Agricultural Research for

Ethiopian Renaissance

Challenges, Opportunities and Directions

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Ethiopian Institute of Agricultural Research

Proceedings of the National Conference on Agricultural Research for Ethiopian Renaissance held on January 26-27, 2016, in UNECA, Addis Ababa to mark the 50th Anniversary of the establishment of the Ethiopian Institute of Agricultural Research (EIAR)

The views expressed in this publication are those of the authors and do not necessarily represent those of Ethiopian Institute of Agricultural Research

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Table of Contents

Foreword

Because of its role as the main engine of economic growth as well as a source of livelihood and employment for the majority of the Ethiopia population, the Ethiopian governments that exercised power over the past six-seven decades have given significant attention and priority to the sector. Despite the fact that these efforts have resulted in significant improvement in agricultural production and productivity since the mid-1990s, the improvements are still far from meeting national food security needs as well as the need to meet the raw material needs of local industries as well as the need to generate quality products for export markets. Needless to say, there have been and still are many important constraints to improve and "transform" Ethiopian agriculture. In general terms the main constraints focus on inappropriate land use and farming systems, inadequate use of improved technologies, continued dependence on annual rainfall and poorly integrated market linkages.

Obviously, minimizing the above-enumerated constraints will significantly remove some of the pressing problems. It has been known for a long time that a well-developed and integrated national agricultural research system is one of the major tools for developing technologies and practices for minimizing, if not removing, the constraints. This knowledge was first put to work in Europe with the establishment of agricultural research/experiment stations in France and England in the 1840s. East Africa (mainly Kenya, Sudan and Uganda) had their first agricultural experiment stations in the 1910s. Ethiopia, on the other hand, has its first formalized and reasonably well structured agricultural research program with the establishment of the former Institute of Agricultural Research (IAR) in the mid-1960s, although some experimental activities were being undertaken at the Ambo and Jimma agricultural high schools in the late 1940s and at the former Imperial College of Agriculture and Mechanical Arts (today's Haramaya University) in the early 1950s. The IAR was mandated to not only undertake research in its research centers but also coordinate agricultural research in other national agricultural research institutions.

Needless to say, the EIAR today is far different and well advanced from its predecessor in several ways. These differences can be viewed from many angles including 1) Structural/organizational, 2) programmatic, 3) human resources and 4) financial. In relation to the structural/organizational aspect, the main difference relates to the division of the nationally unified system into several poorly synchronized "federal" and "regional state" research system. This has led to poor integration and coordination. It is hoped that the newly created National Agricultural Research Council will improve the future situation. In relation to the "programmatic" aspect, although, the main focus of the research programs at the beginning was mostly similar with the present (i.e., crops, livestock and natural resources); the contents to date are far advanced today than before. As can be seen in the body of this book, newer and important focus areas such as socio-economics, bio-technology, bio-diversity, research- extension, gender, etc. are added to make research relevant to current and future needs and priorities. It must Alsop be added here that these program developments are strongly supplemented by regional and international cooperation with relevant agricultural institutions. A special mention need to be made of the collaboration with and contribution from International Agricultural Research Centers operating under the CG system such as CIMMYT, ICARDA, ICRISAT, IFPRI and ILRI. In relation to the situation in human resources, the EIAR today can be considered well endowed, although there is still more room for improvement both in terms of quantity and quality. It is important to note that, early in its life, the EIAR (former IAR) depended heavily, both in program and infrastructure development, on the technical support provided by the United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO) of the United Nations. We should acknowledge these important contributions. Finally, the funding of EIAR to date is quite substantial, thanks to the good will and interest shown by the various Ethiopian governments, past and present. The annual budget for research has grown from below a million at the beginning to more than 500 million today, although it should be indicated that the Government's financial support to national agricultural research should be not less than 2 % the national Gross Domestic Product (GDP), as agreed by African Heads of State some time Ago.

The above narrative, however briefly, summarizes a fifty-year journey in building the Ethiopian NARS, lead and guided by EIAR and its predecessor. Despite weaknesses in some areas, it can be said that a lot has been achieved in many respects. So, what have been the specific achievements to date? First and foremost, the mere fact that the apex organ for national agricultural research has succeeded in remaining intact and active over so many years despite two serious national political crises is a major achievement in itself. Secondly, the system has generated a large number of useful technologies and management practices that has impacted agricultural production and productivity thereby contributing to food security as well as to the growth of the national economy. It must, however, be noted that this statement must be interpreted carefully as it does not fully apply to some sub-sectors such as animals and animal products, food and nutrition management, and agricultural mechanization, to mention just a few. It can be said that the technology generation effort was somewhat biased towards crop, mostly cereal. Besides increase in agricultural production and productivity, one of the big achievements of the Institute is the creation of huge demand for agricultural technologies and information by beneficiaries along the value chain, which in reality, is the strong positive side of the success.

Finally, it is imperative for me to touch upon, however briefly, what I think should be the necessary steps to be taken to make EIAR more efficient and effective in designing and implementing agricultural research programs and its support required to meet future technological needs and priorities. As a top priority, the Institute needs to design a strategy to respond not only to the current demand but also for future agricultural technologies and information needs. It must identify and prioritize research areas that have wide applications in maximizing returns, particularly to small scale farmers and herders. This short to medium term policy should be well tailored for further production enhancement through large-scale production systems, wherever possible, both on crops and livestock. It is quite difficult to imagine meeting national needs through the current status of small-scale farmers/herders. There is a strong need for change due to the impending population growth, food and nutrition habits, international trade (Globalization) as well as climate change. Large scale “commercial farming” through efficient use of mechanization must be the goal for the future, wherever possible. This must be strongly supported by expanding irrigation in potentially suitable areas, which is quite substantial, according to national statistical information. It is important to mention the need for agriculture-industry linkage that benefits both farmers/herders and industry. Industry could be used as a vehicle for transferring research results that are used as raw products. EIAR, in collaboration with industry and national/regional extension services needs to open its doors for such collaboration. EIAR also needs to link with agricultural colleges/faculties in appropriate universities not only to enhance training its staff but also conducting high level research which it may not afford to undertake in its facilities. In fact, there are good reasons for seconding its research staff to relevant universities for the above-mentioned purpose. Finally, EIAR needs to do more in answering why and how farmers behave to new technologies. For example, why do farmers refuse or are slow to adopt mechanization as a tool to minimize labor and drudgery in addition to saving time. The same question could be raised with respect to slow or minimum adoption of important inputs such as improved seeds and even chemical fertilizers.

While celebrating the 50th year anniversary of EIAR, compiling and sharing the available knowledge and information to the wider public domain is believed to be of high importance. It gives an overview of what has been done, indicates the gaps in relation to the current needs and shows the way forward in designing and implementing a well thought approach to making. Ethiopian agricultural research more effective, efficient and productive.

Seme Debela, PhD
Former General Manger/IAR

Fifty Years Agricultural Research in Ethiopia and the Need to Adapt to Evolving Agricultural Development Needs

Fentahun Mengistu
DG, EIAR

Introduction

Agriculture in Ethiopia is accorded high priority and significant investments have been made to modernize the sector. The sector is set to play a pivotal role for ensuring food and nutrition security, providing raw materials for industry, generating foreign exchange revenue, and providing employment opportunities for the vast majority of the population. As a result, there have been significant changes in production and productivity growth in recent times.

Should the country fully meet food and nutrition security goals, and compete and thrive in the global market, however, transforming agriculture to the future date of high impact is essential. Future agriculture is expected to consistently increase productivity and revenue while reducing costs, employing fewer resources (land, water and energy) per unit output produced, lessening environmental, economic and social costs, reducing vulnerability to Climate Change effects, and improving resilience capacity. In this regard, scientific research has a lot to offer for agriculture to realize its sustainable development objectives through provision of innovations that help improving productivity and production efficiency, climate smartness of landscapes, etc.

Over 50 years now, the Ethiopian Agricultural Research system has been playing an enabling role in ushering developments in agriculture sector through scientific research and technology development. As the Ethiopian Agricultural Research System celebrates its Gold Jubilee in 2016, therefore, this report attempts to provide a brief account of the Agricultural Research System, its achievements and suggest future research directions.

The Ethiopian Agricultural Research System

The agricultural research system in Ethiopia did not take off at once that its organizational capacity and processes evolved over time. Many authors agree that rudimentary form of agricultural research activities in Ethiopia are traced back to early 1930s. However, agricultural research took roots later in 1950s with the establishment of agricultural high schools and in real terms when a semi-autonomous independent institution established in mid 1960s. Consistent with global practices the evolvement of agricultural research in Ethiopia can be seen categorized by governance models. Before 1940s, there existed only scattered studies as expedition, germplasm collection and introduction, characterization and testing and this period cannot be categorized under any defined model. The Russian scientist Nicolach Vavilov had also made his expedition to Ethiopia during this time (December 1926 and April l927). Between 1940s and early 1950s agricultural schools: Ambo (1947), Jimma (1952) and the then Alemaya College of Agriculture (1954) established with triple functions of education, research and extension by USA Land Grant University model. Later Haramaya University established the Debre Zeit Station in 1953, which makes it the oldest agricultural research station. Between late 1950s and early 1960s various agricultural research facilities were formed (Adams, 1970) and agricultural research was for a short period institutionalized under Ministry of Agriculture and studies were made at Melko Coffee Nursery site, Holetta Ranch and Werer cottonseed multiplication sites. In a bid to conduct oil crops research Bako Research Station was established in 1955 with the support of the Federal Republic Government of Germany.

A well-organized agricultural research began with establishment of the Institute of Agricultural Research (IAR) 1966 as a semi-autonomous institute with financial support from UNDP and FAO (Beintema and Menelik Solomon, 2003). There were also a number of other national research centers established outside of IAR during 1970s such as Plant Protection Research Center (formerly SPL), Plant Genetic Resources Center, Forestry Research Center, Wood Utilization Research Center, National Soils Laboratory and the Institute of Animal Health Research. Research in support of extension efforts was also carried out by CADU (Cohen, 1987). In mid 1980s, in line with the Ten years Perspective Plan (1977-1986) that recognizes 11 main AEZs, IAR was restructured to emphasize AEZ based research that culminated in the establishment of new research centers: Abobo, Adet, Sinana, Pawe, Assosa, Gode, etc. Generally, up until early 1990s the research system has been led centrally with geographical decentralization under a National Research Institute (NRI) model.

In the early 1990s, the Ethiopian NARS underwent administrative decentralization that culminated in the creation of federal and regional research institutions. As a result, a number of IAR centers were transferred to regional States leaving Holetta, Melkassa, Jima, Bako, Werer, Ambo, Kulumsa and Pawe research centers to the federal research institute, IAR. Later IAR subsumed other new institutions: Debre Zeit research station, Biodiversity Institute, Forestry Research Center, Wood Utilization Research Center, Institute of Animal Health Research, National Fisheries Research Center, National Soils Laboratory and Wondo Genet Research Center, and renamed as EARO in 1997. In 2004, with the institute's proclamation amendment EARO fell under the administrative responsibility of MoARD from that of PM office. Further, with federal executive organ revision amendment in 2007, EARO was rechristened to today's EIAR and made answerable to MOA. Generally, research during 1994- 2014 period can loosely be categorized as Agricultural Research Council model. In 2014, steps were taken to establish the Ethiopian Agricultural Research Council, that was ratified by Council of Ministers later in March 2016, poised to provide a national coordination role to the country's NARS which can be regarded as a truly Agricultural Research Council model.

Over the last 50 years 13 director generals led the NARS of Ethiopia. These were: Worku Mekasha, Dagnachew Yirgu (Dr), Semunigus K/M (Dr), Zemedu Worku (Dr), Taye Worku, Seme Debela (Dr), Taddesse G/Medhin (Dr), Seifu Ketema (Dr), Abera Debelo (Dr), Demil Teketay(Dr), Tsedeke Abate (Dr), Solomon Assefa (Dr) and the incumbent- Fentahun Mengistu (Dr).

Research Priority in Different Government Regimes

Agricultural research in Ethiopia has always been following and shaped up by the agricultural development policies of respective regimes. During the imperial period, agriculture especially large scale farming was given focus especially after the third 5 year Plan, 1968-73 (Cohen, 1987) by which time, though minimally, the research focus was to serving large-scale irrigated cotton farms, horticultural farms. During the Derge Regime, in line with the popular Ten-Years Perspective Plan, agricultural research used to focus on resettlement areas, state farms, and surplus producing districts. In the incumbent regime under the Agriculture Development-Led Industrialization (ADLI) strategy, small-scale agriculture is taken a cornerstone of agricultural sector growth. Consequently, the major focus of the agricultural research system are small-scale farmers and herders while due attention is also given to private large-scale farmers.

Success stories of Ethiopian Agricultural Research

The success of the Ethiopian Agricultural Research can partly be gauged by the progress made in agriculture. Agriculture has registered remarkable growth (7.6%) for over two decades now. Between 2004-14 Cereal crops output has increased by 115% and the yield rose by 81% which is partly explained by doubling of agricultural input use (fertilizer & seed) (Fantu et. al., 2015). This has been substantiated by Mellor (2014) as cited by Demese Chanyalew (2015) who reported that in the 12 years' time until 2013, 60% of cereal production increase has come from productivity change while area expansion contributed to 40%. Indeed, Ethiopian Agricultural Research System by the effective leadership of EIAR served a main driving force for agricultural growth through provision of wide-ranging improved technologies in the order of 3000 which some of these flagship technologies are discussed as below.

Crop technologies: Most notable achievements of the Ethiopian Agricultural Research system are unquestionably in crop research. The research system, among others, has been able to develop more than 1035 crop varieties along production packages in 96 crops (Figure 1).

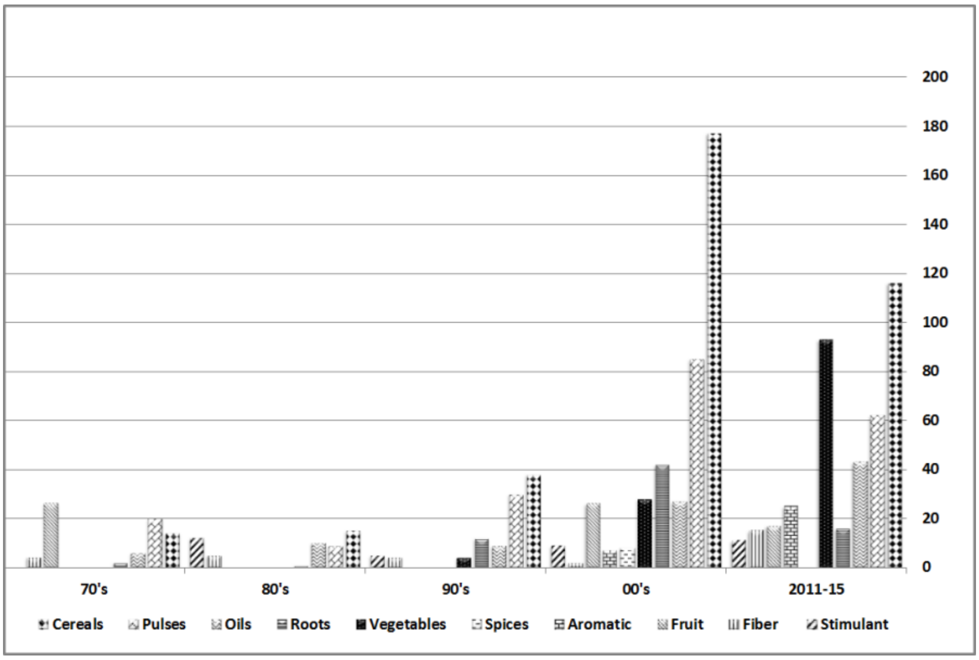

Figure 1: Released crop varieties by category and decade

Maize: the research system has made available over 60 improved varieties including most popular hybrids as BH660 and BH540, 6 QPM and 10 drought tolerant varieties. Today maize is grown by 8.7 m HHS over 2.1 m ha and 7.2 Mmt is produced with an average productivity of 3.4 t/ha (CSA 2014). As a result, maize has now been adpted to diverse agro-ecological zones ranging from the cool highlands to moisture deficit hot lowlands to irrigated lands. Maize is perhaps the only crop that appealed the private and parastatal public seed enterprises alike.

Wheat: more than 100 high yielding, high quality, rust resistant bread and durum wheat varieties have been made available along with their production packages suitable for different agro-ecologies. Today wheat is grown on over 1.7 m hectares with a total production of 4.2 Mmt and a national average yield of 2.5 t / ha which is against 0.6 t in 1960s. Historically, the country has got used to suffer rust disease epidemics and recurrence over the last 4 decades that forced it to abandon one or more of its improved varieties in each decade or less. For instance, Lakech variety was wiped out by stem rust in 1974, Dashen by yellow rust (1988), Enkoy by stem rust (1993), two most popular varieties Kubsa and Galema by yellow rust (2010), Danda'a and Kakaba by yellow rust and Digelo by stem rust (2013). Therefore, the research system has always been grappling with rusts and made replacement varieties timely available.

Tef: It is perhaps a good example of a crop that domestic research showcases its research capability. Some 36 improved tef varieties along with production packages have been developed addressing various growing agro-ecologies. Especially, spectacular success has been achieved with the release of the most popular variety "Quncho", that elevated tef yield to as high as 3 t/ha. Consequently, in 2014 a total of 6,5m households grew tef on a total area of 3.0M ha and 4.4Mmt produced with a national average productivity level of 1.58t/ha.

Barley: 53 varieties have been released of which the majorities are food types; Beka was the oldest malting variety released in 1976 and remains important until date. Holker released in 2011 is the most popular and widely grown variety to date. Introduction of malt barley varieties helped the local breweries save significant foreign currency and raised farmers' income. In 2014, 4m households grew barley on an area of 993,938 ha and produced 1.95 Mmt with a national average yield of 1.97t/ha.

Sorghum: more than 37 varieties suitable for various agro-ecologies have been released. Notable achievements are development of striga resistant varieties, bird resistant varieties, early maturing varieties, malting types and hybrid varieties. Sorghum is the second crop after maize in cereals that hybrid varieties (ESH-1 and ESH-2) have been developed. To date sorghum is grown by 4.8 HHs on a total area of 1.68 mha and production of 3.82Mmt with a national average productivity of 2.28 t/ha.

Industrial crops: apart from durum wheat and malt barley, the research system has developed about 29 open pollinated and hybrid cotton varieties that fed the textile industry. Especially, introduction of "Acala" type cotton in 1960s, accompanied with the "Closed Season" technique contributed to minimizing pesticide spray against pests and enabled sustained production. Since 2004, EIAR also released wine grape varieties which some of them are serving the local wine industry.

Export crops: most notable contribution of the research system is the development of CBD resistant varieties in 1970s that rescued the coffee industry. Thirty-seven improved coffee varieties have been developed that included 3 hybrids and 11 specialty coffee varieties. In 2014, coffee is grown by 4.7 m HHs on a total area of 0.57 mha and 0.42 Mmt harvested with a national average productivity of 0.76 t/ha. In addition, the research system released 21 sesame varieties with a yield potential of as high as 1.2 t/ha. In 2014, sesame is grown by 0.87 m HHs on a total area of 0.42 m ha and 0.29 Mmt production and a national average productivity of 0.69 t/ha. The research system by introducing improved white haricot bean varieties as early as 1970s helped the crop to be one of the major export crops. To date 58 varieties have been developed. In 2014, common bean was grown by 3.2 m HHs on 0.32 m ha with a total production of 0.5 Mmt and a national average yield of 1.59 t/ha.

Horticultural crops: the research system laid the foundation for horticulture production in the country by introducing and adapting various fruits, vegetables, roots, and tuber varieties. For instance, the popular pepper variety-Marekofana, onion varieties, and seed production techniques were made possible because of the research system. The most significant achievement in tuber crops research is that of potato where more than 35 high yielding varieties with productivity level reaching up to 50 t/ha and tolerant to late blight are developed. In 2014, potato was grown on an area of 0.18 m ha and 1.6 Mmt was produced, and the average productivity according to 2015 data was 13.7 t/ha.

Agro-techniques: the research system has also been able to establish several production technologies and agronomic recommendations: fertilizer rates, planting time, spacing, row planting, harvesting, etc; insect pest, disease and weed and abiotic stresses management technologies, post-harvest technologies, utilization technologies, etc.

Livestock technologies

Feed: the research system identified feed technologies sourced from cultivated forage crops, natural pasture/grazing lands, crop residues, agro-industrial byproducts, and multi-nutrient blocks or urea molasses bocks. It has also developed more than 33 forages and pasture varieties.

Cattle: the research system has been able to introduce and adapt exotic breeds such as Jersey and Holstein Friesian and crossed them with local breeds as Boran. The average milk yield (lt) per lactation of Arsi, Barka, Borena, Fogera and Horro cattle improved to 589,713, 592, 595, and 429 lt in that order. Lactation milk yield (lt) for Friesian x Boran Crosses (F_1) and high-grade (75 % Frisian x 25% Boran) crosses using locally produced semen appeared to be 2556 and 2566 lt, respectively. In beef research, average body weight (kg) of local breeds of male cattle fattened with locally available feeds for 3 to 6 months reached 411 for Fogera, 382 for Horro, 355 for Arsi and 338 for Boran.

Sheep and Goats: performance characterization of indigenous breeds, identification of on-farm production constraints, performance evaluation of crossbreeding programs designed to increase meat, wool and milk production were undertaken. Productivity has been enhanced by introducing exotic breeds and crossing with local ones.

Poultry: improved feeding, housing and health management packages have been developed. Some exotic breeds (Fayoumi, Koekoek, Hubbard classic, Hubbard JV, Lohmann Silver, and Dominant D102) have been tested and adapted. An indigenous breed “Horro” has been developed through mass selection and its egg productivity increased form 40 to 60 to 150 to 170 eggs. A white feather synthetic line, a breed suitable for semi-intensive commercial production system is also on its final stage of development. Feed formulation based on local sources has been also achieved for different chicken breeds.

Fishery: water bodies have been characterized for their liminological, physical and chemical features and their suitability and potential for fish production, fish productivity estimated, suitable fish strains identified; fishing gears recommended and fish preservation practice established. In addition, marketing and fish value chain for the major producing areas has been documented. Besides, information on aquaculture management practice generated.

Apiculture and Sericulture: information on characteristics of honey from apis species, management practices, feed and feeding options, low cost hives and identification and control of major bee pests generated. Introduction of movable frame hive technology increased the national average honey yield from 7 to 25kg. Different Queen rearing technologies were developed and promoted. Quality standard for honey and beeswax was established. Some 9-specialty honey of its own characteristic identified. In addition, 20 different pests and predators identified and their control measures recommended. Entrance feeding technology was also developed. Better performing silkworm strains identified, their management practices established, economic feasibility as well as feed studied.

Camel: information has been generated on camel diseases and parasites, traditional production practices, feeds and nutrition, meat and milk handling as well as marketing of camels and their products and socio-economic aspects of these areas. Besides, rangelands’ biophysical characteristics, management and utilization practices as well as socio-economic aspects of associated communities studied.

Natural Resources technologies

As of early 1970s blanket rate of 100 kg ha^{-1} DAP or 50 kg ha^{-1} Urea + 100 kg DAP ha^{-1} was recommended irrespective of crop and soil types. Since then refinement was made and crop & soil type and agro-ecology based nutrient recommendations drawn up for major crops in the major growing areas. Likewise, via P-calibration studies, critical P concentrations and P requirement factors have been determined for major crops and soil types of various agro-ecologies of the country. Extensive study has also been conducted on microbial fertilizers and effective strains recommended. Integrated soil fertility management like incorporation of the green manure plant species have been identified as effective to improve soil fertility and enhance the efficiency of applied fertilizer and increase crop yield. The research system has been able to improve Vertisols management through various ways like using BBF to drain excess water from the field. Besides, techniques of acid and saline soil management have been developed; irrigation technologies as amount, frequency and method of water application have been established for various crops.

Agricultural Mechanization

Agricultural mechanization research began in Jimma and Alemaya Agricultural Colleges in the 1950s and at CADU in the 1960s. Since 1976, the IAR has taken up organized testing and modification of farm implements that later culminated in the establishment of a national coordinating center, AIRIC in 1985. Although, animal drawn mouldboard plough was for the first time introduced to Ethiopia by Italians in 1939 (Kaumbutho et al., 2000) and the BBM technology through vertisol project, EIAR had a valuable contribution in evolving and development of these technologies. As a result, EIAR innovations that are popular and widely known include Mould board plows and Tie ridgers. The research system also introduced multi-crop threshers, milk churner, donkey carts, chain and washer pumps, animal drawn planters, rippers, etc.

Socio-economic studies

The agricultural research system has made many surveys and characterized agro-ecologies and farming systems, identified constraints and opportunities and suggested alternative solutions. It has also made adoption studies and identified factors influencing adoption; assessed the impact of technological change, studied utilization, productivity, profitability and efficiency of resources, risk and risk management, enterprise choice and farm decision-making; performance of input and output market; gender roles and rural labor structures; consumer preferences and consumption pattern, and value chains. It has also extensively demonstrated and popularized technologies to help enhance their uptake.

Adoption and impact of agricultural technologies

While improved technologies proved to offer immense benefits, however, its effectiveness has been circumscribed by the socio-economic, culture and institutions of the local community within which they are applied resulting in most of the benefits from investing in research come only from few best discoveries at any one time. Therefore, despite a number of improved technologies developed by the research system for inefficient technology delivery system and users' incapability they were not satisfactorily taken up in the right time and circumstances they were developed for. Rather quite a number of technologies remained shelved and went out out-of-date before they are used. Consequently, the research system's technology potential has remained unleashed until the recent past to the extent that it created an impression of belittling its efforts.

Consequently, agricultural technology uptake has not been to the desired level to the effect that the productivity gap among the farming community itself (between lead and follower farmers) reaching as high as 50% and between the average farmer and the research recommendation as high as 70%. Even then, there are several showcases that the research system has made visible impact on the nation's agricultural production. A study made to track wheat and maize adoption levels using DNA fingerprinting showed that about 96% of the respondents cultivated improved wheat varieties and 61.4% of them improved maize varieties in 2013. Generally, different studies indicate that wheat and maize have the highest adoption rate of 62-96% and 56-64%, respectively (Dawit pers com.). Likewise, tef has 76%, lentil 40%, chickpea 26% and malt barley 100%. Generally, research efforts together with interventions in other areas helped modernization of the country's agriculture and perform better. Indeed, in recognition of its contribution and impact the research system has been bestowed with various awards. Gold Mercury award for developing and transfer of CBD resistant coffee varieties, national STI awards for wheat, tef, potato, chick pea, lentil, sesame, barley, spices, chicken, bio-pesticide etc.

The future of Agricultural research

Global and country situations are fast changing. Global trends are that agriculture in the 21st century faces multiple challenges: produce more food and fibre to feed a growing population with tightening resources (labor, land and water) necessitating adoption of more efficient and sustainable production methods and adapting to climate change (FAO, 2011). Likewise, country trends are that socio-economic and environmental landscapes are changing fast and agriculture is witnessing fundamental changes and challenges as low productivity.

Therefore, the research system should be in the lookout for evolving national and global opportunities and envisaged challenges that agriculture sector will face in delivering high yielding crops, improved animal breeds, pest and disease management techniques, post-harvest technologies, climate smart technologies, etc. Besides, in Ethiopia for the AEZ complexity there are several unaddressed or less addressed zones as high and low moisture stressed areas, dry lands, frost prone highlands, pastoral & semi-pastoral areas, western humid-hot lowlands, urban/ suburbs, flood plains, etc. Also, in terms of addressing stakeholder and customer demand the research system would need to focus on youth, women, socially vulnerable, commercial farmers, herders, and urbanites, which are either unaddressed or less addressed.

How can agricultural research respond to evolving agricultural development needs?

The research system in order to adapt and respond to the evolving technology demands, among others, it needs to ensure that it follows a sustainable development trajectory and address issues holistically, has a clear strategy, research approach, capacity and capability, and embrace frontier sciences.

The need for research in sustainable agriculture

New prototypes of agricultural research in the 21st century require more efficient and productive agriculture without further endangering ecosystem services. This means that agricultural research should achieve a doubly green revolution that ensures productivity increases while providing adequate responses to environmental concerns, and within the context of sustainable development. This concept dubbed sustainable intensification requires agricultural research to consider ecological and genetic intensification within enabling environments created by processes of socio-economic intensification. Biology-based green revolution as genetic engineering helps to achieve productivity gains, enable crops to be adapted in response to climate change, to be custom engineered for varying ecosystems, and to introduce resistance to biotic stresses (ADB, 2011). Research approaches like climate smart agriculture, conservation agriculture, precision agriculture, micro-irrigation; targeted irrigation, use of drones for insect and disease monitoring, irrigation needs, etc. can also help ensuring a sustainable agriculture to be pursued. Besides, efficient farming systems as composite farming, integrated crop management, integrated nutrient management, integrated pest management, and integrated water management need to be adopted.

