F-statistics for the three parameters of plant damage for 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 and oat	4	20.62**	18.54**	9.28**	8.67**
RWA	4	1.51	0.34	2.60*	3.16*
Barley × RWA	14	0.63	1.15	1.54	0.76

NOTES: DF = degrees of freedom; * & ** = significant at P<0.05 and *P*<0.01 levels, respectively.

Aphid clones were tested on both susceptible and resistant varieties of barley. The barley entries included a resistant line from Shewa (3296-15) (Bayeh Mulatu, pers. comm.), a resistant line from Tigray (848-1) (MeARC, 1997), a susceptible line from Shewa (Kesele) (Bayeh Mulatu, pers. comm.) and a susceptible line from Tigray (Tsaeda Shewa). Oat (*Avena sativa*) was used as the resistant control (Webster, Starks and Burton, 1987). The resistant entries were obtained from the germplasm collection of the then Plant Genetic Resource Centre for Ethiopia and evaluated by the research centres in Holetta and Mekelle. The experimental design, a 5 × 6 (plant entry × RWA clone) factorial randomized complete block design, was replicated four times. 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 (Webster, Baker and Porter, 1991), leaf rolling on a rating scale of 1–3 (Webster, Baker and Porter, 1991) and plant stunting on a scale of 1–5 (Burd *et al.*, 1998). In addition, the aphid biomass was measured.

Results of the analysis of variance for chlorosis, leaf rolling, plant stunting and RWA biomass are presented in Table 1. No significant differences in chlorosis and leaf rolling were found among the RWA clones on the four barley varieties and on oat. The RWA clones, however, differed significantly in plant stunting and RWA biomass. Host reactions among clones were similar. Conversely, the barley entries had a significant effect on chlorosis, leaf rolling, plant stunting and RWA biomass.

Mean chlorosis on plant entries caused by the RWA clones are presented in Table 2. The least chlorotic value on oat was consistent with a mean of 2.00 across RWA clones. None of the barley entries showed significant differences in chlorosis. Shewa and Gonder clones showed the least and highest chlorosis scores, respectively, and these were significantly different (Table 3). The RWA clones of Wollo, Adigrat and Maichew were not significantly different to either Shewa or Gonder.

TABLE 2

Mean values ± SE of chlorosis on the barley varieties caused by RWA clones

	RWA clones					Mean ± SE
	Shewa	Wollo	Gonder	Adigrat	Maichew	
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
Tsaeda 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 ± SE	4 ± 0.4	4.5 ±0.4	5.1 ± 0.5	4.6 ± 0.4	4.6 ± 0.4	

NOTES: Means followed by same letter are not significantly different at *P*<0.05.

TABLE 3

Mean values ± SE of chlorosis, leaf rolling and RWA biomass (mg) for the six wheat varieties, oat and the local barley control

	Chlorosis	Leaf rolling	RWA biomass
Wheat line with *Dn2* gene	3.67 ± 0.2 bc	1.67 ± 0.3 bc	4 ± 0.6 a
Wheat line with *Dn4* gene	2.33 ± 0.1 ab	3.00 ± 0.0 a	18 ± 05 b
Wheat line with *Dn5* gene	4.00 ± 0.3 bc	1.00 ± 0.0 c	4 ± 1 a
Wheat line with *Dn6* gene	2.67 ± 0.1 ab	1.33 ± 0.3 c	5 ± 2 a
Wheat line with *Dnx* gene	2.33 ± 0.1 ab	2.33 ± 0.3 ab	8 ± 1 ab
Wheat line with *Dny* gene	3.00 ± 0.0 ab	2.67 ± 0.3 a	12 ± 3 ab
Oat	1.67 ± 0.1 a	1.00 ± 0.0 c	3 ± 2 a
Tsaeda Shewa (barley line)	5.67 ± 0.1 c	2.33 ± 0.3 ab	15 ± 8 b

NOTES: Means in a column followed by the same letter are not significantly different at $P<0.05$ according to DMRT.

Furthermore, barley varieties did not react differently to the RWA clones, except for 848-1, which was resistant to the Shewa clone and susceptible to the Gonder clone.

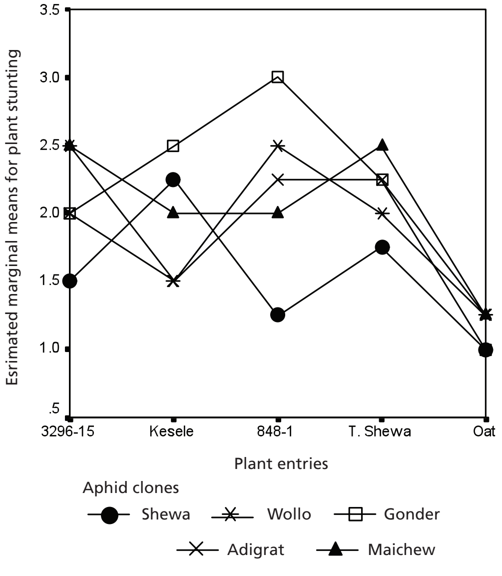
The estimated amount of plant stunting caused by the five RWA clones is presented in Figure 1. Barley entries did not react differently to the RWA clones, except that 848-1 revealed considerable variation. The Gonder RWA clone produced the highest damage on 848-1, whereas the Shewa RWA clone caused the least amount of stunting damage. The values for the RWA clones Wollo, Adigrat and Maichew fall between those of the Shewa and Gonder RWA clones. The Shewa clone did not cause severe stunting damage on Tsaeda Shewa and 3296-15.

The mean values of the RWA biomass for the Shewa clone were significantly different from those of the Wollo, Adigrat and Maichew clones, but not from the Gonder clone. Barley varieties did not reveal significant differences with respect to the RWA biomass (Figure 2). As before, barley entry 848-1 exhibited considerable variation among the RWA clones. The RWA biomass on the resistant control was small, with only one exception, Maichew. The RWA biomass produced by the Shewa clone was less than other clones.

No biotypic variation was found among the five RWA clones tested on four barley varieties. The damage to the plants caused by the different Ethiopian RWA clones was not significantly different, although chlorosis, leaf rolling, plant stunting and RWA biomass revealed more variation on barley line 848-1. The RWA clone from Gonder caused a higher degree of chlorosis, leaf rolling and plant stunting on 848-1 compared with the other RWA clones. This variation in reaction of the same barley line to the RWA clones shows a different fitness among the RWA clones; however, this is too low to determine

FIGURE 1

Comparison of plant stunting caused by the RWA clones for the five barley varieties

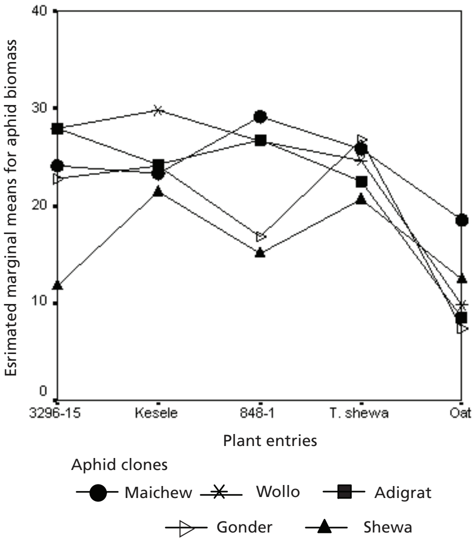


biotypes (Tesfaye Belay, 2003; Tesfaye Belay, Smith and Stauffer, 2004).

The absence of biotypic variation can be attributed to the traditional farming systems of Ethiopian farmers, as they plant mainly landraces. Landraces are mixtures of different genotypes selected over many generations under different stress situations (Ceccarelli and Grando, 1996). According to Smith (1989), avoidance of monocultures and the planting of varieties with different resistance genes slows the development of insect biotypes. One example is the brown rice plant hopper (*Nilaparvata lugens*), which develops on rice cultivars with monogenic resistance (Heinrichs, 1986). To judge from the results of this study, the mechanism of resistance on the barley genotype 3296-15 seems to be tolerance as it produced more tillers and leaves compared with the other barley varieties. This mechanism may hold true for many landraces. Tolerance does not put the RWA under selection pressure, which could result in the development of biotypes that are capable of overcoming the plant's resistance (Panda and Khush, 1995; Kennedy *et al.*, 1987).

FIGURE 2

Response of barley varieties to the five RWA clones, reflected in terms of RWA biomass



BIOTYPIC DIFFERENCES BETWEEN ETHIOPIAN AND NORTH AMERICAN RWA POPULATIONS

Biotypic differences between Ethiopian and North American RWA populations were investigated using resistant wheat varieties from the USA. Six wheat varieties with the *Dn2*, *Dn4*, *Dn5*, *Dn6*, *Dnx* and *Dny* genes were included, along with the resistant oat line and a susceptible barley cultivar. The varieties were proven to be resistant to the RWA in North America. *Dn4*, however, was susceptible to the Czech RWA population (Smith, pers. comm.). Single plants in each pot were infested with approximately 25 RWA adults at the three-leaf stage, according to the wheat growth stages of Zadoks, Chang and Konzak (1974). The experiment used three blocks, which corresponded to three RWA clones (Shewa, Gonder and Adigrat), and eight plant varieties in a randomized complete block design. Evaluation of varieties and data analysis procedures were the same as those followed for barley.

Of the six wheat varieties, significant differences were detected in chlorosis rating, leaf rolling, RWA biomass, plant height and number of leaves. Table 3 details these differences. Four wheat varieties (with genes *Dnx*, *Dny*, *Dn6* and *Dn4*) yielded chlorosis values that were comparable with the resistant control, whereas *Dn2* and *Dn5* showed a chlorosis rating similar to that of the susceptible control. On the leaf rolling scale, *Dn5*, *Dn6* and *Dn2* were not significantly different from the resistant control. *Dn4*, *Dnx* and *Dny* had leaf rolling damage ratings similar to the susceptible control. A comparison of plant height showed no significant difference between *Dn4* and the resistant control. A comparison of *Dn4* and *Dn6* across the parameters revealed that there was no significant difference in chlorosis. Of the two, *Dn6* suffered less leaf rolling and supported a smaller RWA biomass, whereas *Dn4* incurred a greater leaf rolling damage. The RWA biomass was high on *Dn4* and was significantly different from the resistant control.

TABLE 4
Mean values ± SE of chlorosis, leaf rolling and RWA biomass (mg) for the three RWA clones

RWA	Chlorosis	Leaf rolling	RWA biomass
Shewa	2.8 ± 0.1 a	1.7 ± 0.3 a	13 ± 4 a
Gonder	3.3 ± 0.2 a	2.0 ± 0.3 a	5 ± 2 b
Adigrat	3.4 ± 0.2 a	2.0 ± 0.3 a	7 ± 2 b

NOTES: Means in a column followed by the same letter are not significantly different at *P*<0.05 according to DMRT.

The three RWA clones were further tested for biotypic variation, but no differences emerged among the RWA clones for any parameters except RWA biomass (Table 4). The Shewa clone (13 mg) differed significantly from the Gonder (5 mg) and Adigrat (7 mg) clones. All other host reactions among the RWA clones were not significantly different.

As no significant differences were found among the three RWA clones (Shewa, Gonder and Adigrat) with respect to biotypic variation, this indicates that they belong to the same biotype (Tesfaye, 2003; Smith *et al.*, 2004; Tesfaye Belay, Smith and Stauffer, 2004). The Ethiopian biotype showed a reaction similar to that of the Czech biotype and, in particular, the wheat entry with *Dn4* was susceptible to both the biotypes (Smith, per. comm.). However, the results were different for the North American biotype, as *Dn4* was resistant to the American RWA clone (Smith, pers. comm.). Puterka, Burd and Burton (1992) found biotypic variation to exist between the RWA from the former USSR and Turkey. Furthermore, Basky *et al.* (2001) detected differences between the South African and Hungarian RWA clones. In a random amplified polymorphic DNA analysis, Puterka *et al.* (1993) detected slight differences among populations.

GENETIC VARIATION AMONG WORLDWIDE RWA POPULATIONS, INCLUDING ETHIOPIAN POPULATIONS

Source of RWA populations and DNA extractions

The RWA populations used in this study were obtained from Canada, Czech Republic, Ethiopia (Tigray), Hungry, Moldova, South Africa, Syria, Turkey and USA. All specimens arrived in absolute ethanol and were stored at –20°C. DNA was extracted from individual aphids using a GeneEluteTM Mammalian Genomic DNA Kit from Sigma (Saint Louis, MO, USA). Extracted DNA was suspended in 50 µL elution buffer for future use. The quantity of DNA was checked on a 1.0% agarose gel.

PCR of mtDNA

One fragment of the cytochrome oxidase I gene (COI) gene was amplified for seven RWA populations using the primers: C1-J-1718, L2-N-3014, C1-J-2442 and RWACOIR2 (Table 5). PCR was carried out in a 25 µL reaction volume containing 0.2 µM dNTP, 0.2 µM forward and reverse primers, 1 µL template DNA and 1 U of Taq DNA polymerase (Sigma), plus reaction buffer. ddH_2O was added to the final volume. A touchdown thermal profile was used and the PCR was an MJ Research PTC-100 (MJ Research, MA, USA). Amplified products were visualized by electrophoresing in 1% agarose gels, stained with ethidium bromide and photographed under UV light.

TABLE 5

Primers used for amplifying the complete COI gene

Primer	5′–3′ sequence
C1-N-2191	CCC GGT AAA ATT AAA ATA TAA ACT TC
C1-J-1859	GGA ACG GAT GAA CAG TTA CCC CC
C1-N-2329	ACT GTA AAT ATA TGA TGA GCT CA
TY-J-1460	TAC AAT TTA TCG CCT AAA CTT CAG CC
RWACOIF2	CCA GCA GGA GGA GGA GAT CC
RWACOIF3	GCA GGA ATT TCA TCA ATT TTA GG
RWACOIR4	CAA ACA ATG AAT CCT AAT AAC CC
RWACOIF4	GGA ACA GGA TGA ACT ATT TAT CCA CC
RWACOIR3	GGT GGA TAA ATA GTT CAT CCT GTT CC
RWACOIR2	GGA TCT CCT CCT CCT GCT GG
RWACOIF1	CAG TTT AAT TCA CTG ATT TCC
RWACOIR1	GGA AAT CAG TGA ATT AAA CTG

NOTES: The first four were from Simon *et al.*, 1994; the RWA series were designed.

TABLE 6

Primers used for amplifying the *DnaN* and *ptrpE* genes of the endosymbiont *Buchnera* of the RWA

Primer	5′–3′ sequence	Position
dnaNf	CGT TTA ATT ACT AAA AAT AGC	Forward
dnaNr	TTC GTG ATA TAA ATT TCT ACG CC	Reverse
ptrpEf	CAA TAA CCA ACA TTG TTA CTG G	Forward
ptrpEr	CTA AAT AAA AAC AAA AGT GGG GG	Reverse

NOTES: All primers were designed.

PCR of microsatellites

For the amplification of microsatellite loci (S16b and S17b), PCR was carried out in a 50 µL volume. Each reaction included 4 µL of template DNA, 1× reaction buffer, 0.2 µM dNTPs, 0.2 µM forward and reverse primers and 1 U of BiothermTM DNA polymerase (Genecraft, Munster, Germany). ddH_2O was added to the final volume. For both loci, an annealing temperature of 55°C for 1 min (35×) was used. PCR products were loaded on a 2% agarose gel and fragment sizes were estimated by comparison with a 100-bp ladder.

PCR of endosymbiont *Buchnera* – *dnaN* and *ptrpE*

The DNA polymerase III beta subunit (*DnaN*) gene and *ptrpE* were amplified using primers, as presented in Table 6. Reactions were carried out in 50 µL volumes: 4 µL of template DNA, 1× reaction buffer, 0.2 µM dNTPs, 0.2 µM forward and reverse primers and 1 U of BiothermTM DNA polymerase (Genecraft), and ddH_2O was added to the final volume. A touchdown programme was used. PCR products were loaded onto a 2% agarose gel for visualization in Tris-borate-EDTA (TBE). Fragment sizes were estimated by comparison with a 100-bp ladder.

Restriction digestion of *ptrpE* PCR products

PCR-amplified products of the endosymbiont *Buchnera* pseudogene (*ptrpE*) from four distant populations (the Czech Republic, Ethiopia, Turkey and USA) were digested with NIa*III* (New England BioLabs, MA, USA). A total of 20 U of the enzyme was used in a total reaction volume of 20 µL. Each reaction included

1× NE Buffer, 0.8 µL ddH_2O, 0.2 µL BSA and 16 µL of the PCR product. The reaction mixes were incubated for 2 h at 37°C in a water bath. Restriction products were separated by running for 1 h on a 2% agarose gel.

Purification of PCR products

Templates for direct sequencing were prepared by purifying PCR products using a Sigma GenElute Cleanup kit and/or a QIAquick PCR Purification kit (QIAGEN, Hilden, Germany).

Sequencing

Cycle sequencing reactions for COI were performed using BigDye (Applied Biosystems, Foster City, CA, USA). C1-J-1718 and L2-N-3014 were used for sequencing in addition to a number of primers mentioned in Table 6. Extension products were purified from unincorporated dye terminators by precipitating them into microcentrifuge tubes (QIAGEN). Sequences were generated from an ABI Prism 310 Genetic Analyzer (Applied Biosytems). The primers S16bf and S17bf (Wilson and Sunnucks, pers. comm.) were used for sequencing purified PCR products of microsatellite loci S16b and S17b, respectively. *DnaNf* and *ptrpEf* were the sequencing primers for the *DnaN* and *ptrpE* genes, respectively.

Sequence data analysis

Sequences were aligned using Clustal X (Jeanmougin *et al.*, 1998). The sequences were compared using the BLAST search (Altschul *et al.*, 1997). Furthermore, the pseudogene sequences were compared using a functional copy of *trpE*. The complete COI sequence was compared with DNA sequences available in GenBank. Sequences were aligned and translated with the invertebrate mitochondrial genetic code using the MEGA version 2.1 computer software package (Kumar *et al.*, 2001). The amino acid sequence of COI was divided into 25 regions lying in five structural classes (12 transmembrane helices, 6 external loops, 5 internal loops, carboxyl and amino terminals) (Saraste, 1990). The points of transition between these regions were taken from Lunt *et al.* (1996). The number of different amino acid residues observed at each position of protein alignment were recorded, and the variability levels expressed as the average number of amino acids per site in a given region. This analysis was limited to the 510 homologous positions between the ends of the shortest sequence. Statistical tests were carried out using SPSS 2000 (SPSS Inc.). A Kruskal–Wallis test (analysis of variance by ranks) was performed on data sets to test the hypothesis of no difference in the average amino acid variability among the 25 regions of the COI gene.

mtDNA variation among RWA populations

COI fragments, including the NH_2 and COOH regions, were amplified and sequenced from worldwide collections of the RWA populations. A fragment containing 432 base pairs at the 5'-end was sequenced from populations collected in the Czech Republic, Ethiopia, Turkey and USA. The 3'-start region encompassing a 394-bp stretch was sequenced from five populations collected in Canada, Ethiopia, South Africa, Syria and USA. All the sequences generated were deposited in GenBank and accession numbers are presented in Table 7. For both COI fragments, no substitutions were detected among the populations.

Microsatellite variation among RWA populations

Two primers, S16b and S17b, isolated from *Sitobion miscanthi* (Wilson and Sunnucks, pers. comm.), were used for the RWA populations. Primer pairs for loci S16b and S17b amplified products of about 150 and 120 bp length, respectively (Figures 3 and 4). The cross-amplification of the primers isolated from a *Sitobion* species was successful. Sequence analysis revealed that the S16b loci contained (AC)12 (Figure 5) and the S17b loci contained (AC)4AA(AC)2AT(AC)2... (AT)6...(AC)5 (Figure 6). However, no differences were found in the three populations analysed: Czech Republic, Ethiopia and USA.

Endosymbiont *Buchnera* dnaN

About 600 bp of the *Buchnera* chromosome gene (*DnaN*) was amplified and sequenced for four distant RWA populations: Czech Republic, Ethiopia, Turkey and USA. Aligned sequences did not reveal nucleotide polymorphisms. Sequences were deposited into GenBank (Table 8).

ptrpE gene sequence – RFLP

The *Buchnera* pseudogenes of *trpE* from four RWA populations (Czech

TABLE 7

GenBank accession numbers for the COI sequences from worldwide RWA populations

Accession number	Length	Source
AY241699	432 bp	Czech Republic
AY241700	432 bp	Turkey
AY241698	432 bp	USA
AY241697	432 bp	Shewa, Ethiopia
AY241701	394 bp	Syria
AY241702	374 bp	Canada
AY241703	375 bp	South Africa
AY241704	376 bp	USA
AY241705	376 bp	Tigray, Ethiopia

FIGURE 3

DNA bands amplified with S16b primers: (1) Ethiopia, (2) Czech Republic, (3) USA, (4) Turkey, (5) Control, (6) 100-bp ladder

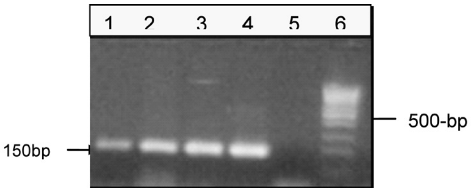


FIGURE 4

DNA bands from RWA populations amplified with the S17b primers: (1) Ethiopia, (2) Czech Republic, (3) USA, (4) Turkey, (5) Control, (6) 100-bp ladder

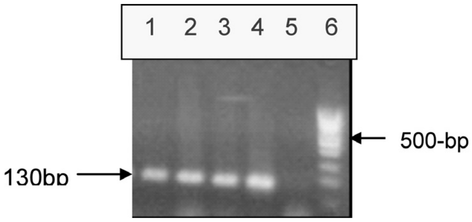


TABLE 8

GenBank accession numbers for *DnaN* sequences from the endosymbiont *Buchnera* of the RWA

Accession	Length	Source
AY254399	654 bp	Ethiopia
AY254398	604 bp	USA
AY254397	653 bp	Czech Republic
AY254396	603 bp	Turkey

FIGURE 5
Sequence of the S16b locus, revealing that the amplified PCR product contained a microsatellite

1 37

TGCGCTAGGGGCAGCCCCCGAGACATAGGGTAGAAAT

ACACACACACACTATTGTTGTAGTATTGCAGTACACA

TACCGACTCTGGCGGTAAATTATTTTTAATTTCGGTT

TTCATTTAACGACACGTGGAACCTTTACTTTTACA

→ 146

FIGURE 6
Sequence of the S17b locus, revealing that the amplified PCR product contained a microsatellite

1 30

TCTCTATGTCGTTATCATCCGATTCTTATT

TTCTTTACACACACAAACACATACACAGTA

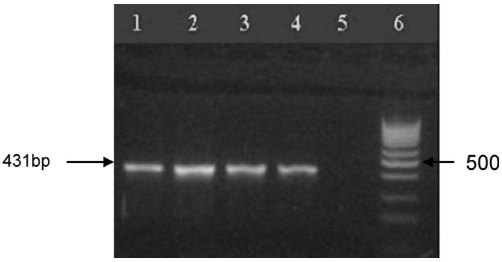
CGCTATATATATATGAATATTATATACTAC

AAACACACACGAGTAACTTACACGGTTCAC

TAACGCGACGGA

→ 132

FIGURE 7
PCR products (431 bp) of the endosymbiont *Buchnera* pseudogene ptrpE amplified for four RWA populations: (1) Czech Republic, (2) Ethiopia, (3) USA, (4) Turkey, (5) Control and (6) 100-bp ladder



Republic, Ethiopia, Turkey and USA) were amplified (Figure 7). Products were sequenced to determine whether the *trpE* pseudogenes in the different *Buchnera*-RWA populations are homologous. Sequence alignments did not yield substantial amounts of nucleotide variation in the distant RWA populations, except for a single nucleotide substitution found in the Turkish population (Figure 8). This substitution proved to be a restriction site. *NIa*III cut once in the Czech Republic, Ethiopian and USA populations, whereas it cut twice in the Turkish populations (Figure 8). Pseudogene sequences were translated; however, mutations were distributed randomly and open reading frames could not be recognized.

Complete COI sequence of RWA

The complete sequence of the COI gene of RWA was sequenced and found to be 1537 bp long. The complete sequence has been aligned with COI sequences of five species of insects from different orders. The RWA COI sequence was deposited in GenBank and given the accession number AY195985. The complete sequence was found to be AT-rich, with nucleotides in the following proportions: 76% A, 10.3% G, 41.6% T and 12.8% C. The percentage nucleotide composition at the first, second and third codon positions of the RWA COI gene are presented in Figure 9. The percentage AT is higher at the 3rd codon position (94.7% AT) than at the two other codon positions.

The COI gene of the RWA attained relative synonymous codon usage values that were greater than 1 for codons ending with T or A (Table 9). The initiation codon for the RWA COI gene is ATA and the stop codon is TAA (Table 10). Translation of the nucleotide sequence with the invertebrate genetic code (Clary

FIGURE 8

RFLP of the endosymbiont *Buchnera* pseudogene trpE using NlaIII, showing the difference between Turkey (135 bp) and the other populations (124 bp). (1) Czech Republic, (2) USA, (3) Ethiopia, (4) Turkey and (5) 100 bp ladder.

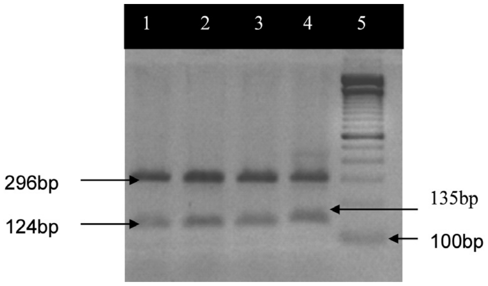
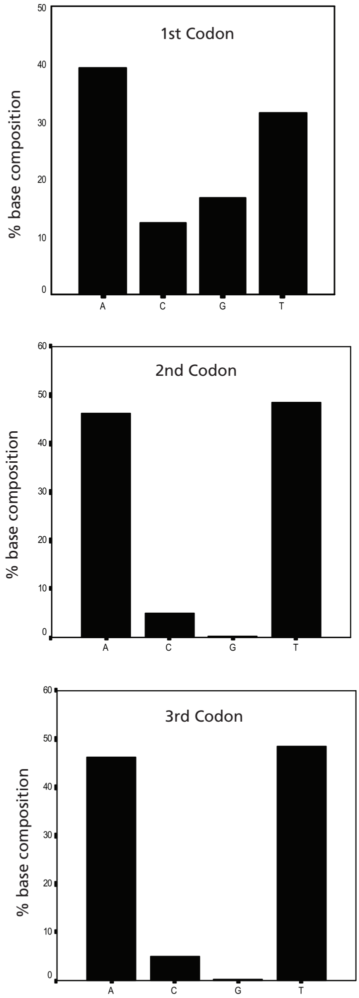


FIGURE 9

Base composition at three codon positions for the RWA COI gene. A higher AT content can be seen on the third codon position relative to the first and second codon positions



and Wolstenholme, 1985) revealed an open reading frame of length 511 amino acid.

Analysis of the amino acid sequence with the Kyte–Doolittle algorithm using the WinPep program (Hennig, 1999) showed 12 transmembrane helices (Figure 10). The same number of transmembrane helices was also obtained when the amino acids were analysed using HMMTOP 2.0 (Tusnády and Simon, 1998).

Translation of the nucleotide sequence resulted in an amino acid sequence with a mixture of residues conserved across all studied species and residue positions of differing levels of variability. Two INDEL events are apparent between the RWA and the other insect species. A 2-bp INDEL was shared by the RWA, *Locusta migratoria*, *Triatoma dimidiata*, *Apis mellifera* and *Drosophila yakuba*, whereas a single bp INDEL occurred in the RWA, *Locusta migratoria*, *Triatoma dimidiata* and *Apis mellifera*. Both INDEL events fall at the 3' end. The COI amino acid sequence was divided into 25 regions within the five structural classes [12 transmembrane helices (M1-M12), six external loops (E1–E6), five internal loops (I1–I5), carboxyl (COOH) and amino (NH_2) terminals] (Figure 11). Alignment of amino acids with known sequences helped to determine the transition points among the 25 regions. In order to test the null hypothesis that there is no difference among the 25 regions, a Kruskal–Wallis analysis was performed that led to rejection of

TABLE 9

Frequency of codons in COI from the RWA. Data computed following the invertebrate mitochondrial translation table. Total number of codons = 511. The relative synonymous codon usage is given in parenthesis

Codon	%	Codon	%	Codon	%	Codon	%
UUU (F)	38.0 (1.69)	UCU (S)	10.0 (1.78)	UAU (Y)	15.0 (1.88)	UGU (C)	2.0 (1.33)
UUC (F)	7.0 (0.31)	UCC (S)	0.0 (0.00)	UAC (Y)	1.0 (0.13)	UGC (C)	1.0 (1.33)
UUA (L)	49.0 (4.98)	UCA (S)	24.0 (4.27)	UAA (*)	1.0 (2.00)	UGA (W)	14.0 (2.00)
UUG (L)	0.0 (0.00)	UCG (S)	0.0 (0.00)	UAG (*)	0.0 (0.00)	UGG (W)	0.0 (0.00)
CUU (L)	3.0 (0.31)	CCU (P)	12.0 (1.92)	CAU (H)	12.0 (1.50)	CGU (R)	0.0 (0.00)
CUC (L)	0.0 (0.00)	CCC (P)	0.0 (0.00)	CAC (H)	4.0 (0.50)	CGC (R)	0.0 (0.00)
CUA (L)	7.0 (0.71)	CCA (P)	13.0 (2.08)	CAA (Q)	6.0 (2.00)	CGA (R)	6.0 (4.00)
CUG (L)	0.0 (0.00)	CCG (P)	0.0 (0.00)	CAG (Q)	0.0 (0.00)	CGG (R)	0.0 (0.00)
AUU (I)	76.0 (1.90)	ACU (T)	11.0 (1.42)	AAU (N)	34.0 (1.84)	AGU (S)	2.0 (0.36)
AUC (I)	4.0 (0.10)	ACC (T)	0.0 (0.00)	AAC (N)	3.0 (0.16)	AGC (S)	0.0 (0.00)
AUA (M)	27.0 (2.00)	ACA (T)	20.0 (2.58)	AAA (K)	11.0 (1.83)	AGA (S)	9.0 (1.60)
AUG (M)	0.0 (0.00)	ACG (T)	0.0 (0.00)	AAG (K)	1.0 (0.17)	AGG (S)	0.0 (0.00)
GUU (V)	8.0 (2.29)	GCU (A)	9.0 (2.00)	GAU (D)	8.0 (1.45)	GGU (G)	6.0 (0.67)
GUC (V)	1.0 (0.29)	GCC (A)	1.0 (0.22)	GAC (D)	3.0 (0.55)	GGC (G)	0.0 (0.00)
GUA (V)	5.0 (1.43)	GCA (A)	8.0 (1.78)	GAA (E)	7.0 (2.00)	GGA (G)	29.0 (3.22)
GUG (V)	0.0 (0.00)	GCG (A)	0.0 (0.00)	GAG (E)	0.0 (0.00)	GGG (G)	1.0 (0.11)

TABLE 10

Summary of data relevant to the COI gene for six species of insects

Organism	Order or sub-order	Initial codon	Terminal codon	Length (bp)	% AT	Accession no.
Diuraphis noxia	Homoptera	ATA	TAA	1537	76	AY195985
Bombyx mori	Lepidoptera	CGA	T	1531	72.7	AF149768
Triatoma dimidiata	Heteroptera	ATG	T	1534	62.9	NC_002609
Locusta migratoria	Orthoptera	ATTA	T	1536	69	X80245
Drosophila yakuba	Diptera	ATAA	TAA	1540	70	X03240
Apis mellifera	Hymenoptera	ATA	T	1566	76	L06178

SOURCES: AF149768 – Belay and Stauffer, 2003; NC_002609 – Dotson and Beard, 2001; X80245 – Flook *et al.*, 1995; X03240 – Clary and Wolstenholme, 1985; and L06178 – Crozier and Crozier, 1993.

FIGURE 10

Kyte and Doolittle (1982) hydropath plot for the RWA COI gene using a window length of 11 residues. The 12 transmembrane α-helices are indicated by dashes above the plot

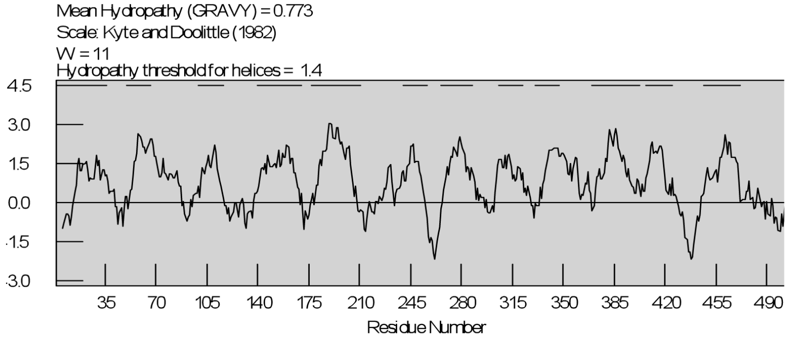


FIGURE 11

Amino acid variation among the 25 regions of the COI protein

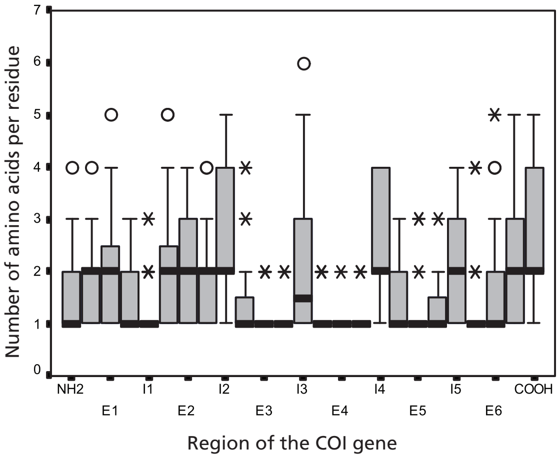
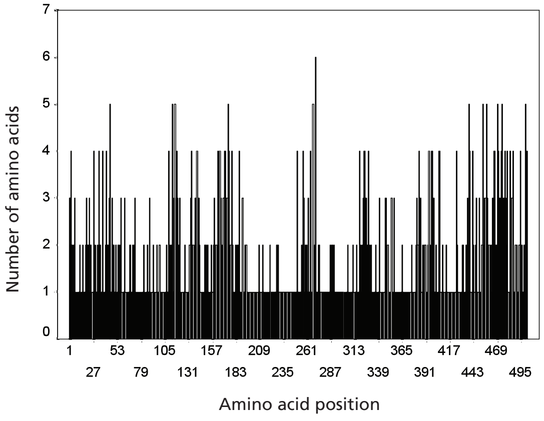


FIGURE 12

A graphical representation of the distribution of amino acid variability (number of different amino acids per residue site) on the COI gene of insects belonging to five different orders



the hypothesis with a probability of $P<0.0001$. When the average variability per residue site was calculated for the 25 regions, no significant differences in variability among the COOH, I2 (Internal loop 2) and I4 (Internal loop 4) were found (Figure 11). The variability in COOH, I2 and I4 was significantly higher than in I1, E3, E4, E5, M5, M6, M7, M8, M10 and M11. Figure 12 shows the number of amino acids per residue site, and it is evident that large differences in the number of amino acids exist along the complete protein sequence.

RWA populations were analysed using the mitochondrial COI gene, two microsatellite loci, and *dnaN* and *ptrpE* from the endosymbiont *Buchnera*. The two microsatellite loci (S16b, S17b) used in this study were originally isolated from *Sitobion miscanthi* (Wilson and Sunnucks, pers. comm.) and revealed a cross-reaction to the RWA. Sloane *et al.* (2001) and Delmotte *et al.* (2002) demonstrated the use of microsatellite primers among the related taxa *Myzus persicae* and *Rhopalosiphum padi*. Thus, none of the markers revealed variation except for a single substitution obtained on the pseudogene *ptrpE* (Tesfaye, 2003; Tesfaye Belay, Smith and Stauffer, 2004). *Schizaphis graminum* (Shufran *et al.*, 2000), *Acyrthosiphon pisum* (Boulding, 1998) and *Therioaphis trifoli* (Sunnucks *et al.*, 1997) have displayed high levels of genetic variation when analysed on a phylogeographical basis. Microsatellites have also revealed genetic variation among *Sitobion* populations (Simon *et al.*, 1999; Wilson, Sunnucks and Hales, 1999). The lack of genetic variability could be due to the recent spread of RWA from its area of origin, as expansion to the Southern and Western Hemispheres occurred in the 1970s. RWA is thus one of the organisms with the fastest rates of range expansion (Wellings and Dixon, 1987). Loxdale and Brooks (1989) reported that aphid species that exhibit high migration show greater homogeneity of gene frequencies and concomitant interpopulation gene flow, whereas species with low migration levels show the opposite.

Most populations included in this study were anholocyclic (Canada, South Africa, Syria, Turkey and USA), whereby reproduction is fully parthenogenic. Apomictic parthenogenesis produces true clones that are genetically identical; exceptions to this occur only rarely due to mutations, chromosomal re-arrangements or mitotic recombinations (Hales *et al.*, 1996). None of the mechanisms mentioned above were able to yield genetic variability in the RWA. It is only through a sexually reproductive stage that aphid populations can greatly extend genetic variation. This is regarded to be the main reason for the high diversity of, for example, *Schizaphis graminum* (Rondani) in the USA (Shufran, Burd and Webster, 1997).

The only variability found was substitution in the *ptrpE* gene of the endosymbiont *Buchnera*. Considering also the sequences already published in GenBank, the Morocco populations seemed to have accumulated more mutations. Martinez-Torres *et al.* (1996) suggested the usefulness of *Buchnera* plasmids with the mtDNA in exploring the genetic diversity of aphids because both are maternally inherited. Birkle and Douglas (1999) found that pea aphid clones with the same restriction site on pseudogenes were found to belong to the same mtDNA haplotype. Furthermore, pseudogenes are non-coding copies of protein-coding genes and are presumed to have evolved without selective constraints (Petrov and Hartl, 2000). Thus, it might be beneficial to more thoroughly explore the *Buchnera* genome and plasmids.

The COI of the RWA has been completely sequenced and it is the first complete COI gene from a representative of the suborder Homoptera. Complete COI nucleotide information in GenBank is available for only one other species, a member of the order Hemiptera. The initiation (ATA) codon suggested for the RWA is consistent with that reported for *Apis mellifera* (Crozier and Crozier, 1993). Similar termination codons (TAA) were also reported for *Phormia regina* (Sperling *et al.,* 1994) and *Drosophila yakuba* (Clary and Wolstenholme, 1985). *Triatoma dimidiata* has a different initiation codon (ATG) and termination codon of a single T (Dotson and Beard, 2001). Organisms that terminate with a single T or TA produce complete termination codons (TAA) by post-transcriptional polyadenylation (Ojala, Montoya and Attardi, 1981.). The initiation codons are known to vary among insect species belonging to the same genus (Beard, Hamm and Collins, 1993.).

At the nucleotide level, RWA exhibits the highest A+T content (76%), which is comparable with that in *Apis mellifera* (Crozier and Crozier, 1993). Most codons of the RWA COI gene end with A or T. The base composition of mtDNA is highly correlated with codon usage, because insect mitochondrial protein genes exhibit a preference for using A+T-rich codons (Crozier and Crozier, 1993). Due to codon preference, the base composition in RWA is particularly biased at the third codon position, totalling 94.7% A+T. The A+T content at the first and second positions are 78.9% and 65.2%, respectively. Similar tendencies have been observed for other insects (Lunt *et al.*, 1996; Navajas *et al.,* 1994; Morlais and Severson, 2002).

In the present study, six species belonging to five different orders were included, and variability among the 25 regions of the COI gene was analysed. The results increase our understanding of variability in the COI gene. Previous reports, by Lunt *et al.* (1996) and Liu and Beckenbach (1992), had indicated that the COOH terminal was the only variable part of the COI gene. Furthermore, the study by Lunt *et al.* (1996) was limited to the five structural classes of the COI gene and insects belonging to three different orders. Our results indicated the suitability of the internal loops I1 and I4 for lower-level analysis of intraspecific variation, in addition to the COOH terminal.

After alignment of the complete COI gene with sequences from various species published in GenBank, variability was found to be distributed throughout the whole length of the COI gene. The most variable regions appeared to be the COOH terminal, internal loop 2 (I2) and internal loop 4 (I4). Internal loop 1 is the most conserved, when compared with the other four internal loops, which are relatively variable. Alignment of 22 animal COI genes also revealed a similar pattern of conservation for the internal loop 1 (Lunt *et al.*, 1996). The functional role of internal loop 1 is unclear (Lunt *et al.*, 1996), but the conserved sequence indicates that it must serve an important role. The functions of the external loops E3, E4 and E5 are unclear but seem to be conserved. Several transmembrane helices (M5, M6, M7, M8, M10 and M11) are also conserved. M6, M7 and M10 are known to provide the metal ligands to interact with the two-haem groups and copper atom that are essential for the activity of COI (Gennis, 1992). M8, which was thought to be essential for the protein-conduction channel, contains polar residues that are completely conserved among all organisms so far studied (Gennis, 1992).

RWA was introduced to Ethiopia approximately 25 years ago. This investigation demonstrated that no biotypic variation is present in several Ethiopian RWA populations when analysed on wheat and barley. Puterka, Burd and Burton (1992) pointed out some biotypic differences among worldwide RWA populations, and Basky *et al.* (2001) found differences between South African and Hungarian populations. We also witnessed biotypic variation between USA and Ethiopian RWA clones. This difference could be due to environmental differences as RWA clones did not reveal genotypic variation (Shapiro, 1976). It is possible that, in the future, new biotypes will be introduced to Ethiopia. Thus, it is recommended that a monitoring system be implemented to obtain biological data approximately every 5 years. Such a system would benefit the barley and wheat breeding programmes.

The molecular markers used in this study, except those for the pseudogene *ptrpE* of the endosymbiont *Buchnera*, revealed no genetic variation among worldwide collections of RWA. This means that such pseudogenes are likely to be valuable tools when examining the genetic diversity of RWA populations. If so, it will be important to obtain the complete sequences of the endosymbiont *Buchnera* pseudogenes (*ptrpE* and *pleuABC*) and compare them with various

RWA populations. Furthermore, the search for microsatellites from RWA populations could shed more light on the population structure. Detection of changes in the genetic structure could, in turn, be used to identify RWA biotypes, which is important information for plant breeders.

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Bionomics, host preference and survival of a coleopterous seedling pest of barley

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INTRODUCTION

In Ethiopia, particularly in Tikur Inchini (8°51'N, 37°42'E) and its environs, root-feeding coleopterous larvae were recorded as the main barley pest, attacking seedlings. Total barley seedling losses have been recorded in some fields in Tikur Inchini where barley was planted after barley, linseed or on land fallowed for several years before being planted to barley (1994, pers. obs.). Farmers in the area had been using seed dressing insecticides, which included: aldrin, dieldrin and heptachlor. However, in the recent past, Carbosulfan 25% ST has been used for dressing barley and wheat seeds.

This root-feeding barley seedling pest was identified as a coleopterous scarabaeid beetle belonging to the family Scarabaeidae, subfamily Melolonthinae and genus Melolontha. As well as this species, Hill (1975) described one *Melolontha* species as the most important root pest in Ethiopia, and Crowe, Tadesse Gebremedhin and Tsedeke Abate (1977) recorded several species of *Schizonychus* as being important root-feeding beetles on different crops.

Melolontha spp. have worldwide importance and are reported to be serious pests, the larvae of which feed on roots of many plant species, including trees (reviewed by Keller *et al.*, 1997). For example, the common European cockchafer, *Melolontha melolontha* L., was found to cause severe damage to crops, grasslands and pome trees in many countries in Europe (Bandaz, 1996; de Goffan, 1996; Forschle, 1996; Malinowski, 1998; Strasser, 1999; Zimmermann, 1998).

From a preliminary observation made in Tikur Inchini, the larvae of the scarabaeid beetle were recovered in fields that in the preceding crop growing season had been sown to barley, linseed, wheat or teff (*Eragrostis tef* (Zucc) Trotter) or had been fallowed. Most of the fallowed fields where the chafer grub larvae were recovered had been more than 1 year under fallow and had established grass cover. Crop seedling damage was, however, very common only in barley and wheat fields (pers. obs.). After the importance of this seedling pest was recognized, studies on the bionomics, seasonal survival and host preference of its larvae were conducted under field conditions in Tikur Inchini and in the laboratory at Holetta (9°03'N, 38°31'E). The results obtained from these studies are reported here.

MATERIALS AND METHODS

Bionomics of the chafer grub larvae

In 1995, barley-cropped fields with high levels of chafer grub population were chosen after sampling in 10 barley fields reported by farmers in the area to have had a serious chafer grub attack in the preceding season. The chosen field had been sown to barley for two consecutive seasons. Its size was about 2500 m^2. Monthly recordings of larval density were carried out for five consecutive months by quadrat (1 m × 1 m) sampling. On each sampling date, the quadrat was thrown into the field five times at random and the soil in the frame was dug out until no more larvae, pupae or adults were recovered. All the recovered larvae, pupae and adults were counted and recorded. The soil excavated from each quadrat sampled was not returned to the pit. Sampling was initiated in January, when all farmers in the area harvested their crops, and terminated by the end of May when the host farmer wanted to plough. Following the results of this monitoring, in 1998, comparisons were made of the bionomics of the insects between fields wherein barley, linseed and teff were grown in the previous season and in a field that was kept fallow for more than 2 years. The procedure used in 1995 was also used in this monitoring, but the sampling period was extended from January to June.

Chafer grub larvae host preference

It has been noted that the insect attacks barley more than teff or linseed. In order to determine the reason for this, a greenhouse experiment was carried out at Holetta. Two seedbeds of 100 cm × 50 cm × 20 cm were prepared from wood and corrugated iron sheets. These boxes were filled with soil brought from Tikur Inchini. The inside of the first box was divided into four compartments and 25 instar II chafer grub larvae were introduced into each compartment. The second box was not compartmentalized and 100 instar II chafer grub larvae were introduced, ensuring there was one larva present in every 50 cm^2 of the box.

In the first test (no choice), seedlings of crops commonly grown in Tikur Inchini, namely barley, teff, linseed and wheat, were raised in Petri dishes and transplanted into each compartment. In the second test (free choice), seedlings of the four crops were transplanted in mixed rows and each crop species was planted in five rows. In both tests, watering was carried out in such a way that the introduced larvae would survive and move about, with no impediment imposed by the wetness of the soil, to feed on the growing seedlings of their choice. In both experiments, the damage incurred on the growing seedlings of the four crops was recorded after 2 weeks.

Chafer grub larvae survival

Survival in bare soil

In Tikur Inchini, newly hatched larvae were found to have their abdomen full with ingested soil. This indicated that the pest depends on the soil as a source of food when its host plant is not available. Based on this, therefore, the survival of the grubs of this chafer grub in different soils with different soil textures and organic carbon content was tested under laboratory conditions.

Soil samples (1 kg) were steam sterilized from each of the four locations: Holetta (9°03'N, 38°31'E; two samples), Ginchii (9°02'N, 38°09'E), Tikur Inchini (8°51'N, 37°42'E) and Denbi (8°48'N, 38°24'E), and were used to fill plastic pots of Ø 25 cm and 20 cm depth. They were then wetted with sterilized tap water and 25 second-instar larvae of the chafer grub were introduced per pot. The response of the introduced larvae to the different soils was monitored, that is, whether the test larvae were avoiding the test soil samples, trying to feed on the test soils, or prevented from moving around freely. Finally, the survival of the test larvae was determined after 6 weeks. In addition, the texture and organic carbon content was determined in the different soil samples.

Survival under barley seedlings

After the suitability of the different test soils for the survival of the larvae of the insect had been established, the survival of its larvae in the Tikur Inchini soil under barley, the most attacked crop under field conditions, was studied. Barley seedlings germinated in Petri dishes were transplanted into pots (Ø 25 cm and 20 cm depth) filled with the test soil and 25 second-instar larvae were introduced per pot. This test soil was used in both steam sterilized and unsterilized form. Watering was carried out twice weekly, which did not affect the growth of the barley plants nor the free movement of the test larvae. Survival of the grubs in steam sterilized and unsterilized bare soil samples were included as checks. The survival of the test larvae in this experiment was determined after 1 month.

RESULTS AND DISCUSSION

Bionomics of the chafer grub larvae

In the 1995 monitoring, the proportion of different life forms of the chafer grub population changed with time; this was recorded for only 5 months and terminated when the farmer started to plough his field. 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 (after crop harvest and until February) the later instars dominated. In contrast, in April–May, the very young ones dominated (Table 1).

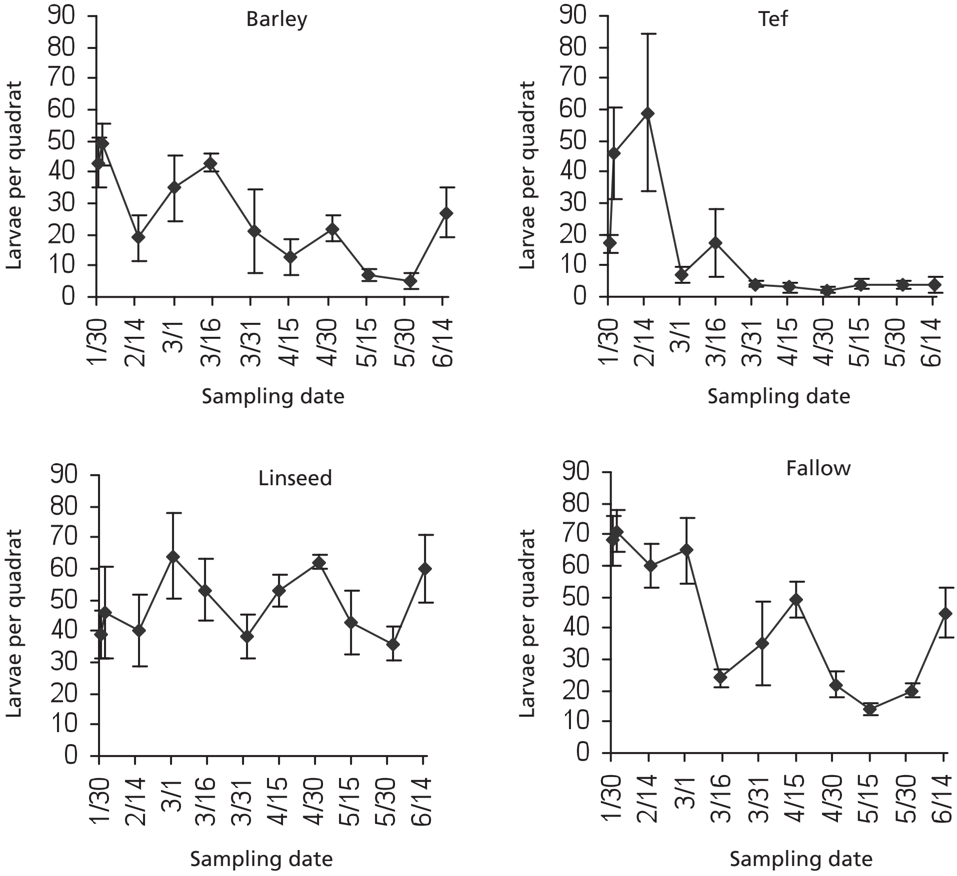
During the first 2 months, mated females were recovered, easily identified by their distended abdomen. In March to May there were very few or no gravid females found. Pupation occurred between April and May (Table 1). All the recovered females were dissected and the number of ready-to-lay eggs were removed and recorded. This was found to be 13–39 eggs per female. The recovered eggs were creamy white, with mid-longitude and mid-latitude dimensions of 1.96 and 1.29 mm, respectively.

TABLE 1
Mean monthly record of the larvae, pupae and adults of the chafer grub, *Melolontha* sp., in barley fields in Tikur Inchinii in 1995

Sampling month	Mean number trapped per 1 m^2 quadrat			Range per quadrat 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

FIGURE 1

Mean dry season survival trends in the populations of larvae of the chafer grub, *Melolontha* sp., in teff, barley and linseed fields and in fallow fields (1998 data)



During this monitoring, the depth of the digs ranged from just 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 greater than 20 cm. In March–April, there were some rain showers, which initiated some plant growth and increased soil humidity. This caused the larvae to rise closer to the surface and they were recovered underneath the growing plants to a depth of 20 cm. The annual variation in the depth at which the larvae were recovered showed that the movement of the chafer grubs was dictated by the change in the moisture gradient in the topsoil and the resulting degree of soil wetness at this depth. During the period of dry spells, the larvae move further down in the topsoil, where they can access moister soil, which provides them with food and the freedom to move about freely. At the start of the rainy season, they were forced to move back closer to the surface and reside underneath the vegetation cover due to the increased moisture at greater depths, which prevents both air circulation in the soil and free movement of the grubs. Thus, any control strategy should aim to disrupt this vertical migration that ensures survival and reproduction of this seedling pest.

The grub population during the monitoring period in 1998, which extended from January to June, was consistently higher in the fallow land and linseed field, whereas in barley and teff fields more larvae were recorded from January to mid-February, and then numbers declined consistently through to the end of the monitoring period (Figure 1). Moreover, the overall mean number of larvae recovered per quadrat was significantly different among the different crops and the fallow land (Figure 2).

All the larvae recovered in the teff field were, by-and-large, first and second instars, particularly in the first 2 weeks of the sampling period, implying that the colonization of teff 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 Figure 1, there was no build up during the remaining sampling period.

FIGURE 2

Mean ±SE number of larvae recorded per quadrat taken fortnightly in barley-, linseed- and teff-growing fields and in a fallow field

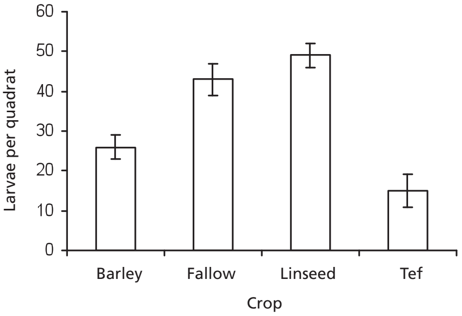
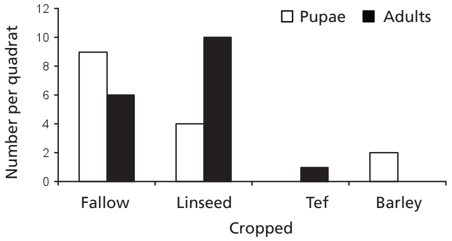


FIGURE 3

Mean total number of pupae and adults of the chafer grub, *Melolontha* sp., recovered between January and June, in teff, barley and linseed fields and a fallow field (Data from 1998)



Eggs were found laid in early March only in linseed and barley fields and in the fallow field, whereas no eggs were laid all through the sampling period in the teff field. Most of the pupae and adults present in the fallowed field were recovered between mid-April and early June. Similar trends were observed in linseed and barley fields, although the recorded numbers were much smaller (Figure 3). In teff fields, 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 teff field. The large population of early instar larvae recovered in the first 2 weeks in teff fields came from eggs laid before the monitoring was initiated.

Chafer grub larvae host preference

In the first greenhouse test, where the crop species were planted in separate compartments, 100% seedling kill was recorded in teff, 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 the second setting, the open bed, the damage on teff was about 80%, whereas the damage sustained by barley, wheat and linseed seedlings were 30%, 35% and 25%, respectively. Based on this, therefore, the most prone to larvae attack is teff. However, under field conditions, most damage was sustained by barley and the least by teff. This total reversal was thought to be due to the land preparation when the crop to be planted is teff or otherwise.

In Tikur Inchini, the planting ground for teff is ploughed more than four times, and then trampled by herds of sheep and cattle immediately after teff is sown. Ploughing for teff is initiated after the soil is wetted well. Thus, the repeated ploughing, which coincides with the natural upward movement of the larvae to close to the soil surface as a result of increased soil moisture at greater depth, exposes the larvae of the chafer grub to predation, and later to killing by animal trampling. The soil compaction from trampling makes it difficult for the surviving larvae to move freely in the soil. Thus, despite the greater preference the chafer grub larvae show for teff in the laboratory, the damage caused to teff under field conditions has been very low. In contrast, barley, wheat and linseed are sown after one ploughing, with a second ploughing for seed covering. This environment provides no impediment to the activities of chafer grub larvae, thus making the damage that might be incurred (particularly on barley and wheat seedlings) more significant. For example, on barley, 44 ±3.19% (n=5 fields) seedling death caused by the grubs was recorded in Tikur Inchini (Bayeh Mulatu, unpublished data, 1997). The farmers in the area do not sow barley, wheat or linseed on well-worked soil. This is because it is not then possible for animal herds to use these fields after they are sown to barley or wheat. Moreover, repeatedly ploughed fields, unless trampled by animals, allow the free movement of the larvae, hence increasing the risk of damage to the growing seedlings of barley or wheat.

The after effects of soil compaction, as practiced by farmers for teff, was observed in fields sown to barley after teff the previous season. In such fields, barley seedlings suffered minimum chafer grub damage (Bayeh Mulatu, pers. obs., 1995), indicating that soil trampling by animals and crop rotation could serve as cultural practices to manage the chafer grub.

Survival in bare soil

Avoidance of the Holetta red clay soil by the test grubs was observed at the start of the experiment. After 48 hours, however, they inhabited the red clay soil; this might have been due to the lack of other options. Movement of the test larvae introduced into the Ginchii heavy black clay soil was very limited. In general, there were large differences in the survival of the grubs in the different soils that had not been sown to crop seedlings (Table 2). However, larvae found alive in the Holetta red clay, Ginchi heavy black clay and Denbi silt clay soils were found to be in poor shape after they had survived 6 weeks in the bare soil. Moreover, most of the surviving grubs in these test soils were found to be infested with mites.

Total organic carbon content was determined in soil samples: the Tikur Inchini loam soil and the Holetta garden soil were found to have high organic carbon content, thus ensuring the survival of greater numbers of the test larvae

(Table 2). These results agree with the reports of Hill (1975) and Richards and Davies (1977), who said that soils with a 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 crop fields, if heavily manured. Thus, in using animal manure to fertilize crop fields, the possibility of colonization of such fields by this chafer grub or other species with similar niche requirements should be considered.

TABLE 2

Percentage survival of the larvae of the chafer grub, *Melolontha* sp., in bare soils from different locations, with different textures and organic carbon content

Soil sample tested			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 Inchini	Loam	14.38	68	12

Survival under barley seedlings

In the Tikur Inchini soil, larval survival was 92% in steam sterilized and 80% in unsterilized samples after the grubs were kept for 1 month under growing barley seedlings. In contrast, survival in bare soil was 52% in steam sterilized and 72% in unsterilized conditions. The test larvae kept under growing barley seedlings were in much better condition than those in the bare soil. The reduction in survival of the chafer grub larvae in steam sterilized and unsterilized bare test soil by 40% and 8%, respectively, when compared with the same test soils but in the presence of growing barley seedlings, indicates that the survival of the larvae of this chafer grub is better when there is a growing host crop on top. This highlights the importance of the insect as a pest of barley.

CONCLUSIONS

It can be concluded that a fallowed field with soil that is poorly worked, but rich in organic matter content, provides the best environment for this chafer grub, ensuring maximum survival and reproduction. Sowing barley, wheat and linseed one after the other will have similar effects on grub population build up. In contrast, repeated ploughing followed by animal trampling helps to minimize the chafer grub population significantly in the following season. These results therefore imply that the management of the chafer grub might best be ensured by practicing crop rotation and using repeated ploughing and soil trampling by sheep and cattle herds when the crop to be sown is teff. The first choice of crop to be sown following fallowing should be teff, and barley, wheat and linseed should follow teff, depending on the farmer's decision. Moreover, when a crop field is to be fallowed, it would be good to practice animal trampling, which might help to reduce the build up of the chafer grub population during the fallowing period.

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Pathology

Achievements of research on Barley Rusts and Powdery Mildew in Ethiopia

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INTRODUCTION

Diseases remain a major biotic constraint on barley production in Ethiopia. As many as 23 fungi, two bacteria, two viruses, and nine nematodes infect barley (Yitbarek Semeane *et al.*, 1996). Scald (*Rhynchosporium secalis*), blotches (*Helminthosporium* spp.), rusts (*Puccinia* spp.) and powdery mildew (*Erysiphae graminis*) are among the most widely distributed foliar diseases in the country (Eshetu Bekele, 1985). Various research centres have been undertaking research toward effectively managing diseases in barley. This paper reviews current leaf rust, stem rust, yellow rust and powdery mildew prevalence, and management options developed in 1994–2005 in various Ethiopian research centres.

PATHOTYPING BARLEY RUSTS IN ETHIOPIA

The pathogens Stem rust (*Puccinia graminis*), Leaf rust (*P. hordei* Otth.), Yellow rust (*P. striiformis* West.) and Powdery mildew *Erysiphe graminis* D.C. (f.sp. *hordei*) on barley were reported in Ethiopia by Stewart and Dagnachew Yirgu (1967). Variation within these pathogen populations has been widely analysed in different countries by various authors (Long *et al.*, 1995, 1998). Previously, limited race information had been reported for *P. graminis* and *P. hordei* populations in Ethiopia, but recently Getaneh Woldeab *et al.* (2006) analysed 381 *P. hordei* isolates collected in 2003 and 2004 from barley grown in the main rainy season, the residual and short rainy seasons, using 12 differentials possessing *RPh 1* to *RPh 12* genes, together with susceptible cultivar L94. In 2003, 113 isolates yielded six pathotypes, whereas 268 isolates from 2004 resulted in seven pathotypes (Getaneh Woldeab *et al.*, 2006). *P. hordei* pathotype distribution by barley production system is summarized in Table 1. Pathotypes ETPh 7611 (matching seven resistance

TABLE 1
Distribution of *Puccinia hordei* pathotypes by barley production system in Ethiopia as detected in either 2003 or 2004

Pathotype	Main rainy season	Residual barley production	Short rainy season
ETPh 7611	+	+	+
ETPh 7631	+	+	+
ETPh 6611	+	+	+
ETPh 7651	+	+	+
ETPh 7671	+	+	+
ETPh 7633	+	+	+
ETPh 7653	+	+	–

SOURCE: Summarized from Getaneh Woldeab *et al.*, 2006.

genes) and ETPh 7631 (matching eight resistance genes) were the most complex virulent pathotypes found in all districts and production systems. Such a distribution suggested that *P. hordei* pathotypes migrate from one production system to another in Ethiopia. Most interestingly, all pathotypes except ETPh 7653 were found in Sinana and Enessie districts in either 2003 or 2004. Pathotypes that occurred in one year did not necessarily occur in the following year, and vice versa. Only two races (77 and 184) had been reported previously from samples collected from Finote Selam, Debre Ziet, Addis Ababa, Fiche and Holetta (Yitbarek Semeane *et al.*, 1996). All pathotypes of *P. hordei* were indiscriminately distributed at altitudes of 2025–3200 masl (Getaneh Woldeab *et al.*, 2006). Samples collected from near Holetta included four races of *P. graminis* (as reviewed by Yitbarek Semeane *et al.* (1996). Since that time, no race analysis work has been done for this pathogen. Although variability has been reported in *P. striiformis* populations outside Ethiopia (reviewed in Getaneh Woldeab *et al.*, 2006), there is no such information for Ethiopia.

BARLEY RUST PREVALENCE AND DISTRIBUTION

Western Ethiopia

Barley disease surveys were conducted in the main season of 1999, and main and off-seasons of 2000 and 2001 in Wellega, Illubabor and Kefa, western Ethiopia. From 92 fields surveyed, the mean prevalence of leaf rust was 70.6% in the main and 59% in the off season (Getaneh Woldeab and Teklu Negash, 2001a). Leaf rust incidence was as high as 75.9% and severity 16.3% in the main season (Table 2). In the off-season, maximum severity of 9% and incidence of 47.5% was recorded for leaf rust. Leaf rust was always more important in Wellega and Illubabor than in Kefa, both in severity and incidence, regardless of season. On average, it was more important in the main- than the off-season barley crops in western Ethiopia. Leaf rust incidence and severity was very low in Kefa during the off season. Leaf rust was not as important here as for other parts of Ethiopia (Getaneh Woldeab and Teklu Negash, 2001a).

TABLE 2
Mean leaf rust and powdery mildew incidence and severity of barley in western Ethiopia, 1999–2001

Season and Province	No. of fields	Leaf rust (%)		Powdery mildew (%)	
		Incidence	Severity	Incidence	Severity
		Main season			
Wellega	72	27.9	3.53	0.93	3.3
Illubabor	16	99.8	33.3	11.5	0.4
Kefa	4	100.0	42.1	0.0	0.2
Mean	92	75.9	26.3	4.14	1.3
		Off-season			
Wellega	48	49.5	14.3	19.7	1.8
Illubabor	12	85.9	10.8	6.4	0.7
Kefa	1	4.4	0.6	2.5	0.2
Mean	61	47.5	8.57	12.1	0.9

TABLE 3
Overall seasonal status of leaf rust, stem rust and powdery mildew in Bale highlands, southeast Ethiopia, in 1996, 1998 and 2005

Disease and Season	Distribution (%)	Incidence (%)			Severity (%)		
	1996	1996	1998	2005	1996	1998	2005
			Leaf rust				
Genna	0–92.3	0–100	0–100	0–100	0–55	0–80	0–85
Bona	11.1–100	0–100	10–100	0–100	0–60	1–100	0–60
			Stem rust				
Genna	0–5.6	0–2	0	0	0–2	0	0
Bona	0	0	0	0	0	0	0
			Powdery mildew				
Genna	0–12.5	0–15	10–30	–	0–5	1–2	0–30
Bona	0	0	2–10	–	0	1–2	0–30

Leaf rust incidence reduced as altitude increased above 2400 masl (Getaneh Woldeab and Teklu Negash, 2001b).. Stem rust and yellow rust were not found in the surveys. Other disease surveys were done during 1996–2000 in more than 20 districts of Illubabor, West Shewa and East and West Wellaga zones by Bako Agricultural Research Centre staff (BARC, 1996, 1997, 1998, 1999, 2000). Of the two rusts encountered (leaf and stem), leaf rust was important in Shambu, Arjo, H/Wellel, Sayo and Gimbi in West Wellaga. Stem rust and powdery mildew had low severity.

Southeast Ethiopia

Disease surveys were conducted for five years in either one both the seasons of *Genna* (March–August) and *Bona* (August–December) widely in the Bale highlands (Sinana, Dinsho, Goba, Goro, Agarfa, Gassera-Gololch, Dodola Adaba and Gindhir) (SARC, 1996, 1998, 2001, 2005). The status of leaf rust, stem rust and powdery mildew in *Genna* and *Bona* is summarized in Table 3. Leaf rust had higher distribution both in *Bona* and *Genna* seasons. Stem rust was recorded only in *Genna,* with distribution of up to 5.6%, and incidence and severity up to 2% in Gassera–Gololcha areas in 1996. Low stem rust was also recorded in 2001 and with very low severity (SARC, 2001). Powdery mildew was one of the minor diseases recorded, found in *Genna* at Sinana Dinsho and Goro with up to 13% fields infested, with incidence of up to 15% and severity up to 5%.

Northeast Shewa

Disease surveys were done in *Belg* and *Meher* seasons in the highlands of northeast Shewa in 1997 and 1998 (DBARC, 2002). Leaf rust and powdery mildew were two of the most widely distributed and severe foliar diseases in both seasons. Disease severity and incidence varied with year (ShARC, 1998/99, unpublished) and crop season. Powdery mildew was always more pronounced in *Belg* than in *Meher* in both severity and incidence, whereas leaf rust was important in both seasons (Table 4), although severity was slightly higher in *Belg*. Leaf rust remained severe during seedling to grain-filling crop stages in *Belg*. Both diseases varied with altitude. Powdery mildew was considered important at altitudes of 2800–2900 masl and leaf rust was minor at 2600–3400 masl (ShARC, 1998/99, unpublished). Stem and yellow rusts were not reported.

TABLE 4

Seasonal status of leaf rust and powdery mildew in northeast Shewa highlands, 1997 and 1998

Disease	Infected fields (%)				Incidence average and range (%)				Severity (%)			
	Meher		*Belg*		*Meher*		*Belg*		*Meher*		*Belg*	
	'97	'98	'97	'98	'97	'98	'97	'98	'97	'98	'97	'98
Leaf rust	73	56	7	47	90 (30–100)	92 (40–100)	80 (20–100)	100	60	60	80	80
Powdery mildew	14	10	18	20	63 (10–80)	30 (10–30)	80 (10–100)	50 (10–50)	10	10	51	20

TABLE 5

Status of rusts and powdery mildew in barley in the Meher and Belg seasons, NE Ethiopia, in 1995–1996

Disease	Prevalence		Severity	
	Meher 1995	*Belg* 1996	*Meher* 1995	*Belg* 1996
Stem rust	++	++	Medium	Medium
Leaf rust	++	++	Severe	Severe
Yellow rust	++	++	Severe	Severe
Powdery mildew	+	+	Light	Light

NOTES: + = occasionally present; ++ = commonly present.

Northeast Ethiopia

Disease surveys were carried out in *Meher* (main cropping) and *Belg* (short rainy period) seasons in barley growing areas of northeast Ethiopia. Disease status was compared qualitatively (SiARC, 1996). The three rusts and powdery mildew occurred in both seasons (Table 5). The distributions of stem, leaf and yellow rusts were not affected by growing season. The levels of yellow and stem rusts were considered severe in NE Ethiopia, in contrast to reports from other parts of the country.

YIELD LOSSES CAUSED BY LEAF RUSTS

Leaf rust

Barley yield losses due to leaf rust were studied in on-station and on-farm conditions in 1994–1996 at Ambo Plant Protection Research Centre (Getaneh Woldeab, 1998). There were significant interaction effects between sowing date and fungicide treatments. The on-station mean disease severity in terms of the Area Under Disease Progress Curve (AUDPC) in unsprayed plots had a range of 666–1278 compared with zero in sprayed plots. There were significantly lower grain yields, 1000-grain weights and kernel numbers per spike in unsprayed compared with sprayed plots. Differences between unsprayed and sprayed plots increased with later sowing dates for all yield parameters (Table 6). Losses were 6.9–40.2% in grain yield, 5.9–27.6% in 1000-grain weight and 0–16.5% in kernel number per spike. At the normal sowing date (16 June), grain yield loss was 23.4% and 1000-grain weight loss 14.3%.

Barley yield loss due to barley leaf rust was further studied by superimposing fungicide treatments on local varieties planted by farmers at Tikur Inchini and Shenen districts of West Shewa in 1995–1997 (Getaneh Woldeab and Fekadu Alemayehu, 2001). When unsprayed, the disease severity (as AUDPC) varied from 2842 in 1995 to 1365 in 1996, with a mean of 1933. Yield losses also varied according to disease severity in each year. Differences (mean) between the plots unsprayed and sprayed with fungicide were significant for rust severity, grain yield, and 1000-grain weight. The mean losses caused by leaf rust were 28.3% for grain yield and 16.6% for 1000-grain weight (Table 7).

TABLE 6

Effect of sowing date and leaf rust, *Puccinia hordei*, on yield components of susceptible barley variety 'Trompillo' at Ambo, 1994–1996

Sowing date	AUDPC		Loss (%)		
	S	US	GY	TGW	KNS
1 June	0.0	661.0	6.9	5.9	0.0
16 June	0.0	1277.7	23.4	14.3	0.2
1 July	0.0	1173.7	28.6	24.1	5.3
16 July	0.0	1040.7	40.2	27.6	16.5

Notes: AUDPC = Area Under Disease Progress Curve; S = sprayed; US = unsprayed; GY = grain yield; TGW = 1000-grain weight; and KNS = kernel number per spike. Correlations of leaf rust severity with both grain yield and TGW were significant ($P<0.001$) and negative.

LEAF RUST RESISTANCE IN BARLEY

Resistance source identification

In 2003, 55 barley genotypes from Ethiopia, comprising 6 malting and 49 food barley varieties, were evaluated for leaf rust resistance at six locations (ICARDA, 2003; KRC, 2004), out of which 38 showed average coefficient of infection (ACI) <32. Most of the current cultivars were in this category (Table 8).

At Ambo, Holetta, Adet, Sheno and Sinana, 150 entries were evaluated for reaction to leaf rust for 2–4 years (Getaneh Woldeab and Temesgen Belayneh,

TABLE 7

Response of local barley variety to barley leaf rust, *P. hordei*, in sprayed and unsprayed plots in Tikur-Inchini and Shenen districts of West Shewa, 1995–1997

Treatment	Leaf rust severity (AUDPC)	GY (kg/ha)	TGW (g)	KNS	NPT
Sprayed	0.0	1993.7	43.3	22.7	213.7
Unsprayed	1932.8	1429.1	36.1	21.0	203.5
Loss (%)	–	28.3	16.6	7.2	4.8

Notes: GY = Grain yield; TGW = 1000-grain weight; KNS = kernel number per spike; and NPT = number of productive tillers per plot.

TABLE 8

Reaction of barley genotypes to leaf rust, *P. hordei*, under field conditions at Kulumsa, Ethiopia, in 2003

Cultivar or genotype	ACI	Cultivar or genotype	ACI	Cultivar or genotype	ACI
IAR (H)-485	32.0	HB 1533	12.0	BN6RIRR01/47	8.0
Ardu-12-60B	24.0	Miscal 21	0.0	BN6RIRR01/51	0.8
Ahor 880/60	0.0	Ardu-12-8C	16.0	BNEth-01/4	16.0
HB 42	2.0	31825	2.0	BN6RIRR01/45	0.4
Shege	4.0	36093	0.4	37774	0.0
Dimtu	24.0	37744	0.0	BN6RIRR01/59	0.8
3390-05	4.0	BEDI-BLACK 6R	0.5	BN6RIRR01/12	2.0
3379-09	4.0	BN6RIRR01/51	0.0	25791	12.0
3297-06	16.0	36093	0.0	BN6RIRR01/14	8.0
Beka	12.0	BN6RIRR01/16	2.0	BN6RIRR01/48	2.0
Holker	12.0	BN6RIRR01/35	2.0	30953	8.0
HB 120	16.0	31825	2.0	BN6RIRR01/41	4.0
HB 52	16.0	BN6RIRR01/17	12.0		

Notes: ACI = Average coefficient of infection.

TABLE 9
Reaction of some barley cultivars to leaf rust, *P. hordei*, during 1989–1994

Genotype	Average coefficient of infection			
	1989	1992	1993	1994
Composite 24	7.0	10.7	30.5	1.3
Ardu-12-60B	1.0	6.7	14.0	0.5
HB 100	1.8	8.0	26.0	0.7
Sheno Bulk	23.0	27.4	60.0	1.8
IAR/H/485	9.6	16.7	46.0	1.5
Beka	3.2	16.1	34.0	0.4
Proctor	0.7	5.0	25.0	0.6
Holker	0.4	0.9	28.0	0.6
Balkr	1.4	13.7	31.0	0.6

TABLE 10
Reaction of barley landraces to leaf rust, *P. hordei*, in 1989–1994

Accession	Average coefficient of infection			
	1989	1992	1993	1994
202533	16.0	2.7	34.0	2.5
202534	15.8	3.4	21.0	7.8
202551	2.3	2.1	26.0	1.3
202552	5.0	2.1	15.0	1.3
202553	4.0	4.1	44.0	2.3
202573	3.2	12.0	36.0	0.5
202593	5.2	4.7	20.0	1.6
202603	2.1	4.0	24.0	0.5
202636	15.8	26.7	40.0	0.5
202654	3.5	1.4	10.0	0.5
IAR/H/485	9.6	16.7	46.0	0.7

TABLE 11
Reaction of differential barley lines to leaf rust, *P. hordei*, in 1989–1994

Variety	Average coefficient of infection			
	1989	1992	1993	1994
Special	1.3	15.4	42.0	2.5
Reka I	0.8	8.7	37.0	1.6
Sudan	7.4	52.6	20.0	1.5
Bolivia	6.0	15.3	31.0	0.7
Oderbrucker	0.1	0.7	0.0	0.4
Quinn	2.0	0.7	0.0	0.2
Egypt	1.6	21.0	36.0	0.2
Gold	0.3	21.3	14.0	0.4
Lachtaler	0.4	28.1	34.0	0.3
IAR/H/485	9.6	16.7	46.0	0.7

1996). Cultivars 'Proctor', 'Holker', Ardu-12-60B and HB 100 (Table 9); landrace accessions 2025-51, 2025-53, 202603 and 202654 (Table 10); and the differential lines 'Oderbrucker' and 'Quinn' were resistant to leaf rust across locations and years (Table 11). The variable response of differential barley lines to leaf rust might indicate the heterogeneity of *P. hordei* across locations and years.

Later, 286 barley landraces were evaluated for leaf rust resistance at Ambo in 1994–1996. Compared with the resistant check Ardu-12-60B, 16 landraces resisted leaf rust more (AUDPC <393) (Table 12). Most resistant landraces were collected from altitudes of 2300–2600 masl, where leaf rust is prevalent. Landraces 4380, 4414, 4367 and 4382 had the least AUDPC. Moreover, leaf rust severity was positively correlated with both earliness and plant height (Getaneh Woldeab and Temesgen Belayneh, 1997).

For two seasons (1995–1996), 65 genotypes were evaluated for response to leaf rust at four locations. Of all the genotypes, EH 1051/F2-147H-31-15 were the most resistant across the four locations. In terms of overall mean ACI, genotypes EH 1041/F2-90H-21-13, EH 1039/F2-61H-13-8, 2026-54, 3302-08, EH922/F2-240H-53-39-1 and 3304-06 were resistant to barley leaf rust (Getaneh Woldeab *et al.*, 1999).

At seedling and adult plant growth stages, 18 barley genotypes were assessed against five leaf rust, *P. hordei,* isolates (Tables 14 and 15). At the seedling stage, PGRC/E 3681, followed by PGRC/E 3365W, PGRC/E 3669 and PGRC/E 4411, prolonged the mean latent period (9.5–9.8 days) of the isolates.

PGRC/E 3681 had the longest latency period at both seedling and adult plant growth stages. Genotypes with mean latent period of >15 days at adult plant growth stage could be used as sources of resistance to leaf rust (Getaneh Woldeab and Teklu Negash, 2001b).

Improved cultivars and 92 genotypes of barley were evaluated for disease resistance at Shambu (BARC, 1999, 2002). HB 42 with 25% leaf rust severity

TABLE 12

Barley landraces with lowest mean AUDPC to leaf rust at Ambo, 1994–1996

Landrace	Origin		Agronomic data		AUDPC
	Province	Altitude (masl)	DH	PH	
4380	Gojam	2540	64	108	210.0
4414	Gojam	2580	67	105	210.0
4367	Gojam	2390	87	100	250.0
4382	Gojam	2580	67	103	268.0
4411	Gojam	2540	65	102	315.5
4410	Gojam	–	65	102	331.5
3365	Arsi	2500	62	108	339.5
3669	Gojam	2350	93	88	341.5
3681	Gojam	2400	91	97	342.0
1640	Shewa	2580	85	85	353.0
3680	Gojam	2330	79	95	358.0
4315	Shewa	3090	79	98	358.4
4415	Gojam	2560	69	105	366.5
4333	Shewa	-	94	80	366.5
4418	Gojam	2570	63	104	391.5
4428	Gojam	2840	84	98	391.5
Ardu-12-60B (Resistant)	Shewa	2400	80	100	393.0
Ambo local (Susceptible)	Ambo	2225	75	92	640.5

NOTES: DH = days to heading; PH = plant height (cm); AUDPC = Area Under Disease Progress Curve.

TABLE 13

Latent period of barley landraces accessions, local and susceptible checks to leaf rust isolates at seedling stage

Test entry	Latent period (days) of leaf rust isolates collected from					Mean
	Ambo	Bekoji	Sheno	Sinana	Tikur Inchini	
PGRC/E 3365B	9.7	9.7	9.5	9.5	9.0	9.4
PGRC/E 3365W	9.0	9.7	9.7	10.0	9.3	9.5
PGRC/E 3669	9.5	9.5	9.7	–	9.2	9.5
PGRC/E 3680	9.2	9.5	10.0	9.2	9.0	9.4
PGRC/E 3681	9.0	9.7	9.7	11.0	9.5	9.8
PGRC/E 4315	9.0	9.0	9.7	10.0	8.5	9.2
PGRC/E 4333	9.2	9.2	9.5	9.7	8.7	9.3
PGRC/E 4367	–	–	–	–	–	–
PGRC/E 4380	8.3	9.5	9.7	9.0	9.0	9.1
PGRC/E 4382	9.5	9.0	9.0	9.2	9.2	9.2
PGRC/E 4410	8.7	9.5	9.5	9.0	9.5	9.2
PGRC/E 4411	9.7	9.0	9.2	9.7	10.0	9.5
PGRC/E 4414	9.2	9.0	9.0	9.7	9.3	9.2
PGRC/E 4415	9.5	9.0	9.0	9.5	9.5	9.3
PGRC/E 4418	9.0	9.0	9.0	9.2	9.0	9.0
PGRC/E 4428	9.2	9.0	9.0	9.5	9.7	9.3
Local variety	9.3	9.0	9.0	9.0	9.0	9.1
Trompillo (susceptible)	9.0	9.5	9.0	9.9	9.0	9.3
Mean	9.2	9.3	9.4	9.0	9.2	–

TABLE 14
Latent period (days) of barley landrace accessions, lines and checks to five leaf rust isolates at flag leaf stage

Test entry	Latent period of leaf rust isolates collected from					Mean
	Ambo	Bekoji	Sheno	Sinana	Tikur Inchini	
PGRC/E 3365B	–	–	–	–	–	–
PGRC/E 3365W	13.0	14.0	13.7	13.5	–	13.5
PGRC/E 3669	14.7	14.2	15.0	13.0	–	14.2
PGRC/E 3680	14.0	13.5	14.7	16.2	13.3	14.3
PGRC/E 3681	16.7	14.0	15.5	14.0	15.7	15.2
PGRC/E 4315	16.0	13.2	14.0	14.7	14.2	14.4
PGRC/E 4333	15.5	13.3	14.0	15.5	16.0	14.9
PGRC/E 4367	14.2	14.2	13.3	13.0	15.0	13.9
PGRC/E 4380	14.7	14.0	14.2	13.0	13.0	13.8
PGRC/E 4382	14.2	14.2	13.0	13.7	14.2	13.9
PGRC/E 4410	13.5	13.5	14.5	14.0	13.5	13.8
PGRC/E 4411	14.0	16.0	–	–	13.0	14.3
PGRC/E 4414	15.0	14.0	15.0	15.0	14.5	14.7
PGRC/E 4415	13.2	14.5	13.7	13.5	13.0	13.6
PGRC/E 4418	14.5	13.3	13.7	13.0	13.0	13.5
PGRC/E 4428	15.0	13.3	13.7	13.5	14.7	14.0
3304 – 06	15.7	13.0	16.3	14.0	17.0	15.2
EH 1041/F2-90H-21-13	–	15.0	–	–	17.0	16.0
EH 1051/F2-147H-31-15	–	–	–	–	–	–
PGRC/E 202654	15.7	17.0	16.0	17.0	16.0	16.3
EH 922 /F2=247H-55-4-16	–	14.0	–	–	17.0	15.5
3302-08	15.3	16.5	17.0	17.0	–	16.4
EH 922/F2-240H-53-39-1	–	–	–	–	–	–
L 94 (susceptible)	13.5	13.5	13.0	13.2	13.0	13.2
Local variety	16.0	13.2	14.2	13.7	13.0	14.0
Trompillo (susceptible)	16.5	14.0	16.0	13.7	14.7	15.0
Mean	14.8	14.15	14.52	14.21	14.54	–

was more susceptible than the other improved varieties, but was high yielding (2200 kg/ha). Line 21544-2 showed 22% leaf rust resistance compared with the susceptible genotype with 63% leaf rust severity (BARC, 2002).

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Achievements in Barley Scald research in Ethiopia

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INTRODUCTION

In spite of its importance, the productivity of barley for farmers in Ethiopia is about 1.2 t/ha. This is attributed to various factors (Hailu Gebre and van Leur, 1996), among which diseases have a major role. Major diseases cause substantial yield losses (Eshetu Bekele, 1985; Bekele Hundie, 2005). Research has been ongoing since the first reviews of barley disease research (Getaneh Woldeab *et al.*, 1996; Yitbarek Semeane *et al.*, 1996). This paper reviews research results on barley scald, including its prevalence, pathogenic variation, losses caused, and methodologies and management in Ethiopia since the first review of barley disease research. It analyses the gaps and suggests future research needs.

SOME BIOLOGY OF THE CAUSATIVE AGENT OF SCALD

The pathogen *Rhynchosporium secalis* is the causal agent of scald, a leaf disease of barley (*Hordeum vulgare* L.), and was first reported in Ethiopia by Stewart and Dagnachew Yirgu (1967). The fungus survives as mycelia on plant debris and diseased volunteer crops and grasses, and sporulates starting early in the cool and wet seasons. Such conditions might facilitate fungal recombination and variation as found in Ethiopia (Kiros Meles and Mengistu Huluka, 1994; Yitbarek Semeane and Fehrmann, 2002). Virulence analysis of 24 *R. secalis* isolates derived from scald samples collected during the main seasons of 1997 and 1998, predominantly from Shewa in central Ethiopia (Yitbarek Semeane and Fehrmann, 2002), revealed 17 pathotypes. Previously Kiros Meles and Mengistu Huluka (1994) had reported 19 pathotypes. Of the 17 pathotypes identified by Yitbarek Semeane and Fehrmann (2002), pathotypes 16 and 17 were the most virulent (Table 1). Furthermore, Kiros Meles, Mengistu Huluka and Deadman (2000) and Kiros Meles, Mengistu Huluka and Abang (2004) reported pathogenic and phenotypic diversity in

TABLE 1
Pathotypes of Rhynchosporium secalis identified and the number of barley differential lines found susceptible to the different isolates of the pathogen

Pathotype	Pathogen isolates	Genotypes susceptible
1	Et 8, 14, 15, 17, 21, 22	Brier
2	Et 6	Atlas
3	Et 11	Modoc
4	Et 10, 19	Brier, Jet, Steudelli
5	Et 30	Brier, Modoc, Steudelli
6	Et 1	Jet, Modoc, Nigrinuum
7	Et 7, 20	Brier, Seudelli, Turk
8	Et 16	Brier, Modoc, Turk
9	Et 9	Brier, Jet, Kitchin, Nigrinuum
10	Et 25	Brier, Forrajera, Jet, Steudelli
11	Et 32	Brier, Jet, Kitchin, Modoc, Seudelli
12	Et 18	Abyssinia, Brier, Forrajera, Modoc, Trebi
13	Et 26	Abyssinia, Brier, Jet, Kitchin, Nigrinuum, Steudelli
14	Et 24	Atlas, Atlas46, Brier, Jet, Steudelli, Turk
15	Et 31	Abyssinia, Brier, Forrajera, Jet, Kitchin Modoc, Nigrinuum Steudelli, Trebi
16	Et 33	Abyssinia, Atlas46, Brier, Forrajera, Jet, Kitchin, La Mesita, Modoc, Nigrinudum, Steudelli, Trebi
17	Et 27	Abyssinia, Brier, Forrajera, Jet, Kitchin, La Mesita, Modoc, Nigrinudum, Steudelli, Trebi, Turk

R. secalis isolates collected from different locations in the country. Moreover, amplified fragment length polymorphism (AFLP) study of various isolates showed genetic diversity in the pathogen population in Ethiopia (Kiros Meles, 2004). These studies highlight that barley genotypes that lack broad spectrum resistance to scald do not last long in the Ethiopian situation. Thus, developing cultivars that combine multiple race-specific resistances with race-non-specific resistance will be the best option to combat the disease. However, surveys conducted to identify pathotypes in the causative agent population may not satisfactorily represent the major barley growing regions. Therefore, sampling of the whole barley production system is desirable to determine pathotype distributions among Ethiopian geographical regions and to identify exhaustively both virulent and complex pathotypes. This information will further assist barley breeding programmes to develop cultivars with much better broad-spectrum resistance to scald.

INCIDENCE AND PREVALENCE OF SCALD IN BARLEY

Southeast Ethiopia

Disease surveys were conducted for five years either in one or both seasons of *Genna* (March–August) and *Bona* (August–December) in the Bale highlands (Sinana, Dinsho, Goba, Goro, Agarfa, Gassera-Gololch, Dodola Adaba and Gindhir Districts) (SARC, 1996, 1997, 1998, 2001, 2005). In each district, 44.1–81.3% of barley fields were infected with scald, with incidence up to 100% and severity up to 80% at Sinana and Dinsho (in both *Genna* and *Bona*), and Goba and Adaba (in *Bona*) (Table 2).

Central northeast Ethiopia

Disease surveys were made in the highlands of North Shewa in 1997 and 1998 in *Belg* and *Meher* seasons, and disease incidence and severity recorded. Most farmers grow barley in the North Shewa highlands in both *Meher* and *Belg*.

TABLE 2

Status and prevalence of scald in two seasons in the Bale highlands, southeast Ethiopia, in 1996, 1998 and 2005

Season	Distribution (%)	Incidence (%)			Severity (%)		
	1996	1996	1998	2005	1996	1998	2005
Genna	0–60	0–100	0–100	0–100	0–80	0–30	0–80
Bona	0–81.3	0–100	10–100	0–100	0–80	1–30	0–80

TABLE 3

Seasonal status of barley scalds in North Shewa highlands, northeast Ethiopia, in 1997 and 1998 in both *Meher* and *Belg* seasons

Year	No. of infected fields		Mean (and range) of scald			
			Incidence (%)		Severity (%)	
	Meher	*Belg*	*Meher*	*Belg*	*Meher*	*Belg*
1997	60	11	75 (40–100)	60 (10–80)	31	21
1998	62	22	75 (10–100)	62 (30–100)	43	53

Scald was one of the most important barley diseases found by this survey, and was one of the most widely distributed, causing severe foliar damage in both *Belg* and *Meher* (Table 3). Its incidence varied with altitude and growth stage of the plant. At high altitudes of 2900–3400 masl, scald was one of the severe diseases encountered. Scald severity also increased progressively, starting from the tillering stage in the presence of high moisture levels. The progress of the disease in relation to severity and incidence vary depending on the density of plants and weeds, and varies from year to year (SARC, 1999).

Northeast Ethiopia

Disease surveys were carried out to identify the status of prevailing diseases in major barley growing areas of northeast Ethiopia during *Meher* of 1995 and *Belg* of 1996 (SiARC, 1996). Scald was one of the most widely distributed and severe of 12 diseases encountered. Scald occurred widely in all surveyed areas and was considered a major disease in both prevalence and severity, in both *Meher* and *Belg* seasons.

Western Ethiopia

Barley disease surveys were conducted in the main season of 1999, and main and off-seasons of 2000 and 2001 in eight districts of Wellega, three of Illubabor and one of Kefa. Scald was one of nine diseases encountered. Of the 92 fields surveyed during *Meher*, 81.5% were infected with scald with 19.1% incidence and 4.63% severity (Table 4). The importance of scald, in both incidence and severity, was more pronounced in Wellega areas during

TABLE 4

Seasonal mean incidence and severity of barley scald in western Ethiopia, 1999–2001

Survey area	No. of fields surveyed	Scald	
		Incidence (%)	Severity (%)
Main season			
Wellega	72	46.7	13.0
Illubabor	16	5.2	0.4
Kefa	4	5.4	0.5
Mean	92	19.1	4.63
Off-season			
Wellega	48	3.4	0.2
Illubabor	12	6.1	1.3
Kefa	1	0.0	0.0
Mean	61	3.2	0.5

TABLE 5

Grain yield and 1000-grain weight and respective losses due to barley scald and net blotch combined over locations (Ankober and Faji) in Meher, 1999–2000

Treatment	GY		TGW	
	Misrach	Landrace	Misrach	Landrace
1999				
Sprayed	2342	2350	40.00	42.0
Unsprayed	2104	1920	36.7	37.0
Mean	2223.7	2135	38.3	39.8
Loss (%)	10.2	18.3	8.3	13.3
2000				
Sprayed	2827	3413	40.4	40.1
Unsprayed	2338	2329	35.8	33.9
Mean	2582	2871	38.1	37.0
Loss (%)	17.3	31.8	11.4	15.3

NOTES: 'Misrach' is an improved variety, and Landrace was the farmers' local variety. SOURCE: Meki Shehabu and Asnakech Tekalign, 2004. GY = Grain yield (kg/ha); TGW = 1000-grain weight (g).

the main season. In the off-season, scald prevalence as a percentage of infected fields was 61.4% on average (Getaneh Woldeab and Teklu Negash, 2001). Scald incidence was only 3.2%, with severity of 0.5%, in off-seasons. During the off-season, the incidence and severity was slightly higher in Illubabor, followed by Wellega. Scald was least important in this part of the country, but varied significantly with growing season. However, other disease surveys conducted between 1997 and 2000 in western Ethiopia (Oromia), in more than 20 districts of Illubabor, West Shewa, and East and West Wellega zones, revealed that barley scald was highly destructive in the highlands of western Oromia, namely at Shambu and Arjo. It affected all farmers' varieties and also released barley cultivars such as IAR H-485 and HB 42; however, HB 42 was less affected (BARC, 1997, 1998, 2000).

YIELD LOSS ASSOCIATED WITH SCALD

Central Ethiopia

Meki Shehabu and Asnakech Tekalign (2004) assessed the magnitude of yield losses associated with scald in farmers' fields at two locations in 1999 and 2000 *Meher* seasons. Grain yield, straw yield, and 1000-grain weight were significantly lower in fungicide unsprayed treatments in all locations and years. Fungicide sprayed treatments were almost disease free. The differences between varieties, and the variety × fungicide interactions, were not significant. The mean grain yield losses were 19.87 at Ankober and 4.86% at Faji, while in 2000 the disease pressure and yield loss was high (37.39%) at Ankober. Over all locations, combined analysis confirmed grain yield losses of 333.9 kg/ha in the 1999 and 786.6 kg/ha in the 2000 seasons (i.e. 14.25 and 24.55% losses; Table 5). Up to 23.7% straw losses were associated with the local landrace variety and 18.8% with improved variety 'Misrach'.

Western Ethiopia

Yield loss due to barley scald was also studied using cultivars IAR H-485 (susceptible), a local variety (moderately susceptible) and HB 42 (resistant), with and without fungicide control, at Shambu station during 2001–2002 (BARC, 2004). The highest scald severity (recorded on a 1–9 scale) was 5.60 on the unsprayed local variety and 4.33 on IAR H-485, while the lowest scald severity (1.67) was in sprayed HB 42. Mean grain yield losses were 31.54, 9.83 and 12.62% for IAR H-485, local check and HB 42, respectively (Table 6). The mean biomass

TABLE 6

Scald disease severity and percentage loss in grain yield at Shambu in 2001–2002

Treatment	Scald severity (1–9 scale)			Grain yield (kg/ha)		
	IAR H 485	Local	HB 42	IAR H 485	Local	HB 42
Sprayed	2.33	3.83	1.67	2366.93	1444.53	2030.67
Unsprayed	4.33	5.00	2.67	1620.33	1302.53	1774.47
Loss				31.54%	9.83%	12.62%

loss ranged from 6.44% in the local check, up to 25.37% in susceptible IAR H-485 (BARC, 2004).

CONTROL MEASURES

Resistance source identification

Old and commercial cultivars were evaluated against major barley diseases at Shambu (BARC, 1999) and Arjo (BARC, 2000, 2002). HB 42, HB 52, A-HOR880/61, HB 120, Beka and Ardu-12-60B were resistant to scald, and were infected only to a level of 3 on the 1–9 scale, whereas susceptible genotypes such as IAR H-485 scored 7. During 2000–2001, another 92 barley genotypes were evaluated against barley diseases, along with HB 42 and a local cultivar at Shambu (BARC, 2002). 229158-1 was almost as resistant as HB 42 to scald (score <2), whereas 208038-15 had a scald infection score of 3. Bekele Hundie, Melkamu Ayalew and Yibarek Semeane (1995) evaluated 224 barley cultivars and genotypes for scald at multiple locations during 1990–1992, and found that 33 had scald severity of <18% across locations. Cultivar 'Osiris', with resistance genes *Rh*, *Rh4*, *rh6*, and *Rh10*, was completely free of scald across all locations.

Differential barley genotypes that respond differently to different pathotypes of the scald disease-causing pathogen were evaluated at the adult plant stage against six virulent *R. secalis* isolates from Ethiopia (Yitbarek Semeane and Fehrmann, 2002). Osiris exhibited resistance to all isolates and had a low disease index, which is a quantitative measure of disease severity, consistent with previous observations (Bekele Hundie, Melkamu Ayalew and Yibarek Semeane, 1995). Atlas 45, La Mesita, and Turk were resistant to four isolates and also had lower disease indices than other genotypes (Table 7). Likewise, Yitbarek Semeane *et al.* (1996) reported that barley genotypes such as HB 42, HB 99, HB 100, HB 114, HB 115 and HB 116 had good field resistance to scald. Moreover, Kiros Meles (1993) reported that Ardu-12-60B, Ardu-12-9C, HB 118 and HB 129 were among varieties that combined scald resistance with high yield.

At Adet, Injibara, Debre Tabor and Motta, 452 genotypes were evaluated against scald during 1994–

TABLE 7

Mean disease index values on adult plants of barley differential lines inoculated with six selected isolates of *R. secalis* from Ethiopia

Differentials	Mean disease index of 6 virulent isolates
Abyssinia	0.51 e
Atlas	0.26 h
Atlas 46	0.31 g
Brier	0.57 d
Forrajera	0.56 d
Jet	0.53 de
Kitchin	0.47 f
La Mesita	0.33 g
Modoc	0.67 b
Nigrimudum	0.46 f
Osiris	0.08 i
Steudelli	0.55 de
Trebi	0.62 c
Turk	0.29 gh
Ardu-12-8c	0.73 a

NOTES: Means followed by the same letter are not significantly different at $P<0.05$.
SOURCE: Yitbarek Semeane and Fehrmann, 2002.

1996. Scald-resistant accessions were submitted to breeders (Table 8) to be used as parents for crossing or to be advanced directly to yield trials.

TABLE 8
Barley genotypes with <10% scald severity submitted for scald resistance breeding

Accession	Severity (%)	Accession	Severity (%)
002	5	063	0
003	10	064	T
011	T	067	0
017	5	069	5
021	T	070	T
022	T	071	0
027	T	075	5
030	T	079	T
034	T	083	T
038	10	085	5
046	10	098	T
050	T	099	T
060	T	101	0
061	T		

NOTES: T = trace; 0 = immunity. SOURCE: Adet ARC, Crop Protection Division, unpublished data from 1996.

From an unknown number of genotypes evaluated during 1996–1997 (SARC, 1996, 1997) genotypes 215232, 215239, 215310, 215434, 215462, 219047, 215363, PGRC/E-047, 215444, 212936, 12938, PGRC/E-067, 212826 and EH22/F2-240H-53-39-1 showed scald severity of <20% at Sinana and Sinja. Hulled and hull-less barley genotypes were also evaluated against scald at Sinana and Dinsho in *Bona*, 1999–2000 (SARC, 1999, 2000). Hulless barleys from the 8th HBSN (entries 15/98, 22, 26, 28, 29, 35, 36, 45, 58, 63, 83, 100, 109) and EH956-F2-8H-6-4 were resistant to scald (i.e. scald severity of <1%). All hulled genotypes evaluated in the 26th IBON, had scald severity of <15% at Dinsho, the location most conducive to barley scald (Table 9).

In 2002, 29 early and 35 late barley lines obtained from the 2001 preliminary screening were re-evaluated against barley diseases in advanced screening at Sinana and Upper Dinsho. Line 1775-6 in the early group and lines 3283-10, 3353-16, 3353-4 and 1643-18 in the late group had better combined resistance to scald and other major barley diseases. For genotypes 1775-6, 3476-14, 3258-20, 1775-1, 3168-8, 1775-8, 1775-8, 1728 14, 172814, 3289-3, 3716-2, 3717-4, 1694-8, 1718-18, 1611-5, 3350-14, 3296-13, 3715-3 and 3572-1 in the early group, and genotypes 3543-18, 3353-16, 3353-4, 1643-18 and 1674-9 in the late group, scald severity did not exceed 30% (SARC, 2001, 2002). However, scald severity was up to 60% for susceptible genotypes in the trial.