The need for system research

In the context of changing socio-economic, cultural and political environment and a higher speed of change & shorter reaction time to prepare for unexpected developments effective approaches of today are insufficient for the future. Strong feedbacks between environmental, social and economic systems increase changes, uncertainty and risks making targeting a single problem inadequate. Farmers' profile and agricultural portfolios are so diverse & complex that providing solutions for one or a few enterprises cannot positively change the entire system; rather it creates a kind of disequilibrium analogue to the concept of the law of the minimum.

Therefore, a-dab-of-this and a-bit of-that approaches cannot profoundly solve farmers' complex problems. Rather, we may need to use systems perspective for which better literacy of agro-ecosystem, socio-cultural and economic situations is needed. Therefore, a much wider research agenda is required that is well beyond the traditional agricultural disciplines (Ritter, 2012) to intervene at landscape level, ecosystems, value chains, etc.. This in turn requires casting a wide net to involve as many stakeholders and far more inter- & trans-disciplinary research. Hence, acknowledging the increased complexity of agricultural systems future agricultural research need to shift from simplicity to complex multi-stakeholder R&D processes, multi-disciplinarily and multiple value chains.

The need for balancing between technology adaptation and generation

The fact that agricultural research is a venture with long gestation period on one hand and public expectation and wish for short-term benefits on the other, presents a tough challenge to the research system. Therefore, to continue to win public support the research system should devise a strategy of a research portfolio capable of providing short-term outputs while keeping long-term objectives of significant outcomes on track. In this regard, it is well known that research findings have the potential to spill both into and out of local areas and that, spillovers have been a pivotal part of the history of agricultural innovation. The agriculture and STI policies of Ethiopia speak emphatically of technology adaptation. Literature also tells us that many developing countries have made progresses through investments that focused first on the entry stage of technical imitation before moving onto innovation.

The research system in Ethiopia has been adapting technologies since 1970s that continued intensified to the present day. While building a national research capacity and capability, technology-shopping needs to continue strengthened to the extent that some technologies would be purchased on a royalty fee basis. NARS should therefore take full advantage of the vast stocks of knowledge that exist elsewhere in the world and tap it to spur innovations in the country. And it needs to do it so, not only just today when we are laggards but also after we catch up to learn from others' unique competences. While such exploitation of proven technologies will provide the greatest gain in the short time and help us live up to the expectations of beneficiaries, however, this will diminish in time. Of course, no country can grow sustainably relying only on technology adaptation indefinitely. Therefore, NARS has to build domestic research capacity to develop adequate homegrown technologies and ensure technology security. The bottom line is that the research system needs to balance between exploitation of proven technologies elsewhere and exploration of new knowledge and technologies within the system.

The need for balancing between applied and basic research

For the last 50 years, our research system has been focusing on applied research, and that was indeed a right direction and needs to continue strengthened. Nevertheless, since new products do not appear full-grown new impetus must also be given to basic research, as it is a leading light of technological progress. Several of the most vital findings of the world have come because of research undertaken with different purposes in mind. Hence, going forward without losing sight of applied research gradually we need to make use of basic research as pacemaker of technological progress in our research system. This will enable us rely on our own efforts, develop our own ingenuity and persevere in freedom and self-sufficiency while protecting our sovereignty.

Leveraging promises of cutting edge sciences

We are now on the cusp of a new era where developments in modern biosciences are providing significant new opportunities for productivity enhancement (ICAR, 2011). Biology-based green revolution as genetic engineering help us achieve productivity gains that would enable crops to be adapted in response to climate change, to be custom engineered for varying ecosystems, and to introduce resistance to biotic stresses (ADB, 2011). Spin-off technologies like genome sequencing and marker-assisted breeding help in tailoring plants and animals to local needs and respond rapidly to climate change and nutrient deficiencies. Therefore, Ethiopian NARS will need to embrace contemporary sciences like modern biotechnology, ICT and remote sensing. In this regard, to scale the heights of modern science and technology EIAR had started agricultural biotechnology research activities a decade ago, and it pioneered to establish a fully-fledged national agricultural biotechnology research center in the eve of its 50th year anniversary. These should take us forward in our endeavor and advance towards the mastery of modern science and technology to improve our research efficiency, better targeting of technologies and also identifying production and marketing environments.

The need for a clear research trajectory

The future, as always, is veiled with uncertainty and hence it would be difficult to draw a clear portrait of a long-term trajectory for agricultural research. To avoid surprising developments in the uncertain world, nevertheless, leading the agricultural research with foresight and anticipatory governance would be crucial. Most importantly, in view of the changing and complex reality, having strategic & long-term orientation of research agenda is very important. Apart the tasks and responsibilities indicated in its proclamations, IAR has not had clear long-term strategies at the beginning. Because of this, in much of its trail especially in its formative and early stages the research system has been mainly relying on its proclamations and proceeds of the different scientific forums of the then time, for instance, NCIC to guide its directions and priorities.

The first attempt to formulate an agricultural research policy was in 1979 by the Ethiopian Science and Technology Commission. The next was in July 1984 when a 10 years Agricultural Development Plan, on which research debossed in, was developed in alignment with the 10 years Perspective Plan. Again, in 1994 there has been an attempt to develop agricultural research policy, though it lacks legal framework and was not put to use. The first systematic effort to formulate a well-organized plan was during that of Strategic Plan Management, SPM in 1997.

In the year 2009, EARO developed a 15-year National Agricultural Research Strategy, which later reframed in alignment with the country-wide institutional reform- BPR. In 2015, a comprehensive far-sighted National Agricultural Research Road Map has been developed by the Ethiopian Agricultural Research Council, which articulates the trajectory of the research system for a catch up through harnessing the power of science. In line with this roadmap and as a continuation of the concluded strategic plan, in 2016 EIAR is preparing a 15-year National Agricultural Research Strategy that its short-term objective is aligned with its GTPII plan. Nevertheless, in addition to the research roadmaps and strategies, there needs to be a national agricultural research policy to guide future public and private agricultural research in the country.

The need for strong research coordination

Ethiopia being a big country with diverse agro-ecological zone and socio-economic settings, it requires varied research services and solutions through a more attuned locally relevant research agenda. In addition, it being a federated country where agricultural development agenda is more of regional, research decentralization is expedient for addressing specific needs of local community and making agricultural research more outward looking, client oriented, and impact driven by bringing agricultural researchers closer to their clients- the farmers.

Cognizant of the above the agricultural research system in Ethiopia has been administratively decentralized in early 1990s following the country's federal structure. Following this, there had to be a mechanism whereby decentralized research and innovation but a central learning process and coordination system put in place; which unfortunately was not. Consequently, as seen over the years the decentralized research system has had several weaknesses of which lack of seamless coordination among the constituents being a serious one. Therefore, the Ethiopian Agricultural Research Council came into picture in 2014 poised to provide overall facilitation and coordination role for the agricultural research system. But, EARC cannot be a replacement for the technical/research level national coordination that has to be effected among NARS entities themselves. At the core of this coordination is a National Commodity Team instituted in a research center designated as Center of Coordination, which EARC needs to expedite to identify such centers. In organizing national commodities, it is advised that Ethiopian NARS follows suit the EMBRAPA experience that combines product, resources and theme approaches. In a nut shell, as science is a collective action NARS constituents need to mobilize all their scientific professionals to collaborate in vigorous spirit with one heart and mind so as to storm strongholds of science.

The need for strong research partnership

It is true that science is cumulative with a snowball effect which much of today's agricultural production uses genetic material and knowledge that had its source thousands of miles away. Today, most fresh challenges like climate change demand a worldwide coordinated effort to tackle the problems. Hence, in today's globalized world it is crucial for the research system's very existence to improve the mechanisms of interaction with other countries, universities, funding bodies, etc. In this regard, EIAR has been serving a gateway for IARs especially CGs. Going forward, therefore, the research system needs to cast a wider net and foster linkage and collaborations with public and private, national and international organizations.

Institutional innovation

The three most important factors influencing change and innovative capabilities are human resources, organizational cultures, and governance structures (Ekboir, et al., 2009). In light of this, the following issues need to be addressed in Ethiopian NARS.

Research governance

Governance is a space for collective action and it includes dimensions of operating processes. Research institutions should ensure that there exist an atmosphere relatively free from the adverse pressure and excessive bureaucracy, and a substantial degree of personal scholarly liberty for scientists work. The agricultural research system varies considerably in various ways from other public service institutions. For instance, the planning time for the subsequent fiscal year is concluded far ahead in the prevailing fiscal year; the final outputs are hardly gotten in the same year of planning; research is a team work which is difficult to evaluate individual efforts, its complex network makes timely financial transaction and report flow difficult. Because of such peculiarities, it is often difficult to apply public service rules and regulations in the research governance.

Taking a leaf from other country's experiences like EMBRAPA (Brazil) and ARC (Sudan), therefore, one option that can be considered in Ethiopian NARS would be to institute the research system as a Public Agricultural Research Corporation. This would release it from the bureaucratic rules used in the public Service administration, and thus give it the flexibility to administer resources and personnel, while the relationship with the outside world and with the private initiative would be much easier.

The need for strengthening agricultural research capacity

Research investment in science and technology requires large amounts of capital, educated labor and sophisticated equipment. Undoubtedly, the NARS research capacity to service agriculture has been substantially improved over the years that it has grown to a full-bodied institution capable of running a nationally coordinated research. Nonetheless, the science today is changing rapidly with the emergence of new tools, methods, techniques and approaches that promise technological breakthroughs (ICAR, 2011). While revitalizing the existing facilities, there needs to be a strong investment on modern line facilities laboratories, field and greenhouse facilities, bioinformatics, geospatial technology, software, and digital technologies.

History indicates that countries that succeeded in catching up have indeed dedicated substantially more resources to the acquisition, assimilation, and adaptation of imported technologies than those devoted fewer resources (Ekboir et al., 2009). In Ethiopia, major fund for agricultural research comes from government sources and it is on an increasing trend. In its year of establishment EIAR started with a total cash investment of only 2.3m Birr (1.4m from Donor) Abebe Kirub and Fentahun Mengistu (2015) and today it reached 495m Birr though most of the money goes for pay roll expenses leaving little money for operational expenses. Despite these positive trends, however, the intensity of the country's agricultural research investment effort remains far below the Sub-Saharan African average (Beintema and Menelik Solomon, 2003) and is one of the lowest in Africa standing just at 0.19% in 2011as against 1.22%, 1.22% and 0.54% for Kenya, Uganda and Tanzania in that order and CAADP target of 1%. Therefore, research financing and intensity need to increase and consistent with the CAADP target commitment the government needs to allocate 1% of agricultural GDP for research. Other innovative financing mechanisms need also to be considered. For instance, government may opt to allocate a certain amount of its levy for agricultural research. The research institutions need to be privileged to use internal revenues (from research byproducts, training and consultancy services, royalty fees, etc.) flexibly for staff motivation and reinforce minor capacity loopholes. Philanthropic organizations need to be encouraged to establish research foundations to fund research. Contractual research like with private firms, cooperatives, and strengthening capacity for competitive grants might also need to be resorted to. In addition, occasionally loan/donor support may need to be solicited especially for capacity building.

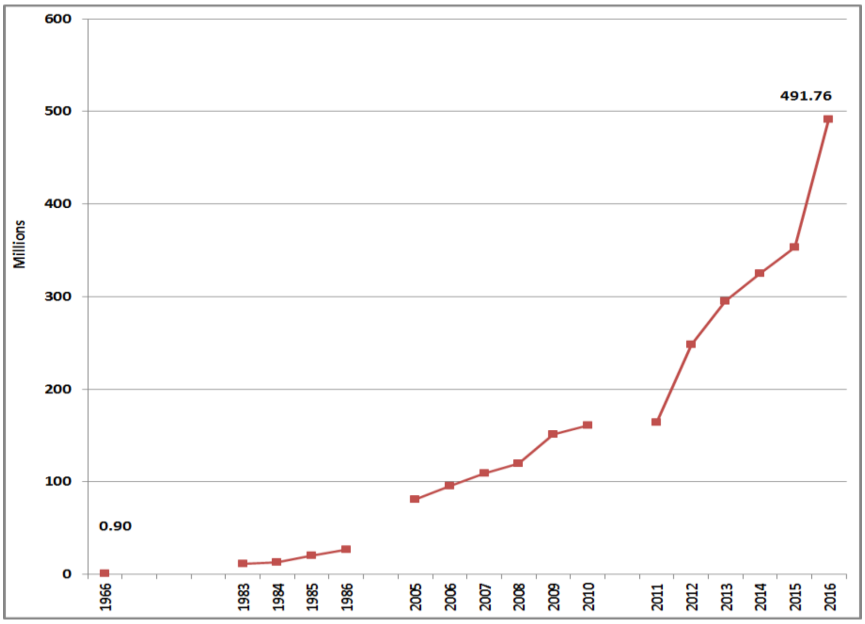

Figure 2. Government budget allocation for IAR/EIAR by year

For modernization of S&T we must have an enormous scientific force with adequate competitive intellect and inner drive. Hence, the research system needs to develop and nurture first-rate competitive scientists of upto the highest global standard and befitting global competition. The NARS scientists of diverse disciplines are the gold nuggets, which the system draws on them for its technology development pursuits. Imbued with good institutional culture and enduring hardship they have devoted themselves heart and soul to their work and made truly successful contributions. If we look back in history, in 1986 EIAR had only 210 researchers (Seme Debela, 1986) that rose to 629 as at 2006 (Tsedeke Abate, 2007) and today EIAR alone has got close to 1000 researchers. Nonetheless, the research system is still to a great extent in the kingdom of necessity. Indeed, Ethiopia has one of the fastest growing but youngest and least-qualified pools of agricultural researchers in Africa. The NARS researchers with BScs (57%) compares with 15% in South Africa, 1% in Brazil and nil in India. Likewise, while our PhD holder researchers stand at 8%, it is 37%, 75% and 86% in South Africa, Brazil and India, respectively (EARS, 2014).

On the other hand, EARS suffered heavy staff attrition of trained staff; of those 385 who have been sent for training between 1995 and 2000, 18% have not returned (Tsedeke Abate, 2007). Following BPR the research system lost 640 researchers of which EIAR alone lost 195 researchers and few support staff (STI, NARS). This has resulted in generation gap, which makes the recruitment and nurturing of younger generation even more urgent. Therefore, there should be a comprehensive long-term work force development and retention strategy. This could include recruiting unique talents; re-engagement of old-handed retirees, joint-appointment, secondment, aggressive long term training at home and abroad, instituting short-term skill development centers, etc.

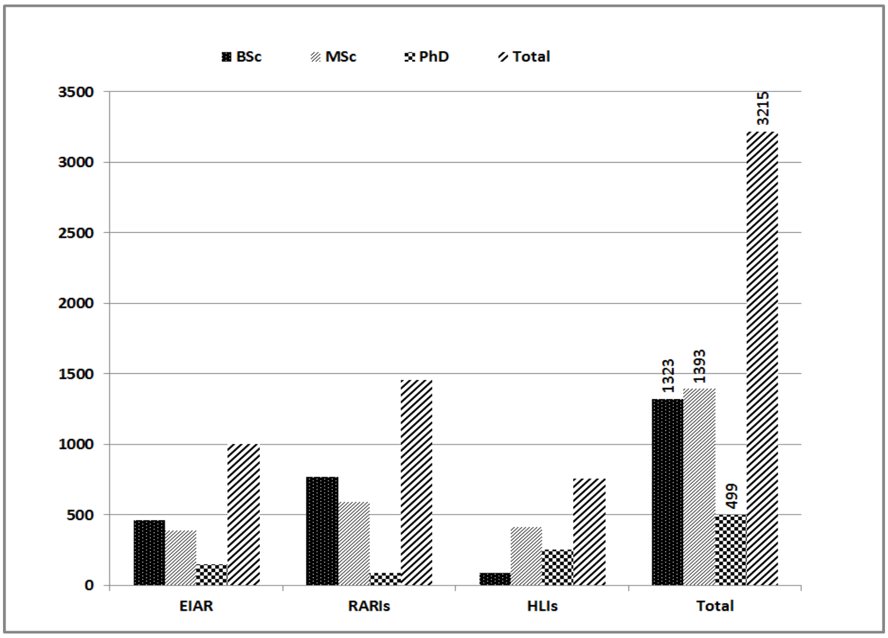

Figure 3: NARS manpower status, 2014 (Source: EARC Roadmap)

Conclusion

The Ethiopian agricultural research has been instrumental in contributing to the improvement of agriculture and economic development. Going ahead, the challenges will likely be much more difficult to deal than today as demand for food and feed is increasing while resource base is dwindling. The hard-won agricultural development gains by yesteryear's efforts need to be sustained in the changing environment for which it needs to be backed up by a strong research.

Without modern science and technology, it is impossible to build a modern agriculture, and without it, there can be no rapid development of the economy. It is the difference in the accumulation of research results over the long haul that accounts for a sizable share of the differences in agricultural productivity observed around the world.

As EIAR enters into another half century, therefore, the lessons learned from the past efforts will need to continue to inform the work of new generations of scientists, farmers, and public and policy makers of this great nation. Nevertheless, agricultural research to respond to evolving needs there needs to be a paradigm shift in the approaches, capacities, speed, etc. of agricultural research. Accordingly, a system perspective and sustainable intensification approaches need to be pursued while leveraging innovative sciences. In addition, a fair balance needs to be struck between technology adaptation and generation, and between applied and basic researches. Clear research strategy, seamless coordination, strong partnership, institutional innovation and capacity building especially for researchers that are the lifeblood of scientific work are all needed. By doing so, it is believed that agricultural research would play a key enabling role in ushering Ethiopian transformation and renaissance.

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Malt Barley Research and Development in Ethiopia: Opportunities and Challenges

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Introduction

Barley (*Hordeum vulgare* L.) is a crop grown by small farmers in Ethiopia, adapted to a range of agro-climatic conditions and highly integrated to the farming system in the highlands. It is cultivated in almost all regions of Ethiopia ranging from 1,400 meters above sea level (m.a.s.l.) to over 4,000 m.a.s.l, demonstrating a wide ecological plasticity (Berhane et al., 1996). It is grown as a sole crop or mixed with wheat, potato and faba beans in the highlands where land holding is very small. Barley is the fifth most important cereal crop in the country after maize, *teff,* wheat and sorghum (Table 1). It is produced on about 1 million hectares of land from which 1.95 million tons of grain is produced annually (CSA, 2015). The average national yield of barley is about 1.96 tons per hectare, which is low compared to the world average of 3.1 t/ha (FAO, 2014). More than 80 % of the barley production comes from Oromia and Amhara National Regional States (Table 2).

Table 1 National Estimates of Area, Production and Yield of Major Cereal Crops in 2014/15 crop season

Crops	No. of small holder farmers	Area (‘000ha)	Production (‘000t)	Yield (t/ha)
Cereals	13,340,462	10,152.01	23,608.62	
Tef	6,536,605	3,016.06	4,750.66	1.57
Maize	8,685,557	2,114.88	7,235.55	3.43
Sorghum	4,993,368	1,834.65	4,339.13	2.37
Wheat	4,614,159	1,663.85	4,231.59	2.54
Barley	4,095,273	993.99	1,953.38	1.96

Source: CSA, 2015

Table 2. Regional Estimates of Area, Production and Yield of barley in 2014/15 crop season

Region	Area ('000ha)	Production (‘000 ton)	Productivity (ton/ha)	% of area	% Total production
Oromya	456.19	1023.91	2.17	46.0	54
Amhara	362.74	588.77	1.58	36.0	31
Tigray	99.05	160.27	1.62	9.5	8.4
SNNP	73.61	132.36	1.72	7.5	6.9
Ethiopia	992.37	1908.26	1.87	-	-

Source: CSA, 2015

Barley cultivation is an old heritage in Ethiopia with a large number of farmers’ varieties and traditional practices. Approximately, 85 % of land allocated for barley in Ethiopia is used for food barley production. On the other hand, nearly 150,000 hectares of land (15 % of total barley land) is used for malt barley production, which is the major input for beer production. Ethiopia has enormous potential for malt barley production though its current share is very small as compared to food barley. Although there is a considerable potential for increased production of high quality malting barley, the production of malting barley in Ethiopia has not expanded enough to benefit most barley growers. Among others, limited number of quality malt barley varieties and associated production technologies to farmers, biotic factors (mainly weeds, insect pests and foliar diseases), abiotic factors (low soil fertility, low soil pH, poor soil drainage, drought and poor agronomic practices), weak technology transfer, poor access to markets and unattractive malt barley price are identified as the main constraints responsible for low productivity and limited expansion of malt barley (Bayeh and Berhane, 2011).

Selection of malt barley has to meet certain quality standards, the most important of which are the protein content, extract yield, plumpness and germination capacity. The availability of malt barley depends on the general conditions of barley production environment. Malt barley requires a favorable environment to produce a plump and mealy grain. The malt barley varieties adapted to Ethiopian conditions require a longer period of ripening. They tend to grow in a relatively cooler climate with uniform rainfall distribution (700-1000 mm). It grows best at altitudes ranging from 2300 to 3000 m.a.s.l. in well-drained soils with pH of 5.5–7.3. In the barley-based farming systems of the highlands of Ethiopia, smallholder farmers have very few alternative cash crops. One source of income could be growing malting barley, which has dependable local buyers in the country. Malt barley technology suitable for the conditions of Ethiopian farmers will surely increase domestic supply by increasing the domestic share of the malting barley market with significant economic benefits to resource-poor farmers.

The barley research and development in Ethiopia is gaining much attention from the government and the private sector especially the malt factories and the breweries, which are the main players for the development of the barley industry. The recent public-private-partnership between the public research and development institutions and the malt factories and breweries have boosted the malt barley production and the beneficiaries along the value chain. However, production and distribution of malt barley of reasonable quality remains a major problem limiting the expansion of malt barley production to new but potential production areas. Thus, there is a need for a concerted research and development effort to expand malting barley production in the country to meet the raw material needs and be able to minimize the cost of import of malt barley. However, the benefits from malting barley research and development depend on the market potential of increased malting barley production. This can be analyzed by the demand and supply trends both globally and at the domestic markets, the potential for expanding production, market competitiveness and the bargaining position of resource-poor farmers vis- a- vis the brewing industry and their role in malt barley production. In this paper progress in malt barley R&D, opportunities and challenges are discussed and recommendations forwarded.

Trends in malt barley production

Production of malting barley has a very short history and it is mainly associated with beer making in Ethiopia, which started in the early twenties with the establishment of the St. George Brewery (Tadesse, 2011). Local malt barley production started in 1974 with the identification and recommendation of three introduced malt barley varieties, namely Kenya, Proctor and Beka to reduce foreign exchange (Fekadu et al, 1996). Research on malting barley started in the early 1960s to identify suitable technologies for local malt barley production and hence to reduce the cost of malt barley imports. Self-sufficiency in malt barley was attained from 1987 to 1989 through annual production of over 19,000 tons of malt. Malt barley production expanded in both Arsi and Bale with the release of Holker, a selection from a local cross in 1979. The establishment of the Asela Malt Factory with a capacity of 20,000 tons of malt in 1984 further strengthened the local malt barley production in Arsi and Bale (Berhane et al., 1996). The demand was met largely by the then state farms and some cooperatives in Arsi and Bale regions. The momentum, however, was not maintained in the latter years due to closure of state farms and breakdown of producer cooperatives. Then after, breweries have reverted back to importing malt to supplement local supply. Producer cooperatives and unions were reorganized but still could not engage satisfactorily to produce malt barley partly because of limited capacity (human and physical) and lack of conducive market and price arrangements. In recent years, investment on breweries has increased and consequently the demand for malt barley has increased significantly. Currently, malt barley production has shown a significant increase both in area and in production but has still been dominantly restricted to Arsi and Bale administrative zones of the Oromia region. The area covered by malt barley production in Arsi, which is the major malt supply producing area, has significantly increased (Figure 1)

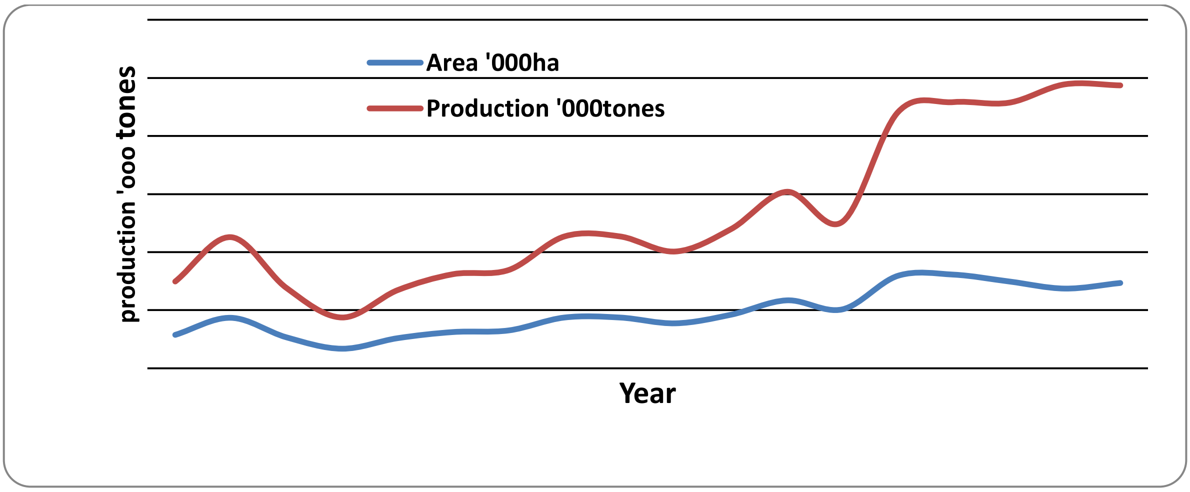


Figure 1 Trends in malt barley production and area allocated in Arsi, 1997-2014
Source: AMF and CSA reports

Achievements in malt barley research

A research program that improves crops that resource-poor farmers already grow as part of their farming systems help them diversify and increase their income. Research on malt barley has been undergoing for the last 50 years with the major objective to investigate the possibility of local malt barley production by developing and introducing appropriate malt barley technologies in order to save the foreign exchange incurred from import of malt. The research has been progressing on many fronts and the main areas of focus are:

1) Evaluating the local collection for suitability of malting purposes;
2) Screening of introductions from Europe, USA and ICARDA;
3) Hybridization of locally adapted elite lines with introduced cultivars for enhanced agronomic performance, disease resistance and acceptable malting quality;
4) Developing optimum crop management practices and fertilizer requirements and;
5) Demonstration and popularization of improved technologies to potential malt barley growing areas.

The malt barley research program has so far released and registered 16 malt barley varieties (Table 3). Of which, eight varieties are under production at different scales in the potential malt barley growing environments (Table 4). The varieties and associated production packages are contributing to increased income source of smallholder farmers in the highlands and enhance the local malt production supply to the malt factory. However, there is a need to develop more malt barley technologies with high yield potential and better quality standards to satisfy the local malt factories and breweries. This demand strong support to the malt barley variety development in terms of modern molecular techniques, small-scale micro malting and NIRS technology.

Table 3. List of varieties released from 1973-2015

No	Malt barley Variety	Year of Release/ Registration	Yield (qt/ha)	Remarks
1	Fanaka	2015	23-47	Introduced/Meta Abo
2	Traveller	2013	25-46	Introduced/Heniken
3	Grace	2013	24-45	Introduced/Heniken
4	IBON174/03	2012	30-57	Selection from introduction
5	Sabini	2011	25-40	Introduced
6	Bahati	2011	25-40	Introduced
7	EH1847	2011	35-44	Local Cross
8	Bekoji-1	2010	23-50	Local Cross
9	Firegebs	2010	28-42	Local Cross
10	Miscal-21	2006	25-46	Selection from introduction
11	HB-1533	2004	26-30	Selection from introduction
12	HB-52	2001	24-47	Local Cross
13	HB-120	1994	24-35	Local Cross
14	Holker	1979	24-31	Local Cross
15	Beka	1973	25-38	Introduced
16	Proctor	1973	2.1-4.4	Introduced

Table 4. Quality traits of Malt barley varieties under production

No.	Variety	Grain size > 2.2mm	TKw (g)	Total protein %	Fine Extract %
1	Holker	95.9	41.1	9.6	80.9
2	Bekoji -1	93.7	46.6	11.8	77.7
3	EH-1847	90.5	46.0	11.1	76.0
4	Bahati	97.0	47.1	10.4	78.6
5	Sabini	73.8	45.0	10.7	78.5
6	Grace	73.6	42.0	9.9	80.0
7	Traveller	90.9	46.0	10.1	84.7
8	IBON 174 /03	92.9	46.5	11.4	79.5
9	Fanaka	92.7	45.0	11.0	78.0

Yield potential experiments comprising six malt barley varieties were conducted in 2009 to estimate progress made in grain yield and quality attributes of malt barley breeding (Wondimu *et.al.,* 2013). Yield potential improvement of malt barley breeding was relatively less marked probably owing to stringent quality requirements. However, when 1979 is considered as a base year (the year Holker variety released), yield potential improvement has risen at annual rate of 28.95 kg ha^{-1}(0.88%) $year^{-1}$ (Figure 2). Generally, absence of yield plateau indicated the potential for further progress in grain yield and grain quality parameters. On the other hand, regression of kernel size of malting barley varieties on year of release showed that the slope is significantly ($P< 0.01$) different from zero indicating improvement in kernel plumpness. Kernel size ≥ 2.5 mm showed significant improvement of 0.27% $year^{-1}$ (Figure 3.) Likewise, malt barley breeding in the past three decades substantially reduced nonstandard seed size (≤ 2.2 mm) in malt industry (-0.21%) $year^{-1}$ (Figure 4).