TABLE 9
Response of hulled barley genotypes to barley scald at upper Dinsho in Bona season, 2000

Genotype	Scald (%)	Genotype	Scald (%)
26th IBON 204/98	0	26th IBON 143/98	0
26th IBON 72/98	0	26th IBON 101/98	1
26th IBON 88/98	15	26th IBON 157/98	10
26th IBON 116/98	11	26th IBON 4/98	1
26th IBON 57/98	0	26th IBON 52/98	1
26th IBON 64/98	15	26th IBON 65/98	0
26th IBON 75/98	1	26th IBON 94/98	0
26th IBON 108/98	1	26th IBON 214/98	0
26th IBON 76/98	0	26th IBON 158/98	1
26th IBON 112/98	0	26th IBON 148/98	0
26th IBON 67/98	6	26th IBON 103/98	0
26th IBON 63/98	1	26th IBON 174/98	0
26th IBON 99/98	5	Ardu-12-8C	30
26th IBON 58/98	10		

During 2003, 96 barley genotypes retained from the 2002 screening were also re-evaluated in advanced screening at Sinana and Dinsho (SARC, 2002, 2003). Compared with resistant check EH-956-8H-6-4 with its scald severity of 50%, 24 genotypes were lower, with 45%. However, scald severity on genotypes 215478, 215479, 215486, 230010, 230603, 235745,

TABLE 10

Barley genotypes with scald severity <20% in upper Dinsho in Bona season, 2005

Acc.	Scald (%)	Acc.	Scald (%)	Acc.	Scald (%)	Acc.	Scald (%)	Acc.	Scald (%)
388	1	6283	20	0728	15	3255-69	5	5628	10
001	5	836	5	160	20	3255-44	5	3255-11	5
025	5	840	15	2228	5	3255-73	10	3255-40	5
0283	20	3255-70	20	2328	15	3028	5	3255-72	20
0284	20	3255-43	5	236	5	351	5	3255-60	10
O288	10	3255-02	5	3255-78	5	355	5	3255-18	10
0368	5	3255-61	5	3255-70	20	365	10	3255-65	5
0636	15	065	0	3255-06	5	3836	15		
605	5	072	15	3255-50	10	535	5		

NOTES: Acc. = Accession.

236116 and 4149 did not exceed 35%. Scald severity reached 70% on susceptible genotypes in the trial. Likewise, accessions retained from a preliminary screening in 2004 and from other sources were re-evaluated at Sinana and Upper Dinsho in two groups in 2005. Genotypes with scald severity of <20% are presented in Table 10. Susceptible genotypes had scald severity of up to 90% (SARC, 2004, 2005).

Host plant resistance screening techniques

A set of 14 differential lines were evaluated against virulent Ethiopian isolates of *R. secalis* at both seedling and adult plant stages (Yitbarek Semeane and Fehrmann, 2002) to determine whether these two stages were complementary or not for identifying scald resistance. Disease scores taken at seedling and adult plant stages were significantly and positively correlated (r = 0.81). Despite this strong association between the two techniques, there were some genotypes that were resistant at seedling stage but became susceptible at the adult stage.

Cultural control measures

Rhynchosporium secalis survives as mycelia and conidia on infected barley residues and seed, and on other grasses. It survives longer in plant residues that remain exposed rather than incorporated into the soil. Thus, disease management must exploit cultural practices: ploughing-in of infected debris and volunteer crops before planting, and rotating barley with non-susceptible crops such as faba bean, field pea or highland oil crops to delay disease onset. Planting healthy seeds could be another scald management option. Planting at the end of June reduces losses due to scald.

Chemical control

Of several fungicides evaluated in Ethiopia, Tilt 250EC and Bayleton 25WP were registered for official use in cereals (Abdurahman Abdulahi, 1997; Abdurahman Abdulahi and Berhanu Gebre Medhin, 1999), including barley. One or two applications of Tilt 250EC at 0.5 L/ha should suppress scald.

CONCLUSION AND RECOMMENDATIONS

Current and previous surveys in Ethiopia have confirmed that scald risk is associated with highland areas where weather is cool and rainfall is high, but also that varies with season, year and variety (SARC, 1996, 1998, 2005; Yitbarek Semeane *et al.*, 1996; Getaneh Woldeab and Teklu Negash, 2001; DBARC, 2002; BARC, 2004). Scald was the least important disease in many parts of western Ethiopia. Disease severity, prevalence and losses were influenced by year, season and variety. Over locations, scald and net blotch combined to give mean grain yield losses of up to 14% in 1999 and 24.62% in 2000 in North Shewa. Likewise, yield losses of 9.8–31.54% resulted from scald in western Ethiopia. Current losses are within the ranges of previous reports. As survey results and loss levels indicate, scald remains a significant disease in barley production.

Pathotype analysis is recent in Ethiopia. Recent variability analyses in *R. secalis* populations revealed 17 to 19 pathotypes in Ethiopia, of which pathotypes 16 and 17 were the most virulent. Genetic diversity in the *R. secalis* population was confirmed using AFLP techniques. Pathogen variability makes scald resistance durability difficult, although one solution is multi-location testing of germplasm in hot-spot areas where the disease is most frequent and virulent, or using such pathotypes in laboratory or greenhouse germplasm screening. Overall, disease and pathotype surveys have not given the actual status of scald and pathotype structures of all barley production systems of Ethiopia. We recommend undertaking disease and pathotype variability surveys across barley production systems and monitoring any possible shift in pathotypes.

Several barley landraces, commercial cultivars and exotic barley genotypes were evaluated against scald, and several resistance sources were found that could be used in scald resistance breeding. Registered foliar fungicides can be used when scald is important, but spray timing and application frequencies need to be refined, along with profitability analysis. Currently registered fungicides are systemic and prone to fungicide resistance development. Low cost contact fungicides should be identified and evaluated alongside new systemic ones.

GAPS AND CHALLENGES

- Yield losses associated with scald remain high but not in all barley production systems, since they are specific to location, assessment techniques and varieties.
- Generating information on pathotypes of the *R. secalis* population has only just begun and the present findings may not represent all barley production systems in Ethiopia.
- Lack of well-equipped greenhouses and growth chambers, and limited opportunities for on-job training in pathotype analysis techniques, are among the challenges faced.
- There are no short-term and long-term storage facilities for the pathotypes identified, and so further use is restricted.

- *Rhynchosporium secalis* survives as mycelia and conidia on infected host residues and grasses. Thus, the possibility of controlling scald by cultural practices such as ploughing-in of infected debris and volunteer crops before planting, and by rotating barley with non-susceptible crops such as faba bean, field pea or highland oil crops, are options that delay disease onset. However, research is scarce on identification of optimal and compatible cultural practices that could be integrated with other scald management options.
- Information on disease epidemiology remains the basis for effective disease management, but there is little known of the effects of weather parameters, management practices, seasons, years and varieties on barley scald epidemics.
- Lack of standard meteorological stations at main research stations and sub-centres, and lack of instruments for measuring weather parameters within crop canopies and around roots, also constrain epidemiological studies.
- Pathogen variability and shifts combine to shorten the durability of varietal resistance and justify routine screening of scald resistance sources in Ethiopia. This is a challenge for breeders and pathologists.
- Currently registered fungicides are systemic and prone to fungicide resistance development, and little work has been done on spray timing, application frequencies and profitability analysis in controlling scald.

FUTURE RESEARCH DIRECTIONS

- Undertake regular disease surveys and characterize *R. secalis* pathotype patterns associated with barley production systems. Map scald-prone areas with pathotype structures. Subsequently exploit the dominant and virulent pathotypes in future routine scald-resistance breeding and refine the resistance sources to be screened in field conditions.
- Conduct a well coordinated assessment of scald losses to identify yield loss in all barley production systems along with development of models to predict yield loss.
- *Rhynchosporium secalis* is variable, with 17 to 19 pathotypes known in the Ethiopian population. Thus germplasm should be evaluated at multiple locations in hot-spot areas with the most frequent and virulent pathotypes, or in laboratory and greenhouses using these pathotypes.
- Identify compatible and optimum cultural practices that could be integrated with various disease management options to reduce disease epidemics and increase yield.
- Investigate scald epidemiology as affected by weather parameters, management practices, production systems, season, year and variety. Develop models predicting scald epidemics, and create awareness of and enable cost-effective disease management options.
- The currently registered fungicides for disease control in cereals are systemic and are prone to fungicide resistance development. Cost-effective contact

and systemic fungicides are therefore needed and studies should consider application frequencies, timing and profitability in scald management.

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Achievements of research on barley *Helminthosporium* diseases in Ethiopia

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INTRODUCTION

In Ethiopia 36 diseases of barley have been recorded (Stewart and Dagnatchew, 1967; Eshetu Bekele, 1985), with the major ones causing substantial yield losses (Eshetu Bekele, 1985; Yitbarek Semeane and Wudneh, 1985; Bekele Hundie, 2005). Research has been conducted in the areas of disease monitoring, disease epidemiology, seed pathology, yield loss, infection process and management of barley diseases since the first review of barley disease research (Getaneh *et al.*, 1996; Yitbarek *et al.*, 1996).

PATHOGENS

Morphological, cultural, and pathotypic variation were studied in *Pyrenophora teres* populations (Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005.). Radial growth of 15 isolates of *P. teres* f.sp. *teres* and *P. teres* f.sp. *maculata* was studied on potato dextrose agar medium (Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005.). There was no significant morphological and cultural variation among isolates causing net and spot forms of net blotch.

Pathotype variation in *P. teres* and net blotch forms

In Ethiopia, net blotch was previously reported to be caused by the fungus *Pyrenophora teres* (syn *Helminthosporium teres* Sacc.) without distinguishing the two forms of this disease (*P. teres* f.sp. *teres* and *P. teres* f.sp. *maculata*) (Smedegaard-Petersen, 1977; Tekauz, 1990). However, recent studies by Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien (2005) showed that, in Ethiopia, net blotch also exists in these two forms. Analysis of samples collected from the northwest and central highlands of Ethiopia with spot blotch symptoms showed that about

TABLE 1
Categorization of pathotypes of *P. teres* f.sp. *teres* and *P. teres* f.sp. *maculata*

Patho-type	Isolate numbers (f.sp. *teres*)	Susceptible genotypes	Isolate numbers (f.sp. *maculata*)	Susceptible genotypes
1	7, 8, 12	0	18, 21, 29, 30	0
2	9, 10, 11	CI 9820	17, 19, 20, 22, 28	CI 9820
3	1	CI 9819	16, 23, 24, 25, 26	CI 5791, CI 9819
4	13	CI 5791, CI 9819	27	CI 9820, CI 5791, CI 9819
5	2, 3, 4, 5, 6, 14, 15	CI 9820, CI 5791, CI 9819	–	–

80% were associated with *P. teres* f.sp. *maculata* while the rest were associated with spot blotch (*Cochliobolus sativus*; Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005.). Consequently, it is believed that a large proportion of what was previously reported as spot blotch caused by *C. sativus* could be spot type of net blotch caused by *P. teres* f.sp. *maculata*. Isolates of each form of *P. teres* varied significantly ($P<0.01$) in virulence (Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005). Thirty isolates have been typed to five pathotypes (Table 1). Pathotype 5 of *P. teres* f.sp. *teres* was more complex than others because it overcame the resistances of three of the ten barley differential lines tested. With regard to *P. teres* f.sp. *maculata*, pathotype 4 was more virulent than others because it could attack three of the ten differentials (Table 1). Variability in the *P. teres* population suggests that barley breeding programmes should concentrate on non-specific types of resistance.

DISEASE PREVALENCE AND STATUS

Diseases surveys were conducted in areas of southeast Ethiopia in *Bona* and *Gena* cropping seasons, and in north, central and west Ethiopia in *Belg/Meher* crop seasons for 2 to 5 years.

Southeast Ethiopia

Surveys in the Bale highlands (SARC, 1996, 1998, 2005) revealed that net blotch is an important foliar disease in distribution, incidence and severity (Table 2). It had a wide distribution in *Genna* (94–100%) and *Bona* (25–100%), but was more severe in *Genna*. Spot blotch was recorded at Goba (*Bona*), Goro (*Genna*) and Gassera-Gololcha (*Bona* and *Genna*), with up to 31% of fields infected, incidence up to100%, and disease severity up to 70%. However, some spot blotch

TABLE 2
Status of *Helminthosporium* diseases in barley by season in the Bale highlands of southeast Ethiopia

Disease	Season	Distribution (%)	Incidence (%)			Severity (%)		
		1996	1996	1998	2005	1996	1998	2005
Net blotch	*Genna*	94.4–100	0–100	0–100	0–100	0–80	0–40	0–80
	Bona	25–100	0–100	1–100	0–100	0–90	1–60	0–100
Spot blotch	*Genna*	0–22.2	0–100	0	0	0–70	0	0
	Bona	8.3–30.8	0–70	0	0	0–20	0	0
Barley stripe	*Genna*	0–60.1	0–10	2–5	0–30	–	–	–
	Bona	0–50	0–30	1–50	0–5	–	–	–

symptoms could be attributed to spot-type net blotch. Barley stripe disease was encountered in all surveyed areas except Goro in *Bona* and Agarfa in *Genna* in 1996. Up to 60% and 50% of fields were infested by barley stripe disease in *Genna* and *Bona*, respectively, with up to 30% and 50% incidence. There was greater incidence in Sinana (Dinsho 10–50%; Goba 0–20% and Adaba 0–30%) than along the other routes surveyed. Compared with net blotch and spot blotch, barley stripe was least spread in the farming areas of the Bale highlands in both seasons; nevertheless, this disease is considered important as associated losses are proportional to its incidence.

Central and northwest Ethiopia

Disease surveys were conducted in the highlands of North Shewa in central Ethiopia along the routes Debre Berhan–Ankober, Debre Berhan–Tarmaber and Seladingay, Tarmaber–Mehal Meda, Sheno–Ginage, and Debre Berhan–Jihur in 1997 and 1998 in *Belg* and *Meher* seasons. The results showed that the Helminthosporium diseases—net blotch (*P. teres*), spot blotch (*C. sativus*) and barley leaf stripe (*P. graminea*)—were most widely distributed in *Meher* season, regardless of the route followed and year (Table 3). Both altitude and year influenced incidence and severity of disease, and disease severity varied with season, and was most severe for *Belg* in 1997 and *Meher* in 1998. Net blotch was severe, whereas spot blotch and barley stripe were minor at altitudes of 2600–3300 masl. Severity of net blotch increased from tillering stage if moisture levels were high (DBARC, 2001/02 Crop Protection Progress Report, unpublished). Severity and incidence also varied depending on density of plants and weeds (ShARC, 1998/99, and unpublished).

Further field surveys were undertaken in northwest Ethiopia in Lay Gayint (Wuhamedhen, Gobgob and Salea), in Central Ethiopia in Angolelana Asagert (Wontu, Kotu and Chacha), and Debre Berhan Zuria (Bakelo, Atakelt and Keyite) in the 2001/2002 main crop seasons. Of the 2250 leaf samples with spot blotch symptoms, 1821 (80.9%) were associated with *P. teres* f.sp. *maculata;* 365 (16.2%) were associated with *C. sativus;* and 64 (2.9%) were other *Helminthosporium* spp. (Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005), indicating that

TABLE 3
Status of *Helminthosporium* diseases in barley in the North Shewa highlands, north Ethiopia, in 1997–1998

Disease	Year	No. of fields infected		Average and range			
				Incidence (%)		Severity (%)	
		Meher	*Belg*	*Meher*	*Belg*	*Meher*	*Belg*
Net blotch	1997	78	4	85 (10–100)	90 (10–100)	31	42
	1998	83	18	82 (20–100)	70 (40–100)	42	32
Barley stripe	1997	42	16	20 (10–50)	40 (10–55)	–	–
	1998	50	25	33 (20–60)	38 (10–80)	–	–
Spot blotch	1997	4	21	63 (40–70)	70 (40–100)	31	
	1998	21	6	99 (50–100)	50 (20–70)	63	31

P. teres f.sp. *maculata* is the spot form of *P. teres*. Disease assessment should be made earlier in the season as spot blotch may have been overestimated. In future net blotch and spot blotch survey work, visual observations need to be confirmed by laboratory microscopy diagnosis to avoid assessing the spot form of net blotch as spot blotch. There was 18% barley leaf stripe incidence reported (Bekele Hunie *et al*., 1994).

Northeast Ethiopia

In disease surveys in northeast Ethiopia, net blotch was the most prevalent and severe in all areas, in both *Meher* and *Belg* seasons. Net blotch severity was high at all crop stages: seedling, tillering, heading and maturity. The survey indicates that net blotch constrains barley production from the earliest crop stages, and could cause economic losses in northeast Ethiopia. Spot blotch and barley stripe were not found (SiARC, 1996).

West Ethiopia

Barley disease surveys were conducted in the main season of 1999 and in both main and off-seasons of 2000 and 2001. Net blotch, spot blotch and barley stripe were recorded in the three areas surveyed. Of 92 fields surveyed during the main season, the mean prevalence of net blotch was 92.4%, and barley stripe was the least (3.3%). In the off-season, 83.6% of fields were affected by spot blotch. Barley diseases were widely distributed in Wellega, followed by Illubabor regions. The mean prevalence of net blotch and spot blotch for the three regions was 73.8 and 65.3%, respectively. Barley stripe was rare (Getaneh Woldeab and Teklu Negash, 2001). Detailed disease surveys were carried out in 1997–2000 in the main crop seasons in West and East Wellega, and Illubabor zones. Net blotch and spot blotch were major barley diseases in the Arjo, Shambu, Sayo, Gimbi, Lalo Asabi and Hawa Wellel areas in East and West Wellega (BARC, 1997, 1998, 2000). The local varieties were all susceptible to these diseases. Some farmers were still growing susceptible local cutivars, but most had shifted to other crops, such as wheat.

Net blotch incidence in the *Meher* season reached 88% in places in Illubabor, with a mean of 65%. In the *Belg* season, it reached 63% in the same zone, with a mean of 35%. Incidence of net blotch was high at altitudes of 2200–2400 masl. Spot blotch incidence reached 47% in Wellega, with a mean of 29.5% in the main season. In the short season, it reached 100% in Kefa with mean of 81% (Table 4). Thus, the incidence of net blotch was highest in the main season, while for spot blotch it was in the off-season. Despite the high incidence of net blotch and spot blotch in western Ethiopia during 1999–2001, the disease severity in both main and off-seasons was low (Table 5) except

TABLE 4
Mean incidence of net blotch, spot blotch and barley stripe on barley in western Ethiopia, 1999–2001

Province	No. of fields	Spot blotch (%)	Net blotch (%)	Barley stripe (%)
		Main season		
Wellega	72	46.8	46.0	0.03
Illubabor	16	0.0	88.0	0.0
Kefa	4	41.6	60.8	0.0
Mean	92	29.5	64.9	0.01
		Off-season		
Wellega	48	78.9	28.7	0.02
Illubabor	12	65.7	62.5	0.0
Kefa	1	100.0	20.0	0.0
Mean	61	80.9	35.0	0.0

for spot blotch in one field in Kefa with 32.0%. This survey revealed that Helminthosporium diseases of barley are not as important in Wellega, Illubabor or Kefa as they are in other parts of Ethiopia.

TABLE 5

Mean severity of net blotch and spot blotch in barley in western Ethiopia in 1999–2001

Province	No. of fields	Spot blotch (%)	Net blotch (%)
Main-season			
Wellega	72	2.63	3.6
Illubabor	16	0.0	9.1
Kefa	4	4.1	5.4
Mean	92	2.24	6.0
Off-season			
Wellega	48	8.0	3.6
Illubabor	12	1.8	11.1
Kefa	1	32.0	2.0
Mean	61	13.93	5.57

EPIDEMIOLOGY OF DISEASES

Basic knowledge of disease epidemiology is crucial to design effective control measures, but few efforts have been made in this area for barley in Ethiopia.

Inoculum sources

There are two inoculum sources for net blotch and spot blotch (infected seed and infected crop stubble), whereas infected seed is the only inoculum source for barley stripe. *Helminthosporium sativum* was routinely isolated from infected seed (Melkamu Ayalew, Bekele Hundie and Mesele Alemu, 1995). Bekele Hundie (2005) analysed barley seeds from various sources for net blotch (*P. teres*) infection in *Bona* of 2002 and *Genna* of 2003. The pathogen was frequently isolated from seeds, but varied with year, season and genotype (Table 6). Its range was 0–7.25% in 2002, and 0–1.75% in 2003, depending on seed source (Bekele Hundie, 2005). Seed infection of 7.25% resulted in 17% transmission efficiency (Table 7). Thus, infected seed would not be a primary inoculum source for net blotch epidemics where disease is endemic, but it would be the means for net blotch spreading to new areas. Accordingly, net blotch management must target methods that help clean infected seed and that stress planting of healthy seed.

TABLE 6

Net blotch seed infection of three barley varieties at Sinana in 2002–2003

Genotype	Seed infection (%)	
	2002	2003
Beka	0.35 b	0.00 b
PGRC/E 1694-5	2.31 a	0.37 a
Holker	0.06 c	0.00 b
Average	0.91	0.12

NOTES: Values in a column followed by the same letter are not significantly different at $P<0.05$

Infection

The infection process of *P. teres* and development among infection phases were followed using resistant and susceptible cultivars and a single isolate from the Sinana Research Station (Bekele Hundie, 2005). Conidia germinated from one end, two ends, and the middle of their cells produced germ tubes within 3 h of inoculation. Germination within 3–6 h and 9–24 h of inoculation differed significantly. Appressoria were formed on anticlinal cells, above stomata, and on intact surfaces of epidermal cells within 3 h. Predominantly, only one of the primary germ tubes produced an infective appressorium. Penetration was ca 9 h after inoculation, predominantly in anticlinal epidermal cells. Appressoria from

TABLE 7

Transmission of *P. teres* from a seed sample (harbouring an average 7.25% seed infection) to seedlings

Seedlings	Replicate				Total	Transmission (%)
	1	2	3	4		
Normal	99	97	100	99	395	
Diseased	1	3	0	1	5	1.25

NOTES: Seed infection transmission efficiency = (1.25%/7.25%) × 100 = 17%

TABLE 8

Net blotch development (as AUDPC) in the three topmost leaves in barley at Sinana, 2002–2003

Leaf position	AUDPC by genotype			
	Beka	PGRC/E 1694-5	Holker	Ardu-12-60B
2002				
F	1.6931 c	2.7853 c	1.4805 c	1.8016 c
F–1	4.5087 b	7.6542 b	4.5620 b	4.1053 b
F–2	9.1010 a	15.6422 a	9.1452 a	7.1610 a
2003				
F	9.3382 c	9.3018 c	6.1116 c	3.8733 c
F–1	16.1942 b	17.0486 b	12.0853 b	6.7598 b
F–2	35.6549 a	34.1879 a	21.8922 a	13.1807 a

Notes: Values in each row followed by the same letter are not significantly different at $P<0.05$; AUDPC = Area Under Disease Progress Curve; F = unfolded topmost leaf; F–1 = second topmost leaf; F–2 = third topmost leaf.

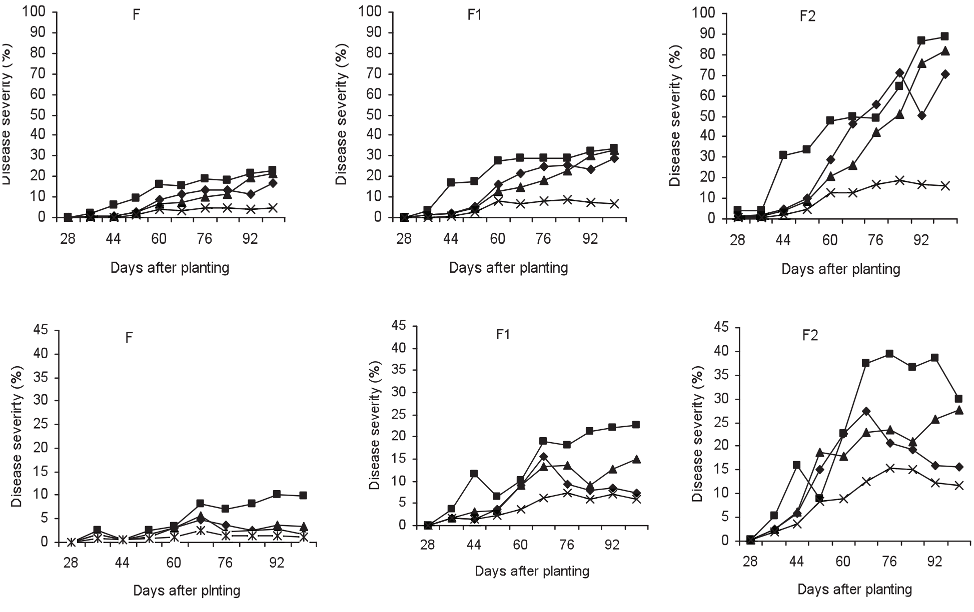
a single conidium rarely infected two host cells. Branches from primary germ tubes did not give effective penetration. Furthermore, there was no penetration wherever papillae-like structures were encountered. Up to two vesicles and intracellular infection hyphae emerged within 12 h of inoculation. All infection phases studied were not significantly affected by resistance backgrounds of the cultivars and were positively and significantly ($P<0.05$) correlated.

Disease onset and progression

Net blotch appeared early at about the three-leaf crop stage (Growth Stage (GS) 13; Zadoks, Chang and Konzak, 1974) in all years and seasons, but with different degrees of severity. Progression was faster in *Genna* than *Bona*. Shapes of the curve represented the sigmoid curve invariably by variety, year and leaf position (Figure 1). Varieties also affected net blotch progression. Difference between

FIGURE 1

Disease progress curves over the years (from left to right) on upper leaf (F), second-most upper leaf (F–1) and third-most upper leaf (F–2) in 2002 and 2003, Sinana, southeastern Oromia, Ethiopia



Key to genotypes: Beka ♦; PGRC/E1694-5 ■ ; Holker ▲ ; and Ardu-12-60B **X**) the most susceptible variety and the other varieties was substantial between 36–52 days after planting in all years. As suggested by area under the disease progress curves (AUDPC) (Table 8), disease progress curves and infection rates, net blotch progress was greater in lower than upper leaves, for all varieties and years. Planting healthy seeds and growing cultivars with seedling resistance, such as cultivar Ardu-12-60B (Figure 1) significantly inhibited net blotch epidemic development.

Correlation

Correlation of net blotch with agronomic and quality parameters was analysed, showing that net blotch severity and grain yield were negatively correlated starting 36 days after planting (about GS 22) and continuing through the subsequent crop growth stages, the unfolded uppermost three leaves, and across varieties. There was a similar correlation for 1000-grain weight. This relationship pattern shows the importance of integrating net blotch control from the early stages of seed and field preparation and at later crop stages. There were significant and positive relationships between net blotch and both grain and straw protein contents (Bekele Hundie, 2005). Thus, farmers may need to know the protein content during net blotch epidemics, since this is an important parameter for malting industries. The relationship between net blotch severity and incidence was positive, but not consistent between years, except for incidence (AUDPC) at 52 days after planting (Bekele Hundie, 2005) at Sinana in 2002 and 2003. Whether to use severity or incidence for net blotch assessment is a choice left to the users.

YIELD LOSS

Net blotch can occur either in complexes with leaf rust or scald, or singly (Bekele Hundie, 2005). Yield losses were assessed under these three conditions in the Bale highlands (Bekele Hundie, Shambel Kumbi and Abashamo Lencho, 2001; Bekele Hundie, 2005), southeast Ethiopia, and in the North Shewa highlands of central Ethiopia (Meki Shehabu and Asnakech Tekalign, 2004).

Southeast Ethiopia

On-farm losses associated with net blotch and leaf rust were studied in *Bona* of 1996–1997 and *Genna* of 1997–1998 under farmers' conditions in Bale (Bekele Hundie, Shambel Kumbi and Abashamo Lencho, 2001). The range of yield losses in *Genna* were 20–35% with a mean of 28%, and 25–33% in *Bona* with a mean of 29%. Net blotch and leaf rust also reduced straw yield by 29% and 22% in *Bona* and *Genna*, respectively.

On-station yield losses associated with net blotch were studied in malting and food barley varieties in *Genna* of 2002 and *Bona* of 2003 (Bekele Hundie, 2005) and the respective losses were 31–41% and 27–59%. These losses were greater than previous reports for state farms in Bale (Terefe Deyessa, 1990) and in on-station conditions at Holetta (Yitbarek Semeane and Wudneh, 1985). Grain and 1000-grain weight losses were predominantly explained by infection of the two leaves under the unfolded top leaves (Bekele Hundie, 2005). About a decade ago, occurrence of net blotch forced Herero and Serofta state farms to resort to use of fungicides (Lema Ebsa, Bekele Hundie and Dereje Tadesse, 1997).

Central Ethiopia

On-farm yield losses due to net blotch and scald were studied at Ankober and Faji in North Shewa in 1999 and 2000 *Meher* seasons. The assessments were made on an improved variety, Mirsrach, and local landraces, using the fungicide Propiconazole (used as complete disease control treatment). Grain yield, straw yield and 1000-grain weight were significantly lower in unsprayed treatments at both locations in both years. Losses were higher in local landraces for all locations and years. However, differences between varieties and variety × fungicide interactions were not significant. In 1999, the mean grain yield losses were 19.87% and 4.86% at Ankober and Faji, respectively. In 2000, both disease pressure and yield losses were very high; average grain yield losses were 37.39% and 14.49% at Ankober and Faji, respectively (Meki Shehabu and Asnakech Tekalign, 2004).

Annually, net blotch in complexes with scald reduced grain yields by 333.9–786.6 kg/ha (14.25–24.55%) in North Shewa. Grain yield losses were also associated with 1000-grain weight reduction. Yield of straw, an important animal feed, was reduced by 8–18% in Misirach and by 20.3–23% in the local unimproved landrace.

GENETIC CONTROL THROUGH RESISTANT GENOTYPES

Commercial and old varieties were evaluated for their reaction to barley diseases during 1997/1998 and 1999/2000 at Shambu or Arjo (BARC, 2002). Genotypes HB 42, HB 52, A-HOR 880/61, HB 120, Ardu-12-60B and 'Shege' were resistant to both net blotch and spot blotch, with reactions of <3 (on a 1–9 disease scoring scale) (BARC, 2002). Among these cultivars, HB 42 was recommended for these areas due to its resistance to net blotch, spot blotch and scald, as well as for its high grain yield. Of 92 genotypes evaluated in 2001 at Shambu, Shasho #22 GO-1, accessions 215448-2, 23536-1, 208038-15-1, 218951-36-1 and 229158-1 had low net blotch and spot blotch damage with severity scores <3 (on a 1–9 disease scale) and are considered resistant to the diseases. The first two genotypes were susceptible to scald. Improved varieties Ardu-12-60B, 'Holker' and 'Beka', together with one susceptible genotype, were compared for resistance to net blotch in *Bona* of 2002 and *Genna* of 2003. Ardu-12-60B was more resistant to net blotch than 'Holker' or 'Beka' (Bekele Hundie, 2005) (Figure 1). Net blotch resistance of 'Harbu' and 'Dafo', cultivars recently released by Sinana Research Centre, were compared. and 'Dafo' was far more resistant than 'Harbu'. Both Ardu-12-60B and 'Dafo' displayed slow blotching, which was confirmed by low AUDPC (Bekele, unpublished).

Ten barley differential lines and one susceptible check genotype were inoculated with 30 isolates of the two types of net and spot-forms of net blotch at seedling crop stages and evaluated using a 1–10 disease scale (Tekauz, 1985). Genotypes

CI 4929, CI 5401, CI 2750, CI 7584, CI 739, CI 2235, and CI 4407-1 were resistant to all 30 *P. teres* isolates (Asnakech Tekaligne, Yitbarek Semeane and Temam Hussien, 2005). Two hundred barley genotypes were screened against barley diseases at Sheno, Faji and Ankober under natural infection during 2000–2003. Genotypes 218957-29, 218957-56, 218957-99, 3441-76, 3441-70, EH1500, 1502, IBON 129/99, F2SXS110/99 and EH1516/F2-48H-2 were resistant to net blotch as well as scald. Disease severity for these genotypes did not exceed 15% (Asnakech Tekalign, unpublished).

Several barley genotypes were evaluated against net blotch, leaf rust and scald in preliminary and advanced screening, and in other nurseries. Of accessions evaluated for diseases at Sinja and Sinana in 1996–1997, accessions 206507, 214782, 215239, 215310, 215434, 215240, 215441, 215448, 215311, 218968 and 218969 sustained less than 20% infection and hence exhibited resistance to net blotch (SARC, 1996, 1997). Among barley genotypes evaluated for barley diseases in 1998–1999, lines 21840-76, 212840-33, 212838-1, 3288-4, 212845-4, and 212840-35 had disease severity of <23%, which indicated they were resistant to net blotch and leaf rust (SARC, 1998, 1999).

Hulless barleys included in the 8th Hulless Barley Screening Nursery 98 (HBSN 98) and hulled barley included in the 26th International Barley Observation Nursery 98 (IBON 98) were evaluated for barley diseases at Sinana and Dinsho in *Bona* of 1999–2000. Net blotch severity of <30% was observed on nine hulled barley genotypes and one local cross (Table 9). Net blotch severity was 60% on the susceptible genotype, 1806-4 (SARC, 1999, 2000).

Among hulled barleys from the 26th IBON 98, 67/98, 157/98 and 94/98, and local cross EH-956/F2-8H-6-4 had a net blotch severity of <25% at Sinana and Dinsho. Susceptible and resistant checks had net blotch severity up to 60 and 15%, respectively. All genotypes evaluated in the 26th International Barley Observation Nursery 98 (IBON 98) were resistant to scald (severity <15%) (SARC, 1999, 2000). Barley lines evaluated in preliminary screening of 2001 and retained from this work were re-evaluated in 2002 as an early set and a late set at Sinana and Upper Dinsho, respectively. Lines 1775-6 (20%) from the early set and lines 3283-10, 3353-16, 3353-4, and 1643-18 from the late set showed good resistance to net blotch, scald and leaf rust. The genotypes in the late set had net blotch severity <30% (SARC, 2001a, 2002). Accessions retained from preliminary screening of 2004 and from other sources were re-evaluated at Sinana and Upper Dinsho in two groups in 2005. Genotypes 3836, 840, 388, 001, 0284, 0288,

TABLE 9

Response of hulless barley genotypes to net blotch at Sinana and Dinsho in Bona, 1999–2000

Genotype	Net blotch (%)		
	Sinana		Upper Dinsho
	1999	2000	2000
8th HBSN 69/98	20	15	25
8th HBSN 30/98	20	15	30
8th HBSN 100/98	10	25	30
8th HBSN 63/98	20	25	30
8th HBSN 26/98	20	20	30
8th HBSN 28/98	30	10	30
8th HBSN 22/98	20	10	30
8th HBSN 43/98	30	25	20
8th HBSN 29/98	20	15	20
1806-4	–	60	40
EH-956/F2-8H-6-4	–	10	15

NOTES: HBSN indicates an entry in the 8th Hulless Barley Screening Nursery (HBSN 98).

0636, 065, 160, 2228, 3028, 365 and 6368L had damage scores of <10% from net blotch. The first two lines resisted best both scald and leaf rust. The recently released cultivar Dinsho had a net blotch severity of 20% (SARC, 2004, 2005).

CULTURAL CONTROL MEASURES

Net blotch

Effect of planting date on net blotch was studied in *Bona* of 1997 and *Genna* and *Bona* of 1998. Net blotch was reduced by August planting in *Bona* and April planting in *Genna*, and there was better grain and biomass yield under Sinana conditions (SARC, 1998). The disease progress curves, infection rates and AUDPC values revealed that net blotch appeared early (at about the three-leaf stage) and progressed upward from the bottom of the crop canopy with time. This was the case for all varieties and years. Differences between resistant and susceptible varieties were substantial, starting 36–52 days after planting, indicating that a net blotch epidemic could begin in the period after planting. Infection phases were studied and none was significantly affected by resistance backgrounds of cultivars; all were positively and significantly correlated, suggesting that interfering with preceding infection phases could negatively affect subsequent infection phases. Each infection phase is the function of the range of all of the preceding infection phases. Net blotch severity and grain yield were negatively correlated starting at 36 days after planting (about GS 22) through to the later crop growth stages and across varieties. The same relationship was true for 1000-grain weight. There was a significant and positive relationship between net blotch and both grain and straw proteins.

The relationship pattern reveals the importance of integrating response to net blotch from the earliest field operation and the earliest crop stages. Thus, net blotch management must account for cultural practices of ploughing-in of infected debris during land preparation. These practices include destruction of volunteer crops before planting; planting healthy seed; and growing cultivars with seedling resistance, such as Ardu-12-60B (Figure 1), and adult plant resistance that delays net blotch infection, delays disease onset and inhibits infection rate, consequently delaying the overall development of an epidemic.

Barley stripe

In nature, barley stripe is strictly a seedborne disease. Growing crops from pathogen-free seed is a very effective means of management. Seasonal effects on barley stripe caused by *P. graminea* were evaluated using seeds produced in the off-season using residual moisture and *Meher* barley production systems. Disease incidence from seeds from the off-season barley production system were least infected by *P. graminea*, and use of this seed source reduced barley stripe incidence by 91.3% in comparison with seed from the main season (AARC, 1992; Getaneh *et al.*, 1996). Efficacy of such a practice was comparable with some effective seed dressing fungicides, being only 7.7% less effective.

CHEMICAL CONTROL MEASURES

Net blotch

TABLE 10

Effect of 1–2 applications of Tilt 250EC on leaf rust, net blotch and grain yield in 1998

Treatment	Season	Leaf rust severity (%)	Blotch severity (%)	Grain yield (kg/ha)
T0	*Genna*	31.8	17.1	1628.6
	Bona	35.0	9.3	979.8
T1	*Genna*	22.1	14.2	1999.7
	Bona	11.8	6.4	1628.9
T2	*Genna*	13.8	12.2	1975.0
	Bona	14.0	6.8	1822.6
	Significance = *Genna / Bona*	$P = 0.000$	$P = 0.044$/NS	$P = 0.009/0.000$

NOTES: T0 = no application; T1 = single application; T2 = two applications; P = probability; NS = not significant.

Of several fungicides evaluated in Ethiopia (Terefe Deyessa, 1990), Tilt 250EC and Bayleton 25WP were registered for official use in cereals (Abdurahman Abdulahi, 1997; Abdurahman Abdulahi and Berhanu Gebre Medhin, 1999). One and two applications of Tilt 250EC at 0.5 L/ha (Table 10) suppressed leaf rust and net blotch (SARC, 1998). One and two applications of Tilt 250EC were evaluated on local food barley at Sinana (SARC, 1999); a single application increased grain yield by 433 kg/ha and two applications by 531 kg/ha; biomass was increased by 1819 and 2421 kg/ha, respectively. Of 1 to 3 applications of Tilt 250EC (0.5 L/ha) at various crop growth stages during 2002 and 2003 at Sinana (Bekele Hundie, 2005), two applications (one spray at GS30 and another at GS39) improved grain yield by 23% and 1000-grain weight by 4–6% in both years. Fungicide applications suppressed net blotch infection by suppressing infection rate.

Seed dressing fungicides

Spot blotch (black point) and barley stripe

The possibility of controlling *Helminthosporium sativum* by seed treatment was assessed in the laboratory at Adet (Melkamu Ayalew, Bekele Hundie and Mesele Alemu, 1995). Vitavax/prochloraz at 3 g/kg, Vincit at 2 g/kg, Baytan Universal at 1.5 g/kg, Prelude Universal at 2 g/kg and Agrosan 'H' at 2 g/kg all effectively controlled *H. sativum*. Likewise, the same seed treatments were evaluated against loose smut (Bekele Hundie *et al.*, 1994) by seed dressing at 10, 30 and 90 days before planting; efficacy did not vary with time of seed dressing. All seed treatments gave 98% control of barley stripe.

Net blotch

Dividend 3DS (applied at 100, 150 and 200 g per 100 kg seed) and Apron Star (at 250, 375 and 500 g per 100 kg seed) were evaluated on malting barley variety 'Beka' and food barley 'Fallibayie' at Sinana on-station in 1998, to check their effect on yield and associated diseases. Net blotch tended to decrease in Apron Star dry treatments, except at the highest rate in 'Beka', although not significantly different from the control. Grain yield was increased by 516–845 kg/ha in the malting and 880–1062 kg/ha in the food barley from Apron Star treatments (Table 11). Biomass was increased by 2000–3417 kg/ha for food barley and 666–1833 kg/ha for malting barley as a result of these treatments (SARC, 1998).

TABLE 11
Effects of seed dressing and foliar fungicide application on leaf rust, net blotch and grain yield of two barley varieties in 1998

Pesticide	Treatment	Rate (g per 100 kg seed)	Net blotch (%)		Grain yield (kg/ha)	
			Beka	Fal.	Beka	Fal.
Dividend 3DS	Dry	100	7.0	7.0	1639.3	1091.1
	Dry	150	13.3	4.0	1447.8	1437.9
	Dry	200	13.3	4.0	1515.1	1136.4
	Slurry	100	13.3	10.0	1760.2	1429.9
	Slurry	150	13.3	10.3	1471.5	1065.6
	Slurry	200	16.7	1.0	1723.9	1713.6
Apron Star 42WS	Dry	250	13.3	4.10	2345.3	2015.4
	Dry	375	16.7	1.0	2352.3	2197.9
	Dry	500	26.7	7.0	2674.9	2160.8
Tilt 250EC	Single spray	0.5 L/ha	16.7	–	1869.3	–
	Twice sprayed	0.5 L/ha	10.3	–	1950.9	–
Control	–	–	20.0	4	1829.4	1135.8
LSD ($P<0.05$)"			9.01	NS	538.0	783.8

NOTES: Fal. = variety ‘Falbeyie’; NS = Not significant.

Apron Star also reduced leaf rust significantly. As a follow up study, Apron Star with the same rates as previously, together with Gaucho Raxil at 100, 150 and 200 g per 100 kg, and foliar fungicide (Tilt 250EC) were evaluated on food barley ‘Aruso’ and malting barley ‘Beka’ at Sinana on-station and Selka on-farm in 1999 (SARC, 1999). The effects of seed dressing alone and seed dressing × foliar spray interaction did not differ significantly for most agronomic parameters and diseases, for all locations and varieties. At Sinana, Apron Star applied at 250, 375 and 500 g per 100 kg seed increased grain yield by 433.1–531 kg/ha in ‘Aruso’ compared with the check. Gaucho Raxil applied at 100, 150 and 200 mL per 100 kg seed increased grain yield by 645– 816.5 kg/ha. The yield increment could also be associated with control of shoot fly by Apron Star and Gaucho Raxil (SARC, 2001b). Thus, these studies indicated that Apron Star should be tested more extensively and incorporated in integrated disease management.

CONCLUSION AND RECOMMENDATIONS

Results of the barley disease surveys undertaken in southeast, west, north-west, northeast and central Ethiopia at irregular intervals were reported in the progress reports of Federal and Regional Research Centres. Helminthosporium disease surveys should sample all barley production systems, and areas prone to Helminthosporium diseases should be mapped and published yearly in a manner usable by farmers. Currently, net blotch and spot blotch are important in Ethiopia in distribution, incidence, severity, yield losses and pathogen variability. Pathotypes of *P. teres* populations have been studied in limited areas. Similar coordinated and systematic work should be done for both *P. teres* and *H. sativum*, to subsequently type the most frequent and virulent pathotypes by barley production system and use them for resistance screening. Epidemiological studies on net blotch suggest possible cultural management options for integrated disease management. Research on relationships between Helminthosporium disease epidemics and weather parameters, cultural practices, management, season and year—all preconditions for developing prediction models—have not received attention. Yield losses associated with net blotch remain high, but are specific to variety, location, farming practice and season, and cannot represent the whole barley production system. Future studies of losses associated with Helminthosporium diseases should be conducted to aid the development of yield loss prediction models for one or more barley production systems.

Lines resistant to net blotch and spot blotch have been identified from exotic barley landraces (although most effort has been for net blotch) and could be used in disease resistance breeding. Seed produced in the residual barley production system were least infected by *P. graminea* and are recommended as planting material in main seasons, which are more conducive both for barley production and barley stripe.

August and April planting dates reduced net blotch and increased yield at Sinana, so the effect of planting dates on Helminthosporium diseases needs to be determined in areas where they are important. The current price of barley is high in Ethiopia and Helminthosporium disease control by fungicide could be an economic option. Thus, the two fungicides currently registered for use in cereals could be demonstrated to farmers. New foliar fungicides should be evaluated for use in barley production systems at times when there could be unsatisfactory barley resistance to the diseases. Seed dressing fungicides identified as effective on barley stripe must be verified and registered, and their use encouraged on farms. Moreover, research on integrated Helminthosporium diseases management needs to be strengthened.

GAPS AND CHALLENGES

- Yield losses associated with net blotch remain high and location-specific, and do not represent all barley production systems.
- Generating information on pathotypes of the Helminthosporium pathogens has just begun, and much work will be necessary to describe all pathotypes associated with barley production systems across Ethiopia.
- Research on the identification of optimal and compatible cultural practices is scarce, although the work on net blotch epidemiology suggested the importance of integrating cultural practices with other management options, such as use of plant resistance and fungicide application.
- Research on the effects of change in weather parameters and management practices on disease epidemiology have not received attention.
- Developing high-yielding varieties that simultaneously combine resistance to one or more pests, such as net blotch and shoot fly, is a serious challenge for pathologists, entomologists and plant breeders.
- Helminthosporium diseases are partly initiated by planting infected seed and this could be exploited in an integrated disease management strategy.

Despite this, no seed-dressing fungicide is registered to control seed-borne Helminthosporium pathogens in Ethiopia.

FUTURE RESEARCH DIRECTIONS

- Carry out regular disease surveys characterizing pathotype patterns associated with *P. teres* and *H. sativum* to determine areas of their dominance in Ethiopia. Then the dominant and virulent pathotype(s) should be used in disease resistance breeding or in refining resistance sources detected under field conditions.
- Identify combined resistance sources to net blotch and shoot fly in collaboration with entomologists and plant breeders.
- Work to identify various compatible and optimum cultural practices to inhibit Helminthosporium diseases alone or in integrated disease management, and so increase yield.
- Research net blotch and spot blotch epidemiology as affected by weather parameters and various management practices, and thus contribute to more effective disease management strategies.
- Continue to identify cost-effective fungicides to effectively control both foliar infection and seed-borne Helminthosporium diseases.

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Achievements of research on barley Smuts, Ergot and Root and Foot Rot diseases in Ethiopia

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INTRODUCTION

Purely seed-borne diseases such as smuts (Stewart and Dagnachew Yirgu, 1967) and barley stripe cause losses commensurate with their incidence in Ethiopia. Likewise, root and foot rot diseases also contribute to the generally low yield of barley. Smuts and root diseases have been surveyed and their management options studied since 1993 by various research centres. This paper reviews root rot and smut survey results, and their management options as identified by various research centres in Ethiopia, and analyses the gaps and suggests future research needs.

SMUTS IN BARLEY

Southeast Ethiopia

Disease surveys were conducted during 1996, 1998, and 2005 in the highlands of Bale (Sinana, Dinsho, Goba, Goro, Agarfa, Gassera-Gololch, Dodola Adaba and Gindhir), either in *Genna* (March–August) or *Bona* (August–December) or both (SARC, 1996, 1998, 2005). Loose and covered smuts had a wider distribution than eye spot (Table 1). Eye spot had an incidence of 0.5–28% between Sinana–Dinsho in *Bona* and *Genna*; and 2–40% at Adaba in *Bona*, where wheat monocropping is widely practiced. Covered smut had a distribution of up to 87.5% in *Genna* and 100% in *Bona*; incidence reached 30% in *Genna* and 15% in *Bona*. Loose smut distribution reached 61% in *Genna* and 100% in *Bona*, with incidence of up to 20% in 2005. Both smuts had limited distribution and low incidence in the Bale highlands in

TABLE 1
Status of seed-borne diseases of barley by season in the Bale highlands in 1996, 1998 and 2005

Disease & Season	Distribution (%)	Incidence (%)		
	1996	1996	1998	2005
Covered smut				
Genna	0–87.5	0–10	1–5	0–30
Bona	0–100	0–5	1–5	1–15
Loose smut				
Genna	0–61.1	0–15	0–1	0–10
Bona	0–100	0–3	1–5	0–20
Eye spot				
Genna	0–9.7	0–0.5	0	0
Bona	0–25	0–40	0	0

comparison with net blotch, leaf rust and scald in both crop seasons (SARC, 1996, 1998, 2005). Both smuts, however, are considered important in both seasons, as the losses they cause are proportional to their incidence. Both covered and loose smuts are more important than in other parts of the country (this publication).

TABLE 2
Mean incidence of barley covered smut and loose smut by season, western Ethiopia, in 1999–2001

Province	No. of fields surveyed	Covered smut (%)	Loose smut (%)
	Meher		
Wellega	72	2.7	0.0
Illubabor	16	4.9	0.0
Kefa	4	0.0	0.0
Mean	92	2.54	0.0
	Belg		
Wellega	48	1.0	0.1
Illubabor	12	0.8	0.5
Kefa	1	2.1	0.0
Mean	61	1.20	0.2

Western Ethiopia

Disease surveys were conducted in the *Meher* season of 1999 and in both the *Meher* and *Belg* of 2000 and 2001 in Wellega, Illubabor and Kefa regions. Nine diseases were recorded, including the two smuts (Table 2). Covered smut was greater in *Meher* than in *Belg*, with mean prevalence 95.6% in *Meher* and 86.7% in *Belg*. The mean prevalence of covered smut for the three areas surveyed was 91.5% (Getaneh Woldeab and Teklu Negash, 2001). The incidence of covered smut was very low, despite its high prevalence. Covered smut was more important than loose smut, which had rare occurrence; only 6.6% of the fields were infested in *Belg,* with an incidence <0.5% (Getaneh Woldeab and Teklu Negash, 2001).