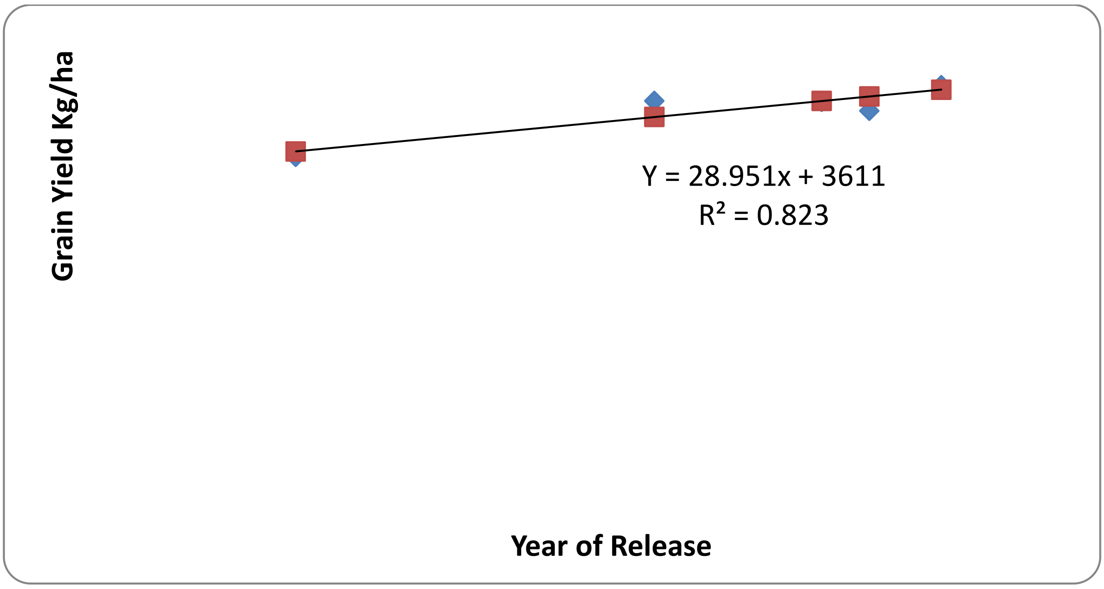
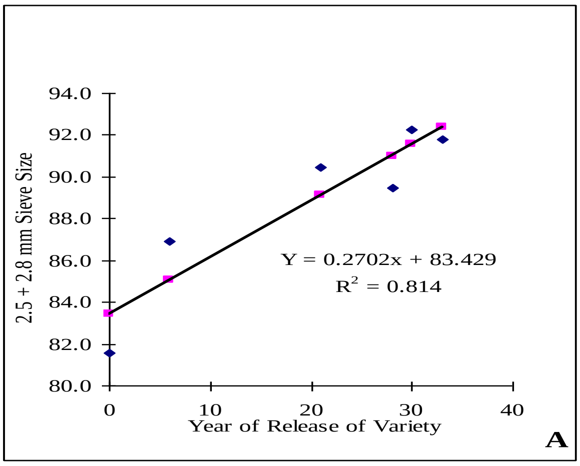


Figure 2. Genetic progress in grain yield



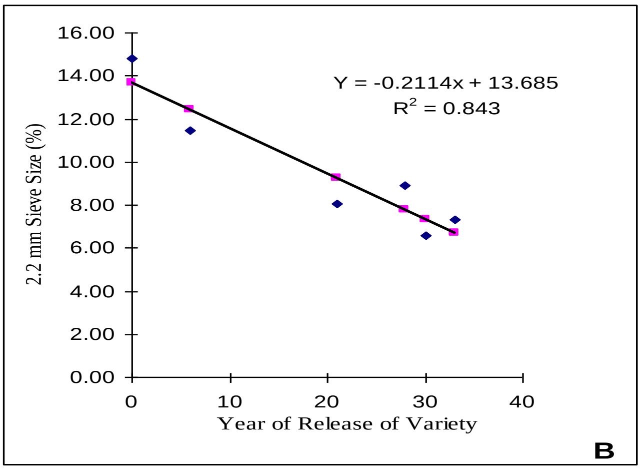


Figure 3. Genetic progress in grain size (2.5 mm +2.8 mm)

Figure 4. Genetic progress in grain size (< 2.2 mm grain size)

Useful research outputs in malt barley technology generation, promotion, capacity building and facility development were achieved during a five-years (2009-2014) public private partnership (PPP) project supported by the Assela Malt Factory and four breweries (Bedele, Meta, Harar and BGI). The project has strengthened the malt barley research capacity through financial support and enhances malt barley production through scaling up of available malt barley technologies. As a result, notable progress has been made in raising production in the project areas of the Central Highlands, Bale and Arsi covering 28 woredas.

Demand and supply of malt barley in Ethiopia

The malt and beer industry are increasing in Ethiopia where international giants like Heineken and Diageo are expanding their market. Now the government owned Assela Malt Factory, is the major malt supplier with an annual capacity of 36,000 metric tons and the newly established malting factory in Gonder started to produce 16,200 tons of malt per year. Although, this new malt factory will undoubtedly contribute towards fulfilling the malt demand, there will still remain unmet demand because of the establishment of new breweries such as Raya, Habesha, Dashen-Debrebirhan, BGI- Hawasa and Heniken - Walia as well as the planned expansion of the others. Following privatization of the breweries, the capacities of the local breweries has increased further widening the domestic demand and supply of malt barley (Table 5). Beer production has increased from 1 million hectoliters in 2003 to roughly 10.5 million hectoliters in 2016, registering an annual growth rate of 20%. With the envisaged expansion of current breweries and new entrants, demand is expected to reach about 179,350 thousand tons of malt, which is about 233 thousand tons of raw malt barley.

Table 5. Current breweries capacity and expected malt demand (2000-2015)

Year	AMF malt barley supply (tones)	Malt Barely imports (tones)	Value of imports '000USD	Total malt barley consumption (Tones)	% Domestic supply
2000	11,752.20	3,042.30	1596.31	14,794.50	79.44
2001	9,948.80	9,623.94	4344.63	19,572.74	50.83
2002	15,960.80	5,509.00	2516.10	21,469.80	74.34
2003	14,665.10	5,428.19	2807.41	20,093.29	72.99
2004	15,256.20	6,200.36	3574.72	21,456.56	71.10
2005	15,945.30	10,913.23	6048.58	26,858.53	59.37
2006	14,967.50	26,967.33	14394.22	41,934.83	35.69
2007	10,423.00	32,194.85	23887.72	42,617.85	24.46
2008	16,819.60	30,826.45	31287.76	47,646.05	35.30
2009	11,526.40	22,541.38	20050.69	34,067.78	33.83
2010	22,595.10	34,182.41	21024.03	56,777.51	39.80
2011	25,727.70	34,522.01	25151.78	60,249.71	42.70
2012	20,724.30	40,024.89	27846.03	60,749.19	34.11
2013	34,424.90	37,541.76	27748.04	71,966.66	47.83
2014	35,783.90	59,327.20	41032.34	95,111.10	37.62
2015	33,204.60	63,526.21	37645.99	96,730.81	34.33

Table 6: malt barely supply and import (roasted and non-roasted) from 2016 to 2018

No.	Brewery	Current Capacity (MHL/Y)	Malt Requirement (ton)	Expansion/New in 1- 3 years	Malt Barley grain Requirement (ton)
1	St. George brewery of BGI	2.6	44,200	-	57,460
2	Dashen Brewery of Tiret and Duet and vasart from two plants	2.9	49,300	-	64,090
3	Meta brewery of Diageo	1.6	27,200	-	35,360
4	Heniken Brewery from three plants	2.5	43,350	-	56,355
5	Habesha Brewery with Bavaria	0.3	5,100	0.35	6,630
6	Raya brewery with BGI 40 % share	0.6	10,200		13,260
7	Zebidar Brewery			0.35	
TOTAL		10.5	179,350	0.7	233,150

Source: Addis fortune.net/content/fortune-news/ and different brewery documents

The malt demand is based on an average requirement of 17 kg of malt to produce 1 hectoliter of beer and 1.3 kg of malt barley grain to produce 1 kg of malt. Currently domestic production potentially covers only 35% of the total annual demand (33,205 tons out of 96,731 tons) (Table 6). As a result, the county is importing significant quantities of malt grain to augment local production (Table 6). Malt imports has grown tremendously reaching 63 thousand tons in 2015 covering 65% of total annual demand and costing the country about 37 million USD (ERCA, 2014). Import of malt has risen tremendously from about 3 thousand tons in 2000 to over 60 thousand tons in 2015 registering 20-fold increases (Table 6). The main reason for such huge increase of import is due to the increased demand of malt because of the continuous expansion of breweries and the limited capacity of the existing malt factories to satisfy the current demand.

Ethiopia imports malt from different countries, mainly from Europe (Table 7). However, in the past five years, France is the dominant supplier to the Ethiopian market with an average share of about 26.1%. Denmark, Belgium and Netherlands had an average share of 22.8%, 19.7%, and 18.0%, respectively.

Table 7. Import of malt (t) by country of origin

Country of origin	2011	2012	2013	2014	2015	% Share
Belgium	33.50	5.52	2.62	25.17	31.55	19.7
China	0.00	2.75	4.40	0.00	0.02	1.4
Denmark	19.39	32.66	24.09	28.03	10.02	22.8
Egypt	0.00	0.00	0.00	1.81	10.47	2.4
France	12.64	31.33	46.39	19.11	20.76	26.1
Germany	4.57	8.53	3.94	9.74	14.24	8.2
Netherlands	29.86	19.21	18.46	9.60	12.95	18.0

Source: Ethiopian Revenue & Customs Authority, 2015

Malt barley marketing and price

The country's requirement of malt is met by local production and import. Assela Malt Factory used to be the only purchaser of malt barley in the country. However, following the start of operation of Dashen Malt Factory (DMF), there seems to appear competition in the market. The demand for malt by the end user breweries is progressively increasing. Since the amount of malt barley produced locally is not sufficient, end users of the product are forced to import from various countries (Table 8).

As shown in Table 8, the price of locally produced malt grain in 2015 was in the range of birr 925-1025, whereas the price for imported malt grain was about 991 birr. Similarly, the average price of locally produced malt grain per quintal in the same year was about Birr 2000. On the other hand, the current price for imported malt grain is slightly higher than AMF current selling price per quintal, which ranged from Birr 2,050 to Birr 2200. There are two possible reasons for the relative low price of imported malt barley grain. First, agriculture in Europe has been heavily subsidized. Second, productivity is high due to mechanized agriculture and high input use. However, Ethiopia has a huge potential to produce enough quantity of malt barely with some changes in the level of malt barley production practice, market development and policy environment.

Table 8. Price of raw malt barley and processed malt in 2014/15

Item	Price per quintal (Birr)	Remarks
Local malt grain - AMF purchasing price	925-1025	Based on quality standards (grade1-5)
Imported malt grain by AMF	991	Malt grain imported from Europe
Local malt - AMF selling price	2000	Malt produced by AMF
Imported malt	2050-2200	Malt imported by breweries
Local market price of grain barley	500-800	Based on color and grain size

Source Various reports of AMF and Breweries

Opportunities in malt barley sub-sector

The growth in demand is driven by economic fundamentals, including population growth, economic prosperity due to changes in real income levels, economic liberalization and social attitudes. Higher income, urbanization, and a larger proportion of young people are expected to continue to drive-up beer consumption and, thus, malting barley demand in the future. The following macroeconomic drivers can be taken as key opportunities that drive the malt barley sub-sector in Ethiopia.

Population growth: Coupled with economic growth, population growth has a tremendous impact on the growth of demand for beer and consequently for malt barley grain. The Ethiopian population is growing at a rate of 2.6%, annually, which along with the prevailing economic growth, induces additional demand for beer and other barley based products.

Urbanization and changes in culture, tastes and preferences: Rapid growth of many cities and the cultural changes where many households are moving away from brewing the local beer called "*tela*" at home in favor of purchasing commercial beer for regular home consumption and functions, parties and other occasions also play important roles. Moreover, there are clear changes in the tastes and preferences of the urban population where they are moving away from "tela" towards commercial beer which further increases the demand for commercial beer and hence the demand for malt grain and malt.

Conducive Business Environment: Given the relative peace and security in the country as well as some incentives from the government, the private sector's involvement in the national economy is gradually increasing and as a result, many private companies are now investing in beer production.

Increased foreign Community: The number of international organizations operating in Ethiopia is growing. As a result, the size of international community in the country is also increasing which spurs more demand for beer.

Foreign Investment: Investment policies and other supports attract foreign investors into the sector. Beer production and marketing is among the most lucrative areas of investment for foreign investors.

A Strength, Weakness, Opportunities and Threats (SWAT) analysis revealed that many opportunities are available, which if appropriately tapped, would spur further development of the sub-sector. Among the opportunities that enhance the development of the malt barley sector include supportive agricultural development strategies and policies, high demand of malt as a result of the engagement of big private companies in the sector, availability of malt barley technologies with good yield and malting qualites suitable for the diverse agro-ecologies, and undeveloped but potential malt barley producing areas, and high demand for the malt barley grain based products.

Challenges in malt barley sub-sector

Despite all efforts, however, malt barley production is still restricted to few areas and productivity is much below the potential. Key constraints that stifle the malt barley sector are:

1. Lack of high quality seeds of improved varieties is among the most important constraints inhibiting expansion of malt barley production to non-traditional malt growing areas.
2. Limited number of malt barley varieties meeting the requirements of smallholder farmers and the industries.
3. Traditional systems of land management and soil conservation. Consequently, land degradation, soil acidity and loss of soil fertility particularly due to soil erosion and continuous mining of the soil for crop production undermine the promotion of malt barley production in the highlands.
4. The land holdings of most farmers in the major barley growing areas of the country are less than a hectare. As is the case with most farming systems in the tropics, the immediate goal of the farmers under such circumstances is to meet the food needs of the family rather than to produce for the market. Hence, farmers may prefer using their land for food crop production. Moreover, malting barley harvested from different small farms is more likely to have high variation in quality, which makes difficult for aggregation and more importantly for maintaining product quality. The absence of substantial land in the highlands that can potentially be brought under large-scale commercial farms also makes input sourcing difficult for the factories.
5. Animal draft power is the major sources of traction for crop production in crop-livestock mixed farming systems. Lack of oxen negatively affects timely land preparation and planting thereby consequently affecting malt barley yields and possibly quality.
6. Farmers and some agricultural officers believe that two-rowed barley is less yielding than six-rowed barley varieties. Malt barley being two rowed type may be considered as low yielding, although there are malt barley varieties that can yield as much or better with appropriate practices than six rowed barley varieties with low screening loss and better malting quality.
7. Other more competitive crops such as wheat (which usually yields more than barley) and potato (regarded as a security food crop in many highland regions) may appear more attractive to the farmers than malt barley. Moreover, more bread wheat varieties have been released over a similar reference period than malt and food barley varieties combined together providing more choices and luring the farmer to the former than the latter.
8. Farmers' experiences with the use of inputs such as fertilizers and herbicides and their adoption into the farming system are not adequate. Farmers seem less attracted by the bumper harvests obtained from the use of these inputs under favorable conditions than a guaranteed but modest level of subsistence production that they are accustomed with and that entails minimum risk. Farmers are reluctant to take loans for the purchase of such inputs because the technologies may not be economical or there may be a risk if crop fail.
9. There exists very little potential for irrigated crop production in the highlands where barley is the major crop. Topography is the major hindrance to utilizing the big rivers for irrigating the highlands with the current level of economic development. However, small stream based irrigation systems that are within the reach of the small-scale farmers have in most cases developed to provide supplementary irrigation for *belg* season or residual moisture barley or other crops production.
10. Although farmers have been producing barley as a major crop for years, they lack the knowledge of specific management practices required for malt barley production. The current extension program emphasizes more on other crops, with very little attention given to malt barley.
11. Stresses such as unreliable rainfall, low temperature and hail damage in major barley producing areas may sometimes pose threat to malt barley production, especially at harvest time.
12. Barley diseases particularly scald net blotch, leaf rust and smuts; insect pests such as shoot fly, aphids, and chaffer grab, cut worms; and weeds mainly grass weeds are major problems for the production of the crop.
13. In some cases breweries are also inclined to imported malt barley with the reason that are getting price advantage.

Prospects and recommendations

The malt barley sub-sector in Ethiopia is in its infant stage. Recently, investment on breweries has increased and consequently the demand for malt barley has increased significantly. Following privatization, the capacities of the breweries has increased further widening the domestic demand and supply of malt barley.

The mismatch between domestic supply and demand on one hand and the favorable biophysical environment on the other indicate that a huge opportunity exists to enhance local production and substitute import. There is a relatively huge domestic market for malt of reasonable quality, where large number of farmers in the highlands of Ethiopia can potentially commit part of their barley area to malt barley production if the economic advantages of growing the crop are apparent, and effective extension and support services are in place. To date, production and distribution of malt barley of reasonable quality remains a major problem stifling the expansion of malt production to new but potential production areas. The recent public private partnership initiative on scaling up of malt barley technologies suggests that the problem could be resolved through concerted efforts of stakeholders. And yet, a lot remains to be done to resolve the seed problem at a national level. A wider production of quality malting barley in the country will therefore save substantial amounts of foreign currency, replacing imports and meeting other local consumption needs. Given the very low unit price of food barley, the production of high quality malting barley, which fetches relatively higher prices, would benefit smallholder farmers in Arsi, Bale, and other barley-producing highland regions. Furthermore, the wide gap between the volume of malt grain produced and the amount commercially traded call for a serious look at the malt barley grain marketing strategies currently used by the Asella Malt Factory and other processors. Production of malting barley could therefore serve as a source of cash income and would help to significantly improve the livelihoods of highland farm households in Ethiopia (Bayeh and Berhane, 2011).

The production of malting barley requires the use of quality inputs and agronomic practices. Therefore, if the ordinary barley producers are to take advantage of this niche market, they need to be provided with sufficient training, extension services, and the adequate (in quantity and quality) and timely delivery of productive inputs, including certified seeds of high yielding varieties, fertilizers, pesticides and herbicides. One way of effectively addressing this issue is the establishment of stakeholder platforms comprising Research institutes, bureau of agriculture, farmers, malt factories, breweries, farm input suppliers, small and large traders, and consumers to enhance the efficiency of the malting barley value chain in the country.

Considering the high potential impacts of malt barley, key reasearch and development areas that deserve special emphasis are scaling up/out of productive varitieties, managing acidic soils, location specific fertilizer recommendations and agronomic practices for the prodution of high quality malt, pest mangement, viable seed systems, and favorbale policies to boost malt barley production. These measures could diversify the livilihoods of barley-livestock based farming sytsems of the highlands and the economy of the country. Specifically, the main recommendations are:

1. In addition to the traditional malt barley producing areas of Arsi, West Arsi and Bale, the highlands in other regions could produce substantial amount of malt barley. Therefore, research need to demonstrate the biophysical, social and economic feasibility of the production of malting barley in new but favorable agro-ecologies.
2. Malt barley varieties currently under production (Holker, Sabini, Bahati, Bekoji-1) and the newly released and registered ones (EH1847, IBON 174/03, Fanaka, Grace and Traveller) from the national program are the most likely candidate varieties to be used in potential areas.
3. Appropriate crop management practices are important to increase malt barley production through enhancing malt quality. Thus, due emphasis should be given in developing new crop management practices and fine tuning the existing ones
4. Malt barley research targeted at identifying varieties specifically adapted to high potential areas should also be strengthened. Cultural practices appropriate for these locations should be developed and verified.
5. The current research capacity both in trained manpower and facilities should be strengthened both at federal and regional levels
6. In the current extension program, malt barley should get a “special crop status” particularly in high potential and accessible weredas since malt barley production requires some specific attention and training. Currently there are malt barley production technologies that can be taken to farmers. These technologies are expected to boost malt barley production in these areas at least for the initial period.
7. Soil conservation is another important issue that should effectively be addressed by the extension program since soil degradation is the most important factor that limits production of malt barley in the highlands
8. Enhance early generation seed multiplication of promising lines (pre-release) by NARS and the accelerated release of high yielding varieties (basic to certified) by the public and/or private sector;
9. The seed supply should be strengthened through secondary seed multiplication program. Strengthening the farmer-based seed multiplication scheme by promoting them to seed producing cooperatives is important. Moreover, the Federal and regional seed enterprises should also be encouraged to fulfill its national responsibility by producing quality seeds of malt barley varieties.
10. Cash crops in barley-based farming systems of the highlands are scarce. Malt barley is a likely candidate that could fetch cash to the farmers provided that farmers are paid competitive or better price for the malt barley they produce;
11. The experience of the public private partnership (PPP) in malt barley research and development initiatives demonstrated that there should be a win-win situation for all partners involved in malt barley research, development and business. At least for the initial period, the malt factory and the brewery industry should continue supporting the research, extension, seed production and marketing of malt barley through PPP.
12. In order to facilitate the extension, production (of both seed and grain) and marketing of malt barley, the role of cooperatives (unions and primary cooperatives) is very essential. This will enable the extension and the companies to assist farmers as groups and to carry out activities such as seed multiplication and aggregation of produce that need group effort.
13. The current contractual arrangements started by malt factories and breweries with cooperativesand unions for qualitymalt barley production and supply should be strengthened. There is a need to involve wider stakeholders to implement contract arrangements.

Malt barley is among the priority commodities that have attracted the attention of policy makers in Ethiopia. The government is keen to boost production of malt barley by appropriately supporting smallholder farmers and encouraging commercial farming. Recently, through a public and private partnership involving the Ethiopian Institute of Agricultural Research (EIAR), Assela Malt Factory (AMF) and four breweries (BGI, Meta Abo, Harar and Bedele), efforts are being made to boost malt barley production by strengthening malt barley research and scaling up of available and new malt barley technologies. As a result, there is an encouraging progress in promoting malt barley technologies in the high potential malt barley growing areas of the central highlands, Bale and Arsi. Malt barley has become very important following the rapid expansion of breweries in the country that has resulted in increased demand for malt. The gap in demand and supply can be captured by domestic supply if small farmers have the right technologies and institutional support through effective value chain approach.

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Review of Highland Pulses Improvement Research in Ethiopia: Achievements and Direction

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Introduction

Highland pulses including faba bean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L,) and lentil (*Lens culinaris* Medik.) are crops of multiple merits in the economic lives of the farming communities in Ethiopia. It is believed that these crops have been produced in Ethiopia since antiquity and the country is considered as the secondary center of Vavilovian diversity (Vavilov, 1950; Frankel, 1973; Harlan, 1973; Westphal, 1974; Engels *et al*., 1991; Muehlbauer and Tullu, 1997). Ethiopia is top producer and consumer of these crops in Africa. The crops serve as sources of food with valuable "cheap" sources of protein (Bejiga and van der Maesen, 2006), complementing cereal based diets as major component of the dish in most parts of the country in the range of an ordinary family to the palace. The highland pulses serve as sources of cash to the farmers and foreign currency to the country. They also play significant roles as "break" crops to pests (Malhotra *et al*., 2004; Kirkegaard *et al*., 2008) and in soil fertility restoration as suitable rotation crops by fixing atmospheric nitrogen, thereby result in savings for smallholder farmers from less chemical fertilizer use (IFPRI, 2010), and provide sustainability to the farming system (Gorfu, 1998; Bejiga, G. 2004; Hailemariam and Tsige, 2006; Keneni *et al*., 2012). Currently, faba bean, chickpea, field pea and lentil are grown closely on 1.2 million hectares of land (9.42% of the cultivated land) in Ethiopia from which over 1.95 million tons of seed is harvested (CSA, 2014). The major producing regional states in Ethiopia include Amhara, Oromia, Tigray, Southern Nations Nationalities and Peoples Region and Benishangul Gumz in that order. Most of these crops are produced with rainfall under marginal situation.

Despite the immense economic and ecologic merits, however, the productivity of faba bean, chickpea, field pea and lentil in Ethiopia is far below the potential due to a number of biotic and abiotc constraints, attributed, at least partly, to a combination of several biophysical and socioeconomic constraints in smallholder farms and inadequate technological interventions, which ultimately resulted in one of the least productive enterprise. The inherent low-yielding potential of the indigenous cultivars is among the most important production constraints (Telaye *et al*., 1994; Degago, 2000). Moreover, foliar and root diseases and abiotic stresses like drought, soil acidity, frost and waterlogging are among important production constraints that deserved priority as research objectives.

The Ethiopian Institute of Agricultural Research (EIAR), in collaboration with other national and international research institutions, has been making utmost efforts to contribute to the agricultural development in the country for the last fifty years. The hitherto research efforts made for the past five decades to reverse the situation of low productivity of these highland pulses have resulted in the development of a number of improved production technologies suitable for small scale farmers. In the past few years, Extension Package Programs at the national and regional levels, have proved the superiority of the research developed technologies as compared to farmers own practices, showing that EIAR has been serving as a premier institution developing and promoting agricultural technologies across the country.

Although a number of technologies have been developed and released to producers with the research efforts made in Ethiopia so far, it is hardly possible to say that most of these technologies have been readily accepted, properly utilized and modernized production at farm levels as desired (Keneni, 2007; Keneni and Imtiaz, 2010). Periodic assessment of the past research achievements and understanding of the amount of progresses realized through past research efforts is essential to improve the efficiency and effectiveness of future research endeavors (Tolessa *et al*., 2015).

The purpose of this paper is, therefore, to shed light on the progress of research efforts during the past five decades, identify challenges and opportunities, and propose better alternative approaches to be followed in the future.

History of Highland Pulses Research

The success of any agricultural development program largely depends on whether or not appropriate technologies are developed, made available, accepted and properly used in production. It was recognized long ago that unless and otherwise the realization of these steps was properly and systematically guided, it would have been difficult for Ethiopia to feed the increasing population. The idea of agricultural research in Ethiopia was first conceived after the establishment of the Arsi Rural Development Unit (ARDU) and agricultural colleges like the Alemaya College of Agriculture (now Haramaya University). Research on highland pulses was started by ARDU in the 1950's followed by Debre Zeit Research Center which was then under Alemaya College of Agriculture. The research efforts on crops in general and pulses in particular werestrengthened and organized on a multidisciplinary basis with the establishment of the then IAR (now EIAR) in 1966. Research works on the crops between1972 and1985 were limited to some locations in disconnected efforts. Since mid 1980's, however, wider collaboration between local institutions and with CGIAR Centers, particularly ICARDA and ICRISAT, further incorporated different perspectives into the research system.

Currently, Holetta Agricultural Research Center coordinates nationally faba bean and field pea research, while Debre Zeit Agricultural Research Center coordinates chickpea and lentil research with the collaboration of a number of federal and regional research centers. The main research objectives of the highland pulses include improvingthe productivity of the crops through development of productive cultivars (high yielding, better adaptation, resistant to biotic and abiotic stresses and better seed quality) along with best practice of crop management and protection. The research programs are organized as commodities of multidisciplinary team with specializations in plant breeding, agronomy/physiology, pathology, entomology, weed science, soil microbiology, research-extension, socio-economics and food science. Efforts are underway to maintain the same multi-disciplinary approaches at the collaborating centers.

Production and productivity of highland pulses in Ethiopia

Historical evidences showed that the national annual production of pulse crops in Ethiopia has increased from 600,000 metric tons to closely 2.5 million metric tons between 1961 and 2011. The periodical increments were attributed to increased areas under production and improved productivity per unit area of land. Currently, more than 1.2 million hectares of land has been cultivated to faba bean, chickpea, field pea and lentil in Ethiopia. During the last ten years (between 2005 and 2014), the area under faba bean cultivation was increased from 456,919 to 538,458 ha (15.14%), chickpea from 202,010 to 229,721 ha (12.06%), field pea from 233,087 to 275,386 ha (15.36%), and lentil from 84,895 to 125,831 ha (32.53%). The productivity of faba bean, during the corresponding period, was increased from 1.122 to 1.842 tons/ha (39.09%), chickpea from 1.048 to 1.845 tons/ha (43.20%), field pea from 0.782 to 1.379 tons/ha (43.29%), and lentil from 0.679 to 1.265 tons/ha (46.32%) (CSA, 2005; 2014). The national average annual production of these crops in Ethiopia has tremendously increased during the last decade as a result of increased areas under production and improved productivity per unit area of land, even if there is much more gap to be bridged in the future. The future plan of the Ethiopian Government is to increase faba bean productivity by 32.50% at the end of GTP II (2020), chickpea by 53.85%, field pea by 32.27% and lentil by 30.50% (MoA, 2016 GTP II Draft Document) (Figure 1).

This GTP could be achieved for many reasons. First, even if the productivity of most of the pulses in Ethiopia could not be undermined as compared to the global average (Akibode and Maredia, 2011), many countries like Egypt, China and Sudan achieved better yields and Ethiopia, if concerted inter-institutional efforts are made, could attain their levels. Second, the national average yields for most of these crops are low (1.3-1.8 tons/ha) and stagnant but, based on on-farm yield potential of the currently available improved varieties with recommended crop management and protection practices, the national average productivity should have reached 2.0-3.0 tons/ha for pulses (Jarso *et al*., 2011). Contrary to the expectation, the gap between on-farm productivity of improved varieties with the component packages and the national average is very wide (Figure 2). A substantial increase in productivity was not realized in as a result of many interplaying factors among which poor targeting of varieties (varietal relevance), inadequacy of improved seed and seed system, lack of proper application of improved packages by the farmers /sub-optimal syndrome/ and production under marginal condition.

Major production constraints

Ethiopia is located in part of the globe where poverty and human suffering from food shortage had been most prevailing. The major production constraints of highland food legumes that cause lower productivity and product quality in Ethiopia are associated with stresses from the adverse conditions for crop growth and production imposed by biological (biotic stresses) and environmental (abiotic stresses) factors. The biotic stresses including foliar and root diseases, field and storage insects, and non-parasitic and parasitic weeds are among the most important production constraints that contributed to a significant crop yield reduction both in terms of quantity and quality while the crops are still in the field (pre-harvest) and after harvest before the ultimate utilization (post-harvest) (Table 1). For some of those pests, particularly for the newly emerged ones like faba bean gall (*Olpidium viciae*) and *Orobanche* (*Orobanche crenata*) on faba bean and Pea bruchid (*Bruchus pisorum*) in field pea, there is limited knowledge and tolerant germplasm developed so far in Ethiopia to overcome their negative effects. Past research evidences in Ethiopia showed lack of sources of complete resistance/tolerance to some biotic stresses, particularly field and storage insects. The abiotic stresses include soil acidity, deficiency of soil nutrients, low external inputs with poor agronomic practices used by the farmers, and drought and frost (Table 1).

According to Bunters *et al*. (1996), farmers may attempt to improve their farming condition but it is generally accepted that the farmer's own innovative capacity can lead only to a minor improvement over the current practices and more fundamental change can occur only if farmers are supported with formal science-based knowledge. Even if a number of improved technologies of different legume crops have been developed and released with the research efforts made so far as presented below, the release of technologies by itself did not mean much as they were not well popularized, multiplied and availed and ultimately adopted by farmers. Improved technologies of these crops are not yet sufficiently put under production and most of the cultivated areas in the country are still under the traditional production system.

Farmers traditionally give least priority to food legumes in general in terms of land and input allocation and poor crop management starting from land preparation compared to cereals. Among the key management inputs, chemical fertilizers are the number one most important but they are the most expensive in Ethiopia as far as production inputs are concerned. The rate of fertilizer applied to food legumes by the farmers, for instance, is very low or nil with no or late weeding. The major constraints attributed to the low productivity in smallholder farms, therefore, include inadequate technological interventions and advisory services.

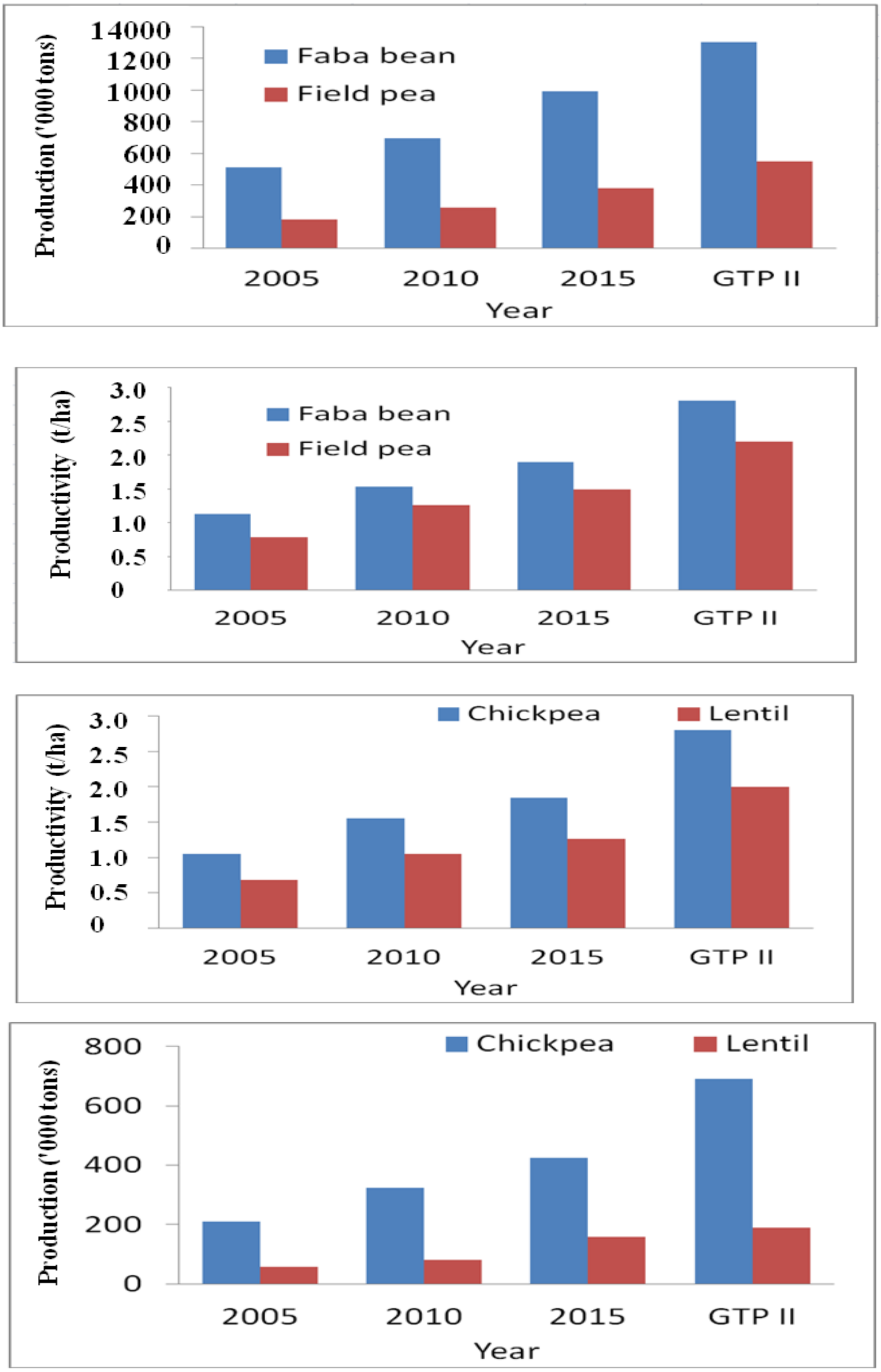

Figure 1. Trends of productivity and total annual national production in faba bean, chickpea, field pea and lentil between 2005 and 2015 in Ethiopia showing the steadily but smoothly increasing productivity despite the stagnation in cultivated areas (Sources: modified from CSA Data and MoA GTP II Draft Document)

Table 1. Faba bean, chickpea, field pea and lentil production constraints and challenges that deserved high research as prime priority areas in Ethiopia

Crop	Diseases	Insects	Weeds	Abiotic stresses
Faba bean	Chocolate spot (*Botrytis fabae*), rust (*Uromyces viciae-fabae*), root rot (*Fusarium solani*), faba bean gall (*Olpidium viciae*)	African bollworm (*Helicoverpa armigera*), bean bruchids (*Callosobruchus chinensis*)	Broad-leaved, and grass weeds, parasitic weed (*Orobanche crenata*)	Waterlogging, frost, moisture stress, soil environment (poor fertility and acidity), poor cultural practices
Chickpea	Ascochyta blight (*Ascochyta rabiei*), root rot (*Fusarium oxysporum*)	African bollworm (*Helicoverpa armigera*), cutworm (*Agrotis spp.*), bean bruchids (*Callosobruchus chinensis*)	Broad-leaved, and grass weeds	Waterlogging, moisture stress, soil environment (poor fertility), poor cultural practices
Field pea	Ascochyta blight/spot (*Mycosphaerella pinodes*), powdery mildew (*Erysiphe polygoni*)	Green pea aphid (*Acrythosiphon pisum*), African bollworm (*Helocoverpa armigera*), bruchids (*Bruchus pisorum*)	Broad-leaved, and grass weeds	Waterlogging, frost, moisture stress, soil environment (poor fertility and acidity), poor cultural practices
Lentil	Rust (*Uromyces fabae*), Ascochyta blight (*Ascochyta fabae*), root rot (*Fusarium oxysporum*)	Pea aphid (*Acrythosiphon pisum*), African bollworm (*Helocoverpa armigera*), bruchids (*Callosobruchus chinensis*)	Broad-leaved, and grass weeds,	Waterlogging, moisture stress, soil environment (poor fertility), poor cultural practices

Achievements of past research

Development of Basic Genetic Information

Progress from breeding largely depends on knowledge of genetic information, the sum total of which makes the whole background concepts and principles of plant breeding. These include the right choice of germplasm (genetic variability among the genetic materials), characterization and evaluation of germplasm, right choice of optimum selection environment and the right secondary selection criteria, inheritance of primary and secondary traits in a given environment, knowledge of genotype by environment interaction and performance stability of genotypes across environments (Falconer, 1989). Highland pulses breeders have developed basic information on extent and pattern of genetic diversity among germplasm accessions of highland pulses (Mekibeb *et al*. 1991; Tadesse *et al*., 1994; Tanto *et al*., 2006) including faba bean (Keneni *et al*., 2005a), chickpea (Workeye, 2002; Dadi, 2005; Keneni *et al*., 2012), field pea (Keneni *et al*., 2005b; Keneni *et al*., 2013) and lentil (Fikru, 2006; Fikru *et al*., 2011) at morphological and/or molecular levels. The studies showed that it would be possible to make genetic progresses from selection in landraces collections, introductions and their crosses except for some difficult traits like field and storage insect pests (Ali, 2006; Damte and Dawd, 2006; Keneni *et al*., 2011).

Multivariate approaches based on the biological responses of the crops were used to cluster the test environments into groups having similar ranking of all the genotypes with similar magnitude of G x E interaction which has important implication on deciding the environments for screening and evaluation of genotypes (Taye *et al*., 2000; Wolabu, 2000; Jarso and Keneni, 2004; Keneni *et al*., 2006; Jarso *et al*., 2006; Tolessa *et al*., 2013). The environments in each cluster are expected to have a similar contribution to G x E interaction as compared to the environments in the different groups of the cluster. It was also confirmed in faba bean that selection of genotypes under undrained condition is efficient for identification of genotypes for the drained target environments on waterlogged vertisols (Keneni *et al*., 2001). The right secondary selection criteria, inheritance of primary and secondary traits in a given environment, genotype by environment interaction and performance stability of genotypes across environments were also studied by different workersas reviewed elsewhere (Bejiga and Daba, 2006; Fikre and Bejiga, 2006; Jarso *et al*., 2006; Keneni *et al*., 2006).

Varietal Development

There is no question that improved seed is a prime background source input through which other component technologies are transferred to farmers. Sources of genetic variation for genetic improvement of these crops in Ethiopia include germplasm collections from important production complexes of the country, introduction and acquisition of genetic materials from international sources like ICARDA and ICRISAT, and crossing of selected parents from all sources. Some were received at their earlier filial generations to select better-performing segregants under the Ethiopian conditions. Most of the landrace collections utilized in the breeding programs were either received from the Institute of Biodiversity or through target collections by breeders in collaboration with the Institute of Biodiversity.

We have been usually following a best parent by best parent hybridization scheme in order to bring together desirable characters from a number of parents into a single genotype. We have also been following a sort of defect removal strategy by conversion of the otherwise well-adapted varieties into their improved versions by a backcrossing scheme. In this case, the exotic materials, with desirable characters, but not adaptable would be crossed with the local adapted materials that lacked some of useful characters like diseases resistance and larger seed size. In addition to the bi-parental crosses, population improvement with recurrent selection method using honeybee as a crossing agent was also practiced very rarely. Sources of gene for desirable characters like large-seeded and diseases resistant types have been identified from ICARDA and ICRISAT materials.

Creation of genetic variation is followed by identification and isolation of plants having the desired combinations of characters in their progeny. In the screening nurseries, the selected genotypes are evaluated for good pod setting, early flowering and maturing, diseases tolerance/resistance, and for qualities such as seed size and color. Introductions, collections and segregants from hybridization are usually grown either with artificial inoculations of the virulent isolates of foliar diseases, on sick plots for root rot diseases or in the hotspot areas for other biotic and abiotic stresses depending on the situation. Insects may also be mass reared on bulk seeds of susceptible cultivars and used for artificial infestation. Pedigree and bulk methods are mostly employed at the selection stages. The newly selected lines or populations are tested for yield and other traits along with the standard check for comparison.

The appropriateness of varieties for release in terms of performance consistency across a range of physical environments is confirmed by multi-location evaluation of varieties with a number of collaborating research centers under the federal and regional research institutes and universities representing different agro-ecologies of the country.

It is obvious that if a variety developed for better agronomic behavior by breeders is unacceptable to farmers for some other reasons and is not adopted at the end of the day, all the resources invested in the development of that variety would be wasted. It is very important, therefore, that farmers are involved in the selection and testing processes. To this end, variety evaluation usually involves farmers at certain level of variety evaluation schemes as part of the regular procedure where it was learnt that farmers (male and female) and researchers have their own unique and common selection criteria (Keneni *et al*., 2002). The participation of the farmers in the process of variety evaluation is, therefore, essential in that selection criteria overlooked by researchers might be addressed when the farmers are involved from the early stage. This is expected to hasten the dissemination of the released varieties, as farmers are the end users. When selection is made for varieties to be finally verified and released, emphasis is given to genotypes that have superior performances and stability over the most recently released variety as a check.

Through consorted inter-institutional efforts, during last five decades, 21 faba bean, 16 chickpea, 17 field pea and 7 lentil varieties have been developed and released to producers from the EIAR Research Centers (MoA, 2014). The yield potential and relative advantages of these varieties over the existing husbandry method showed the potential of improving the low national average (Table 2 and Figure 2), if the varieties are fully adopted and put in production with proper crop managementand protection packages (Tables 2 and 3). However, past efforts were almost entirely limited to optimal conditions, with a least attention to the marginal areas including the drought-prone environments.

Estimation of genetic progress from a breeding program enables to monitor the periodic advancement in the genetic gain of traits of interest. Studies on genetic progresses from breeding efforts in Ethiopia on faba bean (Temesgen *et al*. 2015), chickpea (Keneni *et al*., 2012), field pea (Legese, 2011) and lentil (Bogale *et al*., 2015) confirmed existence of reasonable levels of yield gain with tremendous improvement in seed size (of faba bean and chickpea) over the last decades. Temesgen *et al*. (2015) reported the average cumulative genetic gain over 33 years of faba bean breeding to be 290 kg ha^{-1} for grain yield, 266.3 g per 1000 seeds for seed size and -8.9% for chocolate spot severity. Keneni *et al*. (2011) reported that genetic progress from chickpea breeding resulted in annual rate of genetic progress 21 g/five plants for grain yield in 15 years and a corresponding gain in seed size of 141 g per 1000 seeds during the same period (Figure 3). Bekele *et al*. (2014) later reported that the genetic progress for grain yield was 32 kg $ha^{-1}year^{-1}$(for Desi type) and 23.986 kg $ha^{-1}year^{-1}$(for Kabuli type) over the last 40 years, whereas progresses in seed size were 0.302 g 100 $seeds^{-1}$ $year^{-1}$for Desi and 0.821g 100 $seeds^{-1}$ $year^{-1}$for Kabuli. These studies clearly showed that, through faba bean and chickpea breeding efforts in Ethiopia during the last decades, better genetic progress were obtained both in seed size and grain yield but the former was better improved than the latter (Keneni *et al*., 2012; Bekele *et al*., 2014; Temesgen *et al*. 2015). Legese (2011) reported that genetic progress for grain yield of 22.23 kg ha^{-1} $year^{-1}$ was obtained from over 31 years of field pea breeding. Similarly, Bogale *et al*., (2015) also studied genetic progresses from breeding lentil during the last 30 years and found an average rate of genetic gain of 27.82 kg $ha^{-1}year^{-1}$ at Debre Zeit and 18.02 kg ha^{-1} $year^{-1}$ at Enewari.

Table 2. Faba bean, chickpea, field pea and lentil varieties developed by the EIAR research centers

crop	Year of release	No. of verities released*	Name of verities
Faba bean	Before 1980	4	CS 20DK, NC-58, Kuse /2-22-33, Kassa
	1981-1990	0	-------
	1991-2000	2	Bulga 70, Mesay
	2001-2010	12	Holetta-2, Degaga, , Wayu, Selale, Gebelcho, Moti, Obse, Walki, Dosha, Hachalu, Tumsa,
	2011-2015	3	Gora, Dide'a, Ashebeka
	Sub total	21	
Chick pea	Before 1980	2	DZ-10-11,DZ-10-4
	1981-1990	1	Mariye
	1991-2000	4	Worku, Akaki, Arerti, Shasho
	2001-2010	7	Chefe, Habru, Ejere, Teji, Acos Dubie, Natoli, Minjar
	2011-2015	2	Teketay, Dalota
	Sub total	16	
Field pea	Before 1980	2	FP DZ, Mohanderfer
	1981-1990	2	Nc-95 Haik, G22763-2c
	1991-2000	7	Tegegnech, Markos, Milky, Hassabe, Adi, Holetta-90, Wolmera
	2001-2010	4	Gume, Megeri, Burkitu, Latu,
	2011-2015	2	Bilalo, Bursa
	Sub total	17	
Lentil	Before 1980	0	-------
	1981-1990	2	Chekol, Chalew
	1991-2000	3	Ada, Gudo, Alemaya
	2001-2010	2	AlemTena, Teshale,
	2011-2015	2	Derso, Dembi
	Sub total	7	
	Grand Total	61	

* These do not include varieties developed by the federal research centers and released by Regional Research centers and Universities

Crop Management and Protection Practices

Good varieties alone cannot lead to potential yields beyond a certain limit from suboptimal crop management and protection practices. It is generally believed that future productivity is most likely to increase from integration of mutually beneficial set of crop varieties that efficiently and effectively exploit the best-bet of crop management and protection practices to be provided by the producers. It is also believed that a technical breakthrough in highland pulse crops production can partly be achieved through the temporal and spatial intensification of crop production. System sustainability, multi-disciplinary approaches, and the participation of relevant stakeholders, particularly farmers, in the technology generation and dissemination process should be encouraged.

During the last five decades, different crop management and protection practices, that could bring a significant change in the lives of the small farmers of Ethiopia when applied with improved varieties, have been developed and recommended under different growing conditions.

Appropriate fertilizer and seed rates, planting time and plant population densities have been developed for the major production areas. Strains of Rhizobium for faba bean, chickpea, field pea and lentil were found effective in N fixation and are promising for commercial production (Bejiga, 2004). The desired plant population is roughly 350,000 plant ha^{-1} for faba bean, 300,000 ha^{-1}plants for chickpea, 1,000,000 plants for field pea andlentil. The weed flora associated with faba bean, chickpea, field pea and lentil have been identified and yield losses due to weed competition have been estimated. Critical weed free periods, optimum periods and frequency of hand weeding and weed control using chemical methods have been developed and recommended for major weeds (Table 2). The major diseases and insects in the major production areas of faba bean, chickpea, field pea and lentil have also been identified (Table 3). Improved varieties with different levels of resistance to the diseases have been developed and chemical control measures not only to the diseases but also to the major insect pests have been recommended (Table 3).

A number of studies showed that some legumes might also enhance nutrient availability for associated or subsequently grown cereals. For instance, nitrogen fixation by faba bean was found to have significance spillover effect to subsequently grown wheat in Ethiopia (Gorfu, 1998). Experiences from Ethiopia also proved that mixing of legumes with other legumes not only reduced diseases incidence in mixed cultures (Amare, 1996; Derje, 1999; Kemal, 2002) resulting from the buffering effects of mixtures against diseases (Derje, 1999; Kemal, 2002) and insects (Kemal, 2002) but also better productivity of mixtures compared to the corresponding pure stands (Amare, 1996; Derje, 1999; Kemal, 2002; Tolera and Dhaba, 2004). However, it is advisable to define a mutually beneficial set of crop species as incompatible interspecific mixtures may sometimes enhance instead of reducing diseases and insect pest problems (Keneni *et al*., 2012).

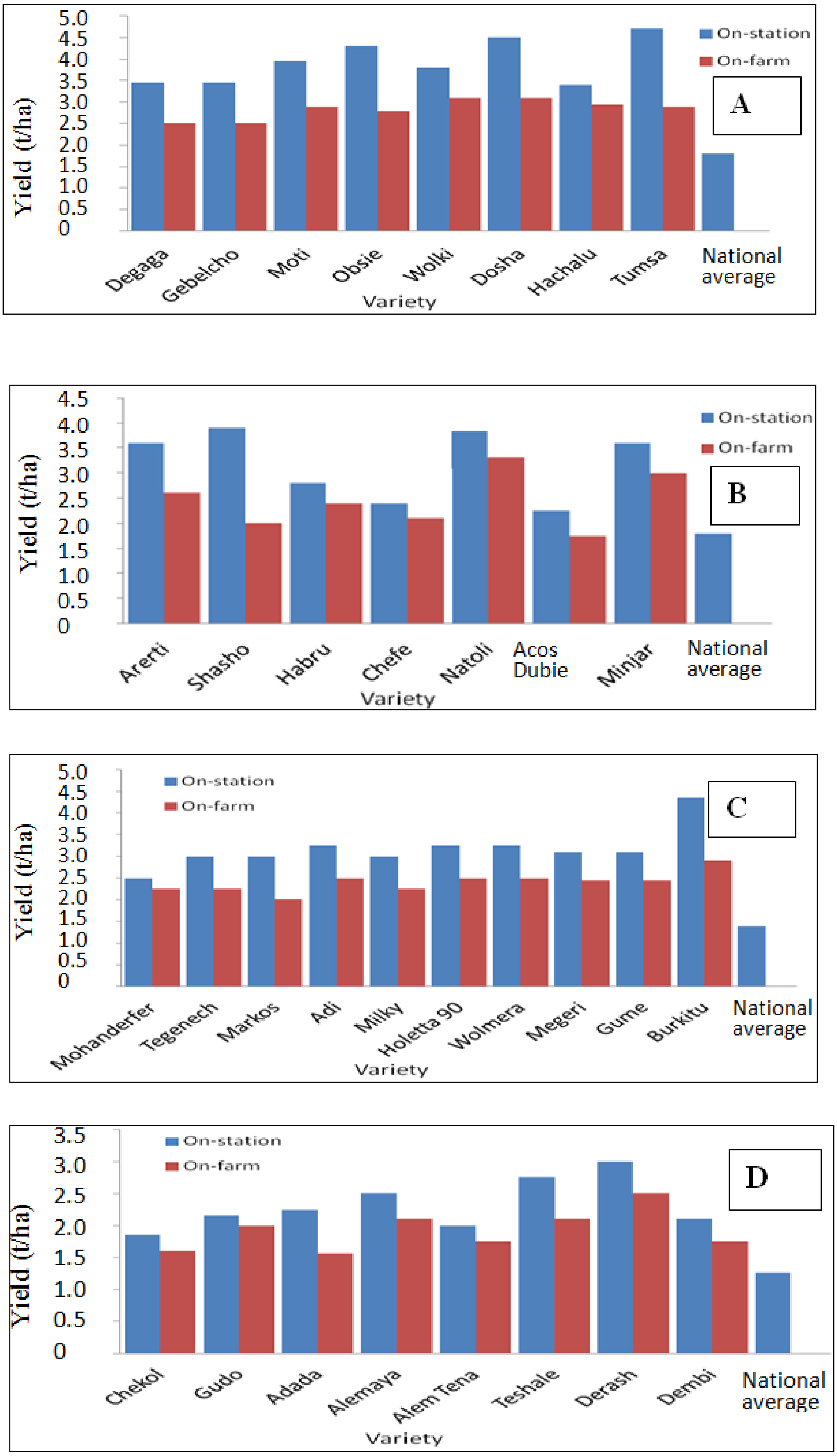

Figure 2. Yield potentials of (A) faba bean, (B) chickpea, (C) field pea and (D) lentil varieties released under on-station and on-farm conditions as compared to the national average productivity of the crops (Source: CSA Data and MOA GTP II Draft Document)

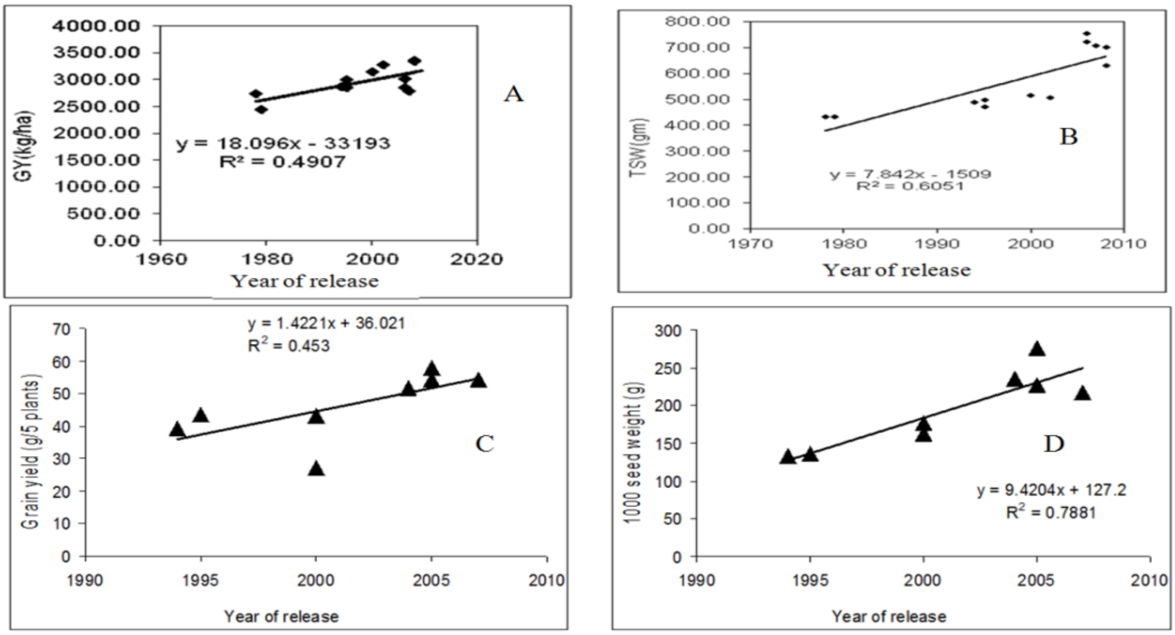

Figure 3. Bi-plots of (A) grain yield and (B) seed size in fababean and (C) grain yield and (D) seed size in chickpea against years of release using a respective oldest base reference variety showing genetic progresses from breeding in the two traits during the past decades (Sources: Keneni *et al*. 2011; Tolessa *et al*., 2015)

Table 3. Agronomic practices recommended for faba bean, chickpea, field pea and lentil

Agronomic practices	Faba bean	Chickpea	Field pea	Lentil
Ploughing frequency	2-3	2-3	2-3	2-3
Sowing date	Mid-June to early July	Late July to early September	Mid-June to early July	Mid July to late August
Seed rate (kg/ha)	180-250	100-180	150	80
Spacing (cm)	40 between rows & 7 between plant	30 between rows & 10 between plant	20 between rows & 5 between plant	20 between rows & 5 between plant
Fertilizer rate (DAP, kg/ha)	100	100	100	100
Weed control	Twice hand weeding	Once hand weeding	Twice hand weeding	Twice hand weeding
	Dual gold and Codal gold (pre-emergence herbicide)	Use of non-selective herbicides two weeks before the final land preparation	Dual gold and Codal gold (pre-emergence herbicide)	Use of non-selective herbicides two weeks before the final land preparation
Rhizobium (examples)	Two strains (FB-1018, FB-1035))	CPEAL 001, CPEAL 004	EAL 320, EAL 302	EAL 600