Northwest Ethiopia

Disease surveys in northwestern Ethiopia in 1988–1992 were reviewed previously (Yitbarek Semeane *et al.*, 1996). Incidence of covered and loose smuts was between 3.3 and 8.5%. Bekele Hundie *et al.* (1994) reported an incidence of 28% for loose smut.

Northeast Ethiopia

Disease surveys were carried out to identify major prevailing diseases in major barley growing areas of northeast Ethiopia (SiARC, 1995, 1996). Loose and covered smuts were the two seed-borne diseases recorded in both *Meher* and *Belg*. Despite their occasional occurrence in both seasons, both diseases had a higher incidence in *Meher* than *Belg* (Table 3). In earlier review work, 25% of loose smut incidence was reported from Wollo, northeast Ethiopia (Yitbarek Semeane *et al.*, 1996).

Central Ethiopia

Disease surveys in central Ethiopia in 1988–1992 detected incidences of covered smut of 2.1% and 7.5% of loose smut (Yitbarek Semeane *et al.,* 1996).

ERGOT IN BARLEY IN SOUTHEAST ETHIOPIA

Ergot (*Claviceps purpurea*) distribution was assessed in Bale during 2002 (Arsi-Bale Plant Health Clinic, unpublished). Seeds from Awasho, Abukar Kolo, Kara Are, Gofingira and Kosa Shekumara areas of Sinana-Dinsho District and Hako, Furuna Koma, Abasa Robe, Sasa Nagelie, Garadiela, Lajo Birbirsa, Waddie, Hako Kara, Fansho and Arda Kara areas of Adaba District were infested with sclerotia of the fungus. Ergot incidence of 10–80% (honeydews) and 2–10% fungal sclerotia were reported from Bale, Arsi, southeast Ethiopia, and Ambo (Yitbarek Semeane *et al.*, 1996). Another earlier survey of field production in Bale and Arsi showed a 5–60% ergot infection in wild oats (Terefe Deyes, 1985).

TABLE 3

Status of floral diseases of barley in northeast Ethiopia in *Meher* and *Belg* of 1995–1996

Disease	Prevalence		Incidence by crop season		Crop stage
	1995	1996	Meher **1995**	Belg **1996**	
Loose smut	+	+	Medium	Light	H, M
Covered smut	+	+	Medium	Light	H, M

NOTES: + = occasionally present; H = Heading; M = Maturing.
SOURCE: SiARC (1995, 1996).

FOOT AND ROOT ROT DISEASES

The status of barley foot and root rots was assessed along four routes in West Shewa, central Ethiopia, during 1995 and 1997 cropping seasons (Tables 4a and 4b). The diseases occurred individually or in combination. The disease incidences varied with growth stage and increased with crop age. The overall incidence of root rot was up to 49.1%, while eye spot reached 14.4% (Getaneh Woldeab, 2002). Take-all disease occurred occasionally in north Ethiopia with a light incidence in *Belg* (SiARC, 1996). Eye spot had limited distribution and low incidence in the Bale highlands, compared with other barley diseases (SARC, 1996); prevalence was 9.7 in *Genna* and 25% in *Bona*, with incidences of 0.5% and 40%, respectively.

PATHOGENS ASSOCIATED WITH FOOT AND ROOT ROT DISEASES OF BARLEY

Several samples collected during the surveys were sent to the Plant Disease Diagnostic and Advisory Laboratory of CABI Bioscience, UK, to identify

TABLE 4A

Mean root rot and eye spot incidences at three crop growth stages for barley in West Shewa in 1995–1997

Growth Stage	Survey route				
	Ginchi–Jeldu	Gedo–Goben	Ambo–Wonchi	Tikur Inchini– Shenen	Mean
			Root rot		
Seedling	21.3	19.0	22.7	18.9	20.5
Stem elongation	39.3	42.2	40.0	35.4	39.2
Flowering	51.2	50.8	44.8	49.5	49.1
			Eye spot		
Seedling	0.99	0.99	0.99	0.99	0.99
Stem elongation	21.7	3.3	4.5	0.99	7.6
Flowering	36.4	8.1	9.1	4.0	14.4

TABLE 4B

Foot rot and root rot symptoms in barley plant samples along four routes in West Shewa, 1995–1997

Disease	Survey Route				
	Ginchi–Jeldu	Gedo–Goben	Ambo–Wonchi	Tikur Inchini–Shenen	Mean
None	29.7	39.1	44.7	40.4	38.5
Eye spot	22.7	3.1	5.7	3.1	6.7
Root rot	38.1	48.6	43.3	49.3	44.8
Eye spot and root rot	28.3	11.1	8.9	3.1	12.9

pathogens associated with foot and root rots of barley. *Pseudocercosporella herpotrichoides*, *Pythium* spp., *Cochliobolus sativus* and *Fusarium avenacium* were involved as causal agents of foot and root rots in barley. The first two pathogens were found along all routes in West Shewa, while *Cochliobolus sativus* was from samples collected from Ambo–Wonchi and *Fusarium avenacium* was from samples collected from Ginchi–Jeldu routes. *Fusarium avenacium* and *Pythium* spp. are new records on barley in Ethiopia (Getaneh Woldeab, 2002).

MANAGEMENT METHODS

Cultural control

Loose smut

In northwestern Ethiopia, for main season planting farmers use seed produced during the off season by utilizing residual moisture and using irrigation water. Research at Adet Research Centee confirmed that this practice can control loose smut incidence by 99% (AARC, 1992; Yitbarek Semeane *et al.*, 1996). This practice was as effective as using fungicides such as Vitavax/prochloraz, Vincit, Baytan Universal or Prelude Universal.

Root rot

Effects of precursor crops and fallow practices on root rot and eye spot were surveyed following four routes in West Shewa during 1996–1997 (Getaneh Woldeab, 2002). Results are summarized in Table 5. The surveys revealed that the number of both eye spot and root rot infected samples was less when barley was sown after fallow than after barley or linseed.

Chemical control with seed dressing fungicides

Vitavax/prochloraz, Vincit, Baytan Universal, Prelude Universal and Agrosan 'H' were tested to control loose smut (Bekele Hundie *et al.,* 1994); all were effective, reducing it by 82–99%.

CONCLUSIONS AND RECOMMENDATIONS

Barley diseases were surveyed in the main and off-seasons in various parts of Ethiopia. Both present and previous surveys indicated that covered smut and loose smut remain important. Recent surveys indicated that smuts varied with the season. Further detailed survey work is required to determine smut status. Effective seed-dressing fungicides for loose smut were identified; these fungicides need to be verified, registered and their use encouraged. Barley seed from off-season barley production produced the least smutted heads and could be used as seed.

Ergot infestation was detected in barley seed

TABLE 5

Effect of precursor crops and fallow practices on incidence of root rot and eye spot in West Shewa, 1996–1997

Precursor crop	No. of fields	Root rot (%)		Eye spot (%)	
		Free	Infected	Free	Infected
Linseed	7	20.9	79.1	88.1	11.9
Barley	15	27.2	72.8	80.5	19.5
Fallow	14	29.9	70.1	91.3	8.7

samples from Bale, although ergotism was not encountered. Monitoring and creating awareness of cultural practices for ergot management are needed.

Eye spot/foot rots (*Pseudocercosporella herpotrichoides*) and root rots (*C. sativus*, *Pythium* spp. and *F. avenaceum*) were important. *Pythium* spp. and *F. avenaceum* were new records on barley for Ethiopia. Both root and foot rot disease incidence increased with advancing crop growth stage. Barley rotation with linseed somewhat reduced eye spot incidence; however, fallowing was better, and should be practiced where there is no land shortage. Overall, there is little information on root diseases and thus current data may not show the whole picture of the disease situation across all Ethiopian barley production systems. This situation invites further, well coordinated root rot and foot rot disease surveys across barley production systems to estimate their economic significance.

GAPS AND CHALLENGES

- Barley smuts remain an important constraint to barley, as indicated by present and previous review reports in Ethiopia. Losses caused reflect their incidence. Moreover, low smut incidence in preceding barley crops results in infected seeds that may not be fit for planting as the next crop.
- Surveys in some parts of Ethiopia suggested that smuts varied with the season of barley production. However, the present data may not represent all barley production environments. This requires further smut disease surveys concerning season, altitude, weather parameters, variety, cultural practices such as harvesting methods, and seed production schemes, with such surveys implemented in a coordinated manner that involves Regional and Federal Research Centres.
- There are no research programmes that target the identification of resistance sources and variety development with regard to smuts.
- Several seed dressing fungicides that were effective on smuts were identified, but there is no registered seed-dressing fungicide for farmer use.
- Ergot infestation assessment, while infrequent, indicated that ergot occurred in Ethiopia. However, there is a lack of routine monitoring work that targets barley production systems, seasons, and updates awareness of its importance and the necessary cultural management practices.
- Eye spot and root rot diseases are important in certain parts of the country and their incidence varied, increasing with crop growth stage. However, data are needed from all barley production environments. Therefore, surveying root rot and foot rot diseases across seasons, production systems, altitudes and weather is a challenge that remains. The present work suggested that both fallow and a linseed followed by barley rotation reduced eye spot, but did not affect root rot diseases.

FUTURE RESEARCH DIRECTIONS

- Undertake targeted surveys for smuts, and root and foot rot diseases, across seasons, weather parameters, varieties and farming practices (such as means of harvesting, sanitation and seed production scheme) so that the data generated is representative of the country.

- Verify that seed dressing fungicides are as effective on smuts as previous fungicide evaluations have indicated, and register them for smut management in barley. Continue to identify new and environmentally friendly seed dressing fungicides that are effective against smuts.
- Routinely monitor ergot incidence and create awareness of the seriousness of this disease. Provide training on possible management options.
- Investigate short-term and long-term crop rotation options that effectively reduce root rot and foot rot diseases. For this purpose, use crops that fit in to barley production systems since infected residues and stubble serve as infection sources for the diseases.

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On-farm evaluation of QTLs: the case of partial resistance to *Puccinia hordei* Otth in southeast Ethiopia

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INTRODUCTION

The majority of important agronomic characters—yield and its components (grain number and grain weight), plant height, days to flowering, and partial resistance to diseases—are controlled by several genes. The number of genes and their interactions control the expression of quantitative traits and are poorly understood in conventional quantitative genetics analyses. Before the development of molecular markers, attempts to localize quantitative trait loci (QTLs) sought to determine their association with morphological markers, but these attempts were successful only in some loci with large effects on a given quantitative trait (Griffiths *et al.*, 1996). Localization of QTLs to small regions within chromosomes requires closely spaced marker loci along the chromosomes. Moreover, there must be parental lines that differ from each other in the alleles carried at a sufficient number of these marker loci. In most cases, these requirements could not be met because of the limited number of morphological markers. The frequently occurring isozyme markers in breeding lines that compensated for some of the drawbacks of the morphological markers enabled the localization of several loci responsible for quantitative traits (Tanksley and Rick, 1980; Tanksley, Medina-Filho and Rick, 1982; Vallejos and Tanksley, 1983).

The construction of dense linkage maps for QTL identification was greatly facilitated by the development of molecular markers based on variation at the DNA sequence level (Paterson *et al*., 1988; Lander and Botstein, 1989; Edwards *et al.*, 1992; Stuber *et al*., 1992). Lander and Botstein (1989) developed a strategy known as QTL mapping, which uses molecular markers to map QTLs. Various molecular markers (DNA markers), such as restriction fragment length polymorphisms (RFLPs) (Botstein *et al*., 1980); random amplified polymorphic DNA (RAPD) (Weber and May, 1989); simple sequence repeats (SSRs); and amplified fragment length polymorphism (AFLPs) (Vos *et al*., 1995), have been developed for the construction of dense linkage maps. Several RFLP, AFLP and SSR markers have been mapped on the barley genome in different populations (e.g. Heun et al., 1991; Becker and Heun, 1995; Qi and Lindhout, 1997). QTL mapping and related developments in molecular marker technology have consumed a substantial amount of resources, with the expectation that identified QTLs and knowledge of their map positions would be used in marker-assisted plant breeding to accumulate QTLs with positive effects.

However, wide use of marker assisted selection (MAS) is far from practical, especially in developing countries that lack facilities and technical capacity. Data for QTL identification comes from specific environments and controlled experiments that are not usually representative of target environments in developing countries, and need to be tested under natural production conditions before the data can be used in a breeding programme.

This paper summarizes the performance of some QTLs for partial resistance to barley leaf rust under natural epidemic development in the southeastern highlands of Ethiopia. The paper also reviews types of resistance against the pathogen, their mechanisms, durability and the polygenic nature of partial resistance.

TYPES OF RESISTANCE TO BARLEY LEAF RUST

Barley leaf rust (*Puccinia hordei* Otth) is a major barley disease in Ethiopia that reduces grain yield by an estimated 14% (Yitbarek Semeane *et al.,* 1996). Resistance to the pathogen exists as hypersensitive or non-hypersensitive mechanisms (Parlevliet, 1976a, b). With complete hypersensitive resistance, usually race-specific, the infection causes little or no macroscopic effect (Niks, 1986). A number of race-specific (*Rph*, synonym *Pa*) genes for resistance to barley leaf rust have been mapped on the barley genome (Table 1). Partial resistance is a non-hypersensitive resistance that reduces epidemic development in a susceptible infection type (Parlevliet and van Ommeren, 1975). Among susceptible host plant genotypes, there are quantitative differences in level of infection severity. Niks (1986) showed that plant cell wall penetration as well as pathogen growth and reproduction are less successful in a partially resistant plant than in a more susceptible one, resulting in reduced infection frequency and growth rate of the fungus, and hence a longer latent period. Parlevliet (1986) concluded that genes for partial resistance to barley leaf rust pleiotropically reduce the infection frequency, increase the latent period and reduce the rate of sporulation. Partial resistance, measured as epidemic progress in the field, is highly correlated with latent period (Parlevliet and van Ommeren, 1975).

TABLE 1
***Rph* genes for resistance to barley leaf rust in barley**

Locus	Chromosome position
Rphx	Long arm of 1 (7H); considered allele of *Rph3*
Rph1	Short arm of 2 (2H)
Rph2	Short arm of 7 (5H)
Rph3	Long arm of 1 (7H); considered allele of *Rphx*
Rph4	Short arm of 5 1H)
Rph5	3(3H)
Rph7	Short arm of 3 (3H)
Rph9	Long arm of 7 (5H); considered allele of *Rph12*
Rph10	Long arm of 3 (3H)
Rph11	Long arm of 6 (6H)
Rph12	Long arm of 7 (5H); considered allele of *Rph9*

SOURCES: Hayes *et al.*, 1996; Roane and Starling, 1989; Feuerstein, Brown and Burdon, 1990.

DURABILITY AND POLYGENIC NATURE OF PARTIAL RESISTANCE

Partial resistance behaves largely in a race-non-specific manner (VanderPlank, 1963) although small differential interactions may occur in barley (Clifford and Clothier, 1974; Parlevliet, 1977, 1978b). The resistance is more durable than hypersensitive resistance (Clifford, 1972; Parlevliet and van Ommeren, 1975) as there is no major-gene-for-major-gene interaction, and therefore a low probability that all genes become susceptible at the same time. It is inherited polygenically (Parlevliet, 1976a, 1978a). The phenotypic variation in resistance among genotypes shows a continuous range rather than discrete phenotypic classes (Clifford, 1972; Parlevliet and van Ommeren, 1975; Parlevliet *et al.*, 1980). It is therefore difficult to assign a particular genotype unambiguously to a particular phenotype. Phenotypic selection for partial resistance is more difficult than selection for hypersensitive resistance. However, Parlevliet and van Ommeren (1975) and Parlevliet *et al.* (1980) suggest that it should be fairly easy in barley leaf rust, due to the relatively high genetic variation for resistance in the crop.

QTLS FOR PARTIAL RESISTANCE TO BARLEY LEAF RUST

Detailed studies on partial resistance to *P. hordei* in barley began in 1972 at Wageningen University in the Netherlands (Parlevliet and van Ommeren, 1975). Since then, considerable fundamental information has been generated regarding its genetics (Parlevliet, 1976a, 1978b), mechanism (Niks, 1986), selection methods (Parlevliet and van Ommeren, 1975; Parlevliet *et al.*, 1980), and the relationships among components of partial resistance (Parlevliet, 1986).

A number of QTLs have been mapped for quantitative resistance to several barley diseases (Ivandic *et al.*, 2003; Williams, 2003; Backes *et al.*, 1996; Pecchioni *et al.*, 1996). QTLs for resistance to Fusarium head blight (Mesfin *et al.*, 2003) and stripe rust (Castro ***et al.***, 2002, 2003) have been mapped recently. Several QTLs have also been identified for various agronomic traits, including plant height, grain yield, and days to heading (Baum *et al.*, 2003), kernel weight (Nevo *et al.*, 2004), malt quality (Marquez-Cedillo *et al.*, 2000), straw quality (Grando *et al.*, 2005), and for tolerance or resistance to abiotic stresses like aluminium toxicity (Raman *et al.*, 2002).

Fourteen QTLs have been mapped for partial resistance to barley leaf rust in two mapping populations in the Netherlands (Table 2). Three of these QTLs, *Rphq13* (7H), *Rphq10* (4H) and *Rphq3* (6H), were effective at the adult plant stage, with ***Rphq3*** also effective at the seedling stage, and have been mapped in the cross L94 × 116-5 (Qi *et al.*, 2000) and L94 × 'Vada' (Qi *et al.*, 1998, 1999). Two other loci, *Rphq11* and *Rphq12*, effective at the seedling stage, have been mapped in the cross L94 × 116-5 (Qi *et al.*, 2000). One more putative QTL, provisionally named here as *Qch2*, has been described on chromosome 2H in the L94 × 116-5 population.

VERIFICATION OF QTLS UNDER NATURAL EPIDEMIC DEVELOPMENT

Partial resistance to a pathogen works in minor-gene-for-minor-gene interaction and mapping can only be conducted using one specific isolate at a time. However,

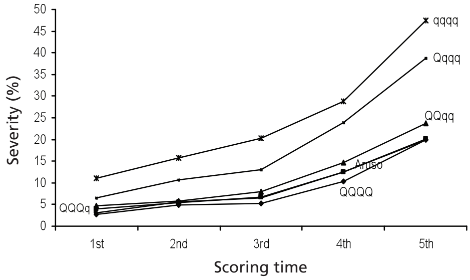
TABLE 2
QTLs mapped for partial resistance to barley leaf rust in two populations[1]

QTL	RLP Expl. (%)	AUDPC Expl. (%)	Population	Isolate	Chromosome
Rphq1	1.9	0.9	L94/Vada	1.2.1	1(7H)
Rphq2	19.9	3.8	L94/Vada	1.2.1/24	2H
Rphq3	14.8	15.7	L94/Vada, L94/116-5	1.2.1/24	6H
Rphq4	11.9	44.7	L94/Vada	1.2.1/24	7(5H)
Rphq5	4.3	3.7	L94/Vada	1.2.1	4H
Rphq6	7.7	1.4	L94/Vada	1.2.1	2H
Rphq7	6.3		L94/Vada	24	7(5H)
Rphq8	9.4		L94/Vada	24	1(7H)
Rphq9	7.1		L94/Vada	24	1(7H)
Rphq10	6.1	5.5	L94/Vada, L94/116-5	1.2.1/24	4H
Rphq11	20.0		L94/116-5	1.2.1	2H
Rphq12	4.5		L94/116-5	1.2.1	2H
Rphq13		9.2	L94/116-5	1.2.1	1(7H)
Qch2			L94/116-5	1.2.1	2H

NOTES: RLP = Relative latent period; AUDPC = Area under the disease progress curve; Expl. = The proportion of the phenotypic variance explained. SOURCES: Compiled from Qi *et al.*, 1998, 1999, 2000.

under natural conditions a given cultivar needs to grow with an unknown pathogen population. Therefore, the effectiveness of a QTL under natural infection across environments needs to be verified before being used in routine breeding programmes. The performances of four QTLs—*Rphq13* (7H), *Qch2* (2H), *Rphq10* (4H), and *Rphq3* (6H)—originally mapped in the cross between L94 (susceptible line) and a partial resistant line 116-5 using isolate 1-2-1 (Qi *et al.*, 2000) were evaluated under natural infection and epidemic development in three environments in the southeastern highlands of Ethiopia. Ninety recombinant inbred lines of barley with varying combinations of the four QTLs were grown in evaluating the QTLs. The experiment was conducted at two locations: Sinana, located 2470 masl in a bimodal rainfall area; and Herero, 2365 masl in a unimodal rainfall area, At Sinana, the experiment was conducted in 1999 in two seasons locally known as ***Bona/****Meher* season (June–September) and *Ganna/Belg* season (March–July), and at Herero in the same year in ***Meher*** season. The two seasons of Sinana are hereafter referred to as Sinana-*Meher* and Sinana-*Belg.*

FIGURE 1
Leaf rust epidemic development (%) in five genotypes and the local check 'Aruso', an average of three environments under field conditions; Q = 116-5 genotype at each QTL, and q = L94 genotype



The disease epidemic development was measured during the growing season in five genotype groups and the local check 'Aruso' (Figure 1). Disease severity was consistently lowest in the genotype with all its alleles from the partially resistant parent, and highest in the genotype with all its alleles from the susceptible parent. The severity on 'Aruso' was the same for the genotypes with three QTLs. This indicates that 'Aruso' has some QTLs for partial resistance to the pathogen. These putative QTLs in 'Aruso' could be the same as any three of the four QTLs in 116-5 or could be other unknown type and number of QTLs.

Differences in the area under disease progress curve (AUDPC) between the environments were significant ($P<0.05$) in all gene combinations. Average AUDPC was 437 in Sinana-*Belg*, 263 in Sinana-*Meher*, and 77 at Herero. Table 3 shows the percent reduction in AUDPC due to each QTL. Each QTL significantly reduced AUDPC in all of the three-locus × environment (E) combinations, *Rphq13* × *Qch2* × *Rphq10* × E (referred to as 13×2×10), *Rphq13* × *Qch2* × *Rphq3* × E (13×2×3), *Rphq13* × *Rphq10* × *Rphq3* × E (13×10×3) and *Qch2* × *Rphq10* × *Rphq3* × E (2×10×3), and in the four-locus × E combination, *Rphq13* × *Qch2* × *Rphq10* × *Rphq3* × E (13×2×10×3). Only the alleles from the partially resistant parent, 116-5, reduced AUDPC, with reduction ranging from 4% at *Qch2* locus in the 2×10×3 combination to 47% at the *Rphq3* locus in the four-locus combination analysis (Table 3). *Rphq3* was the most effective locus in all three-locus × E analysis, reducing AUDPC by 45–47%. This locus has been mapped as a plant growth-independent QTL, being effective at both seedling and adult plant stages, with the highest explained variance in the mapping population (Qi *et al.*, 2000). The *Qch2* locus was the least effective.

The performances of *Rphq10* and *Rphq3* loci differed with environment in both three-locus and four-locus analyses (Table 4). The range in reduction in AUDPC due to *Rphq10* locus across environments was 31–42% in the 13×2×10×3 gene combination to 34–49% in the 13×2×10 combination. The significant interaction of the locus with environment was merely due to changes in magnitude from one environment to another, and was effective in all environments in all QTL combinations. The *Rphq3* locus reduced AUDPC by about 50% in both seasons at Sinana in all gene combinations, but was not effective at Herero (Table 4).

TABLE 3
Reduction of leaf rust AUDPC (%) due to main effects of four QTLs in relation to AUDPC in the susceptible parent in different QTL combinations

QTL combination	Locus			
	Rphq13	***Qch2***	***Rphq10***	***Rphq3***
13×2×10	17	10	39	
13×2×3	15	8		46
13×10×3	11		36	45
2×10×3		4	38	46
13×2×10×3	10	5	35	47

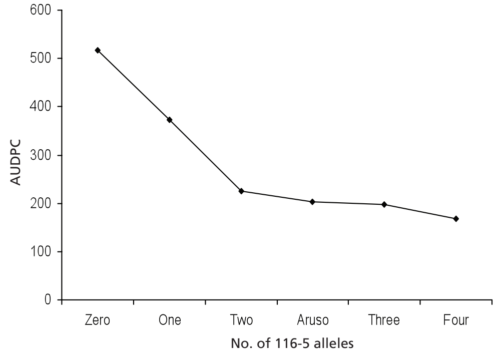
NOTES: E = environment. QTL combinations are 13×2×10 = *Rphq13* × *Qch2* × *Rphq10* × E; 13×2×3 = *Rphq13* × *Qch2* × *Rphq3* × E; 13×10×3 = *Rphq13* × *Rphq10* × *Rphq3* × E; 2×10×3 = *Qch2* × *Rphq10* × *Rphq3* × E; 13×2×10×3 = *Rphq13* × *Qch2* × *Rphq10* × *Rphq3* × E.

TABLE 4
Effect of two QTLs across environment in different QTLs combinations in reducing AUDPC (%) relative to AUDPC in the susceptible parent

Locus	QTL combination	Environment		
		Sinana-*Belg*	Herero	Sinana-*Meher*
Rphq10	13×2×10	34	35	49
	13×10×3	31	40	44
	2×10×3	34	32	47
	13×2×10×3	31	36	42
Rphq3	13×10×3	49	2	48
	13×2×3	48	6	50
	2×10×3	49	-0.4	49
	13×2×10×3	50	4	50

NOTES: E = environment. QTL combinations: 13×2×10 = *Rphq13* × *Qch2* × *Rphq10* × E; 13×2×3 = *Rphq13* × *Qch2* × *Rphq3* × E; 13×10×3 = *Rphq13* × *Rphq10* × *Rphq3* × E; 2×10×3 = *Qch2* × *Rphq10* × *Rphq3* × E; 13×2×10×3 = *Rphq13* × *Qch2* × *Rphq10* × *Rphq3* × E.

FIGURE 2
Mean leaf rust AUDPC as affected by the number of alleles in 116-5 at four QTLs. 'Aruso' included as a check



Rphq13 and *Qch2* loci were stable across environments, but there was some two-locus interaction with each other and with other QTLs in one or more combination analyses. The epistatic interactions, however, were only due to changes in magnitude, and therefore do not rule out the incorporation of any two loci into a breeding line. Pyramiding the loci is important to protect a variety by means of a residual resistance in case one of the loci is defeated.

All the three-way, four-way and five-way interactions were non-significant. On average, the highest disease reduction was when all the four loci were present (Figure 2). When at least any three of the four QTLs were present, they acted additively, indicating the possibility of accumulating the loci in a breeding line for a high level of partial resistance that is effective across environments.

In conclusion, breeding for partial resistance is indispensable for developing varieties with durable resistance. The prospect of MAS for partial resistance to barley leaf rust is high, as the majority of QTLs evaluated were effective under natural epidemic development across environments; any interaction was only due to changes in the magnitude of effect. *Rphq3* was the only locus that was not effective at one of the three environments, Herero. The four loci acted additively except for some interactions that were solely due to changes in magnitude of effect, not due to changes in direction. Breeding for quantitative traits in general and for partial resistance in particular could benefit from the various QTLs being mapped in advanced research institutes and international agricultural research centres. Useful breeding lines could be identified through evaluation of QTLs for various quantitative traits under natural production conditions in collaborative projects between these and the national agricultural research system. The collaboration could grow into the area of MAS.

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Achievements of research on Barley and Cereal Yellow Dwarf viruses infecting barley in Ethiopia

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INTRODUCTION

Barley yellow dwarf (BYD) disease, caused by a group of luteoviruses known collectively as Barley yellow dwarf viruses (BYDVs), is economically damaging and the most widespread disease of cereals worldwide (Burnett, 1984). Severely infected crops often produce no grain. Based on the principal aphid species that transmit different isolates of BYDV, Rochow (1970) characterized and designated five strains of the virus (BYDV-PAV, BYDV-MAV, BYDV-RPV, BYDV-RMV and BYDV-SGV). More recently, the International Committee on Taxonomy of Viruses (ICTV) accepted the five barley yellow dwarf virus strains as distinct species in the family Luteoviridae (van Regenmortel *et al*., 2000). The species BYDV-PAV and BYDV-MAV were placed in the genus Luteovirus, and BYDV-RPV was renamed as Cereal yellow dwarf virus (CYDV-RPV) and placed in the genus Polerovirus. The other two species, BYDV-RMV and BYDV-SGV, have yet to be assigned to a genus. The recent classification by ICTV and that of Rochow (1970) were used in this paper.

As for other crop plants, formal research on virus diseases of barley in Ethiopia dates back about 15 years. Since the first report of BYDV in Ethiopia by Stewart and Dagnachew Yirgu (1967), all research activities reported until 1989 were based either on field visual observations or only small sample sizes and few locations (Agranovsky, 1986; Abdulrazak Yusuf *et al*., 1992; Dereje Tadesse *et al*., 1993). The information generated was scanty, inconclusive and unrepresentative.

This paper reviews research results from systematic, intensive and representative surveys on the occurrence and distribution of BYDVs and CYDV-RPV in the major barley growing areas; the impact of the dominant BYDV species (BYDV-PAV) on the yield and growth of barley; wild and cultivated grass hosts of the viruses; and host plant resistance studies conducted over the last 13 years (1994–2006).

FIGURE 1
Map showing BYDV and CYDV survey areas and routes in Ethiopia

SURVEY, IDENTIFICATION AND GEOGRAPHICAL DISTRIBUTION OF BYDV AND CYDV-RPV

BYD disease on barley in Ethiopia, based on visual field symptoms, was first reported by Stewart and Dagnachew Yirgu (1967), regardless of the BYDV strain(s) or species responsible. This report was based on only symptomology and was not confirmed by any standard laboratory diagnostic methods suggested for BYDV (i.e. biological, serological or molecular means). Subsequent surveys, using serological diagnostic methods, were carried out in 1984–1989 by both national and foreign researchers (Agranovsky, 1986; Abdulrazak Yusuf *et al.*, 1992; Dereje Tadesse *et al.*, 1993). These studies confirmed the occurrence of only BYDV-PAV and BYDV-MAV in barley, but covered only a few barley growing areas. Moreover, these surveys had very small sample sizes, were scattered, not representative and inconclusive. They were reviewed by Eshetu Bekele (1986) and in Hailu Gebre and van Leur (1996). Results of systematic, comprehensive and representative surveys (Figure 1) conducted in 1994–2001 during both the *Meher* and *Belg* seasons are presented here.

TABLE 1

Distribution and occurrence of BYDV and CYDV species in barley fields in central Ethiopia, during the main rainy season of 1995

Zone & District	Fields surveyed	Samples tested	No. of samples tested positive for serotype					
			PAV	MAV	RPV	RMV	SGV	Mixed
Arsi								
Bekoji	13	325	15(8)	10(4)	8(3)	4(3)	10(7)	7(7)
Asasa	10	250	7(5)	4(4)	4(3)	3(3)	8(3)	4(4)
Kofale	4	100	0	4(2)	0	1(1)	0	0
Sagure	1	25	0	0	0	0	0	0
Assela	3	75	0	0	0	1(1)	0	0
Iteya	3	75	0	0	0	0	0	0
Dera	1	25	0	0	0	0	0	0
Subtotal	35	875	22(13)	18(10)	12(6)	9(8)	18(10)	11(11)
North Shewa (Amhara region)								
Ensaro	4	100	0	2(1)	1(1)	0	0	0
Inewari	1	25	0	0	0	0	0	0
D/Birhan	6	150	0	8(4)	3(2)	0	0	1(1)
Angolela	10	250	5(4)	4(3)	0	0	2(1)	0
Subtotal	21	525	5(4)	14(8)	4(3)	0	2(1)	1(1)
North Shewa (Oromia region)								
Chancho	8	200	0	0	4(3)	0	0	0
Yaya Gulale	3	75	0	0	0	0	0	0
Hambiso	4	100	0	0	0	0	0	0
Muketuri	6	150	0	0	2(2)	0	0	0
Mendida	1	25	0	0	0	0	0	0
Sheno	1	25	0	1(1)	0	0	0	0
Sendafa	1	25	0	0	0	0	0	0
Subtotal	24	600	0	1(1)	6(5)	0	0	0
West Shewa								
Holetta	4	100	3(2)	1(1)	0	0	0	1(1)
Ginchi	9	225	2(1)	4(2)	1(1)	1(1)	1(1)	1(1)
Ambo	3	75	0	2(1)	0	0	0	0
Jeldu	2	50	2(1)	2(1)	2(1)	0	1(1)	1(1)
Gedo	7	175	1(1)	2(1)	0	2(1)	2(1)	2(2)
Chitu	7	175	3(2)	3(3)	3(2)	2(2)	7(4)	4(4)
Tikur	1	25	2(1)	0	0	0	0	0
Subtotal	33	825	13(8)	14(9)	6(4)	5(4)	11(7)	9(9)
Grand total	113	2825	40(25)	47(28)	28(18)	14(12)	31(18)	21(21)

NOTES: Figures in parentheses indicate number of fields in which BYDV was detected. SOURCE: Berhanu Bekele *et al.*, 2001.

SURVEYS IN THE MAIN SEASONS (1994–2001)

Central region (1994, 1995, 1997 and 1998)

There were severe BYD symptoms and epidemics in barley fields of West Shewa during the *Meher* season of 1994. Tissue blot immunoassay (TBIA) (Makkouk and Comeau, 1994) indicated that BYDV was present in 19 of 25 locations (76%) surveyed and disease incidence was up to 40% in some locations (Berhanu Bekele *et al.*, 1995). In the 1995 *Meher* season, four barley growing administrative zones in central Ethiopia (Arsi, North Shewa, N.W. Shewa and West Shewa) were surveyed.

In Arsi, disease symptoms typical of BYDV, such as yellowing and stunting were common at higher altitudes, particularly >2500 masl. BYDV, either in single or mixed infection, was detected in 23 of 35 barley fields surveyed in this zone. BYDV incidence was relatively high in Bekoji, Asasa and Kofale Districts. All five BYDV species were detected in Arsi, particularly in Bekoji and Asasa Districts (Table 1). The dominant species detected was BYDV-PAV (27.8%), followed by BYDV-MAV and BYDV-SGV (each 22.8%), CYDV-RPV (15.2%) and BYDV-RMV (11.4%). There were mixed infections of two or more species only in Bekoji and Asasa (Table 1).

In North Shewa Zone of the Amhara region, of 21 fields sampled in four districts, BYDVs were detected in 12 (57.1%) fields at 2550–2800 masl. In this zone, all BYDVs and CYDV species were detected, except BYDV-RMV. The most widespread type in North Shewa was BYDV-MAV (57.7%), followed by BYDV-PAV (19.2%), CYDV-RPV (15.4%) and BYDV-SGV (7.7%).

In North Shewa Zone of the Oromia region, of 24 fields surveyed in seven districts, the disease was identified in samples from only five (20.8%) fields in three districts. Only BYDV-MAV and CYDV-RPV were detected, and CYDV-RPV was most common.

In West Shewa Zone, BYDV was detected in 14 of 33 fields (42.4%) surveyed in seven districts, either in single or mixed infections. The -MAV type was most common (28.5%) in West Shewa, followed by -PAV (26.5%), -SGV (22.4%), -RPV (12.2%) and -RMV (10.4%). There were mixed infections of two or more types in nine samples (Table 1; Berhanu Bekele *et al.*, 2001).

In Arsi Zone, of the four districts surveyed during the 1998 *Meher* cropping season, BYDV was identified from barley samples collected between altitudes of 2350 masl in Asasa District and 2870 masl in Bekoji District. Severe symptoms typical of BYD described for barley, such as yellowing and stunting, were commonly observed in most areas sampled in Kofale District at altitudes of 2520–2610 masl. BYDVs and CYDV were detected in 46 of 64 (72%) fields in this zone, either singly or in mixed infections, and in 209 of 1600 samples tested (13%). Among the four districts, there were high incidences of disease in Asasa, Kofale and Tiyo, in order of importance, and least in Bekoji district. TBIA demonstrated that all the five species (BYDV-PAV, -MAV, -RMV, -SGV and CYDV-RPV) were detected in samples from Asasa, Kofole and Tiyo Districts of Arsi Zone. However, only BYDV-MAV, CYDV-RPV and BYDV-SGV were in samples from Bekoji District. BYDV-PAV was the most frequently detected virus in Arsi Zone (3.6% of samples), followed by BYDV-RMV (3.5%), BYDV-MAV (3%), BYDV-SGV (2%) and CYDV-RPV (1%). There were mixed infections of various combinations in all districts except Bekoji. In Arsi, of 64 fields inspected, 20 were planted to malting barley and 44 to food barley (20 local and 24 improved cultivars). In Asasa District, for example, BYDVs and CYDV were identified from 14 food barley varieties, of which nine were local ('Aruso') and five were improved ('Sheneka', HB 42 or Ahor 83/91). The disease was also identified from two fields planted with an improved malting barley, 'Beka'.

In the two districts of West Shewa Zone at the time of survey, 39% of barley fields were at booting, GS 49 (Zadoks Growth stage (GS); Zadoks, Chang and Konzak, 1974); 32% were at milky (GS 71); 21% at flowering (GS 65); and 7% at heading (GS 83) stage. The altitudes of surveyed areas were between 2400 masl in Tikur Inchini District and 2525 masl in Shenen District. In Tikur Inchini, BYDV-PAV was the most common in 5% of samples, followed by BYDV-SGV (5%), -MAV (4%), -RMV (3%), and CYDV-RPV (2%). However, BYDV-MAV was the most widely distributed (4%), followed by BYDV-PAV and -SGV (3% each), CYDV-RPV (2%) and -RMV (0.3%) in Shenen District. Overall, in West Shewa, the BYDV-PAV, -MAV and -SGV species were nearly equally distributed (4%), followed by CYDV-RPV and BYDV-RMV (2% each; Table 2; Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003).

North region (1998/1999–1999/2000)

During the surveys in the north region, there was heavy rain. Disease symptoms, aphid infestation, BYDVs, and CYDV-RPV were rare. In these regions, most barley was local varieties.

In Gojam, BYDV-PAV, -SGV and CYDV-RPV were not detected in any samples (Table 2). However, TBIA indicated BYDV-MAV and -RMV in three of the 13 fields surveyed (23.1%). BYDV-MAV was identified from only two samples in one location, and -RMV from 10 samples in two locations. The three species (BYDV-PAV, -MAV, and -RMV) were detected in 27% of fields in Gonder, where -PAV was identified at three locations in six samples (0.9%), -RMV at five locations in 10 samples (1.5%), and -MAV in only one sample in one location (Table 2). In Wollo, BYDVs and CYDV were identified from seven samples from three locations. BYDV-PAV was detected in samples from Dilba area in Guba Lafto district (North Wollo) at 3200 masl in two of the 500 samples tested. The other viruses detected in this zone include -MAV and -RPV, each from two samples at altitudes of 2500 and 2300 masl, respectively. BYDV-SGV was identified from only one sample in Dilba area. There was mixed infection of two types (-PAV and -SGV) in Dilba area of Guba Lafto District in North Wollo (Table 2). In the southern zone of Tigray Regional State, however, only -PAV was detected in one sample collected from Maychew area (Berhanu Bekele *et al.*, 2003).

West region (Meher seasons 2000–2001)

In West Shewa, the surveyed areas were > 2400 masl. Most barley fields showed typical symptoms of BYD, with the highest severity score of 9 (on a 1–9 scale) in some fields of Goban area in Chelia District. BYDV-PAV was detected in 500 of 675 (74%) plants tested. BYD severity score range was 5–9 (on 1–9 scale) in 21 of 27 locations sampled. Of eight districts assessed, there was high disease incidence in Tikur Inchini, Nono, Chitu, Wayu, and Chelia (Table 3; Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003).

In west Ethiopia (Jimma, Illubabor and East Wellega areas of west Oromia Regional State), barley fields at the time of sampling were at flowering (GS 61;

TABLE 2

BYDV and CYDV species detected in barley in central and north Ethiopia in the main crop seasons of 199702000

Zone & District	Fields surveyed	Samples tested	No. of samples tested positive for serotype				
			-PAV	-MAV	-RPV	-RMV	-SGV
Arsi (199701998)							
Lemu-bilbilo	16	400	0	3(1)	1(1)	0	5(5)
Gedeb	16	400	24(11)	14(7)	12(8)	43(15)	12(5)
Kofale	16	400	20(10)	15(6)	5(4)	8(4)	12(6)
Tiyo	16	400	14(7)	10(6)	2(2)	5(5)	4(3)
Subtotal	64	1600	58(28)	42(20)	20(15)	56(24)	33(19)
West Shewa (1997–1998)							
Tikur Inchini	16	400	21(9)	14(9)	9(7)	13(7)	20(10)
Nono (Shenen)	12	300	8(6)	13(6)	7(4)	1(1)	8(6)
Subtotal	28	700	29(15)	27(15)	16(11)	14(8)	8(16)
Central region total	92	2300	87(43)	69(35)	36(26)	70(32)	41(35)
Wollo (1998–2000)							
Dessie Zuria	8	200	0	1(1)	1(1)	0	0
Ambassele	1	25	0	0	0	0	0
Guba lafto	3	75	1(1)	0	0	0	1(1)
Muja	1	25	0	0	0	0	0
Gidan	1	25	0	0	0	0	0
Maket	6	150	0	0	0	0	0
Subtotal	20	500	1(1)	0	0	0	1(1)
South Tigray (1998–2000)							
Ofla	2	50	0	0	0	0	0
Korem	4	100	0	0	0	0	0
Maichew	2	50	1(1)	0	0	0	0
Kuha	1	25	0	0	0	0	0
Ambalage	4	100	0	0	0	0	0
Subtotal	13	325	1(1)	0	0	0	0
Gojam (1998–2000)							
Dejen	1	25	0	0	0	0	0
Dangila	3	75	0	0	0	0	0
Marawi	3	75	0	0	0	0	0
Bahir Dar	5	125		2(1)		10(2)	
Kosober	1	25	0	0	0	0	0
K/ Dega Damot	1	25	0	0	0	0	0
Subtotal	14	350	0	2(1)		10(2)	
Gonder (1998–2000)							
Bahir Dar	3	75	0	0	0	1(1)	
Hamusit	1	25	0	0	0	0	0
Anbasmi	1	25	0	0	0	0	0
Libo Kamkam	1	25	0	0	0	0	0
Teda	5	125	3(1)	1(1)	0	6(2)	0
Tikl Dingai	2	50	0	0	0	1(1)	0
Kola Diba	1	25	1(1)	0	0	0	0
Woreta	1	25		0	0	0	0
Farta	3	75	2(1)	0	0	0	0
Gaint	4	100	0	0	0	2(1)	0
Dabat	1	25	0	0	0	0	0
Debark	1	25	0	0	0	0	0
Amba Giorgis	1	25	0	0	0	0	0
Subtotal	26	650	6(3)	1(1)	0	10(5)	0

NOTES: Figures in parenthesis indicates number of fields positive for BYDV.

SOURCE: Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003.

40%), heading (GS 85; 20%), and booting (GS 47; 40%) stages. There were typical BYD symptoms in a few locations, such as the Kalita area of Sokoru District in Jimma Zone at 1900 masl. BYDV-PAV was identified in 14% of locations, and from six of 925 (0.65%) samples tested (Table 3). BYDV was detected at altitudes of 1900–2400 masl (Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003).

TABLE 3

BYDV-PAV detected on barley in west Ethiopia during main rainy seasons of 2000–2001

Zone & District	Fields surveyed	Samples tested	Samples tested positive for	
			BYDV-PAV-2000	BYDV-PAV-2001
Jimma				
Sokoru	1	25	1	1
Subtotal	1	25	1	1
Illubabor				
Dedessa	2	50	1	1
Gechi	1	25	–ve	–ve
Bedele	9	225	–ve	–ve
Subtotal	12	300	1	1
East Wellega				
Jimma-Arjo	2	50	–ve	–ve
Diga-leka	2	50	–ve	–ve
Gudaya Bila	1	25	–ve	–ve
Sayo	2	50	–ve	–ve
Jimma Ganati	3	75	1	1
Shambu	8	200	1	1
Abay choman	4	100	–ve	–ve
Kombolicha	2	50	–ve	–ve
Subtotal	24	600	3	3
West Shewa				
Chelia	4	100	88	4
Nono	4	100	96	4
Inchini	2	50	49	2
Chitu	4	50	49	2
Ambo	2	50	19	2
Jeldu	6	150	103	6
Adea berga	4	100	25	4
Wayu	1	25	24	1
Subtotal	27	675	500	27
Total West Region 2000/2001	64	1600	505	32

NOTES: –ve indicates negative. SOURCE: Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003.

BYDV DURING BELG SEASONS

In 1996 in North Shewa Zone of the Amhara region, samples were collected from altitudes of 2525–3050 masl. BYDV was detected in seven of 11 fields, with most infections in Wesha-Weshe areas of Debre Berhan district at 2950 masl (Table 4). In this region, the -PAV type was the most common (32.7%), followed by -RPV (25.5%), -MAV and -RMV (14.5% each) and -SGV (12.7%). In North Shewa Zone of the Oromia region, BYDV was detected in 13 of 14 fields. The most common type was -SGV (32.3%), followed by -RMV (21%), -PAV (19.4%), -RPV (16.1%) and -MAV (11.3%) (Table 4). Among four districts surveyed in West Shewa, BYDV was detected in three (Table 4). There were mixed infections of two or more types in the two North Shewa Zones, but not in West Shewa (Berhanu Bekele *et al.*, 2001).

There were additional surveys in central and west regions in 2001. In these surveys, nearly all barley fields were sown to local varieties that grow under low precipitation and residual moisture. In West Shewa, of 250 barley samples from six locations in Dendi and four in Ambo Districts, -PAV was identified in only two samples (0.8%). Disease incidence and severity were very low (1–3) in most locations. Similarly, barley, wheat and oat varieties grown for seed multiplication at the Plant Protection Research Centre had low incidence and severity of BYDV-

TABLE 4

Distribution and occurrence of BYDV and CYDV species in barley fields in central Ethiopia in the short rainy season of 1996

Zone & District	Fields surveyed	Samples tested	No. of samples tested positive for serotype					
			-PAV	-MAV	-RPV	-RMV	-SGV	Mixed
North Shewa (Amhara region)								
Ankober	7	175	10(5)	0	5(2)	3(1)	4(2)	2(2)
Debre Berhan	2	50	8(4)	8(3)	9(4)	5(2)	0	4(4)
Debre Sina	1	25	0	0	0	0	3(1)	0
Ensaro	1	25	0	0	0	0	0	0
Subtotal	11	275	18(9)	8(3)	14(6)	8(3)	7(3)	6(6)
North Shewa (Oromia region)								
Sheno	6	150	4(1)	4(2)	5(3)	9(5)	6(2)	2(2)
Muketuri	2	50	0	3(1)	0	0	7(3)	0
Hambiso	4	100	0	0	4(2)	3(1)	5(2)	0
Mendida	2	50	8(2)	0	1(1)	1(1)	2(1)	1(1)
Subtotal	14	350	12(3)	7(3)	10(6)	13(7)	20(8)	3(3)
West Shewa								
Sebeta	4	100	2(1)	3(1)	0	2(1)	4(1)	0
Holetta	2	50	0	0	0	5(1)	0	0
Adea Berga	1	25	0	0	0	0	0	0
Adis Alem	1	25	3(1)	0	0	0	3(1)	0
Subtotal	8	200	5(2)	3(1)	0	7(2)	7(2)	0
Grand total	**33**	**825**	**35(14)**	**18(7)**	**24(12)**	**28(12)**	**34(13)**	**9(9)**

NOTES: Figures in parentheses indicate number of fields in which BYDV was detected.
SOURCE: Berhanu Bekele *et al*., 2001.

PAV, except on a local barley variety collected from Meskale Darkina area in Bale (southeast Ethiopia) and a wheat variety 'Opta', which had medium (5) to high (7) levels of infection. In East Wellega, BYDV-PAV was recovered from only one sample in Jimma-Arjo and two in Leka-Dulecha Districts (Table 5).

BYDV-PAV was not detected in 625 samples from 25 localities in North Shewa Zone of the Oromia Regional State (Table 5). In Arsi, BYDV was identified in nine of 175 samples (5%) from Tana District, and not in any of 100 samples from Hetosa District (Table 5). In four other districts of West Shewa Zone, BYDV-PAV was detected in four of 75 samples (5.3%) collected from three locations in Addis Alem District, in two of 100 samples (2%) in Dendi District, in two of 50 samples (4%) in Ambo District, and no BYDV was detected in samples from Adeaberga District (Table 5). In North Shewa Zone of the Amhara Regional State (Table 5), BYDV-PAV was detected in 18 of 700 samples (2.6%) from 25 localities in eight districts. Most BYDV-positive samples were from Ankober District, representing 12% of the 100 samples tested, followed by Keiyt District (16%), Bosana Werena (1%) and Debre Berhan (0.6%) (Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003).

BYDV-RELATED YIELD LOSSES

An assessment of yield loss due to BYDV was carried out at Inchini and Goban (West Shewa) where high levels of infection were obtained repeatedly in consecutive years. The experiment was conducted at both locations during the main rainy seasons of 2000/2001 and 2001/2002. There was significant BYDV infection at both locations in both seasons (Tables 6 and 7). The mean losses in grain yield due to BYDV were estimated at 21.2 and 35.2% in local barley varieties at Goben and Shenen, respectively. The mean differences between healthy and infected plants were highly significant at both locations (Tables 6 and 7). Biomass was also significantly different between infected and healthy plants at both Shenen and Goben, and tiller count was significant at Goben but not at Shenen. However, difference in mean plant height between infected and healthy plants was highly significant at Shenen but not at Goben.