Table 4. Major insects of faba bean, chickpea, field pea and lentil

Crop	Major insects	Control methods (examples)
Faba bean	African bollworm (*Helicoverpa armigera*)	• Single spray with Cypermethrin at the rate of 150ga.i. ha^{-1} when infestation starts • Endosulfan 39% EC 2 l ha^{-1}
	Bean Bruchids (*Callosobruchus chinensis*)	• Actellic (2% dust) 50 g 100 kg^{-1} of seed • Application of Primiphos-methyl at the rate of 40g100kg^{-1} (6-8 ppm)
Chickpea	African bollworm (*Helicoverpa armigera*)	• Single spray with Cypermethrin at the rate of 150ga.i. ha^{-1} when infestation starts • Endosulfan 39% EC 2 l ha^{-1}
	Cutworm (*Agrotis* spp.)	• Apronstar 42 WS 250 g 100 kg^{-1} of seed
	Bean bruchids (*Callosobruchus chinensis*)	• Actellic (2% dust) 50 g 100 kg^{-1} of seed • Application of Primiphos-methyl at the rate of 40 g 100 kg^{-1} (6-8 ppm)
Field pea	Green pea aphid (*Acyrthosiphon pisum*)	• Spraying Primor 50%WP at the rate of 0.5 kg a.i. ha^{-1} when 35% of the plants are infested
	African bollworm (*Helicoverpa armigera*)	• Single spray with Cypermethrin at the rate of 150g a.i. $ha^{-1}$when infestation starts • Endosulfan 39% EC 2 l ha^{-1}
	Bruchid (*Bruchus pisorum*)	• Fumigation with aluminum phosphide at the rate of 1-3 tablets per ton • Pyrethrum flowers applied at 1% W/W ratio • Field spray with Cyperimethrin at the rate of 40 a.i. ha^{-1} or endosulfan at 350 g ai ha^{-1} • Actellic (2% dust) 50 g 100 kg^{-1} of seed
Lentil	Pea aphid (*Acrythosiphon pisum*)	• Spraying Primor 50% WP at the rate of 0.5 kg a.i. ha^{-1} when 35% of the plants are infested • Actelic dust 50 g 100 kg^{-1} of seed
	African bollworm (*Helocoverpa armigera*)	• Single spray with Cypermethrin at the rate of 150ga.i. ha^{-1} when infestation starts • Endosulfan 39% EC 2 l ha^{-1}
	Bruchids (*Callosobruchus chinensis*)	• Actellic (2% dust) 50 g 100 kg^{-1} of seed • Application of Primiphos-methyl at the rate of 40 g 100 kg^{-1} (6-8 ppm)

Table 5. Major diseases of faba bean, chickpea, field pea and lentil in Ethiopia

Crop	Major diseases	Control methods (examples)
Faba bean	Chocolate spot (*Botrytis fabae*)	• Resistant varieties • Foliar application of Chlorotholonil at the rate of 2.5kg ha^{-1}a.i when infection reaches 30% • Mancozeb at the rate of 3kg ha^{-1}a.i. when infection reaches 30% • Crop rotation and debris management
	Rust (*Uromyces viciae-fabae*)	• Resistant varieties • Spraying Mancozeb at the rate of 2.5kg ha^{-1}a.i. weekly when infection reaches 5%.
	Black root rot (*Fusarium solani*)	• Water Drainage using broad bed and furrows (BBF) and Camber beds • Resistant varieties
	Faba bean gall (*Olpidium viciae*)	• Residue management • Mancozeb (Unizeb® 80% WP) at 2 $kgha^{-1}$ • Mancozeb 64% + Metalaxyl M-4% (Ridomil® Gold MZ 68 WG) at 3 $kgha^{-1}$, • Triadimefon (Bayleton® WP 25) at 0.7 $kgha^{-1}$ • Resitant varieties
Chickpea	Ascochyta blight (*Ascochyta rabiei*)	• Resistant varieties • Crop rotation and Residue management • Mancozeb (Unizeb® 80% WP) at 3 kg ha^{-1}
	Root rot (*Fusarium oxysporum*)	• Drainage using broad bed and furrows (BBF) and Camber beds • Resistant varieties • Apronstar 42 WS 250 g 100 kg^{-1} of seed
Field pea	Ascochyta blight (*Ascochyta pisi*)	• Resistant varieties • Chlorotholonil or Metalaxyl (RidomylMZ) at the rate of 2.5kg and 1.0 kg a.i. ha^{-1}, respectively.
	Powdery mildew (*Erysiphe polygoni*)	• Resistant varieties • Spraying Benomyl at the rate of 2kg ha^{-1}a.i every two weeks when infection reaches about 5% • Crop rotation and debris management
Lentil	Rust (*Uromyces fabae*)	• Resistant varieties
	Ascochyta blight (*Ascochyta fabae*)	• Resistant varieties • Mancozeb (Unizeb® 80% WP) at 3 kg ha^{-1}
	Root rot (*Fusarium oxysporum*)	• Drainage using broad bed and furrows (BBF) and Camber beds • Resistant varieties • Apronstar 42 WS 250 g 100 kg^{-1} of seed

Technology Scaling-up

A strong technology scaling-up program, therefore, has played a vital role in the efforts made to improve livelihoods of poor farmers in Ethiopia. Almost all technologies released/recommended for wider use by farmers need to be verified and demonstrated to farmers.

Success in achieving food security, which is practically the ultimate goal of almost all breeding programs, largely depends on sustainable backing of the production with appropriate technological interventions. Different platforms were used at different times to enhance research-extension–farmer linkage programs. To mention but a few, pre-extension demonstration and technology popularization program, use of farmers' research groups for technology promotion, farmers field schools, and pre-scaling up of agriculture technologies by research centers in collaboration with other partners and institutionalization of agriculture and rural development partners linkage advisory councils (ARDPLACs) at federal, regional, zonal and *werda* levels. The target of all these approaches and some others was to create an efficient interface between the research system and extension (Assefa *et al*., 2011).

The pre-scaling up activities of technologies generated through the national Agricultural Research System brought about a considerable promise in substantially improving the agricultural productivity and production in various parts of the country (Abate, 2006). Thousands of farmers benefitted from the pre-scaling up programs particularly in Amhara, Oromiya, SSNPP and Tigray regions where thousands of tons of improved seeds of faba bean, chickpea, lentil and field pea were distributed. Thanks to such activities, small-scale farmers were able adopt improved technologies, boost their yield and transform their agriculture. For instance, farmers who participated in the pre-scaling up of technologies between 2007 and 2009 in regions mentioned above got, on average, agrain yield advantage of 61.2 % from faba bean and 58.7% from chickpea (Assefa *et al*., 2011).

Socio-economic Studies

Considerable investments have been made to develop a number of highland pulses production technologies in Ethiopia as discussed above. As compared to other sub-sectors like cereals, however, it is yet hardly possible to say that these investments have modernized the production and boosted the actual productivity as desired. It is obvious that if a technology developed for boosting agricultural productivity is not adopted at the end of the day by farmers, all the resources invested in the development of that technology would be wasted. Despite previous investments in research, a number of socio-economic problems challenged the adoption of improved technologies as reviewed elsewhere (Elias, 2006; Fasil and Kiflu, 2006; Legesse and Adam, 2006). The major ones include: insufficient supply of improved seeds, limited ability to afford production inputs by the farmers, lack of skill and competence among farmers, competition from other staple crops receiving favorable policy support and market associated problems (Gezahegn and Dawit, 2006). The low understanding of farmers regarding the profits they are making with each crop and the monetary and non-monetary values of pulses. Experiences showed that technology adoption particularly of legumes follow a step-by-step pattern where components of the same package may be adopted separately at different times, resulting in low productivity of the component technology because of lack of synergy among the components (Keneni *et al*., 2006). Nevertheless, the situation is currently changing as the Ethiopia Government is now taking significant steps to encourage the production grain legumes as "high value" crops and market prices are improving.

Challenges and opportunities of highland pulses research

Challenges

Mismatch between selection and target production environments

A number of workers believe that past approaches did not fully appreciate the existence of diversified production domain and need for technological options between resource-poor and resourceful farmers as different recommendation domains. It is an obvious fact that the best level of crop productivity in terms of both quantity and quality of product could be achieved from the "best-bet" combinations of improved cultivars and the application of knowledge based crop management and protection practices. However, only resourceful farmers may afford the expenses of production inputs that help them alter their growing environments through the application of improved inputs (including improved seed and fertilizers) and agronomic practices that suit newly developed cultivars (Keneni, 2007).

Consideration of varietal selection vis-à-vis actual target production environment is vital to maximizing gains from breeding efforts. The tradition across most of the breeding programs in Ethiopia is to develop varieties under optimum environments/management despite the fact that marginal environments/management characterizes the ultimate target production environments. Even though tangible scientific evidence from the Ethiopian context is scanty, the complaint that the varietal generation processes in developing countries do not take into consideration the target production systems (Hawtin *et al*., 1988) should be considered seriously.

Farmers have to afford to take up the whole production packages along with the varieties. However, the majority of the resource-poor farmers may not afford to apply optimum agronomic practices and the cost of production inputs.

Among the key management inputs, commercial fertilizers are the most important but expensive. The rate of fertilizer applied by the farmers is either very low or nil compared to the rates recommended from research. If G x E interaction between selection and target production environments is large enough to the extent that it results in rank order changes (cross-over type of interaction) among the performances of the genotypes, it means that the two environments are distinctly different and they do not represent one another and, hence, the best genotype under selection environment may not, in most of the cases, be the best under the target environments (Keneni *et al*., 2001; Keneni and Imtiaz, 2010). Farmers needed to be empowered to alter their growing environments to suit the newly developed cultivars.

Where marginal situations dominate, breeders must recognize the unique situations and fit varieties to the bio-physical and socio-economic needs. Contrary to breeding for optimal situations, the process in which cultivars are adapted to fit the prevailing growth environment is encouraged instead of the environment being altered to fit the cultivars (Wallace and Yan, 1998).Fitting the growing period of the crop genotypes to the probable period of availability of the limiting resource under different scenarios through genetic manipulation is absolutely essential. For terminal moisture stress, for instance, developing crop cultivars for earliness or cultivars that can complete their lifecycle before the on-set of terminal moisture stress could be one option. One may also think of cultivars with modest demand that do not exhaust the available moisture at the early stage of development but that can fairly distribute throughout their lifecycle. Cultivars that can continue with growing and yielding only with residual moisture at the later stage could also be considered under the same scenario.

The breeding approach is also based on selection for sole cropping while mixed cultures of different species (e.g. faba bean with field pea) also prevail in the actual target production environments. It is hardly possible to prove that the varieties developed so far for optimal situations under sole culture have been readily accepted, properly utilized and boosted productivity under mixed culture.

Appearance of new threats and lack of sources of resistance/tolerance

Appearance of new threats like parasitic weeds, *Orobanche crenata*, and faba bean gall at the top of existing ones in the northern part of the country coupled with absence of readymade varieties that overcome the negative effects of these newly emerged threats and lack of prior experience of dealing with these threats is becoming a serious concern. Lack of parental sources of resistance/tolerance to *Orobanche*, insects (field and storage) and faba bean gall resulted in limited crop protection technologies including post-harvest technologies. Abscission of flower buds and immature pods in faba bean particularly when the crop is grown under sub-optimal conditions for the reasons that is not yet clearly determined by research is another serious challenge.

Competition from cereals

There is no balanced inter-sectoral development resulted in competition from cereals where more significant level of investments and efforts have been made worldwide to develop better technologies particularly improved cultivars over long periods of time under a situation where pulses are less prioritized. The triple bond of nitrogen (N2) that exists in the atmosphere (Lindemann and Glover, 2003) needs large amount of energy to be “broken” during N fixation (Hubbell and Kidder, 2003). Adenosine triphosphate (ATP), from oxidative degradation of sugars and related molecules, manufactured by the host-plant during photosynthesis and transferred to the nodules are the main source of energy in symbiotic nitrogen fixation process (AFRNA, 1992). This process, coupled with protein production, results in a compromised yield in food legumes.

Some studies show that for each gram of nitrogen fixed by Rhizobium, the plant contributes 1-20 grams of fixed carbon from photosynthesis (Hubbell and Kidder, 2003). For instance, a soybean plant may divert 20-30 percent of its photosynthate to the nodule instead of to other plant functions when the nodule is actively fixing nitrogen (Lindemann and Glover, 2003). A review by Keyser and Li (1992) also indicated that for each kilo gram of nitrogen fixed, 10 kg of carbohydrate is required.

It is expected that the genetic potential of improved highland pulses production technologies developed so far may not be exhaustively exploited as in some cereals even after a countrywide popularization of improved production packages that proved the superiority of the improved technologies over the old-age practices. This could be attributed to the low priority given by public extension to pulses, least priority farmers give to food legumes in general in terms of land and input allocation, and relatively poor crop management and protection practices provided to pulses by the farmers as compared to cereals.

Lack of capacity to serve multi-dimensional interests

The big challenge to highland food legumes breeders is the difficulty of serving multi-dimensional interests with the limited financial, technical and material resources they have at their disposal. In addition to the diversity of local needs emanating from the physical environments, farming systems and consumers' preferences, export qualities and standards may apparently deserve at least equal level of priority as breeding objectives. The generation of technologies conducive for mechanization (unlike cereals) stagnated at its early infancy mainly because of the indeterminate behavior and low priority given to legumes.

Breeding in unpredictable environments with maximum temporal and spatial variability is less successful interms of effectively and efficiently exploiting the resource base. For instance, cultivars developed for optimum condition may not perform under marginal conditions. In the same way, cultivars constituted for terminal drought may not be tolerant when the drought stress comes early in the growing season or when it comes in the middle of the season (Amede *et al*., 2004; Ceccarelli *et al*., 2004). Due to demonstration efforts of improved agricultural technologies over the years, the demand for additional improved technologies is drastically increasing vis-à-vis the limited capacity in terms of technology multiplication and supply. Lack of technologies that meet export standards, requirements for industrial raw materials and import substitution emanating from the weak research system in terms of technology generation efficiency, level of skilled human resources and infrastructure including irrigation and laboratory facilities are other areas of incompetency.

Lack of effective technology multiplication and supply system

Lack of effective technology multiplication, input delivery and marketing system has slowed down adoption of technologies. There is no query that seed is a prime background input through which other component technologies are siphoned to farmers. Currently, not more than 10% of the area under pulses is grown to improved seeds. Despite the critical importance, however, there has been chronic shortage of seeds and the research system could not at all satisfy the demand for early generation seeds required by commercial producers for adequate production of certified seeds. The formal and informal seed sectors have only a limited capacity to produce the necessary quantity of seed to meet the national demand. The involvement of private investors in this sector is almost nil as far as pulses are concerned. Formal seed systems are usually interested in producing seeds of cereals and not legumes. The higher seed rates per unit area of land required in these crops is another problem to satisfy the growing demand particularly with legume crops like faba bean, chickpea, field pea and lentil. There is no doubt that, with the current pace of legumes seed production, we would not meet the national plan to double or triple productivity in order to feed the increasing population.

Opportunities

Availability of Technologies

Existence of experienced backup research programs and partnership for sustainable technology development would serve as an effective and efficient background base for further research and development in Ethiopia. As a result of research efforts during the last decades, a number of improved technologies including improved varieties and crop management and protection practices have been developed for faba bean, chickpea, field pea and lentiland the future efforts would be a matter of building on past successes Studies on genetic progresses from breeding efforts of faba bean, chickpea, field pea and lentil proved existence of reasonable levels of yield gain over the last three decades (Legese, 2011; Keneni *et al*., 2012; Bogale *et al*., 2015; Temesgen *et al*., 2015).

Successes of Prior Scaling Up Activities

A series of knowledge dissemination, producers training and scaling up of technologies resulted in steadily increasing productivity and made farmers aware of the importance of improved technologies of various crops. It is believed that more technologies will be released from research and the demand for additional technologies is expected to increase because more farmers will realize the benefits of using improved technologies. Recently, there is a nation-wide scaling up of "high value" crops production technologies which is already underway that paved the way for more technologies to come and more scaling up plans to be initiated..

Risks of Cereal-Cereal Monoculture

This is a time when risks of cereal-cereal monoculture in some potential production areas are already considered a national threat both at technical and policy levels. Failures of a number of wheat varieties almost immediately after release due to their susceptibility to the major diseases have already been encountered in Ethiopia and a number of them have shortly been put obsolete. The whole process of this genetic vulnerability is believed, at least in part, to have been aggravated by cereal-cereal monoculture which resulted in excessive build up of diseases inoculums particularly in areas like Arsi and Bale. Pulses, being the best crops for rotation with cereals, are important not only in soil fertility restoration but also as "break" crops to pests and weeds.

Increasing demand for pulses in Local and export Markets

Currently, there is a positive output to input price ratio with good local and export marketsparticularly for exportable pulses (FAO, 2011). There is tremendous opportunity in Ethiopia for highland pulses export because of the competitive advantage of geographic proximity to major export markets, growing world population (growing demand) and shift towards healthy foods (pulses instead of meat) in many countries but the production should obviously be supported by technology.While Ethiopia has a huge potential for growing and exporting various pulses, however, achievements to date are very low because of low production and productivity (Adenew, 2009).

Conducive Policy Environment

There are high political and technical ambitions to develop science-based agricultural production in Ethiopia. First, agricultural development is not only a matter of food self-sufficiency and security however the government as a leading economic sector for a rapid industrialization also considers the sector. The second Growth and Transformation Plan (GTP II) of the Federal Democratic Government of Ethiopia was designed with much higher goals than GTP I and there is a high commitment to promote food legumes in particular (MoA, GTP II Draft Document).

Highland food legumes are among the "high value" crops in the new development strategy of Ethiopia. As potential export crops, they apparently have a special opportunity for better promotion in afew years to come. It is believed that more varieties will be expected from research and the demand for high quality seed is expected to increase through the current package program, as more farmers will realize the benefits of the use of quality seeds. It is expected that food legumes would get the priority that they would have deserved in GTP II particularly in terms of technology multiplication and dissemination and technology scaling-up programs where farmers, researchers, extension agents and other stakeholders will work together as a united force in order to meet the expected developmental goals of the country.

Future research and development directions

Past faba bean, chickpea, field pea and lentil research successes in Ethiopia cannot be undermined by any standard but the successes were not immune of technical limitations and challenges. The demand for quality products at the national and international levels is dynamic that there is a dire need to improve the research systems and approaches. The targets to be attained during the next decades dictate, in addition to empowering researchers at the centers of excellence, some necessary actions should be taken to strengthen the collaborative research centers in order to bring about the desired changes. What are the important actions?

Decentralization of the Breeding Process

Three breeding approaches may be sought in order to improve productivity of highland pulses under different environments. The first strategy targets specific adaptation for exploiting genetic potential of cultivars that are responsive to optimum environments. The ultimate goal of this approach is yield potential based on the full exploitation of productivity improvements from the best-bet combination of genotype, crop management and protection, and the synergistic interaction between them. This strategy is advantageous in terms of boosting crop productivity but could be useful only for potential production areas.

The second strategy is breeding for specific adaptation ofcrop cultivars that are adapted to marginal environments like the drought-prone, nutrient deficient and soil acidity-prone areas. This strategy includes breeding genotypes for resource use efficiency, i.e. genotypes that are able to mobilize the limiting resources like nutrient and moisture in greater amounts (acquisition efficiency) and better use for yield formation (use efficiency). The ultimate goal here is not to exploit the genetic potential of the crop but it is rather fitting the cultivars to the environment (e.g. moisture regime) by developing varieties with modest demand for resources and having resistance to and performance under stressed conditions.

The third approach is breeding for widely adapting (stable) varieties that consistently perform well under various environments. The goal is not only for higher average performance but also for consistency in higher average performances of crop varieties under a range of environments.The concept of performance consistency theoretically seems attractive but it is unlikely that one can easily recover genotypes that consistently better perform across distinctly different environments due to the differential response of genes to such varying environments, as it is practically impossible to collect together genes responsible for superior performance in all environments into a single genotype (Annicchiarico, 2002). In the tropics and the sub-tropics in general (de Boef *et al.,* 1996) and Ethiopia in particular (EMA, 1988), environmental differences are great. It may be expected that the genotype by environment interaction, or the differential response of genotypes in different environments, is also very high (Falconer, 1989).

Legumes are normally believed to be more liable to the negative impacts of high genotype by environment interaction (Hawtin *et al*., 1988). Therefore, the best genotype under one environment may not also be the best under another. Under such situation, decentralization of the primary breeding centers for different breeding thematic areas into different eco-geographical regions for targeted breeding and developing a modest capacity may be necessary in years to come. In addition to Holetta and Debre Zeit Agricultural Research Centers, which are mainly catering for optimal conditions, Mekele may be best for breeding drought tolerance, Debre Berhan for breeding for frost tolerance, Alamata for breeding for resistance to *Orobanche* and faba bean gall, Sinana for *belg* production, and Ambo for root rot resistance.

Broadening Genetic Basis in the Source Germplasm

Breeding progress depends on the magnitude of genetic variability among the genetic material under consideration, heritability of a given trait in a given environment and the level of selection intensity applied (Falconer, 1989).Broadening genetic basis of source materials through development of source materials of these highland pulses for potential environments, for biotic and abiotic stressed environments and for special end use qualities is absolutely essential. This could be achieved by employing aggressive hybridization, landraces collection and introductions programs.

Ethiopia is the secondary center of genetic diversity for many legume crops that owns an immense wealth of genetic diversity for many traits (Hagedorn, 1984; Mekibeb *et al*., 1991) that could be considered as a noble opportunity to be exploited.

The application of alternative breeding techniques like recombination of desirable characters from many elite genotypes (Inter-varietal hybridization) into a single progeny line through parallels of multiple crossing would help in the process of broadening genetic bases of the parental stocks. Conversions of the otherwise well adapted released varieties into their desirable versions through incorporation of the responsible genes by employing repeated backcrossing (or marker assisted selection where possible) seem to be the best strategy not only in terms of time saving but also in terms of effectiveness and efficiency.

Breeding efforts are made to develop varieties to overcome effects of some of the production constraints like storage and field insects, frost and *Orobanche*. However, it is hardly possible to say that these efforts have reached their desired peaks of fruition because of a number of specific limitations impeding major advances. Specific legume crops suffer specific problems but lack of resistance/tolerance sources among the primary gene pools may be the most important. Application of alternative breeding techniques like mutation breeding and introgression (via distance hybridization) of desirable genes from the wild relatives may be necessary in order to create more variability in the background germplasm.

Use of modern and cutting edge science

The conventional research approaches have been used extensively to address the major research problems facing resource-poor farmers in Ethiopia. However, there have been and will continue to be barriers to achieving the desired level of improvement using these approaches. Among the drawbacks of the conventional approaches include less responsive and slow technology generation/adaptation or product development process. For effective utilization in breeding programs of the wealth of genetic resources available in Ethiopia and elsewhere with our development partners, however, advanced-level use of modern breeding techniques particularly use of biotechnological tools for generation of basic genetic information and alternative technologies for better end use, nutritive value and best processing quality deserve a special attention.

Biotechnological tools should be utilized in genetic characterization of germplasm, DNA fingerprinting for identification of genotypes, marker assisted selection and for genetic transformation. Problems associated with the need for long backcrossing cycles and gene pyramiding with the conventional breeding methods have already been resolved when molecular techniques are used (Higgins *et al*., 1998). It would also make possible easy identification of desirable genes in related and unrelated species and efficient transfer of these genes into the genotypes of interest (Poehlmand and Sleper, 1996; Acosta-Gallegos *et al*., 2008).

The application of biotechnology is very important to generate basic information on the type of “odours” that produce the signal that attracts most of the field insects to the host, characterization of the genes involved in the “secretion” of these odours, whether or not biotypic variation exists among the most important insect pests, signaling mechanisms and pathways between parasitic weeds like *Orobanche* and the host crops, genetic mechanisms behind the signaling and further establishment of the relationships, and identification and characterization of the compounds interact to produce resistance responses.

There is a dire need to launch rapid variety development and evaluation system using molecular techniques (and off-season nurseries supported with irrigation) for faster variety release and application in production. It is strategically advisable that future efforts should focus on validation and adoption of existing genetic markers developed elsewhere by other laboratories for marker-assisted introgression of traits of interest as starting marker development just from the scratch may take a longer time and/or ultimately show lesser probability of success to generate good results within short time. The conversion of the otherwise well adapted released varieties into their desirable versions through incorporation of the responsible genes employing marker assisted selection (MAS) seem to be the best strategy not only in terms of time saving but also in terms of effectiveness and efficiency.

Decentralization of the early generation Seed multiplication

Even though best-bets of highland food legumes technological options suitable for production in Ethiopia have been developed, the integration of these technological options into the whole farming system is lagging behind the expectation. The existing centralized breeder seed maintenance and initial multiplication practices by the research coordinating centers shall be critically examined and innovative systems would be put in place. The establishment of decentralized seed system where each collaborative research center will be self-contained by multiplying breeder and basic seeds of varieties adapted to their respective zones and supplying to the regional seed enterprises and cooperatives for further multiplication and distribution to farmers becomes very necessary. There is a high need for empowering collaborative research centers through training staff and building facilities important for decentralized breeder seed maintenance and initial increase, thereby linking collaborative research centers with regional seed enterprises and seed producers cooperatives. The faba bean, chickpea, field pea and lentil research coordinating centers, namely Holetta and Debre Zeit Agricultural Research Centers, should regularly provide nucleus seeds of improved highland food legume varieties to the collaborative research centers.

Summary and conclusions

During the last five decades (1966-2015), the faba bean, chickpea, field pea and lentil research programs have strived to develop and avail improved production technologies, thereby contributed to enhanced food security, increased household income of the farming communities and foreign currency earnings of the country. These included development and demonstration of improved technologies and provision of initial seed to farmers. A large number of germplasm of these crops were explored where the respective teams were able to develop and release a long list of faba bean, chickpea, field pea and lentil varieties along with the best-bets of crop management and protection options, which have been pivotal for the development of the pulse sector in this country. Efforts to scale-up these technologies to the wider user at the national and regional levels brought about a significant change in the lives of the small farmers in Ethiopia.

The past research for development endeavors were, however, not immune of technical limitations in terms of technology generation, multiplication and availing to the users. The mismatch between selection and target production environments, competition from the other sub-sectors, appearance of new threats and lack of sources of resistance/tolerance to some of the pests, difficulty of serving multi-dimensional interests with a limited capacity and capability (using only the conventional approach), and lack of effective technology multiplication and supply system and inconsistency in the market are among the factors that challenged research system. There were not only challenges but also opportunities which include availability of starter technologies from the past research efforts, the successes of prior scaling up activities which paved the way for similar endeavors in the future, risks of cereal-cereal monoculture, the increasing health consciousness of people and the need for crop rotation which become clear both at technical and policy levels, periodically improving local and foreign markets, and the conducive policy environments.

It is believed that the demand for improved production technologies is expected to increase with time as more farmers realize the benefits. Seeds of improved varieties, particularly varieties that fulfill export standards, are not yet sufficiently developed and made available to the needy farmers. In addition to the local needs emanating from the physical environments, farming systems and consumers' preferences were not well addressed in terms of technology generation. Farmers are also not well acquainted with export qualities and standards. It is only through steadily but gradually improving standards in the future and, along with it, market orientation that highland pulses production can become a profitable business than a means of survival.

Building capacities and capabilities of the coordinating and collaborating research centers through different sorts of technical, material and financial backstopping hold good promise for sustainably generating need based options of technologies, make them available to farmers and ensure proper promotion and application in production. Efforts should be made to ensure that the research and development process will continue autonomously to bring benefits rapidly to a large number of people through enhanced involvement of collaborative research centers by decentralization of the research process and seed system. Broadening genetic basis in the source germplasm to enable the creation of options of technological packages and use of modern and cutting-edge-science also needs adequate investment in capacity and capability building.

It goes without much saying that EIAR has been playing a reputable role in furthering the legacies of highland pulses R4D, thereby reducing poverty and improving livelihoods at the national level. The pioneering role this esteemed Institute had played early in the history of highland pulses research realized the identification of varieties and crop management and protection practices that increased yield, resistance to stresses and improved quality. However, it is believed that there is still a high "dormant" potential to be exploited in these crops to improve livelihoods of Ethiopians. This potential, which in part can be released through "breaking" this dormancy using modern scientific tools, had been only partly released during the last five decades through the efforts of many pioneering researchers in EIAR.

It is our strong confession that a few agricultural interventions alone cannot lead to the realization of potential yields beyond a certain limit. We generally believe that future productivity is most likely to increase from integration of mutually beneficial set of disciplines and institutions with diversified mandates in technology generation, multiplication, promotion and market/product creation. There is further need to encourage multi-disciplinary approaches, system sustainability with temporal and spatial intensification, and the participation of relevant stakeholders including farmers, in the technology generation, multiplication, promotionand proper application in production. In conclusion, a holistic approach where each discipline and R4D partners including donors complement/supplement each other is absolutely essential. It would only be through concerted inter-institutional efforts that we could bring about a real technological breakthrough and successes in the difficult task underway to best serve the betterment of livelihoods of poor farmers in Ethiopia.

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Lowland Pulses Research in Ethiopia: Achievement, Challenges and Future Prospect

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Introduction

Lowland part of Ethiopia is characterized by high temperature, and insufficient, erratic and unreliable rainfall during the growing period. Further, in these lowland parts of the country, the growing season is also short. Therefore, crops which can adapt in these climatic condition are indispensable. Among the suitable crop which fit to these condition are lowland pulses. The most important lowland grain legumes which grow in most parts of the country include common bean /haricot beans (*Phaseolus vulgaris L*), cowpea (*Vigna unguiculata*(L.) Walp.), pigeon pea (*Cajanus cajan*(L) Millsp.) and mung bean (*Vigna radiata*(L.) Wilczek).

Although lowland pulses research was started in the country around late 1960's, nationally coordinated research was started in the then Nazareth, now Melkassa Agricultural Research Center in early 1970's. Since then, several lowland pulses have been introduced and evaluated across years and locations throughout the country for adaptation and productivity. However, among these lowland pulses the national lowland pulse selected common bean as a priority crop and has been engaged in technology generation and promotion.

Area coverage and production of lowland pulses in Ethiopia

In the past, lowland pulses, mainly common beans, were mainly grown in the central, southern, eastern and western part of the country. Currently, common beans production has expanded to the north western and northern eastern part of the country (Figure 1). Common bean is the second most important grain legume in the country in terms of area coverage and production. The importance of common bean has been increasing from time to time in area coverage, total production and average productivity (Figure2, 3 &4). The most recent production and area coverage (for main and Belg production seasons) was 568 thousand tons and 520 thousand hectares, respectively, in the 2013/14 (2006EC) as shown in Figures 5 (CSA, 2013/14). This remarkable increase in both hectarage and production is due to the development of new bean varieties, increased bean demand and enhanced interventions in research as well as in development (Abate, 2012). Moreover, bean production expansion is also due to its predominantly grown for cash in the central Rift Valley as well as at the new production areas (Northern part of the country), but in other parts mainly at the southern part of the country it is a major staple food supplementing the protein source. As shown in figure 5, production of beans is mainly concentrated in the main season (Meher),i.e. from June to September, which accounts for 63% of the total production while the remaining 37% is produced during short growing season (Belg) from February to May(CSA, 2014).

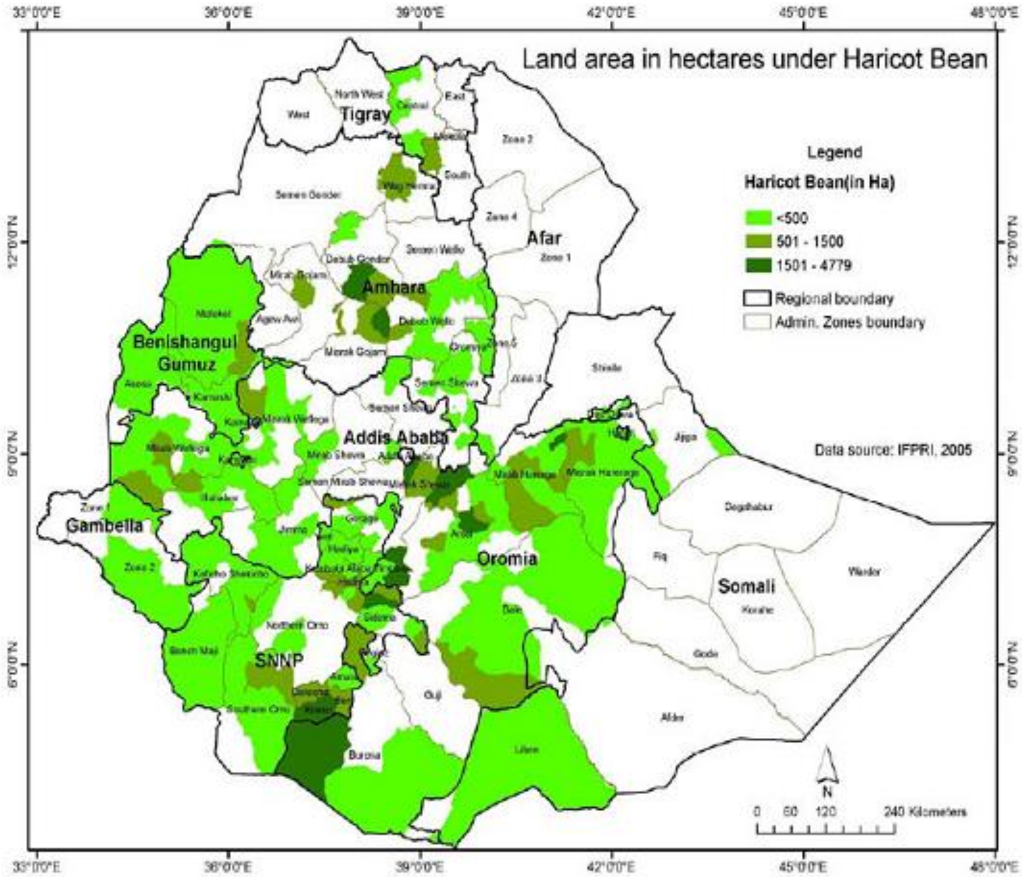

Figure 1: Geographic distribution of common bean production in Ethiopia for the year 2005 (Source: Alemu, et al. 2010)

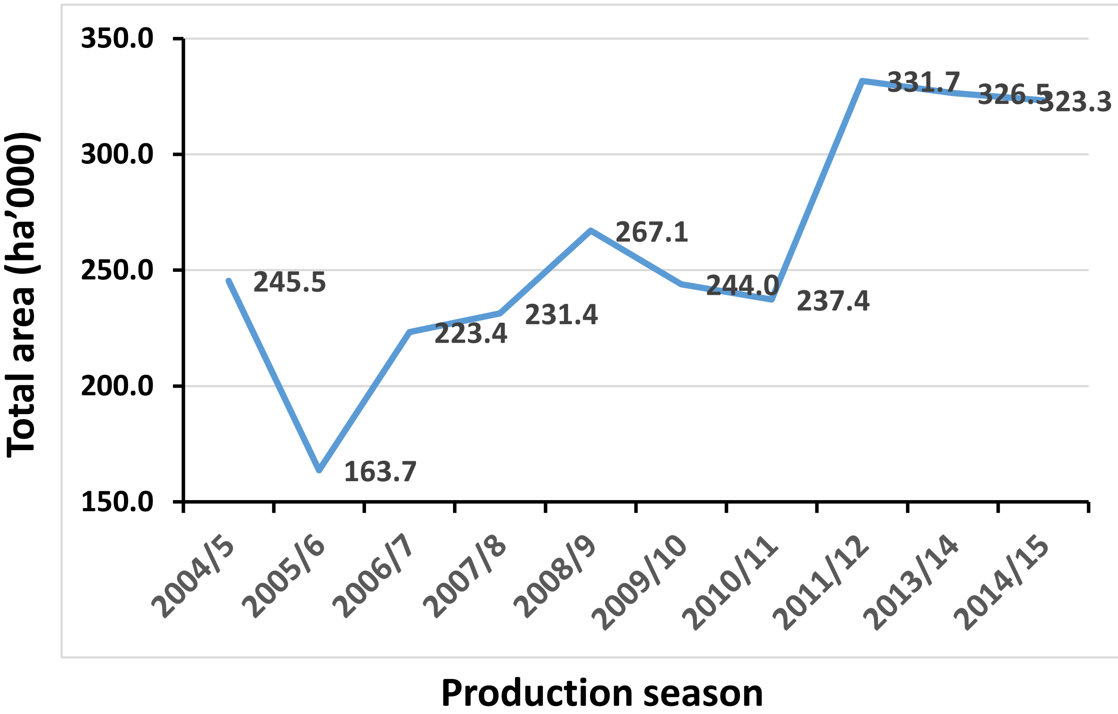

Figure 2: Area under common bean production for the years 2004/5 to 2013/14 main cropping season (CSA, from 2004 to 20014).

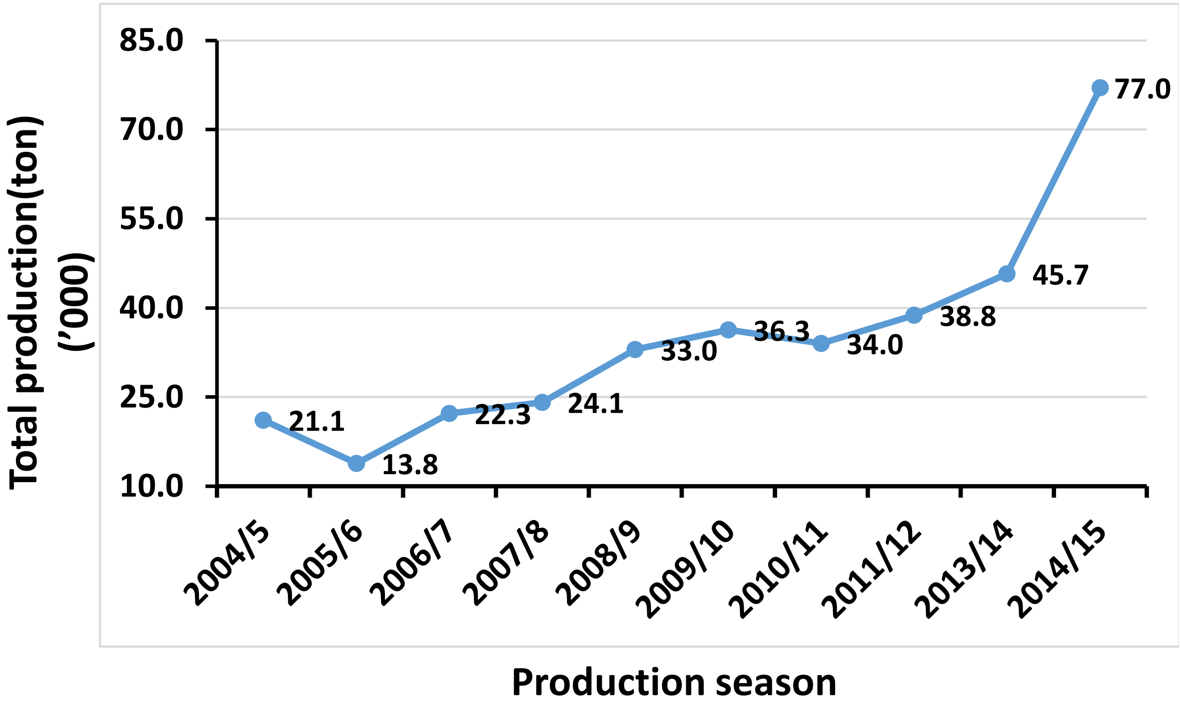

Figure 3: Total production of common bean for the years 2004/5 to 2013/14 main cropping season (CSA, from 2004 to 20014).

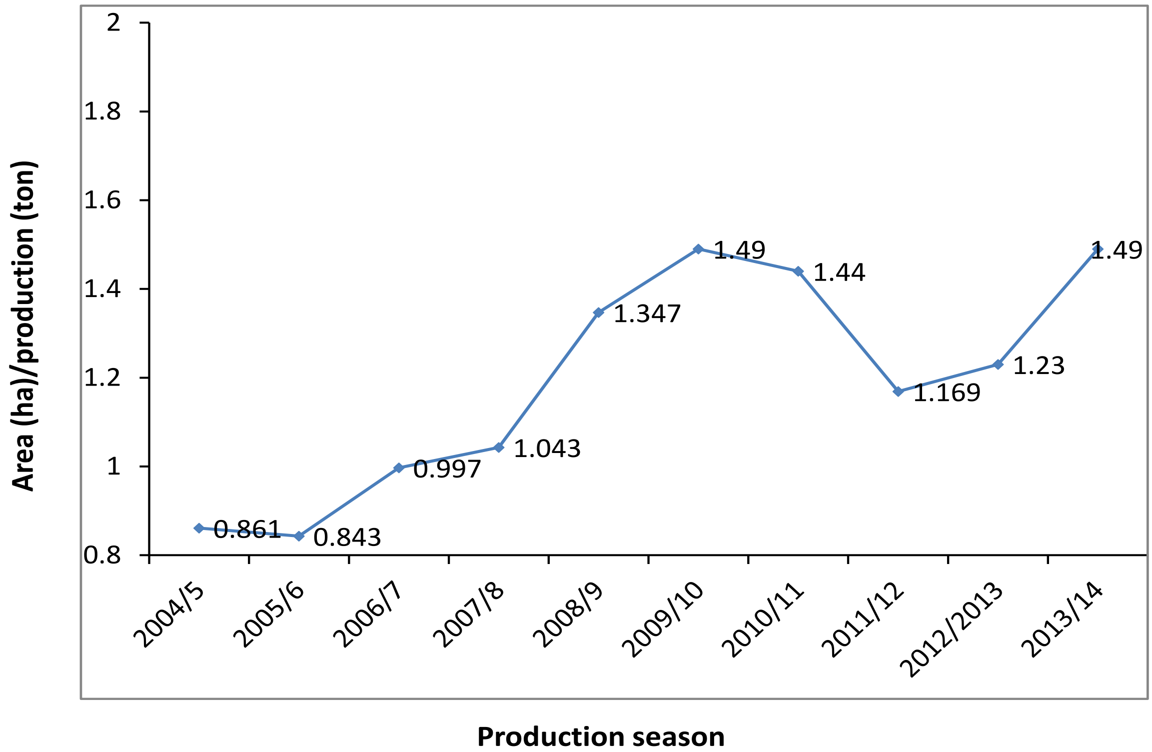

Figure 4: Average productivity of common bean for the years 2004/5 to 2013/14 cropping season (CSA, from 2004 to 20014).

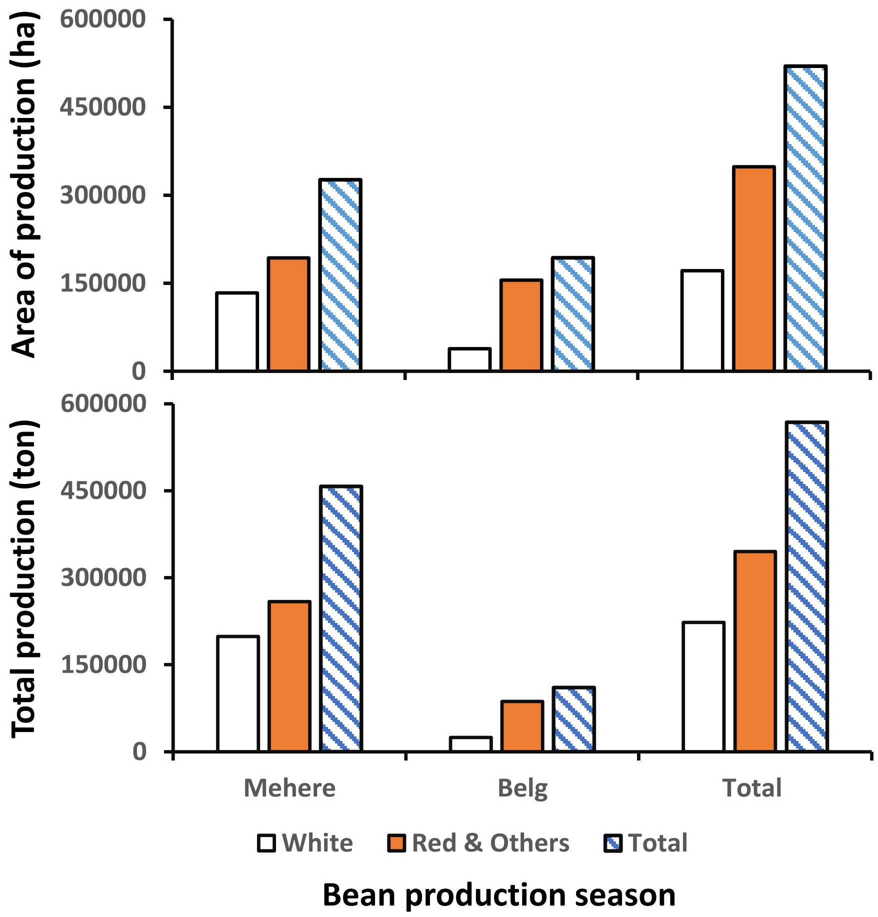

Figure 5. Common bean production area coverage and total production in two growing seasons for the year 2013/14 (2006E.C.) . Source: CSA (2014).

The statistics of other lowland pulses especially cowpea and pigeon pea are not covered by Central Statistics Agency (CSA). However, recently mung bean has been included by CSA sample study. Accordingly, although mung bean is produced in both Meher and Belg seasons, it is mainly produced in the Belg season. As indicated in Figure 6 the total production of mungbean in 2013/14 (2006EC) growing season, was 40.7thousand tons on 50 thousand hectares of land (CSA, 2014).

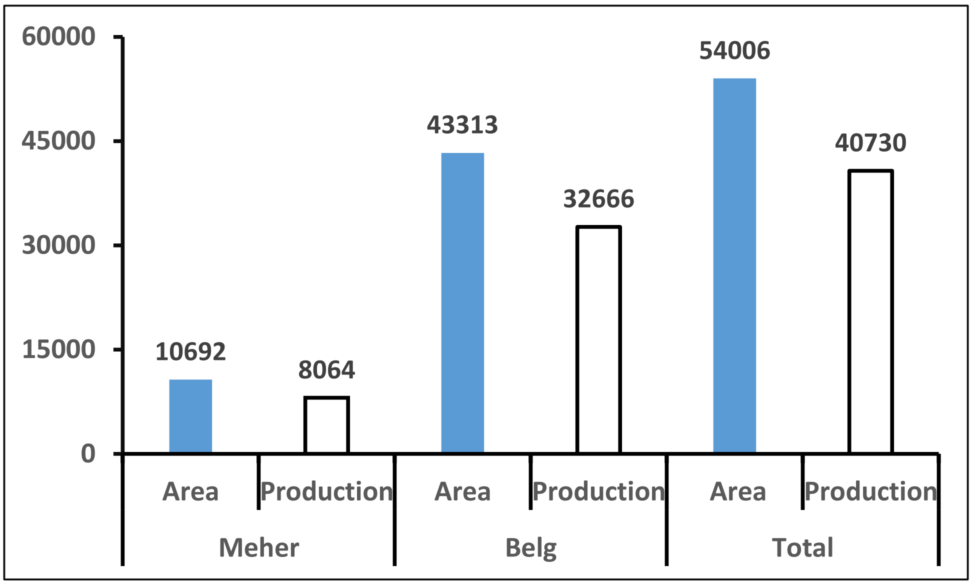

Figure 6 Production area coverage and total production in two bean production seasons for the year 2013/14 (2006E.C.) growing season. (Source: CSA (2014).

Importance of Low land Pulses

As source of protein-rich food

Lowland pulses are extensively consumed in traditional dishes in lowland part of the country. Although, the dry seed of common bean, cowpeas, pigeon pea and mungbean is used for preparing different types of food, green pods of beans and cowpea, and leaves of cowpea are also consumed as vegetables in some parts of the country. Commonly, the dry seed of these lowland pulse can be prepared in different forms like, Nifro (boiled beans), mixed with sorghum or maize, flour/ split grain can be used to prepare stew (“wat”), whole seed can be used to prepare “sambusa” or soup.

Since, most types of lowland pulse mature early, they are often harvested before other crops and hence they are available during the annual "hungry gap" and sometimes the only food crop to survive on in a short growing season and hence substantially contribute as a main food security crop. The protein content of the lowland pulses is greater than 20% and the amino acid composition (high in lysine) is suitable to complement cereals and other staple foods in the diet. The dietary importance of lowland pulses is especially high in southern Ethiopia where Enset and other starchy root crops require adequate supplementation with protein sources. In the south and western part of the country, they are also grown in a double cropping/relay cropping system in the Belg season and supplement the protein requirement for smallholder farmer’s throughout the year. Therefore, these pulses are cheap protein source for resource-poor people.

Source of income for smallholder farmers

Lowland pulses, especially common bean and mung bean, are among the major sources of income for smallholder farmers especially for those who grow white pea beans in central Rift Valley, eastern and northern Ethiopian. Currently other common bean market classes like speckled and red beans market demand in the world has increased and they are also under export and at the same time serve as source of income for the growers in the southern & north western part of the country. Thus, the smallholder farmers who grow these market classes are also generating substantial income from the sale of their produce. The production of common beans and mung bean in the main and Belg seasons has also enabled the farming community to gain income throughout the year. Since these legumes mature earlier than other crops, the income obtained from the sale of beans is found to be the main source of cash used for covering school fees for their children, repaying input credits and for covering expense of different holidays. Hence, farmers consider these lowland pulses as source of their income and are the main contributor to improvement of their livelihood.

Source of foreign currency earnings

Being source of cash for smallholder farmers, common bean and mung bean are the main export commodities for the country among the lowland pulses. Among common bean market classes, most of the white pea beans produced in the country are exported. Almost all export production comes from small farms, mostly in the Central Rift Valley (CRV) but also from southern, eastern and western zones; and recently from northern part of the country. The export value of beans increased steadily during the last 22 years from USD17.9 million (1989/90) to 100 million in 2012/13 (Figure 7). There is still unsatisfied demand both for the export small and large white pea bean, speckled and red beans for export market, sowing the need for continuous effort for technology generation and promotion in the country (personal communication with exporters).

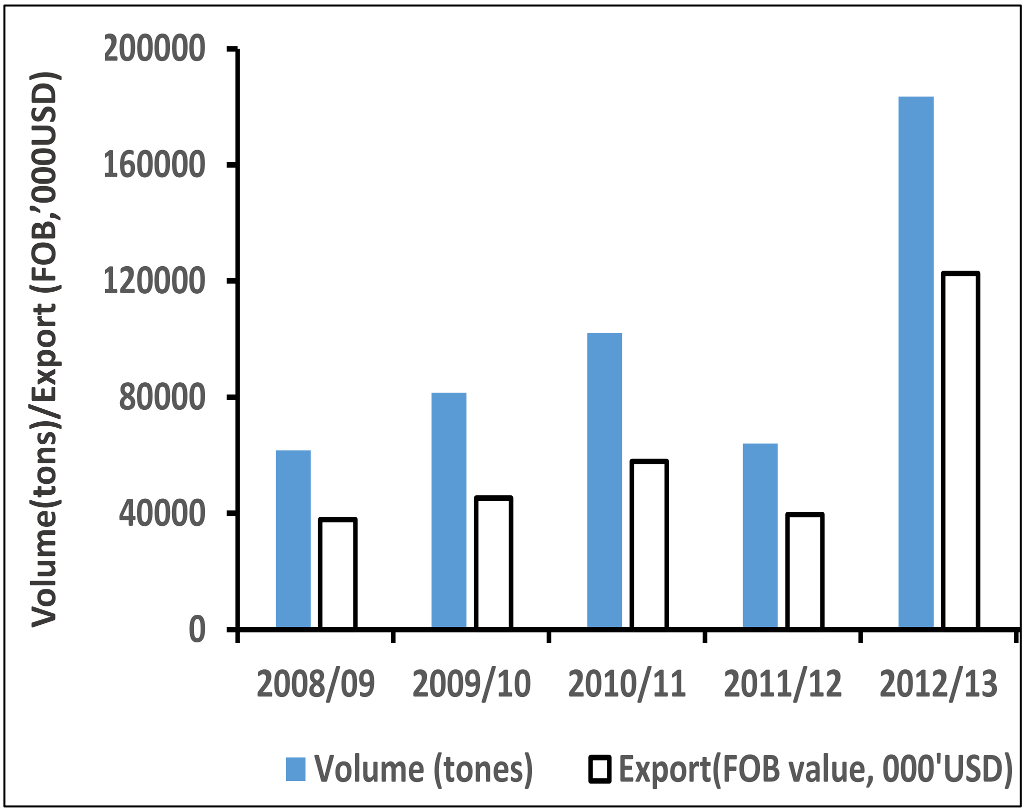

Figure 7. Export of common bean from 2008/9 to 2012/13 cropping season.(Source, EPOSPEA 20014)

Raw material for local industries

Dry beans are potential crops for canning and are good raw materials for agro-industries. However, so far common bean in Ethiopia is cleaned and graded using different agro-processing facilities and dry beans will be packed in different packages and exported directly abroad. Hence, dry bean processing as a canned food is so limited. This will be one of the future investment opportunity which might also improve on added value based food product production and export.

Role of lowland pulses in cropping systems

The wide range of growth habits of lowland pulses for example common bean has enabled the crop to fit into different cropping systems. Early maturity and drought adaptation properties of common bean enabled it to play a vital role in farmer's strategies for risk aversion in drought-prone areas.. Prostrate bush types achieve rapid ground cover, compete well with weeds and save labor for other farm operations. Soil erosion is relatively low under a bean crop canopy. Climbing beans are widely grown on homestead fences in the west, where they can make full use of the long growing season.

Shade tolerance and early maturity contribute to the preeminent position of lowland pulses as understory inter-crop in sorghum, maize, chat and coffee in southern, western and eastern part of the country. Early maturity common bean & mung beans make them an ideal crop for intensification of existing cropping systems. Double cropping lowland pulses in eastern and southern Ethiopia has been developed indigenously in response to land scarcity, enabling farmers to harvest two or three crops in a year. Hence, lowland pulses play a great role in the farming system of the country and contributed to enhanced production of this crop and improves the benefit from its production by the growers.

Challenges in producing lowland pulses

The productivity of lowland pulses is low due mainly to biotic and abiotic stresses.

The main abiotic factors limiting the production of lowland pulses include moisture stress, low soil fertility especially N and P, and soil acidity. The climatic condition of lowland areas of the country is unpredictable and unreliable. Furthermore, terminal drought is also common in the lowland parts of the country. This problem is mostly prevalent in the central Rift Valley, northern and Eastern part of the country. Low soil fertility is common across lowland-pulses growing areas of the country while soil acidity is prevalent in the western part of the country.

The major biotic factors are diseases and insect pests. The type and severity of these constraints depends on the agro-ecology of the growing areas. In the dry lowland areas, such as the central Rift Valley areas of the country, diseases of common bean are common bacterial blight, hallo blight, rust and anthracnose while the major insect pests in this area are bollworm, flower beetles and bean stem maggot. In the humid and high rainfall lowlands and mid altitude areas, diseases like angular leaf spot, floury leaf spot and anthracnose are production limiting factors while the economically insect pests are bollworm and bean stem maggot. The postharvest insect pests, bruchids, are common in all bean and cowpea growing areas of the country. Moreover, aphids are also production constraints at cowpea growing area of the country.

Apart from the above-mentioned constraints, low yield potential of the lowland pulse varieties farmers are using, limited promotion of the available lowland pulse technologies, and inadequate seed multiplication and dissemination of improved varieties are also important bottle necks of lowland pulses production in the country. Moreover, fluctuation of common beans price in local and world markets, and sub-standard quality of the beans are also the main challenges for promotion of beans technologies.

Hence, addressing these production challenges through strategic research would be vital to improve the production and productivity of lowland pulses in the country. Moreover, minimizing challenges of seed availability, market, quality, etc., of common bean through functional linkage with relevant institutions, and through policy dialogue would be critical to improve the benefit from this sector.

Achievements and Impacts

Varietal development

The aim of the lowland pulses breeding program is to increase production and productivity of lowland pulses through provision of high yielding varieties which are preferred by consumers and export market, and are tolerant to major biotic and abiotic stresses. To achieve this objective, the program uses different strategies to broaden the genetic base of lowland pulse crops through introduction, hybridization and collection of land races. Moreover, the national program also introduces and adapts new market oriented (demand driven) lowland pulse varieties to respond to the development need of the country. To date, substantial number of lowland pulse varieties have been released by the national program and partner research centres. Excluding the four varieties of common bean released before 1990 (Mexican 142, Black Desse, Red Welayita, and Brown speckled), which are obsolete currently, nationally 13 exporttype varieties (for export market) mainly white pea beans (Table 1), and 38 different coloured beans varieties (“food” type), mainly for local consumption and contribution to food security (Table 2) have been released. Moreover, three mung bean varieties meant for export market and nine cowpea varieties for local market and consumption were also released (Table 3). However, variety generation for other lowland pulses was sluggish, though three pigeon pea, one adzuki bean and two lima beans varieties had been recommended for production before 1990’s, due to the research priority given to common bean. However, recently, one variety each of pigeon pea and adzuki bean have been released for production. Most of the lowland pulses mainly common bean varieties have been promoted to benefit the smallholder farmers and enhance the export earning of the country.