Earlier, a yield loss assessment was carried out for one season at Bekoji research site, Arsi Zone, under natural infection conditions using two released food barley varieties (Ahor 880/61 and HB 42) during the *Meher* season in June–October 1996. Due to favourable seasonal weather conditions for disease development and aphid vectors, notable data on yield loss due to BYDV were obtained at Bekoji. Infected plants showed intense leaf yellowing and severe dwarfing, with average severity scores of 6 and 3, respectively, for Ahor 880/61 and HB 42 (on a 0–9 scale). The mean losses in grain yield due to BYDV were estimated at 79.67% for Ahor 880/61 and 51.34% for HB 42. On average, compared with healthy plants, plant height was reduced by 16.06% for infected HB 42 and 34.45% for infected Ahor 880/61. However, there was no significant reduction in tiller number for HB 42, but a very significant reduction in tiller number for Ahor 880/61 (Table 8). There was a significant correlation between disease severity and both yield loss and height reduction. There were strong negative correlations (r = –0.809 and

TABLE 5

Occurrence of BYDV-PAV in barley in central and western Ethiopia during the short rainy season of 2001

Zone & District	Fields surveyed	Samples tested	No. of samples tested positive for BYDV-PAV
North Shewa (Oromiya Region)			
Berehealeltu	4	100	–ve
Kimbibit	1	25	–ve
Abichu & Ghna	5	125	–ve
Mukaturi	4	100	–ve
Degem	4	100	–ve
Sululta-Mulo	7	175	–ve
Subtotal	25	625	–ve
Arsi			
Tana	7	175	9
Hetosa	3	75	–ve
Subtotal	10	250	9
West Shewa			
Addis Alem	3	75	4
Adeaberga	1	25	–ve
Dandi	4	100	2
Ambo	2	50	2
Subtotal	10	250	8
North Shewa (Amhara Region)			
Hagere Mariam	2	50	–ve
Chacha	4	100	–ve
Bosana Warena	4	100	1
Debre Sina	5	125	–ve
Debre Berhan	7	175	1
Ensaro & Wayu	1	25	–ve
Keiyt	1	25	4
Ankober	4	100	12
Subtotal	28	700	18
East Wellega			
Jimma-Arjo	12	300	1
Leka-Dulecha	7	175	2
Subtotal	19	475	3
West Shewa			
Dendi	6	150	2
Ambo	4	100	–ve
PPRC	7	175	7
Subtotal	17	425	9
Grand total	109	2725	47

NOTES: –ve indicates negative or absent.

SOURCE: Berhanu Bekele, Abdulrazak Yusuf and Makkouk, 2003.

r = –0.919) for HB 42 and Ahor 880/61, respectively, between yield and severity; and r = –0.955 for HB 42 and r = –0.966 for Ahor 880/61 between height and severity. There was no disease epidemic in the following season, and so there were no yield loss data for 1997.

TABLE 6

Effect of BYDV on growth and yield of local barley variety at Goban, West Shewa, in 2001

Treatment	PH	Mean tillers (no.)	Biomass (g)	Yield (g/plot)
Healthy (–ve)	103.8	2.22**	9.96**	5.19**
Infected (+ve)	108.44	1.58	7.59	4.09
Mean loss (%)	–	28.8%	23.8%	21.2%

NOTES: ** indicates significant at P<0.01. Difference between control and infected plants are tested by t-statistic. PH = mean plant height (cm). SOURCE: PPRC, 2004.

TABLE 7

Effect of BYDV on growth and yield of barley at Shenen, West Shewa, in 2001

Treatment	PH	Mean tillers (no.)	Biomass (g)	Yield (g/plot)
Healthy (–ve)	103.51**	2.51	9.80**	3.92**
Infected (+ve)	92.61	2.44	7.50	2.54
Mean loss	10.5%	–	23.5%	35.2%

NOTES: Difference between control and infected plants are tested by *t*-statistic. PH = mean plant height (cm). SOURCE: PPRC, 2004.

BYDV HOST RANGE IN ETHIOPIA

BYDV infects more than 100 plant species belonging to the family Gramineae, including *Phalaris* spp., *Bromus pectinatus*, *Digitaria scalarum*, *Dactylis glomerata*, *Setaria* spp., *Hyparrheneia* spp., *Panicum coloratum*, *Chloris gayana*, *Avena fatua*, maize, sorghum and other volunteer grasses. These have all been reported as wild or alternative hosts to BYDV and its aphid vectors (Adugna Haile and Kemal Ali, 1985; Haber, 1990; El Yamani, 1992). These grass species exist in barley growing areas of Ethiopia (Stroud and Parker, 1989). Wild grasses can support the survival of both the virus and the aphid vectors through dry periods, from which infection transfers to newly growing barley plants in the following season. The role of these grass species in harbouring the virus has not been studied in Ethiopia. A field survey to investigate the host range of BYDV was carried out during *Meher* and *Belg* seasons of 2000/2001, *Meher* seasons of 2001/2002, and a greenhouse study using artificial inoculation to determine the occurrence and distribution of BYDVs in wild grasses in barley growing areas of Ethiopia. In the 2000/2001 *Meher* season a total of 5861 grass samples of different species were collected from 113 locations in 44 districts. Of various types of grass species tested, BYDV was recovered from 13: *Setaria pumila*, *Snowdonia polystachya*, *Lolium temulentum*, *Phalaris paradoxa*, *Avena fatua*, *Setaria* sp., *Bromus pectinatus*, *Andropogon abyssinicus*, *Phalaris acquatica*, *Hyparrhenia collina* and two unidentified weeds (Berhanu Bekele, 2004). During the *Belg* season of 2000/2001, of the 2758 samples collected

TABLE 8

Effect of BYDV on growth and yield of barley at Bekoji, 1996

Genotype	Plant height (cm)		Tiller count		Yield (g/plant)		Mean loss
	H	I	H	I	H	I	
HB 42	110.20	92.5	4.47	4.25	9.35**	4.55	51.34%
Ahor 880/61	108.18	70.91	4.13	2.45	11.17**	2.27	79.67%

NOTES: Difference between control and infected plants were tested by *t*-statistic. H = healthy; I = Infected; ** = Significant at *P*<0.01. SOURCE: Berhanu Bekele, 1998.

TABLE 9

Grass weeds and forage cereals identified as alternate hosts of BYDV, short rainy season of 2000/2001

		Host plants tested									
Zone	No. of districts (sites)	*Avena fatua*	*Lolium*	*Bromus*	*Phalaris*	*Snowdonia*	Emmer wheat	*Setaria* sp.	*Andropogon*	Unknown	Samples collected
Arsi	2 (10)	–	–	–	–	–	–	–	–	–	427
W. Shewa	3 (8)	–	–	–	–	–	–	–	–	14+	461
NW. Shewa	6 (25)	–	–	–	–	–	–	–	–	–	925
N. Shewa	6 (21)	–	–	–	–	–	–	1+	–	–	945
Total samples collected											2758

Source: Berhanu Bekele, 2004.

TABLE 10

Grass weeds and forage cereals identified as alternative hosts of BYDV, main season 2001/2002.

		Host plant genera tested								
Zone	No. of districts (sites)	*Lolium*	Oats (wild and cult.)	*Snowdonia*	*Bromus*	*Phalaris*	*Andropogon*	*Setaria*	Unknown	Total samples
Arsi	Kofale	25+	9+	6+	9+	3+	–	–	3+	
	Bekoji	–	4+	–	4+	3+	–	–	–	
	Tiyo	–	–	–	–	–	21+	8+	–	
	Digelu-Tijo	–	–	–	–	–	–	–	–	
	Subtotal									804
Bale	3 (6)	–	–	–	–	–	–	–	–	504
North Shewa	Ankober	–	1+	–	–	–	–	–	–	691
North Shewa	7 (11)	–	–	–	–	–	–	–	–	694
East Shewa	1 (1)	–	–	–	–	–	–	–	–	17
Total samples										2708

Source: Berhanu Bekele, 2004.

(Table 9) from Arsi (427), West Shewa (461), Northwest Shewa (925) and North Shewa (945), BYDV-PAV was recovered from 14 plants of unidentified grass species in West Shewa and in one plant of *Setaria* sp. in North Shewa (Table 9).

During the *Meher* season of 2001/2002, BYDV-PAV was recovered from all grass species sampled in Arsi Zone (Table 10). Of the four districts, the virus was identified from six of eight grass species. There were 2710 grass weeds sampled from Arsi (804), North Shewa, Amhara region (691), Bale (504), N Shewa, Oromia region (694), and East Shewa (17). BYDV was detected in 95 plants of eight weed species sampled in three districts (Kofale, Bekoji and Tiyo) in Arsi, in one oat sample from Ankober in North Shewa and in none of the samples from Bale, North Shewa, Oromia region, and East Shewa. Weed genera from which BYDV was detected in Arsi were *Lolium*, wild and cultivated oats, *Snowdonia*, *Bromus*, *Phalaris*, *Andropogon*, *Setaria* and one unidentified weed species. Of these weed species, BYDV-PAV was identified from six in Kofele District, the majority being *Lolium* spp. (Table 10). BYDV-PAV was also detected in three of eight grass species in Bekoji, two of eight species in Tiyo, and none in Digelu-Tijo. In the remaining surveyed zones, the virus was only detected in one oat plant in Ankober District of North Shewa (Table 10).

In addition to the field survey, seeds of some grass weeds and forage cereals were collected and raised in a greenhouse for host range study during the main season of 2000/2001. These plants were artificially inoculated and tested for BYDV-PAV using TBIA. BYDV was recovered from 16 oat lines, three grass weeds and four forage cereals (Table 11).

TABLE 11
Grass weeds and forage cereals tested for BYDV-PAV by artificial inoculation in 2001/2002

Host plant	No. of plants tested	BYDV +ve
Setaria pumila	10	–
Avena abyssinica (wild oat)	10	+ (9/10)
Snowdonia polystachya	10	–
Phalaris paradox	10	+ (4/10)
Sorghum halepense	10	–
Avena fatua (wild oat)	10	+(10/10)
Avena sativa (cultivated oat)	10	+(5/10)
Lolium temulentum	10	+(4/10)
Tagetus minuta	10	–
Andropogon sp.	10	–

Source: Berhanu Bekele, 2004.

Under natural infection, BYDV-PAV was more prevalent on grass species during the *Meher* than in the *Belg* season. Low levels of BYDV-PAV during the dry period may be associated with the activities of vectors. It is also possible that low levels of the virus during the dry period may be due to an absence of suitable living grass species.

HOST PLANT RESISTANCE STUDY

Screening for BYDV host resistance in barley was conducted in 2000–2005 under natural field infection in hot-spot areas (i.e. Goben and Shenen). Artificial inoculation was also used to obtain high disease pressure and ensure infection. From the Institute of Biodiversity Conservation and Research (IBCR), over 1000 barley landrace accessions were obtained and screened. The collections were purified using IBCR descriptors. Artificial inoculation (Gildow, 1990) was carried out using viruliferous local colonies of aphid vectors (*Rhopalosiphum maidis*) (Jedlinski, 1981) and cultures of local BYDV-PAV isolates. Among 1000 lines tested repeatedly at both locations, 42 were selected as the best tolerant or resistant lines, and retained during the 2005 *Meher* season. This material was then used in a greenhouse for further study using artificial infection.

CONCLUSION AND RECOMMENDATIONS

- In studies during the review period, pertinent baseline information on the status of all BYDVs and CYDV species reported in the world were developed for barley in Ethiopia.
- All BYDVs (BYDV-PAV, -MAV, -RMV and -SGV) and CYDV-RPV occurred either singly or in mixed infections in many surveyed areas in the main and short rainy seasons. From the surveys and from previous reports,

it is evident that BYDV-PAV was predominant in Ethiopian barley varieties, followed by BYDV-MAV, as generally occurs elsewhere.

- It is interesting to note the relatively high occurrence of the BYDV-SGV species in 1995 and 1996, and BYDV-RMV in 1997/98 surveys in central Ethiopia (Arsi and Shewa), whereas they have a very limited distribution worldwide. Such a shift in the dominance of BYDV species in some years and locations requires further investigation.
- Generally, there were high virus incidences, and BYD luteoviruses and the CYD polerovirus were most widely distributed and prevalent in central Ethiopia (Arsi and Shewa surveyed zones) and low in areas of north and west Ethiopia.
- Variation in disease incidence across the regions was most likely due to, among other factors, differences in varieties grown and farming system practices. In central Ethiopia, for instance, improved varieties were the most commonly cultivated, whereas in north and west Ethiopia farmers mainly grow local landraces, which might have a buffering effect and/or inherent resistance to the disease compared with the improved lines. Similarly, in north and west Ethiopia, farming systems are a mix of crops of different families (both BYDV host and non-host). However, at the time of surveys, cereal monocropping dominated farming systems in central Ethiopia (especially Arsi), which hosts the viruses.
- The occurrence of all viruses in barley in both the main and short rainy seasons aids the continued survival of the virus between cropping cycles. Furthermore, the presence of BYDV and CYDV aphid vectors in Ethiopia, in addition to the large number of wild grasses on which the viruses and their aphid vectors may survive during the dry period, serve as primary inoculum sources for the following season's barley, and can contribute toward disease epidemics. This seem to hold true especially in Goben areas (Chelia District) and some localities in Shenen District (West Shewa Zone), where high disease incidence and epidemics occur every year.
- Yield loss studies in some localities of West Shewa and Arsi showed that viruses cause high yield losses under severe infection. High BYDV incidences and severity regularly occur in Chelia and Shenen Districts of West Shewa Zone, and sporadically in Bekoji, Asasa and Kofele Districts in Arsi Zone. This, therefore, indicates the need to design appropriate control measures.
- Host plant resistance studies under field conditions gave promising results, where some disease resistant or tolerant genotypes were developed from local landraces and exotic materials. Better use of these materials in barley improvement programmes is essential to reduce the significant barley yield losses that will otherwise occur, especially in Chelia and Shenen Districts (West Shewa Zone), Bekoji, Asasa and Kofele Districts (Arsi Zone) and other potentially high BYD-risk-prone areas of the barley growing highlands in central and southeast regions.
- Generally, from the above studies, there is evidently a need to develop integrated BYD management options that combine host resistance, cultural

practices targeted at controlling wild and alternative hosts, and chemical control of aphid vectors.
- There is an immediate and urgent need for barley breeders and virologists to work hand-in-hand to incorporate recently developed BYD-resistant gene(s) into cultivars with good agronomic traits by using conventional or marker-assisted breeding.

GAPS AND CHALLENGES

- Regular monitoring is needed of shifts in dominance, severity and distribution of BYDVs and CYDV species in major barley growing agro-ecologies in the country, both during the main and short seasons.
- Molecular, serological and biological characterization is needed of Ethiopian isolates of BYDVs and CYDV species to determine whether or not different strains (serotypes) of the species identified are present.
- Detecting gene(s) conferring resistance to the field-screened local barley genotypes supposedly resistant or tolerant to BYDVs and CYDV using molecular tools (PCR, RFLP and others).
- Study and identification of epidemiological factors contributing to disease build up, thus enabling the development of disease forecasting models that warn farmers to apply appropriate control measures before the disease causes considerable yield losses.

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Weeds

Achievements of research on weeds and their management in barley in Ethiopia

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is a major crop for large numbers of people living in the cooler, semi-arid areas of the world. In tropical Africa, Ethiopia is the only country where barley is a major crop, being the fifth most important crop both in area under cultivation and in production after teff, maize, sorghum and wheat. It is grown mainly in the highlands of the country and represents approximately an 11% share of the total area where grain is cropped (CACC, 2003). It is predominantly grown at altitudes ranging from 2000 to 3000 masl in various regions of the country. Barley is produced in both the main rainy season and the short rainy season. It is preferred by subsistence farmers because of its ability to grow on marginal farms, unlike other cereals. Traditionally, barley is cultivated under no or little external inputs such as fertilizer or chemicals to control the major pests. Barley has a wide range of uses. Its grain is used as a staple food, for malting and for making local drinks, and is sold for cash. Its straw and stem stubs are used for animal feed and thatching. The annual average national yield of the crop is only 12 000 kg/ha (CSA, 2005). The low national average yield, which is far below the world average, could be partially attributed to poor weed management, which results in high competition from weeds.

Barley is a crop plant that is very sensitive to weed competition and suffers the greatest yield reduction through competition to its third to sixth leaf stage (Stroud, 1989). This is approximately between two and four weeks after emergence. Weeds emerging after this time have less competitive effect, but may interfere with the harvest and act as a subsequent source of infestation of the fields. Stroud (1989) also reported that the average yield loss in barley is about 18% when the crop has received no weed control. Today, grass and sedge weeds are more problematic in barley production than broadleaf species because of the selective nature of available herbicides and the difficulties of distinguishing between species while hand weeding. This paper reviews in-country research associated with the effects of weeds and weed management on barley yields, carried out over the last 13 years.

IMPORTANT WEEDS OF BARLEY

The production of barley is frequently limited by several weed species (Table 1). Of the 81 weed species reported to be associated with barley in Ethiopia, 26 of them are major, problematic ones (Rezene Fessehaie, 1986; Fasil Reda, 1996; Kedir Nefo, Feyissa Tadesse and Tilahun Geleto, 1999; Takele Negewo, 2001). These reports indicate that the most widespread broadleaved weeds in barley are: *Amaranthus hybridus, Cerastium octandrum, Chenopodium album, Chrysanthemum segetum, Commelina* spp., *Convolvulus arvensis, Datura stramonium, Erucastrum arabicum, Galinsoga parviflora, Galium spurium, Guizotia scabra, Medicago polymorpha, Polygonum nepalense, Scorpiurus muricatus* and *Tagetes minuta*. Among grass weeds, *Avena abyssinica, Avena fatua, Bromus pectinatus, Digitaria scalarum, Lolium temulentum, Phalaris paradoxa, Setaria* spp. and *Snowdenia polystachya* are the most important ones. Weed species, their density and

TABLE 1
Weed species recorded in barley plots in Ethiopia and some of their characteristics

Botanical name	Family	Recorded as	Characteristics		
Achyranthes aspera L.	Amaranthaceae	x	a/p	d	rs
Agrostis spp.	Graminae	x	a	m	rs
Amaranthus hybridus L.	Amaranthaceae	xxx	a	d	rs
Amaranthus retroflexus L.	Amaranthaceae	x	a	d	rs
Anagallis arvensis L.	Primulaceae	xx	a	d	rs
Andropogon abyssinicus (Fresen) R.Br.	Graminae	x	a	m	rs
Argemone mexicana L.	Papaveraceae	x	a	m	rs
Avena abyssinica Rich.	Graminae	xxx	a	m	rs
A. fatua L.	Graminae	xxx	a	m	rs
A. sterilis L.	Graminae	xx	a	d	rs
Bidens pachyloma (Oliv.&Hiern.) Cuf.	Compositae	xx	a	d	rs
B. pilosa L.	Compositae	xx	a	d	rs
Brassica napus L.	Cruciferae	x	a	d	rs
Bromus pectinatus Thinb.	Graminae	xxx	a	m	rs
Carduus spp.	Compositae	x	p	d	rs
Caylusea abyssinica (Fresen.) Fisch.&May.	Resadaceae	xx	a	d	rs
Cerastium octandrum Hochst. ex Rich.	Caryophyllaceae	xxx	a	d	rs
Cirsium vulgare (Savi.) Tenore	Compositae	x	a	d	rs
Chenopodium album L.	Chenopodiaceae	xxx	a	d	rs
C. ambrosiodes L.	Chenopodiaceae	x	a	d	rs
C. fasciculosum Aellen	Chenopodiaceae	x	a	d	rs
C. procerum Hochst. Ex Moq.	Chenopodiaceae	x	a	d	rs
Chrysanthemum segetum L.	Asteraceae	xxx	a	d	rs
Commelina africana L.	Commelinaceae	xxx	a/p	m	rs/rv
C. benghalensis L.	Commelinaceae	x	a/p	m	rs/rv
C. latifolia Hochst. Ex A.Rich.	Commelinaceae	xxx	a/p	m	rs/rv
Convolvulus arvensis L.	Convolvulaceae	xxx	p	m	rs/rv
Corrigiola capensis Willd	Caryophyllaceae	xx	a	d	rs
Cotula abyssinica Sch. Bip. ex Rich	Compositae	x	a	d	rs
Cyanotis barbata Don.	Commelinaceae	x	a/p	m	rs/rv
Cynodon spp.	Graminae	x	p	m	rs/rv
Cyperus blysmoides C.B.Cl.	Cyperaceae	x	p	m	rs/rv

TABLE 1 CONTINUED

Botanical name	Family	Recorded as	Characteristics		
C. esculentus L.	Cyperaceae	xx	p	m	rs/rv
C. rotundus L.	Cyperaceae	xx	p	m	rs/rv
Dactyloctenium aegypticum (L.) Wild.	Graminae	x	a	m	rs
Datura stramonium L.	Solanaceae	xxx	a	d	rs
Digitaria scalarum (Schweinf.) Cniov	Graminae	xxx	p	m	rs
Dinebra retroflexa (Vahl.) Panzer.	Graminae	x	a	m	rs
Echinops macrochaetus (Fresen.)	Compositae	x	p	d	rs/rv
Eragrostis spp.	Graminae	x	a	m	rs
Erucasrtum arabicum Fisch.&May.	Cruciferae	xxx	a	d	rs
Euphorbia spp.	Euphorbiaceae	x	a	d	rs
Fallopia convolvulus (L.) A.Love	Polygonaceae	x	a	d	rs
Flaveria trinervia (Spreng.) C.Mohr.	Compositae	x	a	d	rs
Foeniculum vulgare Miller	Umbelliferae	x	a	d	rs
Galinsoga parviflora Cav.	Compositae	xxx	a	d	rs
Galium spurium L.	Rubiaceae	xxx	a	d	rs
Gnaphalium unionis Sch.Bip.	Compositae	x	a	d	rs
Guizotia scabra (Vis.) Chiov.	Compositae	xxx	a	d	rs
Hygrophila auriculata (Schum.) Heine	Acanthaceae	x	a	d	rs
Leucas martinicensis (Jacq.) Ait.F.	Labiatae	x	a	d	rs
Lolium temulentum L.	Graminae	xxx	a	m	rs
Malva verticillata L.	Malvaceae	x	a	d	rs/rv
Matricaria sp.	Asteraceae	x	a	d	rs
Medicago polymorpha L.	Leguminosae	xxx	a	d	rs
M. sativa L.	Leguminosae	x	a	d	rs
Oxalis corniculata L.	Oxalidaceae	xx	a	d	rs
O. latifolia H.B.K.	Oxalidaceae	x	a	d	rs
O. obliquifolia Rich.	Oxalidaceae	x	a	d	rs
Pennisetum spp.	Graminae	x	p	m	rs/rv
Phalaris paradoxa L.	Graminae	xxx	a	m	rs
Plantago lanceolata L.	Plantaginaceae	xx	p	d	rs/rv
Poa spp.	Graminae	x	a	m	rs
Polygonum aviculare L.	Polygonaceae	xx	a	d	rs
P. nepalense Meisn.	Polygonaceae	xxx	a	d	rs
Raphanus raphanistrum L.	Cruciferae	x	a	d	rs
Rumex abyssinicus Jacq.	Polygonaceae	xx	p	d	rs/rv
R. bequaertii Willd.	Polygonaceae	xx	p	d	rs/rv
Scleranthus annus L.	Caryophyllaceae	x	a	d	rv
Scorpiurus muricatus L.	Leguminosae	xxx	a	d	rs
Setaria pumila (Poir.) Roem & Schult.	Graminae	xxx	a	m	rs
S. verticillata (L.) Beauv.	Graminae	xxx	a	m	rs
Snowdenia polystachya (Fresen.) Pilg.	Graminae	xxx	a	m	rs
Solanum nigrum L.	Solanaceae	x	a	d	rs
Sonchus asper (L.) Hill.	Compositae	x	a	d	rs
S. oleraceus L.	Compositae	x	a	d	rs
Spergula arvensis L.	Caryophyllaceae	xx	a	d	rs
Stellaria media (L.) Vill.	Caryophyllaceae	xx	a	d	rs
Tagetes minuta L.	Compositae	xxx	a	d	rs
Trifolium spp.	Leguminosae	xx	a	d	rs

NOTES: xxx = major weed; xx = important weed; x = commonly occurring weed; a = annual; p = perennial; d = dicotyledon; m = monocotyledon; rs = reproduces by seed; rv = reproduces vegetatively.
SOURCES: Fasil Reda, 1996; Kedir Nefo, Feyissa Tadesse and Tilahun Geleto, 1999; Takele Negewo, 2001.

distribution vary from place to place depending on soil and climatic factors, and farmers' management practices.

IMPACT OF WEEDS ON BARLEY PRODUCTION

In Ethiopia the yield potential of barley is constrained by several factors. These include poor soil fertility, low yielding varieties, weed competition, diseases, insect pests, frost and hail, waterlogging, and shortages of power and implements. The relative importance of these factors tends to be location specific. For instance, at Sheno, the order of importance of these production inhibiting factors is poor soil fertility, poor soil drainage, low yielding varieties, weed infestation and aphids (Adamu Molla, 1996) while at North Gonder it is traditional methods of production, weed infestation and poor soil fertility (Alemu Hailye *et al.*, 1999). In general, low soil fertility and poor crop management practices are the major constraints on barley production in the highlands of Ethiopia, where barley is grown as both a food and a cash crop.

Weeds compete with crops for limited nutrients, moisture, light and space. In Ethiopia, weed problems appear to be worsening in rainfed barley growing regions for three main reasons:

- the subsistence farmer is mainly dependent on cultivation practices and applications of 2,4-D herbicides for weed control. This is because there are limited options for crop rotation and fallowing, and it is impossible for peasant farmers to completely remove grass weeds in cereal crops;
- late emerging weeds. The farmers' unclean seed reserves and farm lands quite badly contaminated with weed seeds contribute to weed problems in the subsequent cropping seasons; and
- wet conditions during the main rainy season favour the rapid and abundant growth of weeds, which results in subsequent heavy weed infestation.

In many barley-producing areas, barley fields are mostly treated with broadleaf herbicides. Under such partial weed management, it is common to observe barley fields infested with grass weeds, causing yield losses of up to 60% in some barley growing areas. Weeds can also play a significant role in harbouring insects, serving as alternative hosts for some diseases, and adding to the cost of production. Weeds not only reduce yields and profitability, but also threaten future cropping when allowed to produce and shed seeds and regenerate.

The competitive effects of these major weeds at various densities on yield and yield components of the crop have been studied (Takele Negewo, Matias Mekuria and Temam Hussien, 2006). Grain yield (GY) decreased from 3287 kg/ha in a weed-free environment to 2833 kg/ha (a 14% reduction) at 20 weed plants/m^2, 2785 (15%) at 40/m^2, 2663 (19%) at 80/m^2, 2465 (25%) at 160/m^2, and 2079 (37%) at 320/m^2. (See Table 2). The increased weed densities were negatively and highly significantly correlated with the GY of barley ($r^2 = -0.59$). The report also indicated that at the highest densities, 320 plants/m^2 of *Avena fatua, Erucastrum arabicum, Guizotia scabra* and *Snowdenia polystachya*, barley grain yields were reduced by 41, 22, 37 and 50%, respectively. Grass weeds were found to be very

TABLE 2

Effects of weed species and density on grain yield (kg/ha) of barley in 2000, 2002 and 2003 at Ambo

Weed species	Weed density (weed plants per m²)							Species mean
	0	10	20	40	80	160	320	
Avena fatua	3285	3102	2906	2836	2626	2059	1952	2681 bc
Erucastrum arabicum	3619	3142	2808	2976	2458	2997	2810	2973 a
Guizotia scabra	3377	3154	2784	2992	3010	2489	2129	2848 ab
Snowdenia polystachya	2867	3020	2835	2337	2556	2316	1424	2479 c
Density mean	3287 a	3104 ab	2833 bc	2785 bcd	2663 cd	2465 d	2079 e	

NOTES: Means followed by the same letter(s) within a column or a row are not significantly different at $P \leq 0.05$ according to t-test of the SAS (Statistical Analysis Software)–GLM (general linear models) Procedure. SOURCE: Takele Negewo, Matias Mekuria and Temam Hussien, 2006.

competitive and harmful to the crop. Moreover, the report mentioned that the reductions in the number of tillers per plant, the number of fertile barley tillers, and the biomass yield due to weed competition were mainly responsible for the crop yield loss.

A non-linear regression equation for weed species competing with the barley cultivar HB 42 was derived using the rectangular hyperbola model proposed by Cousens (1985). The yield data were incorporated into a GENSTAT program. This model provides two parameters of importance in agronomic interpretation: 'A', the maximum percent GY loss by barley under competition from a specific weed species in a given year, and 'I', the percentage GY loss per unit of density as the weed density approaches zero. The percent GY loss (A) was greatest for *Snowdenia polystachya* (66.73) competition with barley, while the percent GY loss per weed plant per unit of area (I) was highest for *Erucastrum arabicum* (0.64) (Table 3). Moreover, when one compared the actual GY reduction of the crop above with the GENSTAT-processed GY loss estimate at both the lowest and highest weed density levels, a similar trend for the competitive order was observed for the weed species. Thus, the rectangular hyperbola model resulted in an acceptable fit of the GY data and accurately quantified the relative competitiveness of those weed species.

WEED COMPETITION WITH BARLEY IN TIGRAY

In Tigray, farmers grow barley under low input and management conditions and in competition with weeds. Farmers predominantly use hand weeding to control weeds. However, in most cases, weeding is typically left until the weeds are well established and have started threatening the crop. Knowledge of the best time for weed removal is limited.

TABLE 3

Parameters of the rectangular hyperbola model(1) fitted to barley grain yield data (kg/ha) at Ambo in 2000, 2002 and 2003, using the GENSTAT program(2)

Weed species	Parameter		
	Y_{wf} (kg/ha)	A (%)	I (% m²/plant)
Avena fatua	3256	57.24	0.47
Erucastrum arabicum	3615	12.26	0.64
Guizotia scabra	2952	41.59	0.50
Snowdenia polystachya	2896	66.73	0.30

NOTES: (1) proposed by Cousens, 1985. (2) computed by Dr Girma Taye, EIAR-Biometrician. Parameters are: Y_{wf} = weed free yield; A = maximum percent yield reduction; I = percentage yield loss per unit of density.

This knowledge is needed to change farmers' fatalistic attitudes about the yield depression that barley suffers as a result of weed growth. Information on the magnitude of yield losses incurred due to weed competition is essential to establish effective priorities aimed at promoting yield increases. Hence, barley weed competition trials were initiated to estimate the yield loss in the Tigray region and gain insights into the optimum time for weeding, and thereby be ablse to suggest alternative weed control methods.

The experiments were conducted in South Tigray Zone at Endamekoni and Wofla, in Central Tigray Zone at Tembien and Axum, in East Tigray Zone at Atsebi Bethans and Habes Batiero, and in Enderta, at Maykeyah and Lachi, during the 1998, 1999 and 2000 cropping seasons.

The treatments were laid out in randomized complete blocks with 3 replications. The treatments consisted of 8 frequencies of hand weeding and unweeded controls. The plot size used was 25 m^2. Local barley varieties were planted by hand by broadcasting. Weeding was conducted according to specified treatments. Weeds were counted one day before weeding by randomly throwing a 25×25 cm quadrat four times per plot. Agronomic parameters, such as plant height and stand count, were taken and the yields per plot were harvested and analysed. Yield losses were estimated by comparing the best yield resulting from the treatment with that of the unweeded controls.

TABLE 4
Major weeds of barley recorded in barley production areas of Tigray

Weeds	Life cycle	Status
Amaranthus hybridus	a	X
Anagallis arvensis	a	X
Avena fatua	a	xxx
Bidens pilosa	a	x
Commelina latifolia	p	x
Convolvulus arvensis	p	xx
Cynodon dactylon	p	x
Cyperus rotundus	p	xx
Datura stramonium	a	X
Galinsoga parviflora	a	xx
Galium spurium	a	X
Guioztia scabra	a	xxx
Leucas martinicens	a	x
Lolium temulentum	a	xx
Medicago polymorpha	a	xxx
Nicandra physalodes	a	X
Oxygenium sp., *Trifolium* sp.	a	x
Phalaris paradoxa	a	xx
Plantago lanceolata	p	xxx
Polygonum sinuatum	a	xx
Rumex bequaertii	p	xx
Scoropirus muricatus	a	xxx
Setaria sp.	a	xx
Tagates minuta	a	xxx
Xanthium spinosum	p	x

Notes: Key to status: xxx = Major weeds; xx = important weeds; x = common weeds. Key to life cycles: a = annual, p = perennial.

The major weeds of barley recorded in the Tigray region are listed in Table 4. Both broadleaved weeds and grasses predominantly occur in the barley field. Among the problematic broadleaved weeds, *Medicago polymorpha, Scoropirus micricatus, Rumex bequaertii, Galinsoga parviflora, Plantago lanceolata* and *Guioztia scabra* were dominant. Of the grasses A*vena fatua, Lolium temulentum, Phalaris paradoxa* and *Seteria* sp. were dominant.

The various broadleaved and grass weeds on the unweeded plots are presented in Table 4. Though the weed composition varies from year to year and between locations, the mean infestations over three years would suggest that grasses and broadleaved weeds are equally problematic in the South Tigray and East Tigray zones, while grasses seem more problematic in Central Tigray Zone, and broadleaved weeds in Enderta. The average estimated barley yield loss due to weed competition in the region was 42% (Table 5).

TABLE 5
Estimated regional yields and percentage loss resulting from weeds in barley production in 1998–2000

Treatments	East Tigray		South Tigray		Enderta		Central Tigray		Mean		Yield increment
	Yield	Loss	Yield	Loss	Yield	Loss	Yield	Loss	Yield	Loss	
Unweeded	925	49.6	1655	42.0	743	39.9	375	37.4	925	42.2	0.0%
Weeded at 15 days	1088	36.3	1907	31.2	1113	0.0	542	23.8	1163	22.8	25.7%
Weeded at 30 days	1231	34.1	2015	30.6	812	32.4	432	33.8	1122	32.7	25.7%
Weeded at 45 days	1113	39.9	1782	37.1	865	29.2	457	26.4	1054	31.6	13.9%
Weeded at 15 and 30 days	1281	35.5	2166	25.1	977	13.3	539	12.2	1241	20.8	34.2%
Weeded at 15 and 45 days	1371	30.5	2102	25.8	915	16.7	397	33.8	1196	26.7	29.3%
Weeded at 30 and 45 days	1489	28.0	2219	20.6	771	37.4	640	10.6	1280	24.2	38.4%
Weeded at 15, 30 and 45 days	1876	9.6	2580	9.2	944	12.5	533	22.1	1483	13.4	60.3%
Weeded as necessary	1701	12.1	2569	8.5	892	20.2	636	4.2	1450	11.2	56.8%

NOTES: Increment is the percentage increase in yield compared with the unweeded check.

In general hand weeding controlled most of the broadleaved weeds as they were easy to identify during weeding. Hand weeding failed to control most grasses, especially wild oat, which resembles the crop. Thus wild oat causes the greatest amount of damage in almost the whole region as the farmers fields are badly infested with this weed.

LOCAL WEED CONTROL PRACTICES

Farmers of the area rely on hand weeding to control weeds, but it is typically late and inadequate. Some farmers' fields remain unweeded while others are weeded once, and a few of them twice. However, the time when weeding is undertaken varies considerably. Farmers have a fatalistic attitude toward weeds: they assume that losses due to weeds are inevitable and they did not know that, in most cases, early germinating weeds can cause the greatest yield decrease. Some do not consider weeds to present serious production constraints on barley production.

Though weeding more that twice resulted in better yields in the South Tigray and East Tigray zones, the advantage gained from additional weeding is much less than the input cost for weeding. Therefore, weeding twice at 30 and 45 days after crop emergence gave optimum yields. However, in practice, farmers were often reluctant to carry out two weedings, for many reasons. Under such circumstances the best time for the first weeding is found to be between 20 and 30 days after emergence.

In other areas, the yields of farms are much lower than those in the South Tigray and East Tigray zones, mainly because of low soil fertility. Weeding more than twice in Central Tigray Zone did not result in increased yield; instead it resulted in an increased labour input. Weeding twice did not result in a better yield than weeding once at 30 days at Degua Tembien. One weeding at 30 days resulted in the optimum yield. In contrast, at Axum, better yields were recorded from weeding twice at 30 and 45 days after emergence.

In Enderta, the highest yields were obtained from one early weeding at 15 days and weeding more than that did not help to increase the yields by much. In general the time of weeding seems to be more important than the frequency of weeding and repeated weeding required more labour, without a corresponding yield increase.

Most of the broadleaved weeds were controlled by hand weeding, but hand weeding failed to control the grass weeds, especially wild oat which resembles the crop. The following recommendations can be made based on the results of these experiments:

- In areas characterized by better soils and higher rainfall, especially in the southern and eastern parts of the country, the grower can benefit from weeding twice, at 30 and 45 days after emergence.
- In areas where weed infestation and soil fertility are low, weeding once at 30 days after emergence gave an equivalent yield return to that obtained from two or three weedings.
- In general, broadleaved weeds were easier to identify during hand weeding. However, grasses, especially wild oat, cause the greatest damage as they compete with the barley crop throughout the growing season. Hence, the introduction of other measures, such as herbicide use, would have immense value in reducing yield losses due to grass weeds

WEED MANAGEMENT RESEARCH IN BARLEY

Weeds are one of the most important factors contributing to the reduced productivity of barley in Ethiopia. It is clear that proper weed management can increase the productivity of the crop in general. However, few investigations have been made in-country to evaluate or determine the effect of different weed management options on weed control and grain yield of barley (Ameha Sebsibe and Alemu Tadesse, 1996; HARC, 1995; Amsal Tarekegne, Hailu Gebre and Francis, 1997; Asefa Taa and Tanner, 1998; Alemu Hailye *et al.*, 1999; PPRC, 2004; Kedir Nefo, Tilahun Geleto and Feyissa Tadesse, 2005; Woldeyesus Sinebo, 2005).

LAND PREPARATION (PLOUGHING WITH OXEN)

Barley requires a smooth seedbed, which is free from weed and crop residues. It does best if the land is ploughed two to three times before sowing and once for seed covering. The first ploughing should be made during the dry season to expose perennial weeds to sunlight. The weeds are allowed to germinate after this first ploughing and then destroyed by a second ploughing. As an alternative, when the main rains begin, weeds that have germinated following the first ploughing are controlled by the use of a non-selective herbicide just before planting (Kedir Nefo, Tilahun Geleto and Feyissa Tadesse, 2005). Asefa Taa and Tanner (1998) reported that grass weeds were markedly reduced by conventional tillage rather than the minimum or zero tillage that is practiced in the southeastern highlands of Ethiopia.

GOOD CROP HUSBANDRY AND COMPETITIVE CROPPING

These require the use of clean seed; proper sowing rate, time and depth; fallowing; crop rotation; fertilizer application; and choice of companion crops. Use of weed-free seed prevents the spread and build up of noxious weed seeds, particularly those having similar seed size and shape to barley seed. A sowing rate of 125–150 kg/ha should be used when broadcast sowing food barley. A sowing time that follows the rain pattern favours crop emergence ahead of weeds, and a planting depth of 3–5 cm allows even emergence and good germination and should be applied to reduce the impact of weeds. Besides restoring the fertility of cropland, crop rotation and fallowing contribute well to reducing the soil's weed seed bank. Asefa Taa and Tanner (1998) indicated that the density of grass weeds was markedly reduced by crop rotation with dicotyledenous crops in contrast to continuous cereal rotations. Sowing barley in the *Belg* season (February to May) after faba bean, vetch and an oat-vetch mixture, which is grown in the main season as a double crop, increased the yields of barley by 40%, 41% and 9%, rspectively, over yields following a fallow. Three different forage crops (*Lolium perenne*, trefoil and tall fescue) have successfully been undersown to barley at Sheno Agricultural Research Centre without significantly reducing the grain or straw yield of the crop. Rather, this helped to reduce the space free for weed establishment (Ameha Sebsibe and Alemu Tadesse, 1996). The results of a mixed cropping trial showed that total yield and total land equivalent ratios (LERs) of mixtures exceeded those of sole crops, especially when the faba bean seed content in the mixture was increased to 75 kg/ha (38%) or more.

Experiments conducted by Woldeyesus Sinebo (2005) in West Shewa and North Shewa zones showed that weed control effects were significant at Altufa and Degem, but not at Tikur Inchini (Table 6). Nonetheless, the relative grain yield due to weed control was also high at Tikur Inchini. At Altufa, fertilizer application, higher seed rate application and weed control increased grain yields by 53%, 21%, and 26%, respectively. At this location, the combined effect of fertilizer, higher seed rate and weed control increased grain yield by 129% (650 vs. 1490 kg/ha). At Tikur Inchini, fertilizer application, seed-dressing insecticide

TABLE 6

Average effects of fertilizer, seed-dressing insecticide, seed rate, and weed control on grain yield (GY) (kg/ha), biomass yield (BY) (kg/ha) and weed dry weight (WDW) (g/m2) in barley, tested on farmer's fields in West and North Shewa Oromia zones, Ethiopia

Factor	Degem			Tikur Inchini		Altufa		
	GY	BY	WDW	GY	BY	GY	BY	WDW
Fertilizer -	1896.3	5061.1	40.5	1259.4	2655.1	958.7	2340.3	86.3
Fertilizer +	2739.5	7933.3	54.8	1700.1	3571.7	1467.4	3802.1	102.5
Insecticide -	2233.8	6181.9	52.4	1441.2	3069.4	1095.9	2798.6	80.4
Seed rate +	2402.0	6812.5	42.9	1488.3	3157.4	1330.3	3343.7	108.4
Weeding -	2181.7	6444.4	48.0	1368.9	2909.7	1075.0	2807.3	94.4
Weeding +	2454.1	6550.0	47.3	1590.6	3317.1	1351.2	3335.1	94.3

SOURCE: Woldeyesus Sinebo, 2005.

and weed control increased grain yields by 35%, 3%, and 16%, respectively. At Degem, because of fertilizer application, seed-dressing insecticide and weed control, the corresponding increases were 44%, 8% and 13%. The combined effects of fertilizer, seed-dressing insecticide and weed control increased grain yield by 82% (890 vs. 1620 kg/ha) at Tikur Inchini and by 88% (1320 vs. 2480 kg/ha) at Degem.

HAND WEEDING

Hand weeding twice has been shown to be the most economic practice and produced the best results in moist areas. The first weeding should be done two to three weeks after emergence (at the early tillering stage) and the second four to five weeks after emergence (at the stem elongation stage). Pulling weeds when they are 15 cm or less is advised as this does not disturb the soil and crop root system too much, and reduces yield loss due to competition. A hand weeding experiment conducted at Holetta in 1987 and 1988 indicated that weeding once by hand significantly affected grain yield. Weeding once by hand increased grain yield by 20% (303 kg/ha) in 1987 and 14% (272 kg/ha) in 1988 over the unweeded checks (Amsal Tarekegne, Hailu Gebre and Francis, 1997).

HERBICIDES

Preliminary analysis of data from herbicidal weed control experiments conducted in 1995 at Holetta Agricultural Research Centre indicated differential responses to the different test varieties (‘V’) in terms of grain yield, 1000-grain weight, crop stand count, plant height, and days to 50% heading ($P<0.01$) (Table 7). Herbicides (‘H’) (linuron at 1.0 kg a.i. per ha, diclofopmethyl at 0.89 kg a.i. per ha and fenoxapropethyl at 0.18 kg a.i. per ha) and the interaction of the main factors (V H) did not show any significant response ($P<0.05$) for all parameters recorded. In general no adverse effect due to the herbicides was observed in any of the barley varieties. The only distinct variation detected was a delay of 50% in the heading period of the test varieties due to the herbicidal effect when compared to the hand weeded check. However, there was a general trend of yield increase from herbicide treatments over hand weeding. Apparently, these differences were attributed to the tolerance exhibited by the test varieties to both the pre- and post-emergence applications of herbicides. Compared to the single hand weeding treatment, the pre-emergence application of linuron and post-emergence treatments of diclofopmethyl and fenoxapropethyl proved to be the most dependable and effective in terms of yield performance for the different test varieties of barley. Because of their effectiveness in controlling *Snowdenia polystachya* and *Avena fatua*, and the low risk of barley injury, diclofopmethyl and fenoxapropethyl could be effective herbicides when grass-weed problems are severe in barley production.

Alemu Hailye *et al.* (1999) reported on the effectiveness of Starane M and Brittox against broadleaf weeds in North Gonder (Table 8). Moreover, Granstar 75 GF (tribenuron methyl) and 2,4-D controlled broadleaf weeds when

TABLE 7
Effect of herbicides as compared to hand weeding on grain yield of different barley varieties

Varieties	Grain yield (kg/ha)				
	Linuron	Diclofopmethyl	Fenoxapropthyl	Hand weeding	Mean
HB 42	2100	2520	2430	2180	2310
Ardu-12-60B	1740	2000	2130	1730	1900
Ahor 880-61	1990	2330	2360	2180	2220
HB 100	2230	2090	2170	2240	2180
HB 99	2320	2960	2590	2290	2540
HB 7	1890	1820	2190	1770	1920
HB 32	2410	2570	2510	2010	2380
HB 37	2040	1740	2180	1590	1890
BEKA	1950	2170	2410	2050	2150
Holker	2100	1970	1740	1900	1930
Procter	900	1230	1080	1030	1080
HB 52	2190	1860	2160	1560	1940
Mean	2000	2100	2160	1880	
LSD (*P*<0.05)"	Variety (V)				2.3
	Herbicide (H)				NS
	Interaction (V×H)				NS
CV (%)					14.1

NOTES: Hand weeding = hand weeding once 30 days after sowing. SOURCE: HARC, 1995.

TABLE 8
Effect of different weed control methods on the grain yield (kg/ha) of barley in North Gonder, 1995–1996

Treatment	Meskeliko	Jagrie	Gombaye	Tegora	A/Giorgis	Dildy	Mean
Starane M	1153	2099	1175	792	1822	1569	1435
Brittox	1980	2550	1387	1233	1803	1744	1783
Farmer practice	1140	2304	1830	482	1862	1241	1476
Unweeded	1250	1509	1391	536	1466	1063	1202
Mean	1381	2115	1445	761	1738	1404	

SOURCE: Alemu Hailye *et al*., 1999.

applied during the active and succulent growth stage (Kedir Nefo, Tilahun Geleto and Feyissa Tadesse, 2005). They also reported that, although it was expensive for farmers at the time of the study, as an alternative to glyophosphate-based minimum tillage it resulted in the highest grain yield under normal rainfall amounts and distribution. Domestic herbicide evaluation reports mentioned the effectiveness of several 2,4-D herbicides (U-46, Helmamine, Herboxon, QUISH Fordat, Amine salt) against broadleaf weeds when applied during the active and succulent growth stage of barley and wheat crops (unpublished).

Small-scale, barley growing farmers, informally interviewed in the central areas of the country during this crop season, revealed that herbicides that killed broadleaved weeds were widely adopted to control weeds (pers. comm.). None of the farmers, however, had access to grass weed or non-selective herbicides. Almost all farmers used the post-emergence herbicides. Local development agents can provide them with advice on the herbicide doses appropriate for the weather conditions and the crop growth stage in order to avoid injury to the barley while maintaining the weed control efficacy of the herbicides. The problem is that farmers rarely hand pull weeds that have not been killed by an application of broadleaf weed herbicides, which results in a weed population shift to grass weeds.

INTEGRATED WEED MANAGEMENT

There is no effective and sustainable single weed control method. Thus, it is very important to integrate different management practices into a cropping-system-based weed management strategy. Integrated weed management is based on knowledge of the biological and ecological characteristics of weeds and how their presence can be modified by cultivation practices. Thus, it is necessary to first build up an effective weed management strategy within a crop sequence, and then to choose the best method for direct weed control during crop growing cycles. Weed management is always inherent in crop management itself, and thus the interaction between weed management and other cultivation practices must be taken into account.

Integrated weed management implies that some short- or long-term strategy is being systematically employed to reduce weed infestations. It involves a degree of foresight and predictability in order to plan treatments and integrate them into the cropping system. In this aspect, no adequate effort has so far been made in the country, although the very recently developed National Weed Research Thematic Area has started to follow this trend.

A study on the effect of ploughing frequency (ploughing with oxen 3, 4 or 5 times) and the time of hand weeding wild oats (20, 40 and 60 days after sowing (DAS)) on barley productivity was made at the Tikur Inchini Research Station of the Ambo Plant Protection Research Centre. As shown in Table 9 below, no statistically significant difference was observed among ploughing frequencies. In contrast, the time of hand-weeding significantly affected the spike length, straw weight, biomass yield and grain yield of the crop. Plots weeded at 20 DAS out-performed the others in all cases. Moreover, the ploughing frequency × weeding time interaction had a significant impact on only the 1000-grain weight of the crop. Thus ploughing three times plus a weeding time of 20 DAS exceptionally out-performed other interactions. The study area has a loam soil type which is fragile; this might be the reason for the indifferent response to ploughing frequency.

TABLE 9
Effect of ploughing frequency and weeding time on grain yield (kg/ha) of barley at Tikur Inchini Research Station, 2003/4

Weeding time	Ploughing frequency			Weeding time mean
	Three times	Four times	Five times	
20 DAS	3177.58	3159.31	3166.85	3167.91 a
40 DAS	2948.37	2917.27	2734.96	2866.84 b
60 DAS	3272.97	3025.04	2830.58	3051.87 ab
Ploughing frequency mean	3132.95	3042.87	2910.80	3028.87

NOTES: Means in a column followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test using the SAS – GLM Procedure.
SOURCE: PPRC, 2004.

CONCLUSIONS

Ethiopian farmers are aware of the problems weeds are causing in their fields, as they are one of the major constraints on barley production. Accordingly, there were some efforts made by agricultural professionals in different parts of the country to manage weeds in barley fields. Although these efforts were uncoordinated, the activities to manage barley weeds were designed to identify appropriate ploughing frequency, hand weeding times, herbicide types and rates of application, crop rotation sequences and seed application rates. Under present conditions, most broadleaf weeds are adequately controlled using cheaply available 2,4-D herbicides. However, no effective and applicable technology has yet been adopted to control grass weed species. Any weed control strategy should mainly focus on the more important weeds.

Research needs to be conducted in the near future to develop economic, effective and sustainable integrated weed management options for the production of barley. The essential feature of an integrated weed management strategy is the incorporation of the various components into the whole to fully exploit the advantages and compensate for the weaknesses of the individual methods. Moreover, it gives priority to all other weed management measures before herbicide use; the measures are governed by long-term plans and ecological thinking. A farmer can select and use weed control strategies that are based on cost–benefit analyses, with due consideration of their impact on the environment.

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End use

Nutritional value of barley and acceptability studies on barley-based weaning products

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INTRODUCTION

Cereal grains furnish both energy and protein for about two-thirds of the world's population (Munck, 1981). According to Marlett (1991) barley is nutritionally superior to other cereals in providing essential nutrients in biologically available forms. The nutritional content of local food barley and barley products are presented in Tables 1 and 2. In the last century, the use of barley as food has decreased compared with wheat because of lesser palatability, poor baking quality and inferior milling characteristics. Nowadays, barley is being used in different forms, such as popped grain, flakes, sprouts, barley starch and sweeteners, malt flour supplements, malted milk, infant food, barley tea or coffee substitute, and as a rice extender.

One of the areas where barley was grown in earlier times was Ethiopia (Harlan, 1979). Today, barley is consumed in many parts of Ethiopia, in various forms, including porridge, gruel, popped (roasted), fermented and unfermented thin bread. Additionally, barley is being used in the preparation of local and commercial alcoholic beverages. In the Middle East, barley grits are widely used, and in Japan and South Korea, pearled barley is used as a rice substitute, often mixed with rice (Pedersen and Eggum, 1983).

Malnutrition is commonly observed in developing countries. From a nutritional point of view, the most vulnerable segments of the population are infants and young children. It is also recognized that malnutrition is widespread among the poorer socio-economic groups, especially those in the rural areas. Faulty feeding habits or the late introduction of weaning foods are considered to be responsible for aggravating malnutrition, which begins at the age of four to six months (Reddy, 1987). At four to six months, the rapidly growing child needs their first solid foods (Berggen, 1982).

Although there are a number of commercial preparations specifically designed for weaning purposes, they are beyond the economic reach of the majority of the population. There is therefore an urgent need to develop satisfactory low cost weaning foods that can be prepared from locally available resources at the household level, using simple processing methods.

The development of new food products, the manufacture of existing products through either different processing methods or the use of new ingredients, and the maintenance of quality control standards, all require the identification and measurement of sensory properties. This type of product-oriented, quantitative information is obtained in the laboratory using trained sensory panels. When food formulas are being altered or new formulas are being developed, product-oriented testing usually precedes consumer testing. Acceptance tests are used to determine the degree of consumer acceptance for a product.

The consumer's acceptance of and preference for foodstuffs are influenced by many factors, including, preparation and consumption value, product cost, packaging and uncooked and cooked appearance. However, sensory factors are the major determinant of the consumer's subsequent purchasing behaviour. This raises questions regarding the acceptability of the product and the socio-economic factors that may affect production and consumption. Therefore, food quality considerations are crucial for the formulation of weaning foods to meet the expectations of consumers for colour, appearance, flavour, taste and texture. There is also a need to evaluate the products further for the consumers' preferences,

TABLE 1
Nutrient content of cereal grains per 100 g of species commonly consumed in Ethiopia

	Barley	Teff (mixed)	Maize	Wheat	Sorghum	Millet
Food energy (calories)	334	336	356	339	338	336
Moisture (%)	11.3	10.7	12.4	10.8	12.1	10.7
Protein (g)	9.3	8.3	8.3	10.3	7.1	8.3
Fat (g)	1.9	2.9	4.6	1.9	2.8	2.9
Carbohydrate (g)	75.4	75.2	73.4	71.9	76.5	75.2
Fibre (g)	3.7	3.6	2.2	3.0	2.3	3.6
Ash (g)	2.0	3.0	1.3	1.5	1.6	3.0
Calcium (mg)	47	140	6	49	30	140
Phosphorous (mg)	325	368	276	276	282	368
Iron (mg)	10.2	59	4.2	7.5	7.8	30.5

Source: Ågren and Gibson, 1968.

TABLE 2
Nutrient content of barley products per 100 g as commonly consumed in Ethiopia

	Barley (flour)	Barley (injera)	Barley (bread)	Barley (porridge)	Barley (boiled)	Barley (roasted)
Food energy (calories)	368	125.8	202.4	134.7	125.3	355.8
Moisture (%)	9.1	68.5	48.5	71.5	68.9	3.3
Protein (g)	8.5	2.6	4.4	2.1	2.8	8.9
Fat (g)	2.0	0.2	0.4	5.5	0.5	2.2
Carbohydrate (g)	79.0	28.4	45.3	19.2	27.4	84.0
Fibre (g)	2.2	0.8	1.1	0.6	0.7	2.8
Ash (g)	1.4	0.3	1.4	1.7	0.4	1.6
Calcium (mg)	17.0	5.0	16.0	6.0	8.0	38.0
Phosphorous (mg)	294.0	72.0	160.0	84.0	100.0	318.0
Iron (mg)	6.3	2.1	3.5	1.6	1.9	4.3

Source: EHNRI, 1997.

nutritional values and storage stability, using quantitative techniques. Information on the specific sensory characteristics of a food must also be obtained by using subjective tests (Watts *et al.*, 1989)

METHODS

Storage and sensory evaluation studies

To determine the shelf life of the weaning food, storage studies were conducted for four consecutive months under two different storage conditions, ambient (25°C and 65% relative humidity (RH)) and accelerated (38°C and 92% RH). About 250 g of the samples were packed in flexible, 250 gauge (62.5 micron) polyethylene pouches having a water vapour transmission rate of 3.6–4.4. Samples were drawn every month for four consecutive months and analysed for moisture content, viscosity, alpha-amylase activity, free fatty acids and peroxide value using standard procedures (AOAC, 1970). The weaning food was cooked to a consistency of 25% slurry concentration and tested for its acceptability by a group of experienced taste panel members. Fresh samples and stored samples were evaluated by the ranking method according to Amerine, Pangborn and Roessler, 1965. The sensory attributes used were colour, flavour (aroma and taste) and texture, which were assessed on a 5-point scale ranging from very good to very poor. The final data were analysed using an analysis of variance followed by Duncan's new multiple range test Amerine, Pangborn and Roessler, 1965).

RESULTS AND DISCUSSION

The mean scores for the sensory qualities of the samples of freshly prepared and stored, barley based products are presented in Table 3. The results of the statistical analysis show that the sensory qualities of the freshly formulated weaning food were very acceptable to the panel judges.

In the case of the stored weaning foods, the results indicated that there were significant differences (*P*<0.05) in almost all the quality attributes after 2 months of storage at ambient conditions (25°C and 65% RH) and after 1 month of storage

TABLE 3

Sensory analysis mean scores for barley-based weaning food packed in polyethylene bags stored under ambient or accelerated storage conditions

Storage period (months)	Stored at 25°C, 65% RH			Stored at 38°C, 92% RH		
	Texture	Colour	Flavour	Texture	Colour	Flavour
Fresh	4.5a	4.4a	4.3a	4.5a	4.4a	4.3a
1	4.5a	3.8b	4.2a	3.6b	3.7b	3.8b
2	4.0a	3.7b	4.0a	3.4 b	3.9b	3.2b
3	3.6b	3.3b	3.6b	2.4c	2.0c	2.2c
4	2.2c	2.0c	2.3c	2.0c	1.7c	2.0c
SEM	±0.15 (49DF)	±0.15 (49DF)	±0.15 (49DF)	±0.16 (49DF)	±0.18 (49DF)	±0.16 (49DF)

Notes: Limits for means: <1 =Very poor; 1–1.5 = Poor; 1.6–2.5 = Fair; 2.6–3.5 = Good; >3.5 = Very good. Means in a column followed by the same letter are not significantly different at P<0.05, according to Duncan's New Multiple Range Test. SEM = Standard error of the mean; DF = degrees of freedom.

under accelerated conditions (38°C and 92% RH). The overall sensory qualities of the samples stored under ambient conditions were slightly preferred. As is evident from the outcome of the organoleptic tests, the extended shelf life of the samples stored at ambient conditions could be about 3 months, while that for the samples kept under accelerated condition could be about 2 months. The acceptability test results revealed that products stored beyond these periods became slightly bitter and developed unacceptable flavours.

Similarly, studies of the tolerance and acceptability of the malted weaning food by children aged 6 to 11 months and 1 to 3 years were conducted for a period of 10 days, with favourable outcomes (Marero *et al.*, 1988). In our study, the maximum shelf life for products packed in low density polyethylene packaging materials might be 3 months at 25°C and 65% RH, and 2 months at 38°C and 92% RH storage conditions.

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Malting barley marketing and malt production from barley in Ethiopia

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INTRODUCTION

Modern malting practice started in Ethiopia in 1974 with the establishment of a small malting plant at St. George brewery in Addis Ababa. The initial capacity of this maltery was 1800 t/year which was later expanded to 3500 t/year. The growing number of breweries at that time and the potential for malt barley production locally necessitated the establishment of Assela Malt Factory (AMF) in 1984, with an initial capacity of 10 000 t/year. In 1996, following the establishment of Bedele Brewery, AMF increased its production capacity by 50%, bringing the total capacity to 15 000 t/year. The new owners of St. George brewery dismantled their maltery because of this and AMF now remains the sole malt producer in Ethiopia. It is located 167 km southeast of Addis Ababa, near Assela town. It is a state-owned factory administrated under the Privatization and Public Enterprises Supervisory Agency. The surrounding highlands, which are generally more than 2300 masl, have long been known to be suitable for malt barley production.

With the present 16% annual increase in local beer consumption, the demand for malt is also increasing at the same rate. According to recent surveys, the local malt demand is of the order of 45 600 t/year, which is more than three times AMF's capacity. AMF is expanding its capacity to increase malt production to help satisfy this demand gap. However, local malt barley supply constraints, in both quantity and quality, remain a threat to the expansion activity.

ECONOMIC SIGNIFICANCE OF THE FACTORY

As the economy of the country is based on agriculture, the role of agro-processing industries contributes significantly to national total economic growth. The direct raw material, other than water, used for the production of malt is 100% malt barley. Likewise, about 90% of the total raw material cost for brewing is malt. Therefore AMF is a very good example of a positive agro-industrial link, making a very important two-way linkage between farmers and breweries. The proximity of the factory to the malt barley producers has also helped strengthen the link between the farmers and the factory. Malt barley has been the only crop with a sustainable market for farmers in Arsi, which includes Tijo-Digalu, Sagure, Lemu and Bilbilo, parts of the Assassa, Kofele, Shashemane and Genale Woredas. At present, the factory's yearly malt barley purchase from these places is about 22 000 t, worth more than 44 million Birr.

The second major contribution of AMF is its role as a source of import substitution. Considering the current local malt price (460 Birr/100 kg), the country saves up to 70 million Birr per year in foreign currency. It is to be understood that this figure is higher when malt is imported because the price of imported malt is currently much higher than that of local malt. Other advantages are, obviously, profit generation for the owner (the government), creation of job opportunities for the citizens, and its contribution as a source of tax revenue for the nation.

MALT BARLEY PRODUCTION

The maltery at St. George Brewery formerly obtained its malting barley from farmers and state farms in Arsi. Then small-scale research was also conducted at Deberezeit and Holetta Agricultural Research Centres to verify the suitability of imported malting barley varieties, such as 'Beka', 'Holker' and 'Proctor'. The varieties, released by the research centres and those imported from abroad as basic seed, were distributed to the farmers and state farms by the then Chilalo Agricultural Development Unit-Arsi Rural Development Unit (CADU-ARDU) that was operating in Arsi. These units also provided support extension services to farmers. They distributed improved seed, fertilizer and other inputs. Following the establishment of AMF in 1984, the state farms in Arsi and Bale were given the responsibility of supplying malt barley to the maltery, and the Ethiopian Seed Enterprise (ESE) was required to maintain continued supply of malt barley seed to the state farms. The factory was also obtaining 20% of its barley requirement from the farmers' cooperatives. Despite some quality problems, there was no supply shortage for the maltery until 1989.

After the declaration of a mixed economy by the then regime in 1989, state farms immediately shifted to producing wheat only, and stopped producing malt barley. The farmers' cooperatives were also dismantled. Since then, the factory has faced a shortage of barley. Also the factory's negotiations with state farms for the production of malt barley on a contractual basis have been fruitless. The state farms argued strongly that malt barley is less productive and hence not as profitable as wheat. Therefore, the factory increased its involvement in extension work with small-scales. For the three years following 1989, the factory faced a critical shortage of barley, but gradually the quantity and quality of supply improved. At present, 94% of the total malt barley supply comes from small-scale farmers and only 6% is supplied by state farms. Strong extension work and better prices for the barley compared with other competing highland crops, especially wheat, are the reasons behind this improvement. Nevertheless, still more improvement is needed to satisfy both the quality and quantity requirement of the maltery.

The barley variety used for malting plays an important role in determining the malt quality and consequently the beer produced from it. The two malt barley

TABLE 1
Malt barley supply to AMF and seed supply to farmers

Year	Barley supply (kg)	Area covered by malt barley (ha)	Seed distributed (kg)	Farm land covered with pure seed (%)
1997	16 645 000	28 721	347 500	8.1
1998	17 423 400	43 409	225 600	3.4
1999	3 867 200	26 594	1 000	0.03
2000	6 520 000	16 800	276 000	10.9
2001	18 436 000	25 857	25 700	0.7
2002	21 924 000	31 153	54 900	1.2
2003	18 170 700	32 545	—	—
2004	23 249 000	43 651	105 700	1.6
2005	20 526 000	43 655	17 500	0.3
2006	13 833 200	38 660	105 700	1.8
Average		33 104	116 000	2.3

SOURCES: AMF and ESE data.

varieties under production are 'Holker' and 'Beka'. These varieties are very old (in commercial production for more than 30 years) and have lost some of their important agronomic and brewing quality advantages. The two major locations where malt barley is currently produced in large quantities are the highland areas on the western side of the Galema belt (the Tiyo, Degelu and Tijo and Bokoji Woredas) and the highland areas of the Kofele and Shashemene Woredas on the southwestern side of Arsi. These areas are known historically as the best food barley production sites in Ethiopia, and hence malt barley also performs well. Amigna Seru Woreda in Arsi and Genale Woreda in Bale are also identified as potential malt barley production areas.

Since ESE does not have an appropriate site for malt barley seed multiplication, a shortage of improved seed is the major problem in all areas producing malt barley. To overcome this, farmer-based seed production is used to supply seed to the farmers. Since the 2003/04 cropping year, farmer unions have been established and have been given the responsibility of collecting and buying at a good price malt barley seed to be distributed later to the farmers. Small-scale, farmer-based seed production is also conducted by ESE. The farmer unions are also responsible for fertilizer distribution to the farmers. Other extension service rendered by AMF to farmers involved in malt barley production include training through demonstrations, roguing off-type barley, post-harvest crop management, advertising new varieties, and helping farmer cooperatives to organize the supply of malt barley to the factory.

QUALITY REQUIREMENT OF MALTING BARLEY

Barley varieties are assessed for their suitability for malting on three major factors: the rate of water uptake, the ease of modification, and the extract potential. Having determined these generally, the individual samples of barley offered by suppliers are subject to physical and chemical scrutiny. The Ethiopian standard for malt barley is still in a draft stage. Therefore, AMF uses its own factory standard, which is adapted from the European Brewery Convention (EBC) standard (Table 2). Based on these standards, the grain supplies from farmers are characterized by a higher proportion of food barley mixture. The supply from the state farms contains almost twice the amount of reject material as that coming from the small-

TABLE 2

Malt barley quality requirement established by AMF in comparison with the EBC standard

Parameters	EBC standard range	AMF standard	Average actual value
Sieve test			
> 2.5 mm	75–95%	>45%	63%
< 2.2 mm + reject	4% for cleaned	16%for unclean	12%
Food barley admixture	—	8% max.	3.2%
Moisture content	12–13%	10–13.5%	13%
Germ. Energy/capacity (%)	98% min.	98% min.	99%
Protein content (dry matter basis)	9–11.5%	9–12%	10.5%
Physical appearance	Yellowish		

TABLE 3

Quality of malt barley supplied to AMF during the period 2001/02 to 2005/06

Crop year	Supply from farmers			Supply from state farms		
	Sieve reject (%)	Admixture (%)	Protein content (%)	Sieve reject (%)	Admixture (%)	Protein content (%)
2001/02	11.7	7.7	10.7	18.4	1.0	11.6
2002/03	10.5	6.4	10.9	21.0	1.2	10.6
2003/04	10.7	4.2	10.5	30.9	0.1	11.6
2004/05	11.0	3.5	10.4	14.5	0.9	12.1
2005/06	15.5	3.4	10.7	17.0	0.7	11.5

NOTES: Admixture of food barley in malting barley.

TABLE 4

Results of large-scale tests on malt prepared from HB 120 and HB 52 at Meta Abo Brewery

Parameter	Unit	Standard	Malt Source		
			Normal Assela	HB 120	HB 52
Wort iodine test	-ve/+ve	-ve	-ve	+ve	+ve
Extract yield	g/100 mL	12.20	12.35	11.72	11.85
Lautering speed	hr	2:00	2:03	2:31	2:13
Last run extract	g/100 mL	Max. 1.2	1.08	1.56	1.27
Fermentation	days	5–7	6	10	8
Alcohol content	%	3.5–4.5	4.15	3.59	3.42

TABLE 5

Quality of malt prepared from HB 120 and HB 52 malt barley varieties

Parameters	EBC standard range	Malt from		
		Beka	HB 120	HB 52
Sieve test (%)				
>2.5mm	80 minimum	85.3	81	80
>2.2mm	5–10	13	13	14
<2.2.mm + reject	1 maximum	6	6	6
1000-grain weight (g)	23–35	33	32	28
Moisture content (%)	3–5.8	5.1	4.5	4.5
Extract on DB, fine (%)	79–82	78.7	80	80
Extract on DB, coarse (%)	77–80	77	76	76
Saccharification, min.	10–15	10-15	15-20	15-20
Speed of filtration	Normal = 1 hour	Normal	Slow	Slow
Protein content (%)	9–11.5	10.2	10.6	10.6
Friability (%)	78–81	76	60	54

scale farmers. In terms of protein content, both sources are within the limit set by the factory (Table 3).

In 2001/02, two new varieties, HB 52 and HB 120, were released by HARC of EIAR, and are still under small-scale production by state farms. However, these varieties are not preferred by breweries because they are of low extract yield and show poor modification. Malt prepared from HB 52 and HB 120 barley lauter poorly in brewhouse operation and beer filtration takes a very long time (Tables 4 and 5). Two other varieties, HB 1533 and Misical 21, were released in 2004 and 2006 and currently they are in the multiplication stage. It is assumed that the malting and brewing quality of the Misical 21 variety is already verified as it is an imported seed, but the quality of the Holetta bred HB 1533 has yet to be proven. At present, EIAR is conducting adaptation trials on some other imported malt barley genotypes from Europe and Kenya at the Bokoji and Koffele trial sites.

MALT BARLEY MARKETING

The major market places are in woredas from the two zones of Arsi that include Shashemene, Kofele, Serufta, Siltana, Bokoji, Merarro, Degelu, Tijo and Sagure. Most of the malt barley produced is supplied to the factory by individual merchants. In most cases there are at least two market participants in the supply chain between the producer and the factory. Small merchants collect the barley from the farmers and supply to the large buyers. The large buyers in turn supply to AMF in trucks. Thus the profit is shared among the farmers, the small merchants and the large buyers. To avoid this ladder and to make the farmer the prime beneficiary, efforts are being made to organize farmers' service cooperatives and unions to collect the barley from the farmer and supply directly to the factory. To facilitate this effort, the factory has arranged to provide its own trucks to transport the barley to the factory at a reasonable price. AMF extension agents also provide consultancy services to the barley purchase committees of these cooperatives to help identify the best quality barley in the market.

The price of the barley is set by the factory based on four main factors. These are the quality of the barley; the prevailing price of other highland crops, like wheat and food barley; the price given by malt barley consumers at major towns; and the factory's profit margin from malt sales. In order to ensure that barley flows to the factory, the price has to be set in such a way that the advantage gained by producing malt barley is higher than that from other competing crops. The factory closely monitors that these condition are met when setting the price.

As indicated above, the factory does not pay the same price for every lot of acceptable malt barley. The best quality malt barley gets the higher price. As an example, the current year's latest malt barley price varied from 227 Birr/quintal to 280 Birr/quintal depending on the quality. The two major quality parameters used to determine the price are the food barley admixture level and the screening loss or reject amount. It should be noted that poor germination energy/capacity, excessive protein, and moisture content beyond the acceptable level can not be compromised when determining the purchase price. Since the introduction of a quality-based price, major improvements have been achieved, especially in terms of food barley admixture level. The food barley admixture level dropped from 6.3% in the 2002/03 crop year to just 3.3% in 2004/05.

QUALITY CONTROL

Since AMF is dealing with a number of individual suppliers, the quality control work is very tedious. The chemists have to take and analysze two different samples from each truck, one at the beginning of the intake and the other about halfway through. This is done because most of the malt barley is collected from individual farmers holding fragmented pieces of land from which different quality barley is produced. The second reason is that some suppliers deliberately mix poor quality barley in the middle or at the bottom of the lot where it is not accessible for sampling. Regulations are set by the factory in order to minimize such cheating. The penalty invoked if such attempts at cheating are attempted repeatedly is that all lots will be rejected.

Once the malt barley is received, it is pre-cleaned to remove any large impurities and metallic substances before it is stored. The barley is kept in silos at an optimum temperature (usually <26°C) in order to maintain its viability. Any infestation is also checked. It is then cleaned and graded, a process by which all impurities, including the unwanted low size barley (below 2.2 mm sieve size) are removed. As freshly harvested grains are dormant up to four to five weeks from harvest time, the germination level is checked before it is sent for processing.

LOCAL MALT DEMAND

The demand for malt is directly derived from the production of beer. Depending on the brewing technology employed and the type of beer produced, 15 to 19 kg of malt is used per hectolitre of brew. The average consumption of malt considered in this paper is 17 kg/hL brew. The malt barley requirement per tonne of malt, as practiced at AMF, is 1.40 t. Therefore 1:1.40 malt-to-malt barley ratios are considered in this paper. Currently there are six breweries in Ethiopia, three of which are state owned and three belong to private companies. Their overall current production capacity is about 2.7 million hectolitre of brew per year. With the growth of the population, economy and an increasing beer consumption culture, a sharp increase in beer demand is being experienced in the country. In trying to exploit this situation, most breweries are undergoing major expansion.

Harrar brewery and BGI have increased their production capacity by 75% and 67%. Harrar Brewery has brought its capacity from 200 000 up to 350 000 hL/year and BGI from 600 000

TABLE 6
Current annual beer production capacity and malt requirement of Ethiopian breweries

Brewery	Brewing capacity (hL)	Malt requirement (t)	Malt barley requirement (t)
Meta Abo	437 000	7 429	10 400
Harrar	350 000	5 950	8 330
Bedele	250 000	4 250	5 950
Dashen	650 000	11 050	15 470
BGI	1 000 000	17 000	23 800
Total	**2 687 000**	**45 679**	**63 950**

Notes: BGI operate the St. George and Kombolcha breweries.
Source: AMF data.

to 1 million hL/year. Meta Abo Brewery has also increased its capacity, from 375 000 hL to 437 000 hL after resolving bottlenecks that existed in some sections of its factory. In one year (2006/06), the total brewing capacity of all the breweries grew from 2.075 million hL/year to 2.687 million hL/year – a 30% increase. Proportionally, the annual malt requirement grew from 35 275 t to 45 679 t in 2006/2007.

According to recent surveys, the country's beer consumption has increased sharply and a beer shortage is being experienced in some towns despite all the breweries producing at full capacity. Since current local malt supply by AMF is just 15 000 t/year, it can be seen that the excess demand is twice that, at 30 679 t/year. This, therefore, justifies expansion of the existing malt plant or installing new malting plants in the country, or both. However, expansion of AMF or the establishment of new malting plants will require adequate local supplies of malting barley. To produce 45 679 t/yr of malt requires 63 950 t/yr of malting barley. Hence, an adequate supply of locally produced malt barley, of an appropriate quality, to meet the demand is crucial for sustainable agro-industrial development of this sector of the economy.

MALT PROCESSING AT AMF

There are two major types of malting methods known today. One is the classical and labour intensive malting method known as floor malting, and the other is the modern and automated method known as pneumatic malting. AMF uses the pneumatic malting method, which is state-of-the-art technology capable of handling tonnes of malt per batch. Thus, once malt barley of the right quality is acquired, there is no problem in producing the best quality malt at AMF. There are three major steps in the malt processing, which are detailed below.

Steeping

Steeping is the first and most important stage of the malting process. Mistakes made during this step will be very difficult to correct later. The purpose of steeping in malting is to clean the barley of any foreign matter, like dust; impart the necessary moisture content; and create a conducive condition for the grain to chit (reveal its rootlets). In this process, a clean batch of barley will be dropped from a silo into a steep tank partly filled with water at ca 15°C. Steep tanks are vertical cylinders with conical bases. Air is passed through the steep water using perforated pipes. These permit more aerobic conditions to prevail in the steep water. When first immersed, the moisture content of the grain increase rapidly, but the rate of increase then slows down progressively. The speed of grain increase is a function of the growth conditions of the barley prior to harvesting, grain size, the barley variety, and water temperature.

The steeping is interrupted after six hours by draining off the water. Each barley corn remains covered with a film of water in which oxygen from its surroundings can readily dissolve. This condition is known as air rest. After a few hours of air rest and carbon dioxide extraction, the barley is re-immersed in a second steep water. This alternation of steeping and air-rest continues until the barley has reached about 42% moisture. By this time, it is likely that the grain has begun to chit.. At this time the embryo becomes active and respiration increases significantly to yield energy, carbon dioxide and water. This creates a massive oxygen demand in the steep water, hence the sparging (rinsing the newly converted sugars out of the grains), extraction of the carbon dioxide formed, and the air rest during steeping. In the absence of oxygen, the embryo has some capacity to metabolize anaerobically by converting food reserves rather wastefully into energy, carbon dioxide and alcohol. As the alcohol concentration increases, it becomes progressively more toxic, in fact the initial stage of germination, i.e. after the hydration of the barley, is anaerobiosis. When the grain chits, there is a rise in oxygen consumption (if oxygen is available) and ethanol production declines. Without a sufficient supply of oxygen the grain will not germinate, and it may be harmed by the ethanol that accumulates during extended periods of anaerobiosis.

Oxygen uptake is slowed by the husk and pericarp and by any film of water covering the grain surface. The grains' microbial population competes strongly for oxygen and in some circumstances may so reduce the availability of this gas to the grain tissue that germination is slowed or even prevented. There would undoubtedly be advantages in controlling the microbial population of the grain, if safe and economical ways of doing this could be found. The most common practice these days is to spray with dilute hydrogen peroxide mixed width gibberellic acid, which in addition to controlling the microbial population will accelerate the rate of malting. The peroxide is harmful to micro-organisms, but it leaves no unwanted residues since it decomposes into water and oxygen, the latter augmenting the oxygen of the air in supporting grain respiration.

Germination

Steeping is normally completed in about 2 days. With modern malting techniques the grains have chitted or started germination by the end of the process. Now that germination has started, the process should be controlled so that the heat and carbon dioxide produced by the oxidation reaction-taking place inside will not hamper the process. Therefore the steeped barley is transferred either wet or dry to the germination equipment and the moisture content maintained at about 42%. The most common type of germination equipment takes the form of a rectangular box fitted with a perforated false floor. The steeped barley is loaded onto the false floor to a depth of 1 to 1.5 m. Water saturated air at about 15°C is blown upwards through the bed. This ensures that there is oxygen available for the embryo, that carbon dioxide is swept away, and that a constant temperature is maintained in the bed. In order that the rootlets do not mat together, a mechanical turner separates the germinating corns. The turning also helps to aerate and maintain an even temperature.

During germination the proportions of the various nitrogenous fractions alter. There is a net decline in hordein protein and a rise in simpler, water-soluble substances. There is a substantial breakdown of the substances in the endosperm;

many protein-hydrolyzing enzymes increase in amount, and simple nitrogenous substances are taken up in quantity by the embryo and are used in the synthesis of new tissues. Apart from the substances leached during steeping there is no loss of nitrogen from the grain during malting. However, the respiratory losses of the dry matter of the carbohydrate component that occur tend to raise the nitrogen proportion of the grain, while the substantial quantity of nitrogen that moves into the roots, which are eventually removed, tends to reduce the nitrogen percentage in the finished malt.

As the germination of the barley continues, so does the degradation of the starchy endosperm, the cell wall, protein and lipids, thereby making the seemingly intact barley grain easily crushable between fingers and, when it is dry, readily friable. This change is generally termed as modification. Maltsters usually follow the progress of modification by rubbing out samples of grain. In poor quality, under-modified malt, the tips of the grains retain their barley character, resulting in hard ends in the kilned product. Depending on the nature of the barley used, four to six days of germination is enough for proper modification. After achieving the required modification in the germination process, germination should be terminated so that the barley is not subject to excessive malting loss through respiration, or over-modified unnecessarily. Termination of germination is achieved by kilning (curing) the green malt.

Kilning

Kilning is a process for arresting germination by simply drying the malt grains. The best method is by blowing hot, dry air through the green malt via the perforated bed of the kiln box. The temperature and the time of kilning depends on the type of malt required at the end. Long and cool drying leads to a pale malt with much of its enzyme content intact, whereas a rapid hot drying produces dark malt deficient in enzymic activity. In this way, a less well modified malt for distilling can be produced. The physics of drying are complex, but they hinge on the fact that a sample of malt has a characteristic water vapour pressure at any particular temperature. The vapour pressure rises significantly with rising temperature. Thus a combination of high airflow and high temperature will dry the malt quickly. It is usual to express the water vapour pressure of the grain in terms of the relative humidity (RH) of the surrounding air (i.e. the RH of air in equilibrium with the moist grain at the prevailing temperature).

The factors that affect the rate of grain drying include (i) the volume of air passing through the bed of grain; (ii) the depth of the bed of grain: (iii) the weight of the water to be removed from the bed of grain; (iv) the temperature of the drying air; (v) the relative humidity of the drying air; and (vi) the hygroscopic character of the malt. Generally, the kilning process can be considered as having three stages.

The first stage is free drying, when the moisture is freely available at the surface of the corn and when the drying rate is dependent on temperature and airflow. The air temperatures used are in the order of 50 to 70°C depending on the final malt type required. During this period, the grain moisture falls to between 10 and 15%. The second stage occurs when the rate of drying is limited by the ability of the moisture to move from the inside of the corn to the surface where it can be evaporated. Air temperatures are in the range of 65 to 75°C and the grain moisture falls to about 5%. Airflows can be progressively reduced during this period, as the rate of evaporation decreases and it is normal to commence partial re-circulation of the exhaust air when its relative humidity drops to 40%. The last stage is the curing stage, when the temperature is progressively increased to 80°C for lager malts and as high as 105°C for Munchner malt. During this stage the final colour and flavour of the malt is established, and the malt moisture drops to 4% for lager malt and to between 2 and 3% for Munchner malt.

Biochemical changes taking place during kilning Stage 1 are a continuation of germination, whilst the moisture content remains in the region of 40%, the temperature is below 50°C and there is a supply of uncontaminated air. Stage 2 is an enzymic phase that occurs while the temperature does not exceed 60°C and as the moisture falls below 30%, the most active enzymes being amylases and proteases and, to a certain extent, the cytolytic enzymes. Towards the latter part of Stage 2, when the higher temperatures occur and relatively high moisture is retained, enzyme inactivation can be rapid. In Stage 3, curing occurs between 80 and 100°C. The main chemical changes are the production of colour and flavour compounds. At this stage only the most thermostable enzymes, like alpha-amylases and endopeptidases, survive. The other heat labile enzymes, like beta-amylases, exopiptidases and beta-glucans, are nearly destroyed. The meloanoidins which develop at this stage are believed to be the important colour forming compounds in the malt. Many other flavour compounds, like hydroxymethylfurfural and maltol, and many heterocyclic compounds, such as pyridines, pyrazines and thiazoles, have also been identified.

After the kilning process is complete, the dried rootlets and some loose husks are removed from the malt by polishing. The rootlets are used as cattle feed. They are rich in vitamins and proteins. The malt needs to be cooled before storage in order to reduce the chance of infestation by insects, to check the development of colour, and to arrest the decline in enzyme level. There is also a belief that malt should be stored for a minimum period of four to six weeks before being processed to beer. There is some evidence that the quality of the wort obtained from the malt improves from this period of storage. As malt is hygroscopic by nature, it is preferable to bag it in waterproof sacks with a lining of plastic film.

CONCLUSIONS

Agriculture is the backbone of the Ethiopian economy. Thus integration of agriculture and industry has a vital role in the economic development of the nation. Local production of sufficient malt barley and malt means supporting the national motto ‘Agriculture leads Industrial Development’. Therefore all stakeholders should play their parts in efforts to alleviate the malt barley shortage (quantity and quality) in the country. In coordination with the malt factory, the local bureau of the Ministry of Agriculture should provide strong extension services to farmers producing malt barley.

Releasing new varieties that have improved characteristics and continuously maintaining the varieties currently in production is the task of the Ethiopian Institute for Agricultural Research, the governmental agricultural research agency. Today, the varieties in production have lost their agronomic characteristics, such as yield, resistance to disease, grain size, etc., and consequently their brewing quality. They are also mixed with other varieties. Suitable, new varieties should be released on a continuous basis, as is the case with other crops, such as wheat.

As was the case before 1991, ESE should multiply and distribute improved seed of varieties released by the researchers. Seed marketing strategies involving credit facilities should also be provided to the farmer through small-scale, rural finance institutions.

The bulk of the barley currently supplied to the maltery is produced by farmers having fragmented and small plots of land, who use archaic methods of production and inadequate levels of agricultural inputs. As a result, the quality and quantity requirements for malt barley are not being met. Therefore, it is inevitable that mechanized farms, owned by either the state or private investors, will be required to produce malt barley alongside the individual, small-scale farmers on a contractual basis.

A framework should be established so that the breweries and AMF can financially support the research and extension activities. Provision should be made for AMF to have its own farm to partially fulfil its needs and produce malt barley seed for farmers.

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Unexploited opportunity in agro-processing: the case of malt barley in Ethiopia

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INTRODUCTION

Malt is the major raw material for beer production. About 90% of the total raw material cost for beer production is malt and the material used for malt production in Ethiopia is malt barley. Asella Malt Factory (AMF) was established in 1984 to supply malt to local breweries. The major sources of raw material (malt barley grain) were state farms and producer cooperatives. During the 1980s, cooperatives in the highlands of Arsi were producing malt barley for consumption at the factory. On average, 20% of the malt barley grain supplied to AMF originated from the cooperatives. However, ordinary farmers did not have much information on malt barley marketing and its utilization by the factory. The reason given for this was that cooperatives were not autonomous under the socialist government and there was a top-down planning process that pushed them to produce while discouraging the private sector. Given the same economic policy, state farms were the major producers and suppliers of malt barley at that time. They were supplying about 80% of the total requirements from 1985 to 1989 (Berhane Lake, Hailu Gebre and Fekadu Alemayehu, 1996). After the economic reform of 1990, the cooperatives were dismantled, while the state farms gradually decreased and finally ceased producing barley in 1999/2000. In 1990/91 they supplied 12 204 t of barley, and the following year they supplied about 44% of this volume. Since then, small-scale farmers have come into the picture and become the major suppliers of malt barley. In the last 10 years, farmers have given due emphasis to the production of malt barley in most parts of the highlands of Arsi (CSA, 2000, 2002). The guaranteed market opportunity created as a result of AMF's reliance on private, small-scale farmers for its malt barley supply has sheltered the farmers from price fluctuations at times when there was instability in the grain market, and eventually triggered competition for the product in the market.

Currently, there are six breweries in Ethiopia. The total production capacity of these breweries is 2.7 million hectolitres of beer per annum. Based on the fact that 17 kg of malt is needed to produce 1 hL of beer, our breweries need 45 679 t of malt to operate at their full capacity. AMF, the only manufacturer of malt in Ethiopia, is able to process and supply 15 000 t of malt (32.8% of the national total malt demand). The balance, 30 679 t of malt, is imported from abroad. This means our farmers have a potential market opportunity that is expected to grow with the increase in investment in breweries. Nevertheless, it is imperative to question why we are importing malt when we have suitable agro-ecologies to produce malt barley grain, and it is possible to process it in the country. Do we have a comparative advantage in malt barley production? What investment opportunities are there in this sector? The major objective of this paper is to indicate the market opportunities that our small-scale farmers and investors have and the comparative advantage of the country in malt barley production and processing.

MATERIALS AND METHODS

Sources of data

The data used for this study were collected from both primary and secondary sources. The primary data were collected through a formal survey undertaken in five districts of Arsi Zone, using a structured questionnaire. Secondary data was collected from AMF and the Central Statistical Agency (CSA).

Sampling technique and sample size

A combination of purposive sampling and two-stage probability sampling techniques were used. In the first stage, the malt producing zone of Arsi was selected. Then five districts, namely Digelu-Tijo, Limu-Bilbilo, Kofale, Kore and Shashamane, were selected from among 21 districts in Arsi Zone. In the third stage, two peasant associations were selected from each district. Finally, 300 farm households were selected using a probability-proportional-to-size sampling technique.

ANALYTICAL PROCEDURES

Data analysis was done using descriptive statistical tools, such as averages, frequencies and a Policy Analysis Matrix (PAM). Analysis of variance (ANOVA), t-tests and cross-tabulations were also used to test hypotheses where appropriate. A PAM was used to investigate the comparative advantage of the country in malt barley production.

Data and modelling assumptions

This study makes use of a PAM to analyse the data collected from different sources. The data required to construct the PAM are yield, various production inputs, and market prices of inputs and outputs. The price used to calculate the private costs was the current market price for grain supplied from domestic sources to AMF. The shadow price used in the calculation of the social costs was based on the world market price of importing malt barley grain from France. For this purpose, the Cost-Insurance-Freight (CIF) price obtained from the European grain price data set, available at http://www.hgca.com, was adjusted for local transportation, insurance and other marketing costs. Information needed for adjustment of the CIF price was obtained from AMF. Labour cost was calculated based on the information obtained from the survey. The shadow price of unskilled and skilled labour was calculated using the conversion factor obtained from the Ethiopian Ministry of Economic Development and Cooperation. Land was valued using the current lease rate in the informal land market in the study areas as a shadow price. Fertilizer and herbicides were valued at current market prices since there is no subsidy for agricultural inputs in Ethiopia. The shadow price for malt barley seed was valued using the CIF price of the malt barley grain after making all necessary adjustments for transportation and marketing costs.

General framework of a policy analysis matrix (PAM)

The PAM is a computational framework developed by Monke and Pearson (1989) and augmented by Masters and Winter-Nelson (1995). It is used for measuring input use efficiency in production, comparative advantage among commodities, and the degree of government intervention. The PAM can also be employed to assess the effects of policies on the comparative advantages of imported vis-à-vis locally produced commodities.

Economic profits are the fundamental components of PAM. They act as signals for the optimal allocation of resources. There are two types of profits. Private profits are evaluated at market prices and social profits are evaluated at social or efficiency prices. If there are no market distortions, the two are often the same. If, however, there are market failures or distortions, then the two would diverge from one another. Their divergence would act as a signal for policy intervention. The general framework of a PAM is presented in Table 1.

Private profitability is calculated as the difference between private revenue (A) and the costs of both tradable and non-tradable inputs (B+C). The prices used in measuring private profitability are domestic market prices. Private profitability demonstrates the competitiveness of the agricultural system, given current technologies, prices of inputs and outputs, and policy.

The next row of the matrix calculates the social profit that reflects the social opportunity costs. Social profits measure efficiency and provide a measure of comparative advantage. In addition, a comparison of private and social profits provides a measure of efficiency. Social profitability, a measure of economic efficiency, is equal to social revenue (E) minus the cost of tradable and non-tradable inputs (F+G). Because social values are the values given under the assumption of no policy interventions and competitive markets for inputs and outputs, exported goods (for both input and output) are measured at the free on board (f.o.b.) price and import goods are measured at

TABLE 1

General Framework of the policy analysis matrix

Value of output		Value of input		Profit
		Tradable	Domestic factor	
Private Prices	A	B	C	D
Social Prices	E	F	G	H
Policy transfer	I	J	K	L

Private profit: D = A-(B+C)
Tradable input transfer: J = B-F
Social Profit: H = E-(F+G)
Domestic factor transfer: K = C-G
Output transfer: I = A-E
Net transfer: L = D-H = I-(J+K)

Source: Monke and Pearson, 1989.

the cost, insurance, freight (CIF) price (Huang *et al.*, 2004). Furthermore, there is a need to adjust border prices for inland transportation costs. A positive social profit indicates that the county uses scarce resources efficiently and has a static comparative advantage in the production of that commodity at the margin. Similarly, negative social profits suggest that the sector is wasting resources that could have been utilized more efficiently in some other sectors. In other words, the cost of domestic production exceeds the cost of imports, which indicates the sector cannot survive without government support at the margin (Mohanty, Fang and Chaudhary, 2003).

The last row of the PAM measures the divergence between the private and social valuations of revenues, costs and profits. In other words, it gives the effect of policies on economic efficiency. Output transfers (A-E), denoted by I, give the amount of output value transferred from society to individuals. Tradable input and domestic factor transfers can be calculated using the same logic.

The PAM framework can also be used to calculate important indicators for policy analysis. These include the Nominal Protection Coefficient (NPC) for outputs and tradable inputs, the Effective Protection Coefficient (EPC), and the Domestic Resource Cost (DRC) ratio. The NPC measures the impact of commodity-specific price interventions, such as import tariffs. The NPC for outputs is given by the ratio of private revenue to social revenue (A/E). An NPC greater than unity implies that the domestic output is protected, and vice versa, if the ratio is less than unity. An NPC for tradable inputs is expressed as B/F (the ratio of the value of tradable inputs at local market prices to the value of tradable inputs at world market prices). The EPC, which measures the total effect of government interventions, can be calculated from the PAM as the ratio of the value added in local market prices (A-B) to the value added in world prices (E-F), i.e. EPC = (A-B)/(E-F). If the EPC is greater than one, it means that government intervention has favoured local production although it is more economical to import the commodity.

The DRC ratio is the ratio of the domestic factors of production in economic values (G) to the value added, again in economic terms (E-F), i.e. DRC = G/(E-F). It indicates the cost of domestic factors that have to be incurred to obtain one unit of value added in economic terms. A DRC ratio less than unity implies that the commodity has a comparative advantage.

RESULTS AND DISCUSSION

Socio-economic and demographic characteristics

The socio-economic and demographic characteristics of farm households play key roles in the agricultural performance of certain areas since they influence the adoptive behaviour of technologies, resource use and decision making. In this study, the most important socio-demographic characteristics of the sample households are categorized into personal and household characteristics. Some of the most important personal characteristics considered in this study are age, sex, level of education, religion and farming experience of the household head.

The household characteristics considered are family size, number of male and female household members, and composition of the household by age group and involvement in farming activities.

Household and personal characteristics

About 93% of the farmers interviewed were male while the rest were female heads of households. In cases where the head of the household was female, the farm operations for malt barley production were found to be accomplished by the female head of the household (40%), elder sons (45%), or hired labour (5%). The average age of the respondents was 45 years. The maximum and minimum ages were 78 and 20 years. On average, each of the respondent farmers had 25 years of farming experience. The youngest farmer had 3 years of farming experience while the oldest had farmed for 60 years. The most common religion in the area was Muslim, followed by Orthodox Christian. As a result, about 23% of the sample farmers had more than one wife. The ethnic composition of the areas is made up of Oromo (88%), Amhara (9.7%), Silti (2%) and Gurage (0.3%).

One of the most important socio-economic factors affecting the adoption of technology is family size through its effect on the labour supply and the demand for farm outputs, among others. The average family size in the areas under investigation was nine persons per household. There was a statistically significant difference in the mean household size among the surveyed districts ($t=6.465$ and $P<0.05$). The highest mean household size was that of Kofele district. Kofele district is the biggest supplier of malt barley grain to AMF.

There were more males than females in 53% of households, while 47% had a higher proportion of females. The age composition of household members would affect the amount of family labour that might be available for agricultural activities. It is generally understood that children up to 14 years and adults above 64 years of age are economically inactive and depend on others. The case of children aged from 10 to 14 years should, however, be treated carefully since this age group can be observed actively participating in every agricultural activity. Even children younger than 10 years would be involved in herding and feeding livestock, protecting crops from birds, etc. Thus, in this study, children between 10 and 14 years of age are considered as an economically active population. Based on this argument and the survey data, about 61% of the population in the study areas was economically active. About 38% of the population was young (under 10 years); this segment of the population may make a certain contribution to the labour force. About 39% of the adult population (15 to 64 years) and 15% of the juvenile population (10 to 14 years) were working on the farm full time, while 36% of adults and 47% of juveniles were working part-time. Just 3.3% of the surveyed population were found to work full-time off-farm and 2.2% part-time. This implies that farming is the major means of livelihood for the population in the study areas.

As indicated in Table 2, the major sources of off-farm income are selling fuelwood, petty trade, casual labour and handicrafts. The most common petty

TABLE 2
Source of off-farm income

Source of off-farm income	Annual off-farm income		
	Mean (Birr/year)	Number	Standard deviation
Gift	325	2	388.9
Handicrafts	615	4	411
Casual labourer	748	5	1195.9
Local beverage	150	2	127.3
Selling fuelwood	1600	2	565.7
Petty trade	1517	13	2031.5
Total	825.9	28	

trade activities are grain and small ruminant trading during slack agricultural seasons. Casual labour involves working for wages in the nearby towns or on the farms of other farmers. Though environmentally devastating, the sale of fuelwood is the most important source of off-farm income. This is especially noticed in slack agricultural periods and when households exhaust their food reserves, particularly after planting and immediately before harvest, times when the households are desperate for food.

Farm characteristics

Land holdings

In subsistence farming, the most important resources for agricultural production are land and labour. Land is a scare resource in rapidly growing populations, such as those of the malting barley producer communities in the highland areas of Arsi. The survey results indicate that the average land holding size per household is 2.98 ha, including the homestead area. The largest land holding was recorded in Qore district (3.83 ha) followed by Lemu Bilbilo district (3.6 ha), while the smallest was recorded in Shashemene (1.6 ha) with a statistically significant difference (F=16.49, $P<0.001$) between districts. Renting and share cropping are the most common methods of obtaining access to farm land in the study areas. Each of the sample households have rented 0.5 ha of land, on average. Renting is most common in Lemu Bilbilo district, where each of the farmers sampled had rented 0.9 ha, on average.

Livestock ownership

Livestock play a pivotal role in the mixed crop–livestock farming system. They are sources of farm power, food and income, and symbols of prestige in the traditional farming community. On average, each of the farm households in the survey area had 15.7 Tropical Livestock Units (Tropical Livestock Unit = 250 kg livestock body weight) of animals. The mean difference in livestock ownership was statistically significant between the four survey districts (Table 3).

The highest average livestock ownership was reported from Qore, followed by Lemu Bilbilo area. The number of oxen owned per household is an indicator of their wealth and also determines the intensity of seed bed preparation. About 9% of the respondents did not have oxen, 16% had a single ox, 42% had a pair of oxen, and 33% had more than a pair of oxen.

TABLE 3
Ownership of livestock (Tropical Livestock Units) per household in the survey areas

Farming district	Mean	Number	Standard deviation
D/Tijo	7.5	101	4.57
Shashemene	4.1	51	3.74
Kofele	6.1	28	3.28
Lemu Bilbilo	10.4	100	6.05
Qore	11.6	22	5.23
Total	8.06	302	5.48

Market-oriented extension intervention (linking farmers to a sustainable market)

Although earlier efforts had laid the foundations for the better adoption and use of malt barley technologies, more focused extension work was done following the dismantling of the producer cooperatives and reduction or elimination of the state farms' supply of malt barley grain to AMF. The effort made by the Research Extension Advisory Council (REAC) in Arsi Zone is worth mentioning at this stage. The most important achievement of REAC in Arsi Zone is the work done to link small-scale farmers with a sustainable market. This could be adopted as a lesson when expanding production of the crop in other regions of Ethiopia, thus making better use of the country's resources.

As a result of the shortages developing in the supply of malt barley grain in the country, AMF was importing malting grain from abroad. However, the REAC investigated the potential in Arsi for producing malting barley and designed a strategy to produce an ample amount of this grain on small-scale plots through intensive extension work. REAC has made tremendous efforts to boost the area of production of malt barley in the zone and also to convince AMF to buy malt barley grain from the domestic market so that the country will save its foreign currency. This has an added advantage in that it creates a sustainable market for small-scale farmers producing malt barley, thus increasing their household incomes, and ensuring food security at the household level. AMF was sufficiently persuaded of the viability of the idea that it strengthened its extension arm in order to get quality grain from domestic production. Finally, it proved possible to produce an ample amount of malt barley grain on small-scale farm fields in Arsi. Although alternative markets are competing to purchase malt barley grain for other uses, the factory is currently buying its raw material from the domestic market alone. From this effort, AMF is collecting about 22 000 t of malt barley grain per annum from the domestic market (which is mainly supplied by small-scale farmers) in Arsi Zone (Figure 1).

As indicated in Figure 1, before1993 AMF used to get most of its raw material from state farms. However, this changed following the government implementing a free market economy. The difference in the amount of grain required by and that supplied to AMF during the period 1998 to 2001 was covered by imports. However, REAC has managed to bring both small-scale farmers and AMF together to their mutual benefit and AMF's current demands are being satisfied from domestic sources. As a result, there was an increase in both the area allocated to malt barley and the amount of grain produced from the year 2001 onwards (Figure 2).