Table 1: Common bean varieties released in Ethiopia for export market since 1990

Name of Variety	Altitude	Rainfall	Date of maturity	Seed color	Productivity (q/ha) Research field	Productivity (q/ha) Farmers field	Year of release	Seed maintaining centre
Ado (SAB 736)	1300-1800	400-750	85-90	Large White	20-25	18-22	2014	Melkassa
Tafach (SAB 632)	1300-1800	400-750	85-90	Speckled	22-26	19-24	2014	Melkassa
Awash-2	1300-1700	400-750	85-90	White	28-31	18-22	2013	Melkassa
Deme	1300-1800	750	85-90	Red Speckled	19-20	18-22	2008	Melkassa
Batu	1300-1950		75-85	Large White	18-25	16-20	2008	Melkassa
Acos-red (DRK)	1300-1950	400-1100	75-82	Dark red	19- 22	16	2007	Melkassa
Cranscope	1300-1950		90-98	Red Speckled	19-27	16	2007	Melkassa
Chorie	1300-1950	400-1100	87-109	White	23	19	2006	Melkassa
Chercher	1300-1900	1000-1200	95-105	White	22-28	21-27	2006	Haremaya University
Argene	1300-1800	350-1000	90-95	White	28	23	2005	Melkassa
Nazret-2	1330-1800	350-1000	90-95	White	20-22	18-20	2005	Melkassa
Awash melka	1400-1900	350-700	-2	White	25	20-23	1999	Melkassa
Awash 1	1400-1800	350-700	90	White	20-24	18-21	1990	Melkassa

Table 2: Common bean varieties released in Ethiopia for local consumption since 1990

Name of Variety	Altitude (m)	Rainfall (mm)	Date of maturity	Seed color	Productivity (q/ha) Research field	Productivity (q/ha) Farmer's field	Year of release	Seed maintaining centre
SER-119	1450-2000	450- 700	85-105	Red	33	25	2014	Melkassa
SER-125	1450-2000	450- 700	85-105	Red	35	22	2014	Melkassa
Dendesu	1300-1650	400-750	75-79	Red	22-30	19-23	2013	Melkassa
Adda	1300-1650	400-750	75-79	Yellow	19-33	17-25	2013	Melkassa
Tinike (RXR-10)	1600-2200	500-1200	90-105	Red	30	25	2012	Haremaya University
Hundene (K-132)	1600-2200	500-1200	90-105	Red mottled	30	25	2012	Haremaya University
Fedis	1600-2200	500-1200	90-110	Red mottled	30	20	2012	Haremaya University
Babile	1600-2200	500-1200	85-105	Red	36	30	2012	Haremaya University
Hirna	1600-2200	500-1200	85-110	Red	30	27	2012	Haremaya University
Morka (ECAB-0056)	1400-2200	400-700	84-115	Red mottled	25	20	2012	Melkassa
SARI-1	1800-2200	500-1200	80-100		25	20	2011	Hwassa
GLP-2	1400-2200m	750-1200	85-90	Red mottled	30	22	2011	Melkassa
Lehode	1200-1900	750-1201	80-100	Cream	24	18	2010	Sirinka
Lokku	1300-1900	1000-1300	82-101	Cream	14-20	13-18	2009	Bako
Kufanziq	1600-2200	500-1200	90-115	Red	40	32	2008	Haremaya Univesity
Hawassa Dume (SNNPR-120)	1800-2200	500-1200	80-100	Red	28	22	2008	Hawassa
Gabisa	1200-1900	1000-1200	87-96	Light yellow	17-35	16-30	2007	Bako
Haremaya	1650-2200	Above 500	90-114	Cream	20-32	15-30	2006	Haremaya University
Mekadima	1300-1800	400-1100	79-102	Red	28	18	2006	Melkassa
Dinknesh	1400-1850	400-1100	82-102	Red	25-30	20-23.5	2006	Melkassa
Hirna	1500-2200	500-1200	92	Red	25-30	16-30	2006	Haremaya University
Fedis	1500-2200	500-1200	93	Red	23-36	15-30	2006	Haremaya University
Batagonya	1500-2200	500-1200	140-160	Cream	18	15	2005	Hawassa
Angir	1300-1900	1000-1300	85-96	Dark Red	23-30	20-24	2005	Bako
Tibe	1300-1900	1000-1300	95-103	Red	22-28	21-27	2004	Bako
Omo-95	1400-2250	350-500	90-120	Light red	17.3-32	19.3	2003	Hawassa

Wedo	1450-1850	660-1025	74-84	Light white			2003	Serinka
Nasir	1200-1800	350-1000	86-88	Red	20.3	23	2003	Melkassa
Dimtu	1200-1800	350-1000	91-93	Red	21.4	22	2003	Melkassa
Ibado	1400-2250	350-500	90-120	Red	20-29	15-20	2003	Hawassa
Zebra	1400-1900	350-700	-	Cream	27.34	-	1999	Melkassa
Tabor	-		98	Red mottled	20.3	-	1999	Hawassa
Goberasha	1400-1900	350-700	-	Red mottled	22.5	-	1998	Melkassa
Bishbesh	-	-	85-95	Red mottled	32	-	1998	Melkassa
Atendaba	1400-1900	380-700	91	Red mottled	23	-	1997	Melkassa
Gofta	1500-2000	500-1200	110	Cream	20.35	15-25	1996	Haremaya University
Ayenew	1700-2000	500-1200	100	Mottled	20.35	15-25	1996	Haremaya University
Roba	1400-1800	350-700	75-95	Cream	20-24	19-21	1990	Melkassa

Table 3 Other lowland pulses (cowpea, mung bean and adzuki bean) varieties released in Ethiopia

No	Name of Variety	Altitude	Rainfall	Date of maturity	Seed color	Research field	Famers field	Year of release	Seed maintaining centre
I	**Cowpea**								
1	Kankati (IT99K-1122)	1000-1850	350-1100	72-81	Red	22-32	17-21	2012	Melkassa
2	Asebot (82D-889)	1300-1650	350-750	75-85	Pink	26	20	2008	Melkassa
3	Bole (85D-3517-2)	350-1850	350-1100	86-95	White with light red eyed	19	17	2006	Melkassa
4	IT 98K-131-2	1100-1750	500 during growing season	110-120	Cream	17.9	14	2006	Hawassa
5	Asrat (IT 92KD-3)	1450-1850	660-1025	95-100	Cream	20-22.5	16.6	2001	Sirinka
6	Bekur (838 689 4)	1450-1850	660-1025	95.4	Red brown	19-21	19.6	2001	Srinka
7	Black eye bean	1000-1850	350-1100	75	White with light black eyed	16.2	14-16	1970th	Melkassa
8	TVU	1000-1850	350-1100	65	Cream	18.2	14-16	1970th	Melkassa
9	White wonder trailing	1000-1850	350-1100	75	Cream	16.2	13-15	1970th	Melkassa
II	**Mungbean**								
1	N-26 (Rasa)	900-1670	350-550	65-80	Green	8-15	5-10	2011	Melkassa
2	NVL-1	450--1670	300-750	60-70	Green	7.5-15	-	2015	Melkassa
3	Boreda	1100-1750	>500		Green	13.5	10	2008	Hawassa
III	**Pigeon pea**								
	ICEAP 87091	1000-1650	350-750	110-120	Cream	10-15	10-13	2009	Melkassa
IV	**Adzuki bean**								
	Erimo (Adzuki bean)	350-1850	350-1100	38-46	Red	22-26	-	2014	Melkassa

Disease management

Due to the main emphasis given to common bean, most disease management researches have focused on beans. Hence, this research review mainly focuses on common bean research findings.

Disease Survey, identification and documentations

Survey and diagnosis of plant diseases is necessary to first determine whether the disease is caused by a pathogen or an environmental factor. Survey data are also useful to give insight into occurrence, distribution and relative importance of the diseases (Rusuka et al. 1997). Comprehensive survey has focused on common bean where diverse diseases have been reported and categorized in to major, medium and minor. Diseases such as anthracnose (*Colletotrichum lindemuthianum*, rust (*Uromyces appendiculatus*) and common bacterial blight (*Xanthomons axenopodis pv phaseol*i (syn X. cmapstris Pv phaseoli) are the major and economically important ones. The diseases are known to occur over wider areas. Other diseases such as Web blight (*Rhizoctonia solani (Thanatephorus cucumeris*), Angular leaf spot (*Phaeoisariopsis griseola*), Ascochyta blight (*Phoma exigua* var *diversispora*), Halo blight (*Pseudomonas sysringae* pv.phaeolicola) and Floury leaf spot (*Mycovelosiella phaseoli*) are also economically important but limited to specific agro ecologies (Abiy *et al*., 2006; Habtu et al., 1996). An account of other lowland pulse diseases mainly Soybean, pigeon pea, cowpea, lima bean and mung bean have been documented. On Cowpea Ascochyta bligh*t (Ascochyta phaseolioru),* Root knot nematode *(Meloidogyne spp.),* false smut *(Synchytrium dolichi)* and Leaf spot (*Phoma bakeriana),* on Mung bean Halo blight*(Pseudomonas phaseolicola)* and on Lima bean (*Phaseolus lunatus):* blight *(Phoma exigua* var. *diversispora),* Rust *(Uromyces appendiculatus)* and Bacterial blight *(Pseudomonas syringaei* pv. *Phaseolicola)* have been reported.

Diseases Management Options

Germplasm screening and identification of host Resistance

Extensive screening of common bean germplasm from diverse sources has been carried out and identified host plant resistance as disease management options. The outcome of this extensive work has enabled the development and release of numerous common bean varieties that possess good level of resistance to major diseases mainly rust, common bacterial blight, Angular leaf spot, Anthracnose etc., Accordingly, earlier released varieties are resistant to one or more diseases. For instance at time of release Awash-1 and Goberash were resistant to angular leaf spot, common bacterial blight and rust. Nasir was resistant to rust, Common bacterial blight, anthracnose and angular leaf spot (MOA, 2011, MOA. 2012, MOA, 2014). Most of the early and recently released common bean varieties are also resistant/moderately resistant to rust and two or more of common bean diseases (MoARD, 2005). Common bean genotypes which possessed multiple disease resistance against anthracnose, angular leaf spot and common bacterial blight have been identified (Fininsa and Tefera, 2006). The identified genotypes have been recommended to be used as sources of resistance in breeding programs. Similarly, early reports also indicated the existence of variability among common bean genotypes for resistance against rust (Habtu, 1994; Habtu and Zadoks, 1995b). Furthermore, Habtu and Zadoks (1994) have also reported the existence of partial resistance (PR) to rust in some common bean genotypes evaluated. Partial resistance has been considered as durable resistance that ensures stable performance of genotypes across the various growing conditions and environments of common beans in Ethiopia. Hence, Habtu and Zadoks (1994) suggested criteria for selecting bean genotypes with PR to rust, as well. Therefore, partial resistance may be a trait worth utilizing in bean breeding program in. Ethiopia. Similarly, sources of resistance against bean anthracnose (*C. lindemuthianum)* have been identified(Tesfaye, 2003). In some cases some common bean genotypes such as *RAZ-18* and *REN-20* possesd field resistance to anthracnose and angular leaf spot at Bako (BARC, 1998). In areas where angular leaf spot is economically important particularly in Southern and South Western part of the country, some common bean genotypes (EMP-233, EMP-212, G-10843 and Dicta-65) identified for their consistent resistance against the disease and floury leaf spot (Lemessa and Tesfaye, 2005).

Cultural practices

Different cultural practices have been reported that serve as cultural control of common bean diseases. These cultural practices include varietal mixture for the control of common bacterial blight (Lemmessa, 2004). For instance, varietal mixtures with the resistant variety, Gofta (G-2816), consistently reduced common bacterial blight incidence, severity, area under disease progress curve and disease progress rate on the susceptible cultivar (Red Wolaita). Generally, disease development decreased as the proportion of the resistant cultivars in the mixture increased (Lemmessa, 2004). The mixture had a maximum of 27% efficacy for common bacterial blight control. The other cultural practice, bean-maize intercropping, has been identified as component of common bacterial blight disease management (Fininsa, 1996). However Lemessa, (2004) indicated that intercropping did not significantly affect angular leaf spot severity. Similarly cultivar mixture has been recommended as one strategy for controlling anthracnose where growing common bean cultivar mixtures containing at least 50% of the resistant cultivar can control the disease (Tesfaye, 2003). The level of control achieved depends upon the proportion of the resistant cultivar in the mixture, i.e., the higher the percentage of the resistant cultivar in the mix the lower the disease. Furthermore anthracnose management options have been recommended to include components that reduce initial inoculum; such as field sanitation, crop rotation whenever feasible, planting healthy seed, early incorporation of bean debris into soil, burning of crop residues and effective seed treatment, in addition to developing resistant cultivars (Fininsa and Tefera, 2001; 2002).

Chemical control

Uses of chemical control on legume crops in general and on lowland pulses in particular are uncommon especially with small scale farmers who produce common bean. The limitation appears due to the high cost of production. However, chemotherapy has been considered for the role it plays in the control of anthracnose, particularly in large-scale bean production. Data generated from efficacy trials on fungicides revealed that a combination of dressing common bean seeds with Benomyl and a foliar spray of bean plants with difenoconazole or foliar application of difenoconazole alone adequately protects common beans against anthracnose (Tesfaye and Pretorius, 2005). Similarly, spraying Benomyl 50WP at a rate of 0.5 g per L significantly reduced Angular leaf spot at Jimma, Ethiopia (Lammes et al., 2011). Supplementary fungicide sprays (Tebucnazole at a rate of 2 liter/ha) at three critical bean growth stages (V4, R5 and R6) reduced angular leaf spot. In the absence of complete varietal resistance, the use of reduced fungicide sprays at specific bean growth stage is recommended for the management of angular leaf spot (Getachew, unpublished report).

Integrated disease management

Practical integrated disease management options for lowland pulse diseases in general and common bean diseases are generally lacking. However, some recommendations have been given on specific diseases. For anthracnose management options, components that reduce initial inoculum such as field sanitation, crop rotation, whenever feasible, planting healthy seed, early incorporation of bean debris into soil, burning of crop residues and effective seed treatment, in addition to developing resistant cultivars were found effective (Fininsa and Tefera, 2001; 2002).

Insect pest management

Beans (*Phaseolus vulgaris* L.) form an important food and cash crop in Africa, particularly in the Eastern, southern, and Great Lake of the continent (Abate& Ampofo, 1996). Ethiopia is the third major producer of bean in Eastern Africa countries next to Kenya and Uganda (Kirkby, 1993). Damage by insect pests is one of the limiting factors to bean production in Africa (Abate & Ampofo, 1996). Although numerous pests attack all parts of beans, bean fly (*Ophiomyia spp*.), African ball worm and bruchids are the most important field and storage pests, respectively (Abate & Ampofo, 1996, Giga & Chinwada, 1993). Bruchids *(Zabrotu subfasicutus* (Bohman) also known as Mexican bean weevil, and *Acanthoscelidus obtectus* (say), the common bean weevil) are important pests of stored beans in the world causing the average losses 13 % (Cardona, nd.). Negasi & Abate (1992) reported that these two species are the major pests of stored beans in Ethiopia.

Bean stem maggot management options

Cultural control

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

Host plant resistance

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

Chemical Control

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

Bruchids management options

Host plant resistance

High level of resistance was detected in RAZ lines and Roba-1 among 56 common bean genotypes from Melkassa, Bako and CIAT and screened for resistance to the Mexican bean beetle at Bako (OADB-ARCS, 1998a; 1998b; Firdissa et al., 2000). Ferede and Tsedeke (1992) also reported the resistance of RAZ lines to the same pest.

One hundred common bean genotypes (73 *Zabrotes* resistant lines from CIAT and 27 lines from Melkassa Bean Breeding Program) were screened and least oviposition was observed on genotypes Raz -8, Brown Speckled and RAZ 20-1.

Several genotypes were less preferred for oviposition and a number of genotypes were identified as resistant based on absence of bruchid emergence hole. According to Tigist (2004), among 15 common bean varieties tested, Red Wolaita, A-197, and Ayenew were relatively resistant to *Zabrotes*. Roba-1 and Brown Speckled, which were reported by Ferede (1994) as resistant to the same pest, were found susceptible in her study. She also reported that high number of eggs resulted in low number of F1 progeny indicating that number of eggs does not show varietal differences in *Zabrotes* resistance (Tigist, 2004).

In an earlier study, nine cowpea lines introduced for their bruchid resistance and a commercial variety White Wonder Trailing were evaluated for resistance to bean bruchids for two seasons; all the introduced varieties had significantly lower levels of infestation and seed damage than White Wonder Trailing (Ferede, 1989). Superior results were obtained from IT 81 D-1137, IT D-985 for the two seasons, and IT 81 D-944 for the 1985/86 season. Tsedeke (1995) indicated that the IITA accession IT-81D-85 showed high level of resistance to the bruchid, and the commonly recommended variety White Wonder Trailing was highly susceptible. However, the resistant varieties were reported to be poor yielders. Hence, it was suggested that the trait should be transferred to high yielding varieties (Ferede, 1989).

Cultural control

The protection of stored grain with inert substances such as wood ash, lime, sand, and tobacco dust is a time honored universal practice that is still in use for preserving seeds. Its effect consists of removal, by sorption or abrasion, of the epicuticular lipid layer, which protects insects from desiccation. Higher insecticidal efficacy is obtained with finer particles. It has been suggested that free movement of the adults for oviposition is prevented by the ash filling the inter-granular spaces. Wood ash was found to have the potential for use on stored sorghum (Adane and Abraham, 1996a). Wood ash 20% w/w and termite mound soil 20% w/w were effective for the control of the Mexican bean beetle on common bean (Anon., n.d). Muluemebet (2003) also tested the role of wood ash and found that it must be applied at 30% w/w to provide effective control of bruchids on cowpea in Gambella.

Botanical control

Neem, chinaberry (*Melia azedarach*), Mexican tea, *Lantana*, and *Tagetes*, each at the rate of 4%, were evaluated against *Zabrotes subfasciatus* on common bean (Tigist, 2004). It was found that botanical treatments increased adult mortality, reduced F1 progeny number, percentage seed damage and seed weight loss. Mexican tea seed and leaf, *Tagetes* seed and leaf and neem seed powder gave better protection than the other botanicals. Lantana was the least in protecting common beans from damage by the bruchid (Tigist, 2004).

Muluemebet (2003) found that Mexican tea seed and leaf powders at higher doses (3 and 6% w/w) significantly reduced oviposition, egg hatchability and adult emergence of *C. maculates* on cowpea. Pre-infestation treatments were better than post-infestation treatments. Neem seed at 3% w/w was better than all other botanicals and had longer persistence as it was effective even after three months of application. It also delayed progeny emergence. Neem seed at 2–3% w/w, neem and Mexican tea leaf powders each at 6% w/w, Mexican tea seed at 3% w/w gave better protection to cowpea seeds, especially when applied before infestation.

Weed management

Weeds cause yield reduction primarily by competing with crop for light, nutrients and space. Efforts have been made to identify and characterize the major weed species, assess crop losses due to weeds and identify effective management methods to reduce the impact of weeds. More emphasis were given to cultural and chemical control. Most research has been also conducted for common bean due to the priority given for this crop. Hence, the review focus on the advances made on weed research on common bean and the major weed species recorded is given in table 4 below.

Table 4: -*Major weed species recorded in major common bean growing areas of Ethiopia*

Broad Leaf Weeds
Commelina spp, Guizotia scabra, Caylusea abssinica , Ageratum conyzoides, Bidens pilosa, Spergula arvensis L, Corrigiola capensis, Portulaca oleracea, Amaranthus spp., Argemone ochroleuca, Datura stramonium, Erucastrum arabicum, Galinsoga parviflora, Nicandra physalodes, Polygonum napalence, Xanthium strumarium, Xanthium spinosum
Grass Weeds
Eleusine indica, Cyperus spp, Cynoden spp, Digitaria spp.,
Invasive Species
Parthenium hysterophorus

Source: Fasil Reda, 2006; Meseret et.al, 2008; Abiy Getaneh and Fasil Reda, 2009

Research findings from different lowland growing areas of Ethiopia (Melkassa, Awassa, Metu and Jima) indicated that yield reduction of common bean due to weed competition were 35, 90, 64.3 and 42%, respectively (Rezene, 1985; Etagagnehu, 1987; Tilahun, 1998). Indirect effects of weeds include harboring rodents, hosting diseases and harmful insects (Amare, 1988).

Out of different weed management practices evaluated for their efficacy and efficiency, the pre-emergence herbicides Dual Gold (1l/ha) & Alanex (4l/ha) and row weeder followed by supplementary hand weeding were selected based on farmers preference (Amare et al, unpublished). Waktole et.al (2013) also reported that managing the weeds with the application of S-Metolachlor at 1.0 kg ha^{-1} + hand weeding and hoeing 35 days after emergence proved to be the most profitable practice. However, under the condition of labor constraint and timely availability of the herbicide, pre-emergence application of s-metolachlor at 2.0 kg ha^{-1} along with 92 kg P_2O_5 ha^{-1} should be used to preclude the yield loss and to ensure maximum benefits.

Abiy (2009) reported that integrated crop and weed management practice significantly affected weed count, weed dry matter, number of pods per plant, number of seeds per pod and grain yield. The highest number of pods/plant, seeds/pod and grain yield were achieved with the combination of row planting, tied ridging, fertilizer, and two hand weeding. These management packages were superior in terms of improving the productivity of the bean varieties significantly. The intensity of weed infestation was lower on fertilized and better managed crop compared to the control. It was evident from the results that the better managed crop performed better despite the higher weed infestation.

Food recipe development

While white pea bean varieties of common bean are produced mainly for the export market, the colored beans are for consumption and local market. Mulugeta et al. (2003), indicated that major dishes such as shiro, soup, sambosa and stew of split beans can be prepared and utilized from common beans. On the other hand, a major problem in the utilization of dry beans is their long cooking time. Cooking time is influenced by variety and location. According to Mulugeta et al.(2003), varieties grown at MARC showed shorter cooking time. Among common bean varieties, Roba-1 and white pea beans have shorter time of cooking.

Common beans are rich source of protein and minerals. According to Mulugeta et al. (2003) and Shimelis Emire and Sudip Rakshit (2004),the protein content ranged from 17.32% to 23.18 %., fat content from 1.38 to 3.46%, fiber content ranged from 2.40 to 10.13 %, carbohydrates from 51.72 to 64.71%, calcium from 64 to 21-220.61mg/100g, zinc ranged 1.34 to 2.90mg/100g and iron from 5.14 to 8.41%. Proximate composition showed greater variation. With regard to minerals, calcium was the most abundant, whereas zinc was low. Varieties Roba-1 and Gofta can be named as micro-nutrient rich beans (zinc and iron).

Processing effects of hydration, autoclaving, germination, cooking and their combinations, on the reduction/elimination of anti-nutrients and improvement of in vitro protein digestibility of common bean varieties were studied (Emire Shimelis and Sudip Rakshit, 2005). Hydration results on reduction of total α-galactosides was attained due to the deferential solubility of the individual oligosaccharides and their diffusion rates. Saponins, trypsin inhibitors and phytohaemagglutinins diminished drastically to undetectable amounts when heating processes (cooking and autoclaving) were subjected. Hydration and germination processes were less effective in reducing trypsin inhibitors, saponins and phytohaemagglutininss compared with cooking/autoclaving processes. Germination process reduced stachyose, raffinose, phytic acid and tannins which was due to metabolic activity. However, the combination of germination followed by autoclaving processes yielded the most promising result. It was concluded that the bean variety Roba-1 exhibited better protein digestibility on processing and thus has high potential to be used as a raw material for the manufacturing of value-added products.

Emire Shimelis and Sudip Rakshit (2008) also investigated the influence of natural fermentation and controlled fermentation in lessening the content of anti-nutrients, α-galactosides and increments in in-vitro protein digestibility of dry beans products. A decrease in raffinose, oligosaccharide, anti-nutritional components and pH was observed in both types of fermentation. The natural lactic fermentation of beans, raffinose concentration reduced significantly to an undetectable level after 96 h of natural fermentation. However controlled fermentation had not any significant effect on the reduction of the α-galactosides content of the flours during fermentation. Although both types of fermentation methods diminish anti-nutrients and improve the nutritional value of the bean flour and indicate the potential to use bean flour as an ingredient for fabricated foods, natural fermentation is an inexpensive method by which consumers can obtain good-quality protein.

The anti-nutritional factor, Stachyose, was the predominant α-galactosides in all Ethiopian common bean improved varieties analyzed. Raffinose was also present in significant quantities but verbascose, glucose and fructose were not detected at all in the samples. Mean values for protein digestibility ranged from 65.64% (in Beshbesh variety) to 80.66% (in Roba-1 variety). Mean values for raffinose, stachyose, sucrose, trypsin inhibitors, tannins and phytic acid were 3.14 mg/g, 14.86 mg/g, 24.22 mg/g, 20.68 TUI x 103/g, 17.44 mg catechin equivalents/g and 20.54 mg/g, respectively. It was found that anti-nutritional factors and protein digestibility were influenced by variety (genotype). Relationships between anti-nutritional factors and protein digestibility were also observed.

Among the improved varieties studied, Roba-1, Red Wolaita, Mexican-142 and Awash-1 were found to be the best food and export type of common beans in the Ethiopian context, because of their higher protein digestibility, lower anti-nutritional factors and other beneficial nutritional parameters.

Seed system and technology promotion

Access to seed of improved bean varieties is the major bottleneck to common bean production in Ethiopia. Most of the bean producers obtain seed of improved varieties from few seed suppliers, who are unable to sufficiently produce and sell seed at reasonable price. To improve the accessibility and availability, a strategy to produce seed of improved varieties at the community level through integrated impact driven seed systems was started in 2004. Through this approach, the access to seed of market demanded varieties increased from less than 20% in 2004 to about 70% in 2014 across major bean growing areas. The seed production and delivery was accompanied by improved crop management techniques to increase crop productivity per unit area. The number of partners who are interested to participate in seed production and distribution has increased from 13 in 2004/5 to 44 in 2013/14. A total of 1211.4 tons of initial seed of different varieties was distributed to different bean growing areas. Between 2004/5 and 2013/14, the seed distributed by national bean research program covered an area of 8,763 hectares and produced 11,844.2 tons of seed. Farmers who have been reached with the seed and information from all sources and spill-over are estimated to be 1,018,266. This accounts for about 31% of bean growers in the country. These numbers of farmers who have received the seed directly from the partners account for about 21% and others assumed to be reached by the spill-over effect and information. With increased production and productivity, which directly relates to the amount of common bean in the local markets, there is also an increase in the number of value chain actors from time to time. Between 2004/5 and 2013/14, the volume of bean export (particularly white pea bean) increased from 61,000 tons to 91,000 tons. Within the same period, 83% increment in revenue was also obtained which directly related to an improvement in price of the product. The general approach and seed delivery done for the last ten year has been discussed below.

Approach for enhancing common bean seed system

Engaging partners

It was recognized that engaging diverse partners is very important to establish decentralized common bean seed production in Ethiopia. Identification and engagement of those partners from different bean growing regions was done through different fora such as annual review and planning meetings at different levels, regional extension and farmers' linkage forum etc. After the establishment of the partnership, planning meetings were held in order to design the mechanisms and amount of seed distribution and type of varieties in each area of operation. This also provided an opportunity to share the roles and responsibilities of each partner. Table 5describes the clear roles and responsibilities of each partner from different regions. Policy makers were also engaged so that they become part of the forum and facilitate the implementation.

Improving the skills and knowledge of partners

To improve skill and knowledge of partners in seed production, awareness creation meetings were conducted every cropping season in the regions. Training of trainers (ToT) courses were organized for the experts from the

Ministry of Agriculture (MOA), community facilitators of partner NGOs, agronomists from farmer' based organizations and seed producing farmers. The training covered all aspects of seed production and marketing.

Table 5. Roles and responsibilities of partners in the decentralized common bean seed production in Ethiopia

Partners	Roles and responsibilities
EIAR & RARIs	• Production and supply of initial seed • Provision of information on new varieties • Support and enhancement of skills and knowledge of partners • Catalyze the bean sub-sector development
Ministry of Agriculture and Natural Resources	• Support to provide knowledge and information to farmers • Policy support for bean research and development • Engage and support private sector investors • Assist distribution and recover the seed after production
Seed Enterprises	• Production andsupply of basic and certified seed • Facilitate training for quality seed production and purchase produced seed
Seed producers	• Test new varieties with support from extension service providers • Produce and market seeds in local markets and to local organizations • Engage local community for wider dissemination of information and seeds
Farmers' Cooperative Unions	• Mobilization of farmers (members) • Provision of agricultural inputs (fertilizers, seed) to famers on loan or cash • Purchase of bean grain from members and communities • Establish market infrastructure for storage and cleaning • Distribute and collect the seed
CIAT/PABRA	• Training partners in seed production and business skills • Support and backstopping in establishing community of practices • Support in the design of innovative seed systems approaches for wider impact

Initial seed production and distribution

Initial seed of preferred bean varieties was multiplied at Melkassa Agricultural Research center (MARC) and other research centers such as Hawassa,Areka, Jima, Bako and Pawe in the rainy season and using irrigation. All information including the name of variety and its characteristics such as maturity date and productivity and seed quality attributes such as germination, purity and production season were printed on the bag and provided in the local language. Two approaches were used to distribute the initial seed:

1) Commercial *Packs*: These packs were used to sell and distribute popular and commercial varieties to areas where beans are produced for sale. The sizes of these bags were 5, 12.5 and 25 kg and they were mainly distributed through primary partners, i.e., partners who participated in receiving the initial seed from a research center and producing the quality declared seed (QDS) or those who distributed to the farmers to be produced. The initial seed is distributed to the partners on loan and in kind bases, which is recovered and distributed to other farmers in the area. After production, the loaned seed were recovered through primary and secondary partners to be distributed to other farmers who need to use the seed in the areas. The amount produced by farmers or other partners is bought by a farmers' cooperative union(FCU) and other organizations such as MoANR, NGOs and other farmers. FCUs either buy at least 30% of the quality declared seed (QDS) produced by farmers or facilitate and link seed market to producers. The quality of the produced seed is checked by MARC and other centers and provided with recommendation letter which describe the quality of the seed.