Analysis of the survey data indicates that all the farmers in the study area were producing malt barley. The general trend for the total area of land allocated to malt barley in Arsi Zone has been increasing. There was a decreasing trend in the area allocated to this crop from 1998 to 2000 (Figure 2) which was a consequence of not enough attention being given to the domestic production of malt barley by small-scale farmers during this period. The general increase in the area allocated to malt barley production in Arsi, a result of linking farmers to sustainable markets,

FIGURE 1

Supply of malt barley grain to Asella Malt Factory (AMF) and its sources

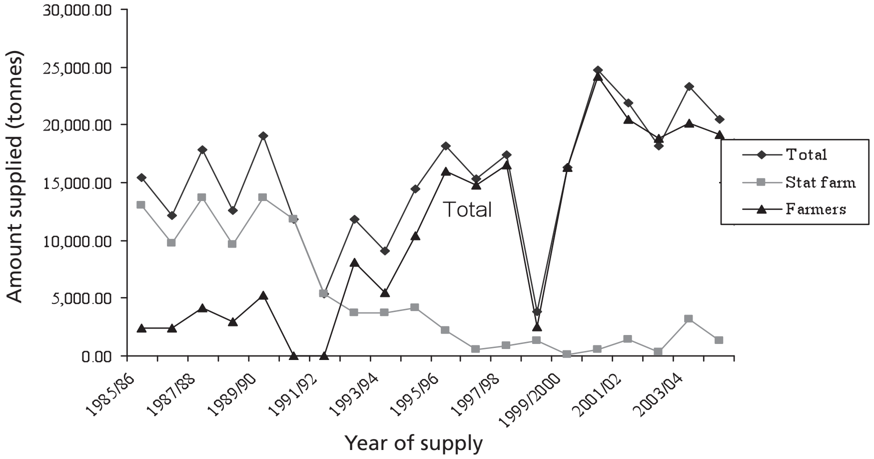
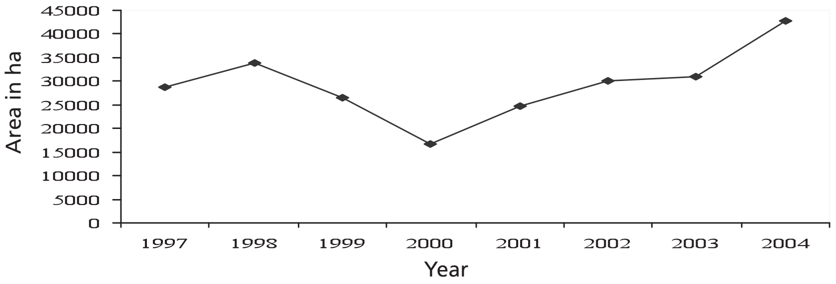


FIGURE 2

Change in the area allocated to malt barley in Arsi Zone (1997–2004)



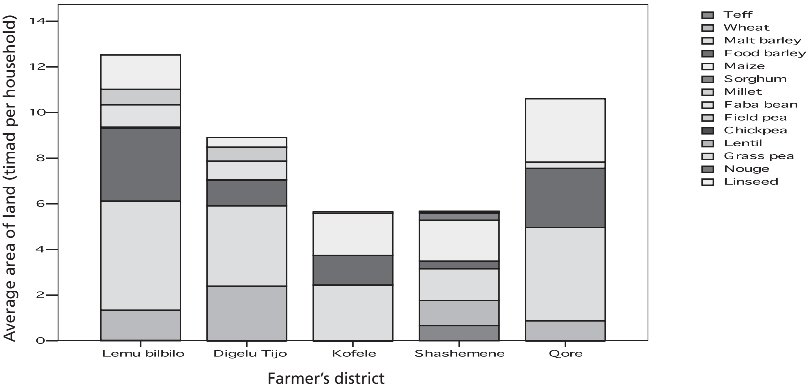
SOURCE: AMF annual assessment

is an indication of the potential that Ethiopia has to expand malt barley production and create opportunities for the large number of farmers and the private sector interested in investing in value adding industries, like malt making.

Figure 3 shows the allocation of land to different crop enterprises. It can be clearly seen that malt barley has had the largest share of land for all crops in the study areas. The general dominance of malt barley in the highland areas where other crops could also be grown indicates that small-scale farmers are responding to the market and will probably do so as long as it is profitable.

The second most important crop varies from location to location. While food barley is the second most important crop in Lemun Bilbilo and Qore districts, wheat and maize are second in area coverage in Digelu Tijo, Kofele and Shashemene districts.

FIGURE 3
Average area of land (in timads per household) allocated to different crops in each district (2002



Note: 1 timad ≈ 0.5 ha.

OPPORTUNITIES IN MALT BARLEY PRODUCTION AND PROCESSING

There are six breweries in Ethiopia. The current total capacity of these breweries is 2.7 million hectolitres per annum, implying a requirement for 45 679 t of malt annually. However, AMF can produce and supply only 15 000 t of malt (32.8% of the national malt demand). The balance (30 679 t of malt) is imported from abroad. Thus Ethiopia is spending about 368 148 000 Birr to import this amount of malt every year. It takes 1.67 t of malt barley grain to produce 1 t of malt, so an additional 51 234 t of malt barley grain is needed in order to satisfy the raw material need of the domestic breweries. The farmers have thus a potential market opportunity which is two to three times their current market volume. The country has suitable agro-ecology for the production of malt barley grain and farmers can produce ample amounts of this grain as long as there is a dependable market for the produce. The problem in this case is that there is just one factory with a limited capacity producing malt. Additionally, the world price of malt is escalating and the domestic breweries are showing a strong demand for malt, which could be supplied from domestic markets. This again is an opportunity for investment in value addition and calls for investors to establish more malting factories that can absorb malting barley grain from domestic sources and supply the breweries. This investment opportunity creates strong backward and forward linkages between agriculture and the industry sector, improves the income of small-scale farmers (better market opportunities), frees up Ethiopian foreign currency reserves that are currently being used to purchase malt in world markets, and also generates employment opportunities in the country.

RESULTS OF POLICY ANALYSIS MATRIX

Both tradable and non-tradable inputs are used in malt barley production. The tradable inputs are seed, fertilizer and herbicide, while the non-tradable domestic factors include labour for ploughing, planting, weeding, harvesting, transporting to the threshing ground and threshing, ox power, and land. A summary of malt barley production inputs, costs and returns, valued at both private and social prices, are presented in Table 4.

Based on the valuation of the inputs and outputs provided in Table 4, a summary of the social and private costs and benefits, and the ratios mentioned earlier, are presented in Table 5. As indicated in the table, producing malting barley locally is both socially and privately profitable. Producing malt barley locally has a private profit of about 1415.2 Birr/t and a social profit of about 2791.67 Birr/t. Since social profitability is a measure of efficiency and comparative advantage, a positive social profit at the margin indicates that the system uses scarce resources efficiently. This confirms that Ethiopia has a clear comparative advantage in producing malt barley locally as against importing it from abroad.

In the PAM (Table 5), the value of the output transfers is negative. This indicates that the social revenue is greater than the private revenue, implying

TABLE 4

Summary of malt barley production costs and the resulting output

	Item	Private	Social	Policy distortion
A	Value of all outputs (Birr)	3000	4500	-1500
B	Total input costs (Birr)	1584.79	1708.33	-123.54
B1	Tradable inputs (Birr)	453.06	579.35	-126.29
	Seed (Birr/t)	252.58	378.87	-126.29
	DAP (Birr/t)	179.55	179.55	0
	Herbicide (Birr/t)	20.94	20.94	0
B2	Non-tradable inputs (Birr)	1131.73	1128.98	2.75
	Labour (work days/t)	137.34	134.60	2.75
	Oxen (Birr/t)	154.39	154.39	0
	Value of land (Birr/t)	840.00	840.00	0
C	Profit (Birr)	1415.21	2791.67	-1376.46

SOURCE: Author's computations from survey data.

TABLE 5

A policy analysis matrix computed for malt barley production in Ethiopia

Values	Revenues (Birr)	Costs (Birr)		Profit (Birr)
		Tradable inputs	Domestic factors	
Private	3000	453.06	1131.73	1415.21
Social	4500	579.35	1128.98	2791.67
Effect	-1500	-126.29	2.75	-1376.46

Private profits = 1415.21

Social profits = 2791.67

Output transfers = -1500.00

Tradable input transfers = -126.29

Domestic factor transfers = 2.75

Net transfers = -1376.46

Private cost ratio [C/(A-B)] = 0.44

Domestic resources cost ratio [DRC = G/(E-F)] = 0.29

Net Profit Transfer [L = I+J+K] = -1623.54

Nominal Protection Coefficient [A/E] = 0.67

Effective Protection Coefficient [(A-B)/(E-F)] = 0.65

Profitability Coefficient [D/H] = 0.51

Subsidy Ratio System [L/E] = -0.31

SOURCE: Author's computations from survey data.

that the government is taxing instead of subsidizing malt barley production. In other words, AMF and other local consumers are purchasing malt barley grain at a lower price than that prevailing in international markets. The PAM result also shows that the value of domestic factor transfers is positive. This implies that the government is taxing domestic factors. Since land and labour are the major domestic factors considered in this case, and the government is taxing land, the positive domestic factor transfer is logical. The value of Net transfers, the third line from the bottom of Table 5, indicates the net effect of all policies on domestic malt barley producers. If the overall effect of all policies or market failures. or both, on input and output prices is in favour of the producer in the short run, the value of net transfers will be positive. However, in the case of Ethiopian malt barley producers, the value of net transfers is negative, indicating that the policies or market failures are working to their disadvantage.

The NPC for outputs that measures the impact of commodity-specific price interventions, such as import tariffs, was found to be 0.67, implying that malt barley production is not protected. Rather, an NPC less than one indicates that domestically produced malt barley output is taxed. The EPC was calculated to be 0.65. This again indicates that the value added in malt barley production in terms of social prices is higher than the value added in terms of domestic prices.

The most important measure of comparative advantage is the DRC ratio. The DRC ratio determines whether the production of a specific crop makes efficient use of the domestic resources. The DRC ratio that measures the cost of domestic factors that have to be incurred to obtain one unit of value added in economic terms for malt barley was found to be 0.29, indicating that Ethiopia has a comparative advantage in producing malt barley.

CONCLUSION AND RECOMMENDATIONS

Results of this study indicate that Ethiopia has a comparative advantage in the production of malt barley grain. Malt barley producers are taxed and the policy environment is unfavourable to them. However, the sector is still competitive and it maximizes both private and social profits. This implies that Ethiopia has an attractive sector for malt barley producers. Moreover, the large gap between the demand from domestic breweries and the current level of supply from domestic sources indicates the availability of investment opportunities in value addition by processing malt barley grain to malt for beer production.

The comparative advantage that Ethiopia has in malt barley production implies that this country needs to identify the major constraints hindering the sector and take the following actions:

- Identify suitable agro-ecologies, promote expansion of malt barley production; and create a competitive market environment;
- Identify the major constraints and opportunities in the malt barley market value chain and take corrective actions for the problems in the system; and
- Invite the private sector to enter the malting sector. This triggers competition in the market and encourages the domestic production of malt barley grain.

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Forage crops productivity and integration with barley in Ethiopia

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INTRODUCTION

The highland areas of Ethiopia (>1500 masl) account for about 40% of the country's total area and support about 80% of the total cattle and human population. The low productivity of crops and livestock in the highlands is mainly attributed to natural resources degradation, largely due to soil erosion and overgrazing, poor soil fertility and recurrent droughts. Though the livestock population is the highest in Africa, productivity is extremely low, primarily due to lack of adequate feed. The increased human population and expansion of cropping lands results in shrinking of grazing lands, and hence more grazing pressure. This contributes to the overall degradation of the natural resources base, which consequently damages the environment. Farmers in these areas have traditionally usd fallowing and other practices to improve soil fertility.

In high altitude areas (>2400 masl), where barley is the dominant crop, the challenges are more critical. Soil fertility is extremely poor and feed shortage is critical, especially during cropping seasons. Despite that, the role of livestock is also increasing. In these areas the major livestock feed sources are crop residues and natural and aftermath grazing lands. Natural pastures that provide the bulk of ruminant feed are constantly depleting, and average annual productivity rarely exceeds 1.5–2.5 t/ha dry matter under a continuous communal grazing system (HARC, 2000). At the same time, crop residues as livestock feed can not meet the nutritional requirements of the animals, due mainly to low protein and high fibre contents. Hence, the need to increase the supply and quality of feed resources is crucial.

There are some options that could possibly be used in order to achieve good results from these interventions. These include the more efficient use of the already available feed and other resources, integrating forage and crop production by targeting increased supply of feed without any significant impact on the main crop, and maintaining output while improving the amount and quality of crop residues through appropriate selection of crop varieties and better management of the residues after harvest. This paper reviews some of the achievements made so far in the screening of forage crops and integrating forage and cereal (barley) production methods in the cooler central highlands of Ethiopia.

SCREENING OF FORAGE CROPS TO FIT INTO BARLEY PRODUCTION SYSTEMS

In the cooler highlands there are few well adapted and productive forage species and varieties available in comparison with the mid- and low-altitude areas. Productive perennial legumes are very limited, except a few species like *Lotus*. Among annual legumes, vetches and clovers perform well and are adapted to the cooler highlands. *Avena sativa* (oats) is an annual fodder plant widely grown as fodder in this ecology and its production practices are well established. Perennial grasses are, however, comparatively less important. Other forage crops that perform well in the cool highlands include the root crop fodder beet, and the multipurpose tree tagasaste.

Due to critical shortage of cropping lands there are only few farmers who allocate land for forage cultivation. Therefore, in addition to the conventional forage production practices, growing forage crops in integration with food crops is a suitable option. This requires screening and evaluating forage crops with desirable features and growth characteristics that best fit or are compatible with the specific feature of food crops in terms of competition for nutrients and light, plant height, canopy, growth habit, days to maturity or forage harvesting.

Screening of forage crops based on the above desired features has been conducted in the various agro-ecologies with highland soil types, seasons and production conditions. More than 40 annual and perennial forage legume species of local and exotic origin have been tested on-farm in the different areas in the highlands, including Adaberga, Menagesha Sellalie, Altufa, Tikur Inchini and Walmera in the central highlands. Usually, germination was good for the majority of the species, but growth thereafter was stunted and failed to establish. Of all these species, very few established successfully. Most of the forage species failed mainly due to very poor soil fertility, cool air and soil temperature, soil acidity, waterlogging, frost or weed competition. Vetches and *Trifolium* species are better performers (Table 1). Similar results have also been reported for other highland agro-ecologies, including the Sinnana, Adet, Sirinka and Sheno areas (Getnet Assefa *et al*., 2005). Further evaluation of promising species of vetch, clover and oat were also made at accession level.

Most of the oat accessions and Hairy vetch accessions gave very high average yields of 17.3 and 7.1 t/ha dry matter, respectively, but in general their performance was highly variable over locations and seasons. Hence there is a need to carefully identify the most suitable species or variety of forage for different agro-ecologies.

Providing starter fertilizer resulted in better establishment and increased yield and

TABLE 1

Biomass productivity (tonne dry matter per ha) of different forage legumes tested at Menagesha and Adaberga in the central highlands of Ethiopia

Forage species	Location	
	Menagesha	Adaberga
Trifolium tembense	1.99	2.16
T. rueppellianum	1.33	2.68
T. quartinianum	1.76	2.32
T. decorum	2.13	2.30
T. steudeneri	1.59	2.95
Vicia villosa ssp. *dasycarpa* cv. Namoi	3.43	6.29
V. sativa	1.85	3.94
V. atteropurpurea	3.29	4.46
V. dasycarpa Lana	3.11	7.16
V. villosa	1.56	5.58
T. repense	1.67	1.33

SOURCE: HARC, 1997.

TABLE 2

Average dry matter yield (t/ha) of forage crops tested at accession level over three years at Galessa

Forage Crop	Year 1	Year 2	Year 3	Mean
Oat (*Avena sativa*)	16.7	19.3	16.0	17.3
Clover (*Trifolium* spp.)	1.0	0.5	—	0.5
Hairy vetch (*Vicia villosa*)	11.0	0.70	9.60	7.10
Common vetch (*Vicia sativa*)	9.1	1.54	0.51	3.72
Narbon vetch (*Vicia narbonensis*)	5.5	0.58	0.44	2.17

Source: HARC, 2001.

nitrogen fixation, which has a positive effect on the succeeding cereal crop (Table 2). Hence, adequate starter fertilizer is required for better and successful establishments of forage legumes, especially for vetch species on soil with very poor fertility, which is common for most highland soils.

INTEGRATION OF FORAGE CROPS IN BARLEY PRODUCTION

Small-scale farmers in the highlands farming systems of Ethiopia prioritize crop production for their subsistence livelihood. However, livestock production depends entirely on crop residues and available natural grazing areas, which provide pasture low in quantity and poor in quality. This is mainly due to shortage of croplands and the overall socio-economic problems associated with population pressure. Under such critical production constraints and socio-economic conditions, growing forage crops in integration with food crops such as cereals could be a practical means of forage development to considerably improve livestock productivity. The possible alternatives are growing forage crops on fallow land, intercropping or undersowing with cereals, and hedgerow intercropping of browse trees in and around crop fields.

Growing forage crops on fallow lands

Forage legumes could be used as break crops in the crop rotation system and in some cases could be used as a green manure. Many experiments in the highlands of Ethiopia have shown that forage legumes fix a tremendous amount of nitrogen, which could be utilized by subsequent crops (Getnet Assefa, Lulseged Gebrehiwot and Tadesse Tekletsadik, 1991; Haque and Lupwayi, 2000). Moreover they also improve organic matter content and physical structure of the soil. However, their effect is directly related to the biomass productivity of the forage crops and the amount of nitrogen fixed in the first year. In high altitude areas, where barley is the dominant crop, vetches, medics and oat–vetch mixture could be used as break crops.

A study on the effect on the subsequent barley crops of planting forage crops during the fallowing period was conducted in the central highlands. In this study, six forage crops—*Vicia villosa* (hairy vetch), *V. dasycarpa* (woolly pod vetch), *V. sativa* (common vetch), *Trifolium quartinianum*, *T. tembense* and oat–vetch mixture (*Avena sativa*+*V. dasycarpa*) were planted on fallow lands during the fallowing period at Galessa for two cycles. A fallow plot was also left as a control to evaluate its forage productivity and its effect on subsequent barley grain in comparison with the cultivated forage crops. Herbage dry matter yields of the different forage crops and the subsequent barley grain yields are shown in Table 3. In both the forage planting years (forage phases), higher herbage yields were obtained from the oat–vetch mixture. Single species vetches and clovers germinated but generally had poor establishment. Hence, their herbage yields were low in both years. The natural fallow produced a tremendous amount of biomass due to the weedy nature of the crop fields in the area. From this weedy biomass some of the dominant weeds are not edible livestock feed; moreover their contribution to soil improvement is not well known.

During the barley planting phase, plots that were planted to forage crops and the control plot were split into two equal halves and barley was planted with and without application of the recommended fertilizer level (41/46 kg/ha N/P). Barley did not significantly respond to fertilizer application. This might be due to the relatively better soil fertility conditions around Gallessa compared with other barley growing areas. In addition, the effect of fallowing could also contribute to a certain extent. Barley also generally has low response to fertilizer application compared with other cereals. At the same time, in spite of low forage yield of vetch in the preceding year, the vetch plots resulted in better barley grain and straw yield than the natural fallow, clover or oat–vetch mixture plots. Oat–vetch mixture, which gave the highest herbage yield in the forage planting phase, resulted however in lower barley grain and straw yield than the pure legumes or natural fallow.

When forage legumes are grown on fallow lands for seed production or if not harvested at the right time for forage (about 50% flowering), it will usually re-seed and may act as a weed in the following year. Such problems with vetch have been reported by some farmers, particularly those farmers involved with contractual forage seed production by the MoA. An experiment was conducted at 3 locations around Holetta to prove that vetches harvested at optimum forage harvesting stage will not re-seed and cause problems as a weed in the following crops (Table 4).

TABLE 3
Average performance of forage crops on fallow lands in the first year and their effect on the productivity of the subsequent barley crop

Forage crop	1st year forage dry matter yield (t/ha)	2nd year barley grain yield (q/ha)		
		F1	F0	Mean
Vicia villosa	1.84	24.65	19.25	21.95
Vicia dasycarpa	2.01	24.75	21.40	23.10
Vicia sativa	1.23	23.65	20.60	22.10
Trifolium quartinianum	0.40	22.20	18.75	20.50
T. tembense	0.46	19.30	15.25	17.28
Oat-vetch mixture	12.00	20.65	22.65	21.65
Natural fallow (control)	5.10	24.25	24.10	24.18
Mean		22.80	20.30	21.54

NOTES: F1 = with fertilizer; F0 = no added fertilizer. SOURCE: HARC, 2002.

TABLE 4
Planting vetch (*Vicia dasycarpa*) as a precursor crop and its effect as a weed in the following cereal (wheat)

Vetch Harvesting stages(Year 1)	1st year Vetch dry matter yield (t/ha)	Second year (Cereal phase)				
		Emergence	GY	SY	PH	Vetch yield
Full flowering	2.52	4 169 b	29.5 a	3.11 a	97. 8 a	0.04 b
Podding	4.23	4 563 b	28.2 a	3.08 a	97.3 a	0.01 b
Seed maturity	2.77	36 113 a	26.8 a	3.07 a	97.7 a	0.09 a
Mean	3.17	14 948	28.2	3.09	97.6	0.05

NOTES: Means in a column followed by the same letter are not significantly different; 2 nd year vetch dry matter obtained from volunteer plants. Emergence= Seedlings/ha after short rains; GY = grain yield (q/ha); SY = straw yield (t/ha); PH = plant height (cm); Vetch yield = vetch dry matter yield (t/ha). SOURCES: HARC, 2003, 2004.

According to the findings of this experiment, forage vetch when harvested at the right stage (about 50–100% flowering), has a very low, almost insignificant, ability to re-seed and act as a weed in the subsequent crop. However, vetch grown for seed could become a weed (Table 4). Therefore proper management practices or weed control mechanism could be employed, such as hand weeding or use of broadleaf killer herbicides, or the field should be allowed to re-seed and grow for forage so that it would be harvested at the optimum stage before seed shattering occurs in the next season.

Another option for growing forage crops in fallow land is practicing relay cropping, wherein on land planned to be fallowed in the following year perennial forage grasses are intercropped with cereals. After the cereal crops have been harvested, the perennial grasses will continue growing during the fallowing period. This has diverse advantages: primarily, the grasses will grow after crop harvest to produce forage and well established forage will be available during the actual fallowing period. This means that on land planned to be fallowed for one year, the grass established by intercropping will stay on the field for 22–23 months. An experiment in the highlands was conducted where in the first year *Phalaris aquatica*, *Chloris gayana* (Rhodes grass) and *Panicum coloratum* were sown in mixture with barley and as pure stands, with and without fertilizer application (41/46 kg/ha N/P). After harvesting the barley, the grasses were maintained as an improved grass fallow (of 22 months duration). And after that the land was prepared in April and planted with barley to assess the residual effect of the grass fallows on the productivity of the following barley crop.

In the first year the grain produced from plots of pure barley plots and barley plots intercropped with grasses were not significantly different (Table 5). However, dry matter forage yield of grasses was very low when intercropped with barley compared with pure stand grass plots in the establishment year. Fertilizer had a significant effect on both grain and forage yield. Among the grasses, Rhodes was the highest forage yielder in both pure and mixed stands. The performance of the grasses after the barley harvest was in great part determined by the amount and distribution of rainfall, particularly during the short rainy season. In this particular experiment, grass biomass yield was very good in the first year due to high and good distribution of rainfall during both the short and main rain seasons, while in the second year forage yield was very low due to erratic and short rains.

Plots of *Phalaris* and *Panicum* had showed a non-significant influence on grain and straw yield of barley compared with the control (Table 5), whereas barley grain yield from Rhodes plots was significantly lower. Application of fertilizer showed a significant increase in both grain and straw yield of barley. In general *Panicum* and *Phalaris* had a positive effect on the following barley crop. However, their forage yield during the fallowing period was significantly lower than from Rhodes. In particular, *Phalaris* grass was found to be less productive than *Panicum* and Rhodes grass. Nevertheless, the amount of forage obtained during the fallowing period was three to four times greater than that harvested in the traditional fallow. The grass covers protected the soil from erosion during the fallow period, when otherwise it would be bare and highly susceptible to erosion. The results of this experiment strongly justified that one year of fallow should be made if the grasses are established by intercropping from the point of view of acquiring adequate amount of forage and protecting the soil from erosion. The total yield advantage of grasses established in pure stands was not beneficial due to the very short growing period and very slow growth during the establishment period. Hence, if pure stand establishment of forages is required during a one-year fallow, very productive annual forage legumes such as vetch or annual grasses such as oat, or their mixtures, are preferable.

Use of perennial legumes for such integration might be more beneficial as break crops; however, productive perennial legumes for the highlands agro-ecologies are scarce. Grasses have also many and substantial advantageous. They add effective fresh organic matter and nitrogen and can draw up minerals from greater soil depth through deep and extensive root systems. These features of grasses improve soil structure and water economy through aggregate stability and permeability (Boonman, 1993). The risk of erosion is also reduced on lands covered with

TABLE 5
Effects on barley grain and straw yields (t/ha) of different grass species intercropped with barley and grown in pure stands on fallow land for one year

Fertilizer	Treatment	Barley + grass phase (Jun-Dec) (t/ha)			Fallow phase (one year fallow) grass forage yield (t/ha)					Barley phase yield (t/ha)	
		Grain	Straw	H#1 Dec	H#2 Jun	H#3 Aug	H#4 Jan	H#5 Apr	Total	Grain	Straw
F1	Pure barley	1.91	2.04	–	f	f	f	f	–	0.88	1.81
	Phalaris	1.96	2.52	0.16	*	2.15 b	1.05 b	0.12 c	3.48	1.20	2.41
	Rhodes	2.39	2.02	0.50	1.42	4.97 a	2.82	1.19 a	10.9	0.78	2.20
	Panicum	2.06	1.96	0.23	1.29	3.93 a	1.59 ab	0.45 b	7.49	1.22	2.34
F0	Pure barley	1.92	2.43	–	f	f	f	f	–	0.47	1.13 ab
	Phalaris	1.60	1.89	0.03b	*	0.45 b	0.39 b	0.33 b	1.20	0.60	1.23 ab
	Rhodes	1.98	2.07	0.13a	0.76	2.46 a	2.94 a	1.45 a	7.74	0.23	0.6 b
	Panicum	1.99	2.22	0.03b	0.45	2.83 a	1.94 a	0.56 b	5.81	0.54	1.34 a
Mean	F1	2.08	2.14	0.30	1.36	3.68	1.82	0.59	7.75	1.02	2.19
	F0	1.87	2.15	0.06	0.60	1.91	1.76	0.78	5.11	0.46	1.09

Notes: H#1–5 = First to fifth harvest of grasses; * = no harvestable forage yield; f = natural fallow; fertilizer treatments: F1 = 41/46 kg/ha N/P fertilizers for barley, and F0 = zero fertilizer level. Dry matter forage yield means in a column and fertilizer level followed by the same letter are not significantly different. SOURCES: HARC, 2000, 2001.

grasses. The lower fertilizer requirement of crops following grasslands is perhaps the most striking effects of crop-grass rotations on crop yields. Though not large, there is usually little response to N dressing following grassland.

Nitrogen fixation by associative symbiosis between grass and bacteria has been reported for *Azotobacter paspali, Azosprillum brasilense* and *Beijerinka indica* (Dobereiner, Day and Dart, 1972). A review of N fixation in tropical grasses has also been given by Crowder and Chheda (1982), who state that this phenomenon holds tremendous potential and is more likely to occur with tropical grasses due to their C-4 photosynthesis pathway. Moreover, one should consider the overall biological productivity of the land rather than analysing the level and effect of each component *per se*, including a grass pasture phase within the rotation, which is an easier way to replenish the soil with organic matter. Immediate benefits, easier and appropriate options are understandably more convincing, especially to small-scale farmers

Intercropping and undersowing

When cropping lands are critically limited and fallowing is still not an option for soil improvement, intercropping or undersowing of compatible annual forage crops, usually legumes, are an alternative means of forage production. Selected annual forage legumes, including *Vicia villosa*, *V. dasycarpa* and *Trifolium rueppellianum,* were evaluated for their compatibility with barley when intercropped simultaneously or undersown at the first weeding of barley with and without application of fertilizer under farmers' field conditions.

All the legumes established well when they were planted simultaneously with barley. Undersowing forage legumes at first weeding resulted in very poor establishment of all the legumes. This is mainly due to very cool and wet soil conditions, which hinder germination, coupled with severe competition from weeds after germination, combining to depress forage species establishment. Application of fertilizer has improved both grain yield of barley and forage yield of the legumes. Growth of vetches, particularly, on plots sown simultaneously with barley has tremendously improved by application of fertilizer, which resulted in depression of the barley performance. At the same time, *T. rueppellianum* did not respond much to fertilizer and had a depressing effect on the performance of barley.

At Adaberga, forage legumes, especially vetches, dominated the barley, resulting in poor compatibility and significant reduction in barley grain yield (Table 6). However, at Menagesha, reasonable forage yield was obtained without any significant reduction or other influence on barley, even under fertilized conditions. This is due to less vigorous growth of vetches. The straw yield showed a positive correlation to the grain yield. In both locations, simultaneous planting of the legumes showed better establishment and forage yield. Hence, this practice seems more advantageous in terms of better establishment and ease of planting than undersowing at first weeding. Despite that, in areas like Adaberga, specially on relatively fertile soils, where vetches depressed barley growth when planted simultaneously, other less vigorous vetch or forage legume species should be identified and used.

TABLE 6

Effect on grain and forage yield of intercropping annual forage legumes simultaneously or by undersowing at first weeding of barley

Treatment	Forage legume	Barley grain (q/ha)				Forage (t/ha dry matter)			
		Adaberga		Menagesha		Adaberga		Menagesha	
		F1	F0	F1	F0	F1	F0	F1	F0
Simultaneous	*V. dasycarpa*	12.07	7.31	14.87	11.00	3.72	2.73	1.55	1.28
	V. villosa	11.17	9.01	14.77	9.71	4.26	2.68	2.28	1.43
	T. rueppelianum	22.88	11.32	12.78	9.32	0.45	0.40	–	–
	Mean	15.37	9.21	14.14	10.01	2.81	1.94	1.92	1.36
At first weeding	*V. dasycarpa*	18.63	12.44	15.34	10.86	0.48	0.04	0.51	0.22
	V. villosa	19.39	9.45	15.94	8.45	0.30	0.10	0.42	0.30
	T. rueppelianum	17.55	9.30	16.66	9.38	0.16	0.14	–	–
	Pure barley	20.96	7.61	15.81	9.21	–	–	–	–
	Mean	19.13	9.70	15.94	9.48	0.31	0.09	0.47	0.26

NOTES: F1 = 41/46 kg/ha N/P fertilizers; F0 = zero fertilizer. SOURCE: HARC, 1998.

Parallel to the intercropping, the performance of the forage legumes when planted in pure stands were evaluated (Table 7). It was observed that forage legumes sown in pure stands on relatively fertile soils and with the application of fertilizer (18/46 kg/ha N/P) performed remarkably well. This suggests that if forage crops were cultivated conventionally under good management practice their potential and utilization will be feasible, especially for farmers with productive crossbred dairy animals, which have better returns.

It is known that barley varieties are different in their height, days to maturity, biomass yield and growth rate. These features have a lot of impact on compatibility when intercropped with different forage legumes. Intercropping of three varieties of barley (HB 42, 'Shege' and the local 'Baleme') and two vetch species (*Vicia villosa* and *V. narbonensis*) were tested on farmer's fields at four locations for two years to evaluate the performance of the barley varieties when intercropped or undersown with different forage legumes. The experiments were carried out with and without fertilizer application at Addisalem, Menagesha, Robegebya and Wolmera.

Initial establishment of the barley and vetches was good on all the test sites. The performance of the barley is given in Table 8 and that of forage legumes in Table 9. Location had a remarkable influence on barley grain and forage yield. Barley performance was very good at Adaberga and Robegebya. Forage legumes produced better at Adaberga compared with other locations. Fertilizer application generally has improved barley grain and straw yield, and increased the average dry matter forage yield of the legumes.

The forage legume *Vicia villosa* performed better than *V. narbonensis.*

TABLE 7

Performance (t/ha dry matter) of forage legumes sown in pure stands with and without fertilizer application at Menagesha and Adaberga

Crop	Menagesha		Adaberga	
	F1	F0	F1	F0
Vicia villosa	5.10	3.99	10.71	6.33
V. dasycarpa	4.93	4.60	8.16	5.74
Trifolium rueppellianum	*	*	3.40	1.00
Pure barley (q/ha)	20.4	12.5	16.0	4.55

NOTES: * = no harvestable yield; F1 = 41/46 kg/ha N/P fertilizer; F0 = zero fertilizer. SOURCE: HARC, 1998.

TABLE 8

Effect of fertilizer and intercropping (vetch species and barley varieties) on barley grain yield (q/ha) at Addisalem, Menagesha, Robegebya and Walmera

Barley – Forage legume	Addisalem		Menagesha		Robegebya		Wolmera		Mean	
	F1	F0	F1	F0	F1	F0	F1	F0	F1	F0
HB 42 + *V. villosa*	22.2	12.4	17.1	4.4	21.9	15.3	17.1	7.8	19.6	10.0
Shege + *V. villosa*	22.2	11.7	11.9	5.5	21.9	13.0	15.0	4.6	17.8	8.7
Balme + *V. villosa*	22.1	10.9	13.0	5.4	24.2	16.4	16.2	5.7	18.9	9.6
HB 42 + *V. narbonenesis*	26.0	18.6	18.3	8.2	25.5	18.6	16.0	6.7	21.5	13.0
Shege + *V. narbonenesis*	24.2	16.0	17.8	2.4	22.2	15.4	14.3	6.8	19.6	10.1
Balme + *V. narbonenesis*	21.8	15.0	13.7	6.5	23.9	19.7	19.0	8.4	19.6	12.4
HB 42	24.6	18.3	17.1	5.6	23.4	13.4	17.8	5.3	20.7	10.6
Shege	24.5	14.7	16.7	5.8	20.3	17.9	13.4	7.5	18.7	11.5
Balme	24.3	16.3	12.5	5.8	24.8	18.0	19.6	8.0	20.3	12.0

NOTES: F1 = 41/46 kg/ha N/P fertilizer; F0 = zero fertilizer. SOURCE: HARC, 2004.

TABLE 9

Effect of fertilizer and intercropping (vetch species and barley varieties) on dry matter forage yield (t/ha) at Addisalem, Menagesha, Robegebya and Wolmera

Barley + Forage legume	Addisalem		Menagesha		Robegebya		Wolmera		Mean	
	F1	F0	F1	F0	F1	F0	F1	F0	F1	F0
HB 42 + *V. villosa*	3.11	2.13	1.06	0.83	1.36	0.97	1.22	1.52	1.69	1.36
Shege + *V. villosa*	2.52	2.69	1.62	0.82	1.36	1.44	1.41	1.77	1.73	1.68
Balme + *V. villosa*	1.29	2.57	0.95	0.68	0.69	0.99	0.63	1.48	0.89	1.43
HB 42 + *V. narbonenesis*	0.01	0.14	0.11	0.49	0.14	0.41	0.17	0.77	0.11	0.45
Shege + *V. narbonenesis*	0.05	0.05	0.08	0.36	0.13	0.33	0.15	0.55	0.10	0.32
Balme + *V. narbonenesis*	0.03	0.04	0.09	0.30	0.16	0.18	0.14	0.96	0.11	0.37

NOTES: F1 = 41/46 kg/ha N/P fertilizer; F0 = zero fertilizer. SOURCE: HARC, 2004.

It had very good compatibility with 'Baleme', and gave a reasonable high forage yield, while it depressed the performance of HB 42 and 'Shege'. This might be due to the vigorous early growth of 'Baleme', which limited the vigorous growth of vetch and competed very well. Without the application of fertilizer the vetches depressed the performance of 'Baleme'.

HB 42 gave higher grain and straw yield, followed by 'Baleme' and 'Shege' when grown both with and without the application of fertilizer. With the application of fertilizer, *Vicia villosa* was better in compatibility with HB 42 and 'Shege'.

From the above results it is clearly shown that compatibility of forage crops with barley during intercropping and undersowing is significantly affected by location, application of fertilizer, varieties of the barley used and the species of the forage legume integrated. Therefore, for successful integration of barley and forage legumes one has to carefully consider these factors and their interplay

Hedgerow intercropping

Tree legumes are important source of high biomass, which could serve as good forage for livestock, as mulch and other purposes. There are only a few tree legumes tested and found productive in the cool highlands in Ethiopia. Kindu Mekonnen, Glatzel and Sieghardt (2008) have reported that tagasaste from the exotic and species like *Dombeya torrida, Hagenia abyssinica* and *Buddleja polystachya* from the native multipurpose trees are performing very well in the cool highlands such as Galessa. Tagasaste is a productive and adapted tree legume in many other cool highland agro-ecologies.

Among other strategies, hedgerow intercropping with cereals such as barley is a suitable production option. Encouraging results has been found in an experiment on tagasaste hedgerow intercropping with barley at Holetta. In this study, barley and tagasaste seedlings were planted simultaneously in the first year. Tagasaste seedlings were planted in rows 4 m apart with 50 cm spacing between plants. After harvesting the barley, tagasaste seedlings continued to grow and were pruned at 50 cm height above ground twice a year, in the early dry season and in late April for land preparation for intercropping barley.

In the first year, barley performance was not affected by tagasaste hedgerows compared with the barley without hedgerows, with average grain yields of 3.39 t/ha when planted with hedgerows and 3.20 t/ha without, and respective straw yields of 3.69 t/ha and 3.45 t/ha (Table 10). The barley crop, however, influenced the growth of tagasaste seedlings, where survival rate was about 72%. Normally when tagasaste seedlings are transplanted in pure stands the survival rate is between 80 and 85% under Ethiopian highland condition (Getnet Assefa, 2007). To improve survival rate and reduce the depression effect of the barley crop, transplanting of tagasaste seedlings could be made some weeks before the barley sowing date rather than simultaneously planting in the first year.

In the second and third years, barley was intercropped in the same field where the hedgerows were established. At the beginning of land preparation the hedgerows were pruned at 50 cm height for ease of land preparation and to avoid shading effects. As shown in Table 11, during the second and third year hedgerows of tagasaste did not affect barley grain and straw yield. The results showed that the effect of tagasaste hedges on the grain, straw and height of sole barley was not significant. However application of fertilizer in plots both with hedges and without hedges gave significantly higher grain and straw yield. The general trend showed that regardless of the hedges, higher yield was obtained for plots supplied with fertilizer. The presence of hedges at 4 m interval did not significantly reduce the barley grain yield. However it gave additional herbage yield for dry season feed. Hedges in barley plots with fertilizer had more edible matter (leaf and edible branch) than the unfertilized plots.

TABLE 10

Effect of tagasaste hedgerows and fertilizer on barley, height, grain and straw yield in the establishment year when tagasaste seedlings and barley were cropped simultaneously

Treatments	Height (cm)	Barley grain (q/ha)	Straw (t/ha)
Barley + No Fertilizer	121.8	18.77	4.70
Barley + Fertilizer	130.7	23.03	6.24
Barley + tagasaste hedge + No Fertilizer	115.9	18.45	5.19
Barley + tagasaste hedge + Fertilizer	120.3	22.44	6.57
Mean	122.2	20.67	5.68

NOTES: 1 quintal (q) = 100 kg. SOURCE: HARC, 1998.

Tables 11 and 12 show the performance of tagasaste in the first and second harvest. Average tagasaste height at harvest was shorter in the second harvest than the first, but the biomass yield was significantly higher. This is attributed to increased branch numbers during the re-growth after the first harvest. The effect of fertilizer on herbage yield was not significant, but fertilizer has a tendency to decrease leafiness and increase branch and stem proportions. The total biomass yield produced per hectare is reasonably high for such a reduced plant density, which means productivity per plant is high. Generally tagasaste hedgerow intercropping of barley is an attractive strategy to improve barley productivity, maintain soil fertility, prevent soil erosion (particularly in undulating and mountain areas like that of the barley growing areas of Ethiopia), produce high quality forage for livestock and improve the overall efficiency of land utilization.

TABLE 11

Performance of tagasaste when planted in alleys at 4-m interval with barley, when the barley is planted with and without fertilizer application in the first harvest

Parameter	Hedgerows in barley	
	F1	F0
Height (cm)	161.7	163.7
Biomass yield (t/ha dry matter)	0.34	0.40
Proportion of fractions in dry matter (%)		
Leaf	53.8	53.2
Edible branch	29.5	24.5
Stem	16.7	22.3

NOTES: F1 = with fertilizer at rate 41/46 kg/ha N/P); F0 = without fertilizer. SOURCE: HARC, 1998.

TABLE 12

Performance of tagasaste hedges at 4-m interval, when the barley was sown with and without fertilizer application during the second harvest

Parameters	Hedgerows in barley	
	F1	F0
Height (cm)	147.3	126.5
Biomass yield (dry matter t/ha)	0.76	0.68
Proportion of fractions in dry matter (%)		
Leaf	48.71	51.85
Edible branch	27.79	26.08
Stem	23.50	22.07

NOTES: F1 = with fertilizer at rate 41/46 kg/ha N/P); F0 = without fertilizer. SOURCE: HARC, 1998.

CONCLUSION

The cooler highlands of Ethiopia are areas faced with various challenges for both crop and livestock production. Barley is the dominant crop, while livestock is an integral part of the system. Increased agricultural productivity is obtained in a better way if the different components of the production are integrated. Forage crops have many advantages in this scenario: they can improve the soil fertility to increase crop productivity and maintain the natural resources, and, moreover, they could be used as a source of livestock feed. In the cooler highlands, several forage crops have been identified for their adaptation, productivity and potential for integration. Some preliminary results have also suggested the possibilities and applicability of different methods and strategies of integration. These results should be strengthened and should be promoted to users to bring about the expected changes in agricultural productivity in the farming system to improve the livelihood of farmers and protect the natural resources for sustainable use.

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Production and nutritional qualities of barley straw in Ethiopia

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INTRODUCTION

Animal agriculture is an integral component of almost all farming systems in Ethiopia. In the highlands, livestock serve as sources of food, employment opportunity, income, draft power and fertilizer, while in the lowlands livestock form the basis of the livelihood for the pastoralist community. These various linkages form the economic and social basis of agriculture and thus have contributed to poverty alleviation and food security. The major feed source, mainly during the dry season, has been residues from different crops. Annually available crops residues in Ethiopia have so far been estimated based on harvest indices of source crops. Actual figure based on farmers circumstances are lacking. Crop residue productivity and its quality has been affected by a number of factors, which include species of the crop, variety, the production location and prevailing climatic condition in the growing area, different agronomic practices, post-harvest management and storage practices.

Crop residues are in general characterized by low crude protein, poor digestibility, high cell wall and cell wall constituents, and are deficient in sodium, phosphorus, copper and zinc. The nutritional qualities of these widely and cheaply available feed resources are well characterized. Moreover, various strategies, such as chemical pre-treatment, use of different supplements and physical processing, have been identified to be of considerable advantage in improving the feeding value of these fibrous feeds. In spite of its increasing importance, due mainly to the declining of natural grazing lands and productivity, the different strategies of straw improvement are not widely utilized. There is also a need to work with crop breeders and agronomists to develop varieties and production practices that maximize otherwise compromised grain and crop residue yields.

Quite substantial amount of by-products of barley are annually produced in Ethiopia and have provided a major feed resource in the mixed crop livestock system of the highlands. Better utilization can be realized through innovations in the crop residue delivery system, which involves efforts by the research and extension systems and by farmers. This paper presents research results on crop residue productivity, utilization and nutritional characteristics, and also assesses the role of crop management practices and variety differences on the qualities and yield of barley straw in the Ethiopian highlands.

BARLEY STRAW YIELD AND BREWERS BY-PRODUCTS PRODUCTION IN ETHIOPIA

Estimates of availability of basal feed in Ethiopia suggest a total of 33.4 million tonne dry matter (dry matter) basal diet is annually produced, of which 57% is crop residues. Total feed/TLU (tropical livestock unit) varies from region to region, with an average of 0.68 t/TLU. The estimates could be a fair approximation of the reality that the available feed is only 40–60% of the annual feed requirement (Table 1) (CSA, 2003).

The availability of barley straw residue varies from region to region, and farmers also have alternative uses for crop residues. Field losses and alternative uses of barley residue accounts for about 6% of total straw produced annually in the country, and the rest is available as livestock feed. About 93% of the total barley straw is produced in the Oromia, Amhara and SNNPR regional States (Table 1) and these regions account for 90% of the total ruminant population in the country. The available barley straw per ruminant population per annum varies from 2.2 kg in Somali region to 38 kg in the Amhara regional state, with a mean of 29 kg/TLU per annum. In addition, a total of 75 600 t of by-product from malt barley grain is annually produced in Ethiopia, with the largest share coming from Meta Abo brewery, followed by Bedele brewery (Table 2)

TABLE 1
Regional availability of barely straw in relation to livestock population in major regions of Ethiopia

Region	Available straw (10^3 t)	Livestock population (106)	Residue (kg) per TLU per annum
Tigray	71	2.46	28.86
Amhara	375	9.78	38.34
Oromia	573	15.79	36.29
Somali	7	3.17	2.20
Beneshangul Gumuz	1	0.27	3.70
S.N.N.P.R	91	7.28	12.50
Total	**1118**	**38.75**	**28.85**

NOTES: SNNPR: Southern nations and nationalities people's region; TLU = Tropical livestock unit.
SOURCE: CSA, 2003.

TABLE 2
Estimated availability of barley brewers grain

Factory	Location	Annual production (t/year)
St. George	Addis Ababa	13 300
Meta	Oromia	31 500
Bedele	Oromia	17 500
Harar	Harari	13 300
Total		**75 600**

SOURCE: OESPO, 1999.

CHEMICAL COMPOSITION OF BARLEY STRAW

The chemical composition and nutritive value of barley straw grown under Ethiopian condition is close to teff straw and native hay (Table 3). Crude protein (CP) and *in vitro* dry matter digestibility (IVDMD) content of barley straw are higher than that of wheat and teff straw, while wheat and teff straw fibre contents are lower than most of the cereal residues. Generally crop residues are characterized by low CP and ether extract (EE), but high cell wall and cell wall constituents content. Their CP content is lower than the threshold required to maintain an animal on

TABLE 3

Chemical composition of barley straw and other dry roughages (% DM basis)

Feed	DM	Ash	EE	CP	NDF	ADF	Lignin	IVOMD	ME (Mj/kg)
Teff straw	92.4	7.1	1.7	6.0	74.5	42.4	7.7	53.20	8.35
Wheat straw	92.9	7.2	1.6	3.9	77.2	48.2	7.9	45.50	7.14
Barley straw	93.1	8.3	2.3	6.2	73.2	45.0	6.3	48.03	7.60
Native hay	92.2	9.5	1.5	6.6	73.8	45.5	8.3	54.50	8.60

NOTES: DM = dry matter; EE = ether extract; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; IVOMD = in vitro organic matter digestibility; ME = metabolizable energy. SOURCE: Seyoum Bediye and Zinash Sileshi, 1989.

a positive N balance, and its fibre content is also higher than the value suggested as limiting intake by animals. However, CP content of barley straw is higher than most of the cereal residues and closer to that of native hay (Table 3).

Of the major ash fractions, silica is the main component. *In vitro* digestibility of barley straw is higher than most of the crop residues, as indicated in Table 3, and the fibre content is lower than most other cereal crop residues. In a chemical examination of the dry matter, it was shown to have about 400–450 g/kg dry matter of cellulose, 300–500 g/kg dry matter of hemi-cellulose and 60–120 g/kg dry matter of lignin (Seyoum Bediye *et al*., 1998). This is an indication that barley straw has relatively better nutritional value than most of the crop residues.

Preston and Leng (1987) reported that straws from various species of grain crops appear to be highly variable in *in vitro* digestibility. In general, the organic matter digestibility (OMD) and estimated metabolizable energy value of barley straw is marginal, which makes barley straw a low quality basal feed. Apart from the low digestibility, a major disadvantage is the low intake obtained when barley straw is given to ruminant animals. According to Seyoum Bediye *et al*. (1998), a cow will consume up to 10 kg of medium quality grass hay, whereas it will consume only about 5 kg of barley straw. Furthermore, voluntary intake of cereal crop residues generally varies from 1.63% to 2.5% and from 1.87% to 1.91% of live weight for small ruminants and large ruminants respectively. It is therefore necessary to consider some sort of nutritional manipulation for barley-straw-based feeding systems.

VARIETAL DIFFERENCES IN QUALITY AND MORPHOLOGICAL CHARACTERISTICS OF BARLEY STRAW

Feeding value of barley straw is influenced by genetics and the environment, and their interaction. Among botanical fractions, the leaf component accounts for the major part (42%) and this fraction has the best nutritive value compared with other fractions (Table 4).

TABLE 4

Proportion of morphological fractions and their respective digestibility for barley and teff straw grown in the highlands of Ethiopia

Straw	Fraction	Proportion (%)	IVOMD (%)
Barley	Leaf	42.01	55.8
	Internode	39.90	29.6
	Node	4.80	49.7
	Chaff	13.20	57.4
Teff	Stem	42.00	29.0
	Leaf	27.00	49.2
	Panicle	20.00	40.9
	Chaff	11.00	61.9

NOTES: IVOMD = *in vitro* organic matter digestibility.
SOURCE: Seyoum Bediye, Zinash Sileshi and Tesfaye Mengiste, 1995.

TABLE 5

Variation in nutritional quality of straw of different barley varieties

Variety	NDF		IVDMD	
	Holetta	Sheno	Holetta	Sheno
HB 100	69.5	67.1	47.1	50.3
HB 99	71.6	65.7	44.3	49.9
Ardu-12-9C	72.8	66.6	44.6	48.2
HB 32	70.7	69.5	47.0	47.9
HB 42	68.1	67.1	46.7	50.3
Local	68.1	71.0	48.0	48.8
Mean	70.1	67.9	46.3	48.8

NOTES: NDF = neutral-detergent fibre; IVDMD = *in vitro* dry matter digestibility. SOURCE: IAR, 1991.

Studies on the morphological fractions of barley straw showed that leaf has the highest proportion (42%), followed by internodes (40%). Among the fractions, the leaf part has highest digestibility (55.8%). Compared with teff straw the leaf portion of barley straw has much higher digestibility (Table 4).

There is variation in nutritional quality between different varieties of barley straw. Research findings at Holetta showed that the variation was in the range of 44.3 to 48.0 and 68.1 to 72.8 for IVDMD and neutral-detergent fibre (NDF), respectively. Similarly, at Sheno, the variation among the different barley varieties for IVDMD and NDF was in the range of 47.9 to 50.3 and 65.7 to 71.0 respectively. Among the barley varieties studied at Holetta, a local variety has shown better nutritional value in terms of its digestibility and fibre content, whereas the improved cultivar HB 42 has shown better nutritional value based on study results obtained at Sheno (Table 5).

EFFECT OF MANAGEMENT AND LOCATION ON QUALITY AND YIELD OF BARLEY STRAW

Application of nitrogen and phosphorus fertilizers has increased straw biomass yield, but no quality difference observed due to application of fertilizer. Late maturing barley variety straw has shown higher straw yield and CP content than early maturing varieties, although early maturing varieties had relatively better digestibility than late setting varieties. Application of fertilizer has increased straw biomass yield, but with no difference in quality of straw due to fertilizer application (Table 6).

The major influence of barley production management is on straw yield. Moreover, location has a substantial effect on straw quality. From Table 7 it can be seen that the CP perentage ranges between 3.2 (Altufa) and 4.2 (Robegebeya), while ranging between 43.2 (Altufa) and 48.2 (Robegebeya) for IVOMD. Quality variations were also observed to be mere reflections of other variants (variety, soil type, climate, harvesting stage, etc.) rather than fertilizer application, under the local test site conditions in the Ethiopian highlands.

TABLE 6

Effect of fertilizer application on yield and quality of barley straw of different varieties

Variety type	No. of cultivars	Fertilizer	Straw yield (t/ha dry matter)		CP%		IVOMD%	
			Mean	Range	Mean	Range	Mean	Range
Late maturing	6	F0	2.48	0.34–5.6	3.70	2.6–5.1	45.73	40.4–50.1
		F1	4.95	0.55–9.7	3.80	2.8–5.3	44.60	40.2–49.4
Early maturing	6	F0	0.63	0.15–1.3	3.26	2.9–3.5	46.68	42.4–48.9
		F1	1.14	0.42–2.0	3.50	3.0–3.6	46.78	42.4–49.8

NOTES: F1 = 41/46 kg/ha N/P; F0 = without fertilizer; CP = crude protein; IVOMD = *in vitro* organic matter digestibility. SOURCE: Seyoum Bediye, Zinash Sileshi and Tesfaye Mengiste, 1995.

TABLE 7

Influence of location and fertilizer application on barley straw yield and quality

Location	CP (%)		IVOMD (%)		Straw Yield (t/ha dry matter)	
	F1	F0	F1	F0	F1	F0
Robegebeya	4.20	4.18	48.23	46.91	0.64	1.10
Altufa	3.20	3.42	43.23	42.50	4.33	8.80
Adaberga	3.90	3.95	*	*	1.30	3.16
Degem	3.26	2.84	46.38	45.78	0.63	1.14
Mean	3.64	3.59	45.94	45.06	1.72	3.55

Notes: * = not analysed; F1 = 41/46 kg/ha N/P_2O_5; F0 = without fertilizer; CP = crude protein; IVOMD = *in vitro* organic matter digestibility. SOURCE: Seyoum Bediye, Zinash Sileshi and Tesfaye Mengiste, 1995.

TABLE 8

Average barley grain, straw yield, harvest indices and quality (crude fibre (CF) and CP) of barley straw in the highlands of Ethiopia

Variety (type)	Grain yield (kg/ha)	Residue (kg/ha)	Total (kg/ha)	Residue-to-grain ratio	Harvest index (%)	CP (%)	CF (%)
Improved (food)	2737	7004	9741	2.6	28	4.40	36.6
Improved (malt)	2918	5972	8890	2.0	33	5.70	36.2
Aruss	3180	5900	9080	1.9	35	4.30	39.0
Local	1982	4665	6647	2.4	30	5.76	35.0

NOTES: Improved food varieties were IAR 485 & A-HOR; improved malt varieties were HB 37, HB 42 & Holker; Harvest index = Grain yield (kg)/Total aboveground biomass weight (kg); CP = crude protein; CF = crude fibre. SOURCE: Daniel, 1987.

Yields of grain and residues are generally highly correlated, as high grain yields are the results of high vegetative growth, which is associated with high production of crop residues. The straws-to-grain ratio for barley is from 1.9 to 2.6. As shown in Table 8, there is considerable variation in crude protein and crude fibre content among straw from different varieties of barley. However, there were no positive correlations between yield and quality parameters of barley straw.

As more and more land is put under crop production, livestock feed becomes scarce and crop residues, particularly cereal straw, remain the major feed source for the animals during the dry period of the year (which spans November through to May). Some estimates indicate that crop residues provide 40–50% of the annual livestock feed requirement.

STRATEGIES TO ENHANCE UTILIZATION OF BARLEY STRAW AS LIVESTOCK FEED

The use of fertilizer-grade urea to treat straw is widespread in many countries. The benefits of urea treatment are to increase digestibility, voluntary intake, protein content and animal performance. Changes in chemical composition in response to urea treatment are variable, depending on the composition of the of crop residue. CP content of crop residue could be increased 2.5 fold (from 4% to 14%) in response to urea treatment, and improvement in voluntary intake is about 25% (from 78 g to 98 g per kg metabolic body weight). Similarly, treatment with urea has been shown to increase digestibility of cereal straw on average by around

TABLE 9

Influence of urea treatment on digestibility of crop residues (percentage dry matter basis)

Residue	Untreated	Treated	Increase (%)	Source
Barley straw	48.0	58.0	10.0	Seyoum *et al*., 2004
Barley straw	46.4	59.4	13.0	Rehrhie Mesfin, 2001.
Teff straw	45.0	55.0	10.0	Seyoum *et al*., 2004
Wheat straw	38.0	48.0	10.0	Seyoum *et al*., 2004
Average	44.35	55.1	10.8	

10.8%. This result has been tested in the central highlands of Ethiopia (Tables 9 and 10) and has proven to be effective, and can be utilized by small-scale farmers.

Quite substantial improvement in animal performance has also been realized in feeding trials conducted in the highlands of Ethiopia, especially if the treated crop residue is supplemented by appropriate supplements (Table 11). Results from experiments in Bangladesh and Sri Lanka have been reviewed by Preston and Leng (1984) and their review indicates that a treated residue can support a daily gain of 500 g in young growing cattle, given a small amount of protein supplement.

Decision regarding use of straw ammoniation, supplementation or combination of both is governed by the input prices relative to each other, to labour cost, the animals' productive state and production level, and price for animal products. In general, as Capper, Thomson and Herbert (1988) summarized, the response of straw to chemical treatment processes to improve its feeding value is variable. The proportions of plant parts in the straw may cause some of this variation. It appears that, in barley straw, leaf-sheath material responds to treatment more than either leaf blade or stem. Also, consideration of the genetic origin and environmental condition during the growing phase of the crops from which the straw is derived could enhance the efficiency of chemical treatment.

BIOLOGICAL AND ECONOMIC RESPONSE OF BARLEY STRAW TO UREA TREATMENT

According to Tesfaye Alemu and Chairatanayuth (2007), more than 98% of barley straw is collected and stored for the dry season. Out of this, 97% of the barley straw is stored in an open area, whereas the rest is stored under shade.

Treatment of crop residue has been shown to upgrade their nutritional worth in terms of intake, N-content and digestibility, and may facilitate their greater contribution to the diet of growing heifers at the expense of concentrates. Urea-treated barley straw had greater crude protein (98 vs 43 g/kg dry matter) and *in vitro* digestibility (53.2 vs 44.9%) than untreated barley straw (Hadjipanayiotou *et al*., 1997). Urea treatment of straw resulted not only in saving in the amount of the expensive protein supplement incorporated into the concentrate mixture, but also in increasing straw intake, leading to enhanced growth rates with smaller quantities of concentrates and better use of straw offered.

Urea-treated barley straw can replace barley hay in diets of fast growing (750–900 g/head/day) Friesian heifers (Hadjipanayiotou *et al*., 1997). The same authors also reported that in intensive dairy production systems where growing females are fed to reach mating weight of 330–350 kg body weight at the age of 14–16 months,

TABLE 10

Response of cereal crop residue to urea treatment under Ethiopian conditions

Type of crop straw	Crude protein (%)		IVDOMD (%)	
	Untreated	Treated	Untreated	Treated
Barley straw	3.68	6.98	48.0	58.0
Teff straw	3.07	7.65	45.0	55.0
Wheat straw	2.41	6.25	38.0	48.0
Mean	3.05	7.29	45.33	53.66

NOTES: IVDOMD = *in vitro* digestible organic matter in the dry matter.
SOURCE: Seyoum Bediye,2004.

TABLE 11

Biological and economic responses of barley straw in the diet of lactating crossbred cows at Holetta

Parameter	Urea-treated barley straw	Urea-treated teff straw	Native hay
Milk yield (L/day)	6.75	7.17	6.82
Milk fat (%)	4.54	4.42	4.23
Milk protein (%)	3.35	3.36	3.47
Benefit to cost ratio	1.89	1.95	1.78
Marginal rate of return (%)	–	3:1	–

SOURCE: Rehrahie Mesfin, 2001..

feeding of ammoniated straw will make this possible, as judged by the enhanced growth rate. Urea treatment of straw resulted in increased nitrogen content and digestibility. The amount of N that was retained on the straw ranged from 39.1% to 59.5% of that applied (1.8 g/100 g dry matter), and was very close to previously reported values (Hadjipanayiotou, 1982; Lawlor and O'Shea, 1979). Similarly, the increase from 6 to 14.6 percentage units) in *in vitro* organic matter digestibility obtained as a result of treatment was almost identical to previously reported values (Hadjipanayiotou *et al.*, 1997).

Urea treatment of straw resulted not only in saving the amount of the expensive protein supplement incorporated into the concentrate mixture, but also increased straw intake, leading to enhanced growth rates with less quantities of concentrate and better use of straw offered. Ammoniation of crop residues using gaseous ammonia or through ensiling (10–30 days) with urea (4–5%) has been found applicable for practical use at present. Preston and Leng (1987) reported that this practice increases digestibility by 5–10 percentage units, improved the nitrogen content of the straw, and enhanced acceptability and voluntary intake of the treated straw by 25–50% compared with untreated straw.

Another option for enhancing utilization of barley crop residues is supplementation with agro-industrial by-products and leguminous forages. Most of the oil seed plants such as noug (*Guizotia abyssinica* Cass), cotton, linseed, groundnut, rapeseed, sesame and sunflower are widely grown in Ethiopia. The cakes of these crops are widely used as a protein supplement with low quality hays and crop residues.

Though animal performance on supplemented crop residue like barley-straw-based diets vary considerably depending on the type and level of supplements available, data on responses to supplementation of crop-residue-based diets suggests an average live weight gain of 555 g/day (ranging from 400 to 700 g/day) for indigenous cattle and 897 g/day (ranging from 820 to 920 g/day) for crossbred cattle. Supplemented barley straw residue diets can support a mean live weight gain of about 550 g/day in local animals. Growth performance for crossbred cattle on similar diets supports a live weight gain of 900 g/day.

In Ethiopia, huge amount of molasses is produced annually. Molasses is used as a palatable carrier for urea and minerals for improving the utilization of crop residues. Molasses–urea mixture is used also as the basis of a supplement with crop residues for routine feeding during the dry season.

Leguminous forage crops, which are rich in protein and usually high in digestibility, have been found beneficial as a supplement to improve intake and digestibility of crop residues.

In general as a rule of thumb, the type of supplementation to be followed is largely governed by biological response and relative economic advantages, and strategies to be followed depend on conditions prevailing in the farming system.

IMPLICATIONS FOR RESEARCH AND DEVELOPMENT DIRECTIONS

The decrease in the natural grazing land available in the highlands of Ethiopia is becoming so severe that it calls for an outstanding solution to mitigate problems associated with animal feed supply in the country, particularly during the dry season. As indicated earlier, the potentials of barley straw from an animal feed perspective in terms of both quality and quantity seem to be quite dependable, and hence could definitely help in augmenting and filling the feed budget gap in the country. Moreover, some other basic issues that deserve mentioning in this context are: rapid population growth, massive demand for livestock products, and strategic choices in transformation of Ethiopian animal agriculture

Research and development endeavours in improving utilization of agricultural and agro-industrial by-products of barley as livestock feed has produced considerable experience with fine tuning to suit specific farming system or socio-economic situations. The following are areas for technical consideration.

Resource base and potential

Better estimates of the availability of straw and stubble grazing are required for accurate planning. Blanket recommendations on conversion factors of grain to straw need to be replaced by local data (landraces vs improved varieties; production system; role of stubble grazing; and their relative contributions)

Treatment of crop residues

Among various chemicals, urea is the most feasible, matured technology with strong on-farm significance. In local situations, attempts are now under way to evaluate on-farm responses (biological, economic and social aspects). Piloting the application of this technology at a community level is a way forward.

Supplementation

Better utilization of crop residues relies on appropriate supplements and the level used in livestock feeding. Research and development efforts should therefore be geared toward the knowledge gained thus far on the mechanisms of how animal responses to by-products of barley can be improved using contemporary knowledge of ruminant nutrition. Choice of appropriate supplements should be based on the capacity to supply rumen degradable nitrogen, undegradable protein, and fermentable carbohydrates. Emphasis should be given to the need for synchronizing release of nutrients for better utilization of the basal diet and supplement.

Currently, there is a growing interest in exploitation of varietal differences within a particular crop residue species. In contrast to the situation with forage grass, no deliberate attempts have been made to include straw quality in cereal breeding or selection programmes. In the mixed crop livestock production system of the Ethiopian highlands, there seems to be potential for selecting a cultivar high in both grain yield and straw quality. Studies on varietal differences in straw quality and the interrelationships of grain yield, straw yields and quality should be given emphasis. Empirical evidence suggests that grain yields and straw qualities (CP, IVOMD) were poorly (r = -0.14-0.22) correlated for a set of 13 cultivars of barley land races and improved varieties considered by Seyoum *et al.* (1998). Similarly, grain yield of maize (8 cultivars released in Ethiopia) were found to be unrelated to stover quality (Adugna Tolera, Berge and Sindstol, 1999) In contrast, after studying 42 finger millet and 30 sorghum stover cultivars, Seetharam *et al.* (1993) and Badve *et al.* (1993) concluded that there exists positive associations between grain and fodder yield, and that the non-significant associations found between fodder yield and other fodder quality parameters do not preclude the possibility of developing cultivars with high grain and fodder yield possessing acceptable fodder quality characteristics. A new dimension of how farmers choose and adapt crop varieties need to be incorporated into variety development, and probably this area could be assisted by modern tools of marker-assisted selection (MAS) technology and near-infrared spectroscopy (NIRS) techniques for robust evaluation of the germplasm.

Among various ways by which genetic variability of animals in crop residue utilization arise, differences in ability to digest nutrients should receive reasonable attention. Available information so far is in favour of *Bos indicus* animals (Zebu type) rather than *Bos taurus* (or their crosses) (Karue, Evans, and Tilman, 1972; Howes, Hentges and Davis, 1963; Philips *et al.*, 1960; Church, 1986). Research must explore in the long term to come up with the most suited animal type to survive on a crop-residue-based diet. When environmental stress is high, native breeds may out-perform exotic breeds, and superiority in genetic potential can only be expressed when environmental conditions are favourable. Genotype × environment interactions are important in the tropics. A genetic basis for differences in gut volume, reflected in differences in fractional outflow rates and particle size, have been noted between and within breeds of ruminants (Ørskov, 1993.). It is therefore appropriate to look into options for better utilization of crop residues by using animals better adapted to feeding on such residues.

CONCLUSIONS

Quite substantial amount of by-products of barley are annually produced in the country and these feed resources continue to be the major feed resources in the mixed crop–livestock system, particularly in the high altitude, cooler highlands of Ethiopia. Better utilization can be realized through application of innovations from research, extension and farmers. promising technologies and knowledge can be transferred by using on-farm testing as spring boards for community-based technology transfer.

In terms of its feeding value, barley straw stands second to teff straw. Brewers grain is a source of escape N and in its feeding value it is closer to other agro-industrial by-products, although its optimal use is constrained by its high moisture content. Stubble grazing is the least researched under local condition. The genetics of straw quality and environmental influences need to be understood and supported by modern tools.

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Technology transfer and extension

Achievements in barley technology transfer and extension in Ethiopia

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INTRODUCTION

Barley is an important cereal crop grown by small-scale farmers for subsistence. Among the major cereals, barley ranks fourth in area and productivity and fifth in total production in Ethiopia (Table 1). It is produced in all regions of Ethiopia, but the major producers are Shewa, Gojam, Arsi, Gonder, Wollo and Bale, from where more than 85% of the total production comes (Chilot Yirga, Fekadu Alemayehu and Woldeyesus Sinebo, 1998). In some parts of Ethiopia, barley is produced twice annually (bimodal rainfall), i.e. during the main rainy season, *Meher* (from June to September), and the short rainy season, *Belg* (from February to April). *Belg* barley is important in Wollo, Bale and North Shewa. Although barley grows in areas between 1800 and 3000 masl, it is predominantly grown between 2000 and 3000 masl (Berhane Lakew, Hailu Beyene and Fekadu Alemayehu, 1996). In high altitude areas above 2700 masl, traditionally known as *dega*, it may be the only crop grown. Barley has a number of attributes that makes it desirable among farming communities in the country because it is a source of food and suitable for the *Belg* season; it performs well in marginal areas; provides an earlier harvest than some other cereals; and requires low investment. Barley straw is a good source of feed and the stem stubs and straw can be used for roof thatch and bedding.

TABLE 1
Average area, production and yield of major cereals, 1979–1996

Crop	Area		Production		Yield	
	'000 ha	Rank	'000 t	Rank	t/ha	Rank
Teff	1757	1	1468	2	0.84	7
Sorghum	1042	3	1402	3	1.35	2
Barley	985	4	1071	4	1.09	5
Maize	1445	2	2390	1	1.65	1
Wheat	782	5	939	5	1.20	3
Millet	220	6	199	6	0.91	6
Oats	54	7	65	7	1.20	4

SOURCE: CSA, 1987, 1990, 1996a, b.

However, barley productivity and production among farmers is constrained by waterlogging, pests such as shoot fly and aphids, diseases, unreliable rainfall, poor soil fertility, frost, use of local cultivars, poor crop management, and inadequate market information and marketing outlets. Research efforts have been underway for a long time to mitigate these problems, and various high yielding varieties have been released and appropriate agronomic practices have been recommended.

Achievements of Holetta Agricultural Research Centre (HARC)

Various extension methods and approaches have been employed to transfer improved barley production technologies. These methods and approaches have been changing with time in concert with changes in the national research and extension system. These include top-down client-orientation, farmer research groups (FRG), farmer extension groups (FEG), informal seed multiplication, training and field days, cross visits, field visits, exhibitions, symposiums, festivals, mass media, demonstrations and popularization. This article reviews the successes and challenges encountered in barley technology transfer and extension, and suggests mechanisms for future enhancements in productivity and production.

METHODOLOGIES AND APPROACHES

In an effort to foster research–extension–stakeholder linkages and enhance barley technology transfer and extension, the Research and Extension Division (RED) was established in 1985 within HARC. In its early stage, RED adopted a top-down approach in which technologies generated by scientists on research stations were handed to extension agents to pass onto farmers. Although, occasionally, outputs from research are simple, cheap, versatile and easily understood (Pound, 2001), in most cases technologies are less amenable to spontaneous diffusion due to their complexity, cost, requirement for specialized knowledge, inputs, or concurrent institutional or policy change. This called for a thorough understanding of the farmers' decision making capacities, priorities, needs, social relations and intuitive knowledge.

Farmers, many agricultural extensionists and some researchers were dissatisfied with the top-down approach to technology transfer and extension. Thus the national research and extension system adopted a new and complementary paradigm which put farmers' needs as the primary priority and sought their active participation in technology generation, transfer and extension. Since 1995 a Participatory Demonstration and Training Extension System (PADETES) has been used to ensure the participation of farmers in technology utilization. It was based on demonstrating to and training farmers, development agents and subject matter specialists on proven technologies of a participatory nature. Thus it was mainly geared towards assisting small-scale farmers to improve their productivity by disseminating research-generated information and technologies (MoA, 1996). PADETES at the research centre level had various forms: Client-Oriented Research (COR), Farmer Research Groups (FRGs), Food Economy Groups, and the Research Extension Advisory Council (REAC). A multidisciplinary team was mandated and actively engaged in on-farm participatory research activities. Evaluation of barley technologies was conducted and the findings were further communicated to the stakeholders concerned.

To complement the above research and extension approaches, extension methods, such as demonstrations, popularizations, training days, field days, cross visits, field visits, exhibitions, symposia, festivals and the mass media were used.

At Holetta, demonstration and popularization of barley technologies were conducted in three zones of the Oromia regional state (West, Southwest and North Shewa). Representative woredas (administrative divisions) within the zones were selected on the basis of priorities set by the zonal council. Representative *kebeles* (neighbourhood associations) within the selected woredas were chosen in consultation with woredas and agricultural and rural department experts. Within the *kebeles,* innovative farmers, who were to grow the crops, were further selected in consultation with development agents at various demonstration and popularization sites. Some 188 farmers, from the Welmera, Ejere, Debre Libanos, Meta Robi, Degem, Berehe, Ada Berga, Sandafa, Ambo, Sululta, Alem Gena, Jeldu, Kersakondalitit and Debre Tsigie Woredas participated in demonstration trials during the period 1993 to 2005. Demonstration trials were organized on a bi-plot base, with one plot receiving the improved method and the other receiving the traditional farming method of the area to grow barley, each method being pursued on a quarter hectare of land and both owned by a farmer (Table 2). The trials were managed by farmers while researchers provided technical advice and inputs. Sample grain yields were taken from both the improved and traditional farming methods and compared to see the performance of the varieties under actual farming circumstances under farmer management.

Once a demonstration variety performed well under the farmer's circumstances, it was further popularized by farmers who were willing to purchase improved seed at a minimum price. Seed of improved barley varieties were sold to participant farmers with full technical support and advice. Sample grain yield was taken from participants and neighbouring, non-participant farmers to compare the yield difference and any consequent benefits.

In the earlier stages of the demonstrations and popularizations, an individual contact extension approach was used, where researchers and technical staff provided advice, counselling and supervision at the household level. Furthermore, farmers were given training in farm management and the agronomic features of the varieties. In order to enhance learning among farmers and make the approach market-oriented, the farmers were organ-

TABLE 2
Treatments and management practices followed for improved and local practices in farmers' fields

Treatment	Improved method	Traditional method
Land preparation	Fine seedbed preparation	Traditional practice
Varieties	Ardu-12-60B, Shege, HB 42, Dimtu	Local cultivar
Seed rate	125–130 kg/ha	Traditional rate
Fertilizer rate	60/60 kg/ha N/P_20_5	Traditional rate
Weeding	2 hand weedings at 25–30 and 45–50 days after emergence	Traditional practice
Plot size	0.25 ha	0.25 ha

ized into groups of from 10 to 15 members. The farmers came together to share experiences, observations, views and options, among other things, during the cropping season. To make this group approach effective, the farmer groups were given training in group formation, group dynamics and leadership roles. Visits to demonstration and popularization trials for evaluation purposes were decided by consensus. Thus, the number of contacts with the researchers and technical staff was determined by each group according to its convenience and how it fitted in with farming activities. They also formed bye-laws for their working groups, along with the procedures they would use to evaluate the sites. Evaluation was conducted in the presence of the researchers, technical staff, development agents and farmers.

In addition, field visits, field days, tours, exhibitions and similar activities were organized to encourage and promote a wider dissemination of the improved technologies. Representatives from various institutions operating within the mandated zones and other specialists, as required, were invited and participated. Extension pamphlets, leaflets, posters and other materials were produced and distributed to participants. Reports, produced in different formats, were communicated to woredas, zonal, regional and federal research centres, external users and other development practitioners. To make it knowledge centered, the training was provided to development practitioners. This allowed them to update their knowledge, attitudes, practices and skills concerning recently developed barley technologies.

Demonstration of barley genotype Ardu-12-60B with recommended practices at different agro-ecological zones, 1993

Twenty-six demonstrations were conducted in eleven woredas of the North, West and Southwest Shewa zones of Oromia regional state (Table 3). In most of the demonstration woredas, the improved method failed to provide yields due to the severe weather—snow and hail—and termite damage. The condition were worst at Sandafa Woreda, where both the improved and traditional farming methods failed to provide yields. The highest mean yield obtained during the season from the improved method was 2720 kg/ha in Degem Woreda and from the local method it was 1860 kg/ha in Ambo Woreda. The lowest mean yields recorded were 440 kg/ha using the improved method at Welmera and 900 kg/ha using local methods in Ada Berga Woreda. The yield difference among woredas and between farmers is due to differences in crop

TABLE 3
Mean yields of the Ardu-12-60B demonstrations in different agro-ecological zones, 1993

Woreda	Number of demonstrations	Yield (kg/ha)	
		Improved	Local
Welmera	6	440	971
Ejere	1	1360	1020
Debre Libanos	1	–	1030
Meta Robi	1	–	1600
Degem	4	2720	1050
Berehe	1	–	1200
Ada Berga	2	–	900
Sandafa	–	–	–
Ambo	2	–	1860
Sululta	4	–	1450
Alem Gena	4	–	1190
Total	26		–

management practices and the agricultural potential of the different areas. This suggests that, before any interventions, it is good to know the cropping history of the area and its potential.

TABLE 4

Mean yields of the HB 42 demonstrations in different agro-ecological zones, 1993–1999

Woreda	Number of demonstrations	Yield (kg/ha)	
		Improved	Local
Welmera	12	1330	1270
Debre Libanos	1	2650	1030
Meta Robi	3	1120	680
Berehe	1	800	1200
Ada Berga	6	1880	1390
Ambo	2	2410	1860
Sululta	4	2150	1450
Alem Gena	4	2090	1190
Degem	11	2010	1200
Ereje	5	2200	1570
Total	49		

Demonstration of barley genotype HB 42 with recommended practices in different agro-ecological zones, 1993–1999

Forty nine demonstrations were conducted in ten woredas of the North, West and Southwest Shewa zones of Oromia regional state (Table 4). In all the demonstration woredas except Berehe, the HB 42 variety provided a better mean yield than the local cultivar. The highest mean yield of 2650 kg/ha for the improved variety was obtained in Debre Libanos Woreda, while the highest mean yield for the local cultivar was 1860 kg/ha in Ambo Woreda. This result might be a consequence of the small number of demonstration trials conducted in these woredas, which positively skewed the yields of farmers who had attended the demonstrations. The lowest mean yield of 800 kg/ha for the improved variety was obtained in Berehe, while the lowest mean yield for the local cultivar, 680 kg/ha, was recorded in Meta Robi Woreda. The low yield in Meta Robi is partially attributable to shoot fly damage. In addition, two demonstrations, one each in Welmera and Sululta, were not successful due to pest problems at the former and soil acidity problems at the latter. The farmers' assessments indicated that HB –42 is very resistant to disease, has high tillering capacity, is lodging resistant, is easy to thresh, has the preferred white kernel, and, above all, is very high yielding. Its early maturity is an advantage in that planting can be extended if the onset of rain is delayed, and it also avoids the October frosts.

TABLE 5

Mean yields of the 'Shege' variety demonstrations in different agro-ecological zones, 1996–2001

Woreda	Number of demonstrations	Yield (kg/ha)	
		Improved	Local
Welmera	11	2160	1386
Ejere	3	2810	1880
Ambo	9	2480	1690
Degem	8	3510	2240
Sululta	4	3150	1900
Jeldu	5	3500	2450
Total	40		

Demonstration of barley variety 'Shege' with recommended practices in different agro-ecological zones, 1996-2001

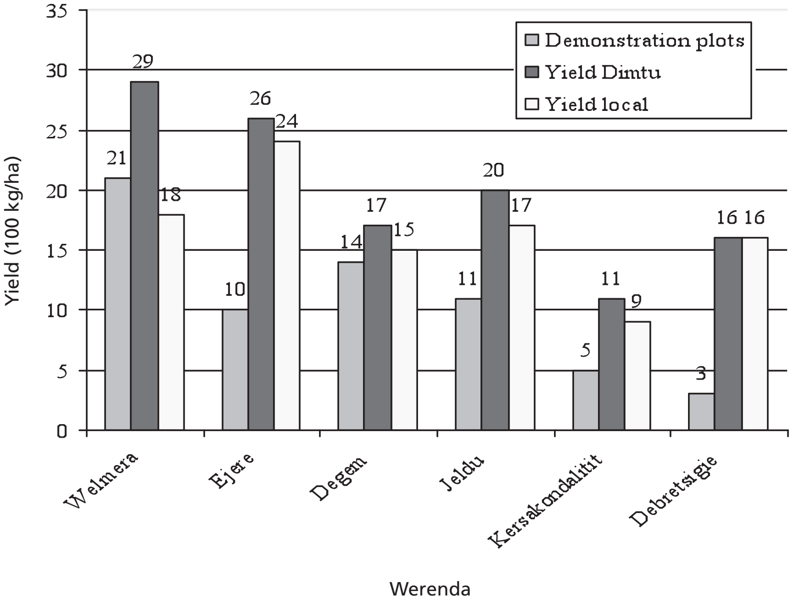
Forty demonstrations were conducted in six woredas of the North, West and South-west Shewa zones of Oromia regional state (Table 5). In all the demonstration woredas, the 'Shege' variety performed better than the local cultivar. The mean yield for 'Shege' ranged from 2160 kg/ha in Welmera Woreda to 3510 kg/ha in Degem Woreda. For comparison, the mean yield for the local cultivar ranged from

13.86 kg/ha in Welmera Woreda to 2450 kg/ha in Jeldu Woreda. Welmera Woreda yielded the lowest mean for both the improved variety and the local cultivar. It was observed that one demonstration plot of 'Shege' in Welmera Woreda was damaged by unnoticed insects (termites) which, it is suspected, could be due to high soil acidity. The farmers assessment showed that 'Shege' has high tillering capacity, is tolerant to poor seed bed preparation, performs better under moderate fertility conditions, is easy to thresh, and is early maturing. Its early maturity is a positive advantage in that planting can be extended if the onset of rain is delayed, and it also avoids the October frosts. The overall assessment indicated that the mean grain yield obtained in the traditional farming method was above formerly achieved in the area because farmers used an earlier released variety, such as HB 42.

Demonstration of barley variety 'Dimtu' with recommended practices in different agro-ecological zones, 2002-2006

Seventy-three demonstrations were conducted in six woredas of the North, West and Southwest Shewa zones of Oromia regional state (Figure 1). In all the demonstration woredas except Debre Tsigie, the 'Dimtu' variety performed better than the local cultivar. In Debre Tsigie Woreda, however, the improved variety and the local cultivar provided the same mean yield. The mean yield obtained using the improved method ranged from 1100 kg/ha in Kersakondalitit Woreda to 2600 kg/ha in Ejere Woreda. In contrast, the mean yield of the local cultivar

FIGURE 1
Mean yields (q/ha) of the 'Dimtu' demonstrations in different agro-ecological zones, 2002–2006



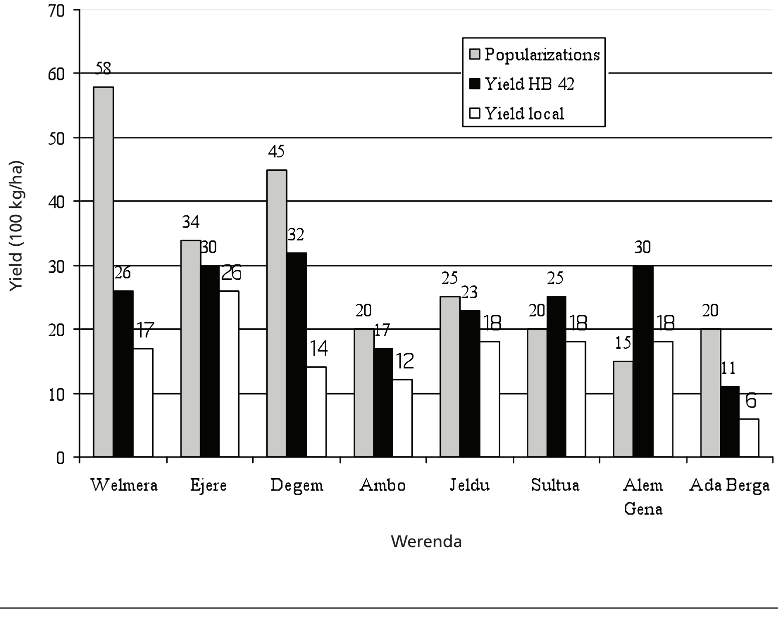
ranged from 900 kg/ha in Kersakondalitit Woreda to 2400 kg/ha in Ejere Woreda. Kersakondalitit Woreda the had the lowest mean yielded for both the improved and local methods, while Ejere Woreda had the highest mean yield for both methods. Since there have been many earlier released varieties of barley, such as 'Shege', HB 42 and mixed HB 42, in the farmers' hands, they used these as checks when employing the traditional farming method. The weather conditions of the year were not as conducive as expected for growing the new barley variety and hence the yield results were below expectation. Farmers, woreda experts and development agents evaluated the performance of the variety from planting to harvesting, and rated it as a good. Some of the good traits mentioned include good *injera* (a pancake-like bread), *kolo* (a snack bread), and *kinche* (a type of bulgur) qualities. Additionally, farmers liked the straw.

Popularization of barley variety HB 42 with recommended practices in different agro-ecologies, 1995–2001

Two-hundred and thirty-seven popularizations were conducted in eight woredas of the North, West and Southwest Shewa zones of Oromia regional state (Figure 2). A large number of farmers participated in the popularization trials because previous demonstrations of the variety, backstopped with field days at the Degem and Welmera Woredas, had created a great demand for the seed. In all the woredas where the popularizations took place, the variety HB 42 performed

FIGURE 2

Mean yield (q/ha) of the HB 42 popularizations in different agro-ecological zones, 1995–2001



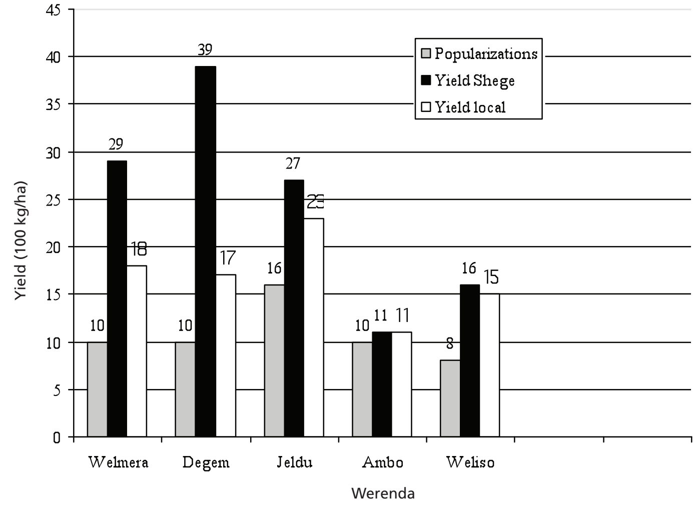
better for the farmers attending than for non-participating, neighbouring farmers. The highest mean yield for the improved method was 3200 kg/ha and was achieved in Degem Woreda. The highest mean yield for the local method was 2600 kg/ha and was obtained in Ejere Woreda by farmers who had not participated in the popularization trials. The lowest mean yields of 1100 kg/ha for the improved cultivar and 600 kg/ha for the local variety were obtained in Ada Berga Woreda by farmers who had not participated in the popularization trials. Generally, the mean yield of the variety in many woredas was much higher than the neighbouring farmers, though data from Sululta Woreda were not obtained in time due to staff changes. According to the farmers, HB 42 is suitable for all soil fertility categories (poor, medium and rich) and hence can be sown on all soil types, unlike other local and improved varieties. In addition, farmers perceived that the variety gives a better yield even with low fertilizer application rates and is not readily affected by weeds and disease. It has a high grain filling capacity with smaller amounts of moisture and is resistant to lodging. With its white grain colour and large seed it also has high market demand. It can be used for more than one food type. As the performance of this variety has been consistent between woredas and among farmers, it has to go through the national extension system or be scaled up and out.

Popularization of barley variety ‘Shege’ with recommended practices in different agro-ecological zones, 2000–2004

Fifty-four popularizations were conducted in five woredas of the North, West and Southwest Shewa zones of Oromia regional state (Figure 3). In all the popularization woredas except Ambo and Weliso, the ‘Shege’ variety performed

FIGURE 3

Mean yields (q/ha) of the ‘Shege’ popularizations in different agro-ecological zones, 2000–2004



better in the fields of farmers who had participated in the popularization trials than in the fields of their non-participating neighbours. Participating farmers obtained mean grain yields ranging from 1100 kg/ha in Ambo Woreda to 3900 kg/ha in Degem Woreda. In contrast, the non-participating farmers obtained mean grain yields ranging from 1100 kg/ha in Ambo Woreda to 2300 kg/ha in Jeldu Woreda. The lowest mean grain yields for both improved and local varieties were recorded in Ambo Woreda. Since varieties have the potential to be spread through farmer-to-farmer seed exchange, 'Shege' will contribute to an overall barley yield increase, at least in the popularized areas. With its white seed colour, the variety has attracted a good market value in all areas. Even though farmers used earlier released varieties, such as HB 42 as a check, it is preferred by farmers even in woredas where its mean yield was comparable to that of the local cultivar. According to the farmers, 'Shege' resists excessive moisture, provides a good yield even on less fertile land, and is not easily affected by the absence of early or late rain, i.e. it maintains its balance under extreme rain conditions. Also it is not affected by frost and produces more straw (height) and has good threshing ability.

Field days

A field day is a group extension method where participants come together to observe and judge the performance of new technology under farm conditions. In addition, policy issues, challenges and future prospects are discussed and agreed upon. In these discussions, future actions are agreed. During the cropping season, field days were organized in the various woredas where demonstration and popularization trials were being conducted. A total of 2405 participants, comprising researchers, participants, non-participating neighbouring farmers, Ministry of Agriculture and Rural Development woreda experts, development agents, technical advisers, media experts and invited non-governmental organizations took part (Table 6).

A cross visit is another group extension method (Table 7) organized to aid farmers to share, exchange experiences, and learn from each other. The intention is to create awareness and obtain feedback on improved barley production technologies. According to the farmers, almost all barley varieties have been well accepted. A cross-visit to Welmera Woreda was intended help farmers to learn about Client-Oriented Research activities and jointly evaluate the objectives set in the experiment. During the visit, farmers demonstrated an interest in producing malting barley varieties as an alternative source of income, and asked for a strengthening of the institutional linkages with breweries. They also declared their interest in obtaining early maturing varieties of barley, given the short rainy season.

Training

Traditionally, training has been viewed as a transfer of expertise from the trainer to learner. The trainer defines what a particular set of learners need to learn. However, to make training more needs based, a needs assessment was conducted and training was provided by subject matter specialists, farmers, development agents, and some experts engaged in rural development in the zones. This

TABLE 6
Number of participants at field days

Year	Woreda	Objective	Farmer	DAs	Researcher	Others	Total
1993	Welmera, Degem	Barley genotype performance evaluation	80	20	30	15	145
1994	Welmera	On-farm barley production	138	15	16	11	180
1995	Welmera	Barley variety popularization	112	25	27	18	182
1996	Welmera	Barley management evaluation	212	54	34	47	347
1997	Welmera, Ejere, Degem	Barley variety performance evaluation	150	10	15	30	205
1999	Jeldu, Welmera	Barley variety performance evaluation	98	16	11	21	146
2000	Sululta, Welmera, Degem	Barley variety performance evaluation	111	21	23	19	174
2001	Jeldu	Barley variety performance evaluation	132	15	14	22	183
2002	Welmera, Degem	Barley variety performance evaluation	84	13	17	28	142
2003	Welmera, Dendi, Degem	Malt barley informal seed multiplication	171	15	22	12	220
2004	Degem, Welmera	Barley variety performance evaluation	166	16	23	18	223
2005	Jeldu, Degem, Welmera	Barley variety performance evaluation	189	13	27	29	258
Total			1643	233	259	270	2405

NOTES: DA = Development Agent.

TABLE 7
Cross-visits among hosting farmers

Date	Place	Discipline incorporated	Researchers	TAs	Others	Farmers	Total
16–18 Oct 2001	HARC	Workshop on FRG	64	-	14	-	78
12 May 2001	Ilala Gojo	Meeting with FRG	12	2	-	21	35
8 June 2001	Ginchi	Meeting with FRG	11	2	1	-	14
8 May 2002	Ginchi	Presentation and plan meeting	66	-	-	-	66
8 June 2002	Ginchi	FRG evaluation	11	1	1	20	33
14–15 June 2002	HARC	FRG evaluation and deciding on-going activities	16	1	2	42	61
10 Oct 2003	Ginchi	Deciding on-going FRG activities	7	6	-	32	45
17 Oct 2003	Welmera	FRG evaluation and deciding on-going activities	8	10	1	26	45
Total							377

NOTES: FRG = Farmer Research Group; TA = Technical Assistant.

approach views training as a learning process: learning new skills, concepts and behaviours. It implies the non-formal education of adults, but in a purposeful and directive sense. Participatory training is a non-formal, on-going process, in which both trainers and trainees learn from each other. In this case, the intent is to build up the confidence of the learners in their capacity to observe, criticize, analyse, and figure out things by themselves. Training was provided for a total of 129 trainees, consisting of agronomists, supervisors, farmers and development agents (Table 8).

TABLE 8
Training and the trainees

Focus of training	Year	Place	Woreda	Farmers	DAs	Others	SMS	Total
Crops	1994	Holetta	34	–	-	68	–	102
Informal seed multiplication	1997	Holetta	4	8	6	–	9	27
Total								129

NOTES: DA = Development Agent; SMS = subject-matter specialist.

Debre Berhan Agricultural Research Centre

Following the release of the first barley variety, 'Misrach', by Debre Berhan Agricultural Research Centre, demonstrations of growing food barley have been conducted near Ankober, Asagirt, Debre Berhan Zuria and Tarmaber since the 1999 cropping season. The demonstrations were conducted in both in the *Belg* (short rainy season) as well as the *Meher* (long rainy season). The *Belg* demonstrations were conducted in the vicinity of Ankober, Asagirt and Mezezo, areas known for their higher *Belg* production in terms of both area cultivated and productivity.

Demonstrations of barley cultivation have also been conducted in the Ankober areas during the *Meher* season, in addition to the previously mentioned *Meher* season producing areas. Field days were conducted in all these areas and farmers gave their opinions about the technology. They indicated that 'Misrach' has high productivity, high tillering capacity, weed suppressing quality, good capacity to withstand hail damage, and an early maturing potential enabling the grain to avoid early rain showers and frost damage. Moreover it is white in colour, which fetches a good market price.

The demonstrations were conducted such that the improved method and the traditional farming methods and the relative performances of the varieties could easily be compared. The improved methods included different varieties ('Misrach' and 'Shege'), seed application rate (125 kg/ha), fertilizer application rate (41/46 N/P), one hand weeding at 25–30 days after emergence, ploughing two or three times, and different sowing dates (around mid June). The traditional farming method involved the use of local varieties without fertilizers and with no weeding.

The results of the demonstrations showed that the improved variety, 'Misrach', and its production package produced higher yields. 'Misrach', with its package, gave a mean grain yield of 2800 kg/ha, while 'Shege', with its package, and the local check gave mean grain yields of 2199 kg/ha and 1625 kg/ha, respectively. A partial budget analysis showed that 'Misrach' and its production method gave a marginal rate of return of 68.3%, while 'Shege' with its package of production inputs was found to be not economically viable. In their evaluation of the technologies the farmers stated that 'Misrach' fits well in the farming system of the Ankober areas, and that it can be used for *Belg* season production because of its relatively early maturity, which means that it misses the dangers of hail in July and August.

In 2000, the results of the demonstrations showed that the improved variety 'Misrach' and its production package gave higher yields. 'Misrach' with its production package gave a mean grain yield of 3142 kg/ha while the local check

TABLE 9

Overall yield performance of barley varieties under demonstration in North Shewa

Barley varieties	Mean yield (kg/ha)
Food barley varieties demonstration results (*Meher* seasons)	
Average yield of 'Misrach'	2603
Average yield of local variety with improved management	2018
Average yield of local variety with traditional crop management	1556
***Belg* season food barley variety demonstration results**	
Average yield of 'Misrach' (*Belg* season)	3568
Average yield of improved variety 'Basso'	2610
Average yield of improved variety 'Mezezo'	2424
Average yield of local variety with improved management	2270

(local variety; Nech Gebs, without fertilizer and weeding) gave a mean grain yield of 1484 kg/ha.

In 2001 the demonstrations were conducted in both the *Belg* and *Meher* seasons on the fields of 12 farmers. The mean yield obtained from 'Misrach' was 3478 kg/ha while the local variety with improved management gave 3022 kg/ha and the local variety with the traditional farming method of barley production gave 2286 kg/ha.

In 2002 a demonstration of 'Misrach' was conducted only during the *Belg* season around Asagirt and Mezezo on six farmers' fields. 'Misrach' with its production package gave 3347 kg/ha while the local barley variety with improved management gave 2052 kg/ha.

For the following cropping seasons the 'Misrach' variety was distributed through the zonal agricultural departments. As a result of these studies, the woreda offices of agriculture adopted the variety and no more pre-extension demonstrations of the 'Misrach' variety were conducted by the centre.

In the fall of 2004, another two food barley varieties ('Basso' and 'Mezezo'), which are suitable for *Belg* season production, were released by Debre Berhan Agricultural Research Centre. At present, these varieties and their production packages are being demonstrated to farmers in the Mezezo, Asagirt and Ankober areas. These varieties have been found to be susceptible to head smut of barley, which necessitates the use of seed dressing fungicides.

Farmers' evaluations of the improved barley varieties 'Mezezo' and 'Basso' show that both of them have long spikes and hence very good yield potentials, their black colour is also preferred for home consumption. 'Basso' is better in productivity, but more susceptible to smut than 'Mezezo'. Both of them are late maturing (>160 days), which might expose them to hail storm damage. The year-by-location combined performance of these varieties is shown in Table 9.

Bako Agricultural Research Centre

Pre-extension demonstrations of the improved barley variety HB 42 and its production package were conducted in two districts of East Wellega Zone in 2002 and 2003. The farmers were provided with the improved variety and its production package to popularize the variety and increase adoption through a farmer-to-farmer extension method. The result indicated that the performance of this crop variety at Shambo was better than that of the local cultivar. The improved variety gave a mean grain yield advantage of 1589 kg/ha; a 91.65% improvement over the yield of the local landraces (Table 10). Furthermore, no disease problems were observed at any of the demonstration plots, suggesting that the variety was well adapted to the area. In addition, the collaborating farmers and their neighbours were amazed by the variety as it has a high yield advantage over the local cultivars. At Arjo, the yield performance of the variety was relatively low; a yield advantage of 375 kg/ha, which was an improvement of 34.72 % on the mean yield of the local landraces (Table 10). The low grain yield advantage achieved in Arjo compared with that in Shambo is mainly attributed to the poor management of the crop by the host farmers. Generally, however, the farmers have a positive attitude towards the variety in the area.

TABLE 10
On-farm demonstrations of the improved barley variety HB 42

Location: Shambo area	Yield (kg/ha)		Yield advantage	
	Improved	Local	Yield increase (kg/ha)	%
Amma chala PA	3767	1833	1934	105.5
Saqala PA	2083	1250	833	66.6
Lakku Iggu	4000	2000	2000	100.0
Gobeya PA	1250	950	300	31.6
Lalo - hidhe PA	1780	1000	780	78.0
Lalo - hidhe 2 PA	1667	1292	375	29.0
Mean	2424.5	1387.5	1037	68.5

SOURCE: BARC, 2003.

GAPS AND CHALLENGES

Holetta Agricultural Research Centre

The following are some of the gaps and challenges that need to be addressed to make processes of barley technology transfer and extension contribute to the national food security and poverty reduction strategies.

Lack of a value chain approach

Demand-driven production of barley varieties requires the incorporation of their values into the production, marketing and consumption continuum. In this case, some of the issues that need to be addressed are post-harvest handling; linking producers to traders, exporters and processors; and communicating and disseminating plans. It is extremely important to bring together all stakeholders who are directly and indirectly engaged in the various processes—from food to fork—associated with the different barley varieties to further refine development.

Scaling up and out

There are a number of improved and promising varieties of barley that need to be distributed to a wider audience. Such an attempt should encourage the allocation of more area for barley production and, consequently, increase total barley production. This in turn will have a greater impact on participating farmers and the national economy.

Weak institutional linkage

In the national research, extension and institutional linkage strategy it is pointed out that without an effective linkage mechanism the research products will remain ineffective. Government policies and development approaches are changing. These strategies have been modified from on-station based technology generation to institutional collaboration. Barley technology improvement requires the active involvement of all institutions and the integration of all activities, from germplasm collection to consumption. The most notable institutions include the agro-industries, processors and exporters. So far it has been observed that these institutions work in isolation and the linkages between them are very weak.

Inadequate information on marketing dynamism

Market-oriented production requires an assessment of updated marketing information so that stakeholders who are engaged in marketing may benefit. This may require that timely price, supply and demand information concerning the local, regional, national and international markets be made available. These are the challenges that the actors who are involved face in the processes of generating, transferring, marketing, processing and application of barley technologies.

Debre Berhan Agricultural Research Centre

The most important gaps or constraints encountered in the course of barley technology transfer activities were the absence of a responsible body for seed multiplication for the improved barley varieties and the lack of integration between research centres, agriculture offices in the woredas, NGOs and other actors involved in agricultural development.

Bako Agricultural Research Centre

The level of adoption of the improved barley varieties and their impact have not yet been assessed. The delivery system is inadequately organized and not sufficiently decentralized. No consecutive interventions have taken place, particularly as regards the provision of seeds, planting materials and farm implements by the organizations concerned.

FUTURE TECHNOLOGY TRANSFER DIRECTIONS

Holetta Agricultural Research Centre

The followings are some of the future directions for barley technology transfer and extension:

- strengthening institutional linkages with all institutions (partnership development);
- making barley technologies part of the crop technologies scale up and out activities;
- generating marketing information and making it available in a timely manner;
- developing value adding chains for the production, marketing and consumption of barley, and
- formulating plans for communication and information exchange.

Debre Berhan Agricultural Research Centre

The future methods for barley technology transfer will be through participatory technology evaluation and dissemination using Farmer Research Groups and Farmer Extension Groups. Moreover, it is time to conduct a diffusion study to evaluate the rate and extent of diffusion of the barley varieties distributed.

Bako Agricultural Research Centre

Considering the performance of HB 42 in East Wellega Zone and the farmers' positive attitudes towards this improved variety, it is important to widely popularize and distribute this barley variety in the region through participatory technology development, evaluation and dissemination processes. This will improve the production of barley in the farming systems of the region.

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