2) Small *Packs:* Such packs were used to avail seed of newly released improved varieties for small-scale farmers with very small land holdings. Since the purpose of the packs is to introduce the improved bean varieties to a number of farmers within a given season, more than ten varieties have been distributed to different regions. The seed packs were sold with fair price (considering the purchasing power of poor farmers to ensure the ownership of the farmers). Four weight categories (250, 500, 750 and 1000 g) were used to pack with similar information on commercial packets.

Planning for action with partners

Each year, a planning meeting was held with partners in order to share roles and responsibilities. Basically, each partner defined their roles and responsibilities, but the purpose of the meeting was to set action plan for the cropping season. The decision on the mechanisms, amount of seed and the varieties to be distributed in each area of operation was also made in this meeting.

Implementation area

The implementation of decentralized common bean seed system was started in the Central Rift Valley (CRV) where more than 40% of the production exists. This covers six districts of Eastern Shoa zone (Boset, Adama, Lume, Bora, Dugda and Adami Tulu JidoKombolcha), three districts of West Arsi zone (ArsiNegelle, Shashamane and Shalla) and two districts of Arsi zone (Sire and Dodota). Different partners have been participating in seed production and distribution in these areas. LumeAdama FCU, Meki Catholic Church, Self Help International and office of agriculture at zonal and district level were the major ones.

Since 2008, other common bean growing areas were included due to Tropical Legume II (TL-II) project. In collaboration with Hararghie Catholic Secretariat (HCS), CARE Ethiopia, Haramaya University, Afrenkelo FCU, Burka Galeyti FCU and offices of agriculture, decentralized seed system began to be implemented in East and West Hararghie zones. In SNNP Region, the Southern Agricultural Research Institute (SARI) was the source of initial seed for the different partners. Bako and Jimma research centers have been involved to provide seeds of improved varieties of common bean to south west and western part of bean growing areas of Oromia region. Pawe research center is the major source of seed for BenishangulGumiz region and parts of Amhara region partners. Sirinka agricultural research center has been involved in providing initial seed for the South Wolo zone. The partners of each center have been involving in the production and distribution of QDS of the preferred improved varieties in each region.

Seed production and distribution

Seed production and delivery

The main purpose of the decentralized seed production and delivery system was to improve access and availability of seed of improved varieties of common bean through different partners. Hence, the number of partners who are interested to participate in seed production and distribution has increased from 13 in 2004/5 to 44 in 2013/14 (Table 6). A total of 1,211.4 tons of seed of different varieties was distributed to different bean growing areas. Farmers' interest in the varieties they wish to grow was also maintained in each region. Between 2004/5 and 2013/14, the seed distributed by Ethiopia National Bean program covered an area of 8,763 hectares and produced 11,844.2tons of seed (Table 7). The produced quality declared seed (QDS) were distributed to different regions by partners and others to be utilized by farmers. Mostly, NGOs and farmer cooperatives unions (FCUs) were involved in distribution of QDS.

Table 6. Amount of common bean basic seeds supplied between 2004/5 and 2013/14 in Ethiopia

Cropping season	Number of varieties	Amount of seed distributed (t)	Number of partners involved
2004/5	9	137	15
2005/6	8	66	23
2006/7	8	83	24
2007/8	7	56	27
2008/9	10	122.4	32
2009/10	7	112.2	36
2010/11	8	98.9	45
2011/12	7	95.50	53
2012/13	5	273.1	44
2013/14	6	167.3	45
Total		**1211.4**	

Table 7. Area coverage and amount of common bean seed produced by partners 2004/5-2011/12 in Ethiopia

Cropping season	Area covered (ha)	Amount of seedproduced by partners(t)	Number of farmers reached
2004/5	1233	1179.6	10616
2005/6	594	556.4	6677
2006/7	747	827.5	12413
2007/8	504	584.1	11098
2008/9	1101.6	1648.7	13440.4
2009/10	1009.8	1671.8	114848
2010/11	890.1	1424.2	342664
2011/12	859.5	1116.4	456010
2012/13	985	1378.5	27000
2013/14	839	1457	23500
Total	**8763**	**11844.2**	**1018266**

Impacts due to enhanced common bean seed system

Due to the systematic, functional technology generation and promotion, the production and productivity of common bean have been boosted (Figure 2 and 3) and the export earnings from this commodity have been also substantially improved for the last ten years (figure 4). Moreover, different investors were attracted to common bean value chain due to improvement of production and productivity of the crop by the value chain actors (farmers, private farms, exporters). Farmers who have gotten change from small scale to investors, like Haile Wako, were also achieved. Moreover, well organized and modern exporter, Agricultural Commodity Supply (ACOS), emerged in the history of common bean business in Ethiopia. ACOS processes and exports 30,000 to 40,000 metric tons per annum. The Ethiopian Commodity Exchange (ECX) was established to facilitate modernized marketing system for five crops among which small white beans are one. This also further contributed to increase in export volume and income.

Future Prospect of Lowland Pulses Research in Ethiopia

The breeding and genetics research in the future will focus on bringing genetic gain in lowland pulse crops by conducting strategic research to broaden the genetic base of lowland pulse crops through introduction, collection, and hybridization. The germplasm will be evaluated following multidisciplinary and participatory approaches to develop high yielding and multiple-stress-tolerant varieties with better adaptation (wide/specific) to different agro-ecologies. The breeding will focus on development of varieties resistant against multiple constraints (diseases, insect pests, drought, low soil N& P), rich in nutrients to address nutritional deficiencies, highergrain yield potential and good market demand, and adaptable to new production niches (tolerant to frost, , salinity, heat), potential varieties that are suitable for mechanization and fit to different cropping systems. To attain these breeding objectives, application of conventionaland molecular breeding techniques, introduction of new lowland pulse crops (e.g, Adzuki bean, Cluster bean) to address new pulse agro-ecologies and broaden accelerated adaptationto different agro-ecologies and cropping systems will be implemented. Moreover, establishment of breeding platforms to enhance knowledge, skills and tools of modern plant breeding, implementation of innovative seed systems for effective and efficient breeder seed maintenance and initial increase, and enhancement of availability and modernization of breeding data management system will be effectively implemented.

In the future, agronomy and crop physiology will also be one of the main tools to support breeding and to bring the desired level of yield gain. Thus, revising the current practice and developing agro-ecological and soil-test based and area specific agronomic recommendations (fertilizer rate & type, planting date, plant population) for lowland pulses for different market classes will be developed. Agronomic recommendationsto enhance lowland pulses productivity and production onproblem soils (acid, saline) will also be developed. Furthermore, optimal practices or technologies for lowland pulses production in different cropping systems (inter-cropping, multiple cropping, relay cropping & double cropping systems) in different agro-ecologies,effective rhizobium strains fordifferent lowland pulses will be developed. Moreover, developing refined recommendations for the use of the combination of inorganic fertilizer and inoculant combination, use of crop simulation models to support the decision making and planning in lowland pulses production under changing climate, soil conditions and crop management practices will alsobe developed.

Crop protection is also one of the main areas of research in the future to improve the production and productivity of lowland pulses. Hence, revising the current information on the economically important pests (diseases, weeds& insects) in Ethiopia and development of agro-ecological and crop based integrated pest management options (IPM) for major pests will be pertinent. To achieve these objectives, identification of source of resistance for major pests, study of epidemiology of diseases, dynamics of insect pests and weeds of lowland pulsesindifferent agro-ecologies, monitoring race patterns and shifts of different diseases/insect pests using conventional laboratory & molecular techniques and development of basic background information for fast diagnosis of pest problems and devising effective control measure, characterizing pathogens (ALS, anthracnose, rust, CBB) using conventional and molecular tool will be implemented.

To enhance the modernization of lowland pulse production, use of modern mechanization would be indispensable. Therefore, development of relevant pre- and post-harvest agricultural mechanization technologies for lowland pulses would be indispensable. Further, linking the mechanization research findings with manufacturers and pre-scaling of proven technologies for wider use should also be effectively implemented.

Promotion of lowland pulse based technologies generated by different research teams would be indispensable to benefit the end users to bring the desired level of impact. To achieve this aim, creation of demand for improved technologies through demonstration and development of functional linkage of stakeholders, dissemination of information and technology, enhancing the role of cooperatives and community through strengthening technology multiplication and farmers to farmer's dissemination capacity will be strengthen and reinforced. Further, development of functional linkage of bean value chain to enhance information and knowledge on improved technologies transfer will be strengthened. Additionally, policy dialogue or advocacy, seminars and promotion of lowland pulses through different media, like published materials, radio, television etc., and finally assessing the impact of research and development interventions of lowland pulses in the country will be conducted to assess the progress and to design future intervention in technology promotion of lowland pulses.

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Cotton Research in Ethiopia: Achievements, Challenges, Opportunities and Prospects

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Introduction

Historically, cotton research in Ethiopia began in 1901 and continued to 1910 by the Italians and later in 1928 by Germans at Upper Awash using Egyptian cotton, *Gossypium barbadense* L. (Reed and Dunn, 1941). After seven years of research work, the project terminated without success. The third phase in cotton research began again by the Italians and after a few years of research work, the Italians proved the possibility of large-scale cotton production in Ethiopia. For the fourth time, cotton research was resumed in 1964 at the then Melka Werer Agricultural Research Station (now WARC) as a research department under the Ministry of Agriculture of the Ethiopian Government, through the assistance of Food and Agricultural Organization (FAO). Later, from 1966 to 1988, cotton research was carried out under Field Crops Department by the then Institute of Agricultural Research (IAR). In 1989, the crop was considered important and raised to commodity level in its research undertakings.

Nowadays, the organizational structure for cotton research is commodity-based and team-led multidisciplinary approach coordinated from Werer Agricultural Research Center (WARC). This is still true for irrigated cotton research. However, very recently in 2016, by the decision of EIAR, the national rain-fed cotton research coordination has moved from WARC to Assosa Agricultural Research center (AARC) in western Ethiopia.

Cotton, though a highly important commodity did not have research sub-centers of its own over the last five decades. Instead WARC collaborated with MoA and the then State Farms for technology testing and demonstrating sites across the country to screen and select cotton lines/varieties for irrigated as well as rain-fed agro ecologies. There are six major agro-ecologies that are suitable for cotton cultivation in Ethiopia.

Cotton Production Constraints

The current domestic cotton production is much below the potential, which poses a constraint with respect to backward integration of the country's textile and garment industry. Further, given the relatively limited use of pesticides and chemical fertilizers by smallholder farmers, Ethiopia has the potential to become a producer of organic cotton. But absence of any administrative body to monitor and certify organic farm practices and lack of separate line of ginneries and other processing and handling facilities to manufacture organic cotton-based products is constraining its growth(1). The various constraints of traditional farming practice in most of the smallholder farmers are lack of good quality seeds, inadequate fertility management, poor post harvesting technologies, lack of integration among actors in the sub-sector, lack of access to credit and financial problems in smallholder producers, and lack of coordinating and regulating body of the subsector in the country(2).

The varieties available in the country are either inadequate or do not meet the required international standards or both. Not much research efforts are made to develop cotton varieties, which can allow the production of cotton with acceptable quality and quantity. The variety needed to produce the type of cotton in great demand in the international market is long fiber cotton, and it is not available in the country. More seriously, minimum research efforts are made to the multiplication of those varieties which are already known and used in other countries. These constraints have seriously challenged the effort to improve cotton productivity and quality. The cotton varieties widely grown in Ethiopia are primarily Deltapine 90 and Acala SJ2 (from USA and Israeli sources). However, these species have been used for more than 20 years, thus giving rise to the serious problem of variety ageing and degeneration. Generally, a variety is limited to about 3-5 years use in the major cotton producing countries, because by renewal of species, yield can be increased by l0-15%., in some cases, even by 30% (Chavan, 2010).

In fact, there is no doubt about low productivity of cotton in Ethiopia, which can be attributed to several critical factors such as lack of integrated and effective pest management measures; poor budget allocation for cotton research and the resultant lack of updated production and management technologies addressed to farmers; absence of seed system in the sub-sector; fragmented small-scale farming system; limited extension services coupled with declining research outputs; meager irrigation practices and heavy dependence on unreliable rain-fed agriculture rather than proper conservation and utilization of water for full and supplemental irrigation at critical stages of the crop; climate change impact (drought, and flood); and competition from more productive crops like sesame and sugar cane production.

Major Research Achievements

Varietal development

From its establishment Werer Agricultural Research Center was mandated for developing genotypes that are suitable for different agro-ecologies to meet the demands of farmers and the textile industries across the country by employing conventional breeding methods. To date, 21 varieties and seven hybrids were released for irrigated areas and five varieties for rain-fed areas based on their merits of seed cotton yield and fiber quality characteristics. A total of 33 varieties have been released by the cotton research department as shown below in Table1. These varieties have been released depending on ranking mean performances of genotypes at individual locations and overall mean performances of genotypes (combined ANOVA) methods through introduction and adaptation and as well as hybridization of lines for generating recombinants, followed commonly by pedigree selection. Since cotton is predominantly self-pollinated, but up to about 30% sometimes higher cross-pollination occurs (Acquaah, 2007), hybridization of lines for generating recombinants, followed commonly by pedigree selection to identify superior genotypes is the most common breeding procedure that has been used by WARC. The cotton research team currently is dealing with the acquisition of more varieties and testing for their adaptation and evaluating them with more emphasis on fiber quality parameters. Moreover, as cotton is more liable to pests, management practices to control them and improved agronomic practices are the core research agenda for the cotton research team.

Table 1. Cotton varieties released by WARC for production since 1966.

No.	Variety name	Year of release	Seed cotton yield q/ha	Ginning percent (GOT%)	Micronaire	Fiber length mm	Fiber strength lb/sq inch	Recommended for
1	A-333-57	1960s	29.3	34.6		-	-	Rain-fed
2	Acala 1517/70	1975	38.9	36.7		-	-	Irrigated
3	Albar 637	1960s	20.6	34.8		-	-	Rain-fed
4	Acala 1517C	Before1970	-	37.2		-	-	Irrigated
5	Acala 1517D	Before1968	-	-		-	-	Irrigated
6	AMS1(70)	1974	25.9	37.6		-	-	Irrigated
7	Werer 1-84	1984	28.6	37.8		-	-	Irrigated
8	La Okra Leaf 2	1986	27.3	38.0		-	-	Irrigated
9	Acala 4.42	1974	23.5	38.6		-	-	Irrigated
10	Reba B-50	1960s	18.0	36.3		-	-	Rain fed
11	Acala SJ2	1986	32.5	34.2	3.2	28.6	79.3	Irrigated
12	Arba	1987	30.0	40.1	3.5	30.2	79.7	Rain fed
13	Bulk 202	1989	33.4	41.0	3.5	28.1	78.3	Rain fed
14	Deltapine 90	1989	38.6	34.8	3.7	27.7	77.3	Irrigated
15	Cucurova 1518	1994	41.7	38.9	3.8	26.9	74.6	Irrigated
16	Cu-Okra	1994	37.6	38.9	4.0	26.1	75.7	Irrigated
17	Carolina Queen	1994	41.8	39.6	3.8	27.2	77.6	Irrigated
18	Sille-91	1997	38.6	39.4	3.6	27.9	72.7	Irrigated
							Fiber strength g/tex	
19	Stam59A	2007	33.4	42.0	4.3	29.8	32.5	Irrigated
20	YD-206	2011	42.0	37.2	3.5	34.4	36.5	Irrigated
21	YD-223	2011	41.3	37.5	3.4	33.8	36.6	Irrigated
22	YD_211	2011	42.2	35.9	3.3	34.2	36.6	Irrigated
23	YD-670	2013	40.0	37.1	3.5	32.0	34.8	Irrigated
24	YD-195	2013	33.7	39.2	3.5	31.7	35.2	Irrigated
25	VBCHB 1203	2013	24.7	36.6	2.9	30.7	32.2	Irrigated
26	VBCH 1527	2013	24.3	29.0	3.6	29.9	34.0	Irrigated
27	STG-14	2014	38.8	42.7	4.22	30.0	31.7	Irrigated
28	Candia	2014	40.6	44.1	4.1	29.0	30.20	Irrigated
29	Claudia	2014	38.4	45.7	4.36	30.9	32.4	Irrigated
30	Gloria	2014	42.6	43.0	4.1	29.4	31.96	Irrigated
31	WARC-CC1	2015	40.7	44.8	4.3	28.8	25.9	Irrigated
32	WARC-AC2	2015	43.0	39.0	3.9	27.7	29.5	Irrigated
33	WARC-GU3	2015	46.2	38.2	3.9	26.1	29.5	Irrigated

Source: (MOARD, 2009, 2014 and WARC Progress Report, 2014, 2015 Unpublished).

Crop Management

Yield potential of the cotton crop largely depends on management practices from land preparation to harvesting. Research and demonstration efforts have been made to implement several recommendations on proper cultural practices such as land and seedbed preparation, time of sowing, seeding rate and spacing, irrigation system, fertilizer rate, weed management, use of cotton defoliant and cotton growth regulator, and proper time of harvesting to ensure increased cotton production and productivity in the county.

Seed cotton is ginned to separate lint from the seed. The ginned seed always contain linters which have to be further de-linted mechanically or by sulfuric acid de-linting usually to prepare the seed for planting. The recommended seed rate of non-acid de linted seed is 30-45kg/ha whereas 15-20kg/ha is enough for sulfuric acid de-linted seed. To obtain smooth naked seed for planting, 10 kg of fuzzy cotton seed can be de-linted with 1200ml of sulfuric acid by thoroughly mixing for 5-7 minutes. Then, the mixture-should be washed by water repeatedly to avoid any residual effect of the acid on seed health. Usually floating seeds are removed and discarded (because of low germination percentage) and sinker seeds are sundried and stored in clean seed bags. The advantage of acid de-linted seeds can be expressed by higher germination percentage and reduced seed cost and save time and producers can use reduced seeding rate than mechanically de-linting process.

The recommended sowing dates for Middle Awash range from April 15 to May 15, for lower Awash from May 15 to June 15.For Gode area in Somali region planting time is best in October and also as double crop in April. For Omorate area in SNNPR the recommended planting time is September/October. In most rain-fed cotton areas, planting begins with the onset of rains. The recommended spacing is 80 cm between rows and 25 cm between plants with a population of 50,000 plants/ha or spacing of 90 cm between rows and 20 cm between plants is another option which is mainly practiced by commercial farms. Sowing depth should be adjusted within 3-5 cm of the soil.

Irrigation studies and agronomic practices

After land preparation and ridging, pre-planting irrigation is recommended about two weeks before planting to ensure satisfactory germination and emergence. After planting, two choices are available to irrigate the cotton crop in the Middle Awash Valley and similar areas. One choice is to irrigate with 75 cm depth water at 2 weeks interval, and the other is to irrigate within 125 cm irrigation depth at 3 weeks interval. Replanting may be necessary when seed emergence is low or unsatisfactory. Whenever thinning is needed, thinning at 4-6 weeks intervals after germination or when the plant attained 15 cm height or when plants get 4 true leaves is recommended.

Fertilizer recommendations

Depending on location specific soil fertility, cotton responds well to nitrogen fertilizer. Use of 46 kg/ha N (100 kg/ha Urea) in a split application of 1/3 at 2nd irrigation and 2/3 at flower initiation is advisable, especially on exhausted old farms of Upper Awash Valley for high yield potential. Also, 64kg/ha N (139 kg/ha Urea) and 46kg/ha P_{2O5} (100 kg/ha DAP) for Upper Awash Valley and 100kg/ha Carbamide for Tendaho farm are recommended rates for better productivity of the cotton crop. The fertilizer application method may be manual or mechanical by tractor mounted broadcaster machine before sowing, followed by disc harrowing and addition of Carbamide during flowering and boll setting (Chavan, 2010).

Regarding blended fertilizer, different yaramila and ammonium sulfate fertilizer levels showed non-significant responses on cotton yield tested at three locations. A three years study on incorporation of a legume cover crop, hemp (*Crotalaria juncea* L.), on black vertisols of WARC from 2005 to 2007 with varying plowing depths resulted in cotton yield increment.

Weed Management Studies and Recommendations

Weeds are one of the constraints affecting cotton production in Ethiopia. Weed management studies showed that cotton yield loss due to weeds at Middle Awash can exceed 94%. Pre-planting irrigation 15 days before cotton planting, to allow a flush of weeds to emerge, and followed by pre-planting machine cultivation can substantially reduce competition from weeds during the early growth stages of cotton. Moreover manual weeding and/or cultivation 15, 35 and 75 days after emergence can assure good weed control in cotton production. Another option is use of herbicides. Fusillade Forte at the rate of 1.5 l/ha spray twice at 40 and 60 days after emergence can result in good control of grass weeds. This recommendation must be supplemented with at least one or two hand weeding to control broadleaf weeds. One manual hand weeding may be required close to harvesting stage to remove weeds that may affect the quality of the lint.

Quantitative and qualitative surveys of weeds growing in association with cotton at Metema and Humera have been conducted. At Metema 45 weed species were recorded compared to 16 at Humera. At Metema species were broad leaves, 13 grass weeds and 1 sedge species, while at Humera 12 species were broadleaves, three grasses and one sedge. At Metema, the dominant weed species at seedling stage were "*Yetijasiga*", Commelina species, *Erafrostis aspera*, *Physalis ixocarpa*, *"Yewushashint"* and *Corchorus* species. Close to harvesting stage of the crop, *Corchorus* species, Awunda, and *Dinebra retroflaxa* were dominant and problematic. At Humera, the dominant weed species at seedling stage were *Dinebra retroflexa*, *Pseudarthria hookeri*, *Launaea* and *Driya* species, whereas close to harvesting stage *Corchorus species*, *Launaea* species, *Dinebra retroflexa*, *Boerhavia erecta* and *Pseudorthria hookeri* were dominant.

Defoliants and growth regulators

Studies have been conducted on cotton defoliant verification, Thidiazuron 120 g/l + Diuron 60 g/l SC was found to be effective defoliant chemical with recommended rate and could be suggested for registration and use in cotton leaf defoliation. The other experiment has been conducted on cotton growth regulator verification, Ethephon 480 g/l SL/plant growth regulator was found to be effective in cotton leaf defoliation but not as boll opener, so couldn't be recommended for registration as growth regulator but it can be used as alternative option for cotton leaf defoliant. In addition, first harvesting time is recommended at 65% boll opening and second harvest is recommended at full maturity (15-20 days after first harvest).

Cotton Pest Management Research

The cotton plant protection research activities were undertaken with full responsibility of Werer Agricultural Research Center.Three major research disciplines, namely cotton entomology, cotton pathology and weed science research were undertaken for a long period. Research achievements by each discipline are described below.

Cotton Entomology Research

Pests recorded: Based on the field survey conducted from 1986/87 to 1995/96, more than 60 insects and two mite species were recorded on cotton crop and their status was categorized as major, minor, rare and sporadic pests of cotton in Ethiopia. Results of the surveys indicated that African bollworm (ABW) (*Helicovera armigera*), aphid (*Aphis gossypii*), leaf worm (*Spodoptera litoralis*), pink bollworm (*Pectinophora gossypiella*), jassid *(Empoasca lybica*), whitefly (*Bemisia tabaci*) and thrips (*Thrips tabaci*) were recorded as key pests (Tsedeke, 1982 and Ermias *et al.*, 2009).

Basic studies: Several basic studies such as Population dynamics for bollworms, armyworms and whitefly, Diapauses behavior studies of the African and pink bollworms, Host range of cotton whitefly (*Bemisia tabaci*), Detection of Insecticide resistance for ABW and cotton aphid were undertaken and the findings were documented as baseline information for planning further management studies.

Biology of the African bollworm

Biology of African bollworm was studied in the laboratory at Werer Research Center. Egg development took 2.2 $\pm$ 0.7 days, while the total larval period was 14.7 $\pm$ 0.8 days. The pre-pupae period took 1.5 $\pm$ 0.4 days. Pupation took place in the soil (at the depth of 1-3 cm) and lasted 7-12 days, 9.92 $\pm$ 1.1 on the average (Table 3). Of the 1,883 pupae studied, 46.3% emerged as healthy moths. The proportion of deformed moths was 16.3%, while death at emergence accounted for 4.1%. Regarding pupae mortality, about 15.6% was due to diseases and about 15.7% was due to desiccation. About 12% of the adults emerged within 7 days after pupation, while 31% emerged 8 days after pupation. Only 4% emerged after 11 to 12 days of pupation. The male to female ratio was 1:1.11. The female moth started egg laying 3 to 4 days (average 2.8 $\pm$ 0.3) after emergence and it was extended for 4 to 5 days. The number of eggs laid per female per day was 50, the total ranged from 8 to 980; the average was 242.2 eggs. Over 47% of the eggs were infertile. Among mortality factors, infertility and desiccation contribute to 20-30% of egg population reduction. Disease infection was the major factor for the mortalities of larvae, pre-pupae, and pupae. In addition, desiccation decreased the survival of pupae by 15-30%, which increased to 40% when the room temperature rose to 37^0C and above. Under temperatures above 35^oC, fecundity decreased and even the surviving adults could not depart after mating and died fixed. From the life table study, the net reproductive rate (R_o) of ABW was 77.98 and the intrinsic rate of increase (r) was 0.78. The total K-value was 0.85 and the generation time was 27.5 days (Geremew, 2004).

Insecticide resistance detection study

Six African bollworm populations (Arbaminch, Dubti, Dukem, Humera, Werer and Zemea) collected from cotton, tomato and chickpea were evaluated for susceptibility to Endosulfan, Lamda-cyhalotrin, Methomyl and Profenofos using topical application, larval immersion and square dipping techniques. The topical application study with the third instar larvae showed that the Arbaminch population was resistant to endosulfan, and the Dubti population was resistant to lamda-cyhalotrin. (Table 3).

Larval immersion studies conducted with Calofos 250 EC/ULV, Ethiosulfan 35% EC and Karate 5% EC indicated that Calofos at eight times lower rate (3.125×10^{-4} g a.i/ml) than the field rate of 2.5×10^{-3} g a.i/ml caused 99.3% mortality. Similarly, Karate caused 98.3% mortality at the rate of 6.25×10^{-5} g a.i/ml, which was eight times lower than the field rate of 5.0×10^{-4} g a.i/ml. Ethiosulfan resulted in 96.7% kill when applied at the field rate of 5.25×10^{-3} g a.i/ml. The subsequent dilution of Ethiosulfan decreased efficacy very fast and resulted in 53.3, 20.0, 6.7 and 3.3% larval death at the second, third, fourth and fifth lower concentrations, respectively. Square dipping study conducted on the third instar larvae for the three insecticides, Calofos 250 EC/ULV, Ethiosulfan 35% EC and Karate 5% EC, showed that Calofos caused 100% mortality of larvae at 1.25×10^{-3} g a.i/ml (twice lower rate), and 86.7% mortality at four times lower rate (6.25×10^{-4} g a.i/ml). Karate and Ethiosulfan caused 99.3% mortality each, but the former at eight time lower rate (6.25×10^{-5} g a.i/ml) and the latter at the field rate. Dilution to the second, third, fourth and fifth lower concentrations reduced the mortality of larvae to 71.7, 53.5, 32.0, and 14.4%, respectively.

The response of ABW to the field rate of Endosulfan was low. On the other hand, effective control of the pest was achieved by very low concentrations of Lambdacyhalothrin and Profenofos ECs. In both, larval immersion and square dipping studies, the order of insecticide efficacy was Karate >Calofos >Ethiosulfan. The low percentage kill obtained from Endosulfan, Ethiosulfan 35% EC confirmed the reduced efficacy of the pesticide against ABW.

Table 2. Susceptibility of African bollworm populations to synthetic insecticides in 2004.

Insecticide	African boll worm populations and status of insecticide resistance					
	Arbaminch	Werer	Humera	Dubti	Dukem	Zema
Endosulfan	3.452MS	1.402S	1.425S	1.62S	(-)S	1.15S
Profenopos	1.249S	1.051S	1.044S	2.00S	(-)S	1.16S
Lamdacyhalothrin	(-)S	3.60S	2.68S	10.40MS	4.24S	3.00S
Methomyl	1.80S	1.21S	1.32S	0.99S	(-)S	1.53S

Source: Geremew, 2004.S=susceptible, MS = moderately susceptible

Insecticide resistance in four populations of cotton aphid collected from Arbaminch, Dubti, Goffa and Werer was studied under the laboratory and field conditions with a slide dip and pot experiments. In the slide dip test, low to moderate levels of resistance was detected for Carbosulfan, Furathiocarb and Deltamethrin by all aphid populations tested. Similarly, the Pyrethroids, Deltamethrin, and Lamdacyhalotrin showed low level of efficacy both in the pot and field experiments indicating the presence of cross-resistance in cotton aphid for the Pyrethroid and Carbamate insecticides (Table 4). Dimethoate, Endosulfan, and Pirimicarb did not show any sign of resistance, although the efficacy of Pirimicarb was very low (Ermias, 2006).

Table 3.Susceptibility of cotton aphid populations to synthetic insecticides in 2006.

Insecticide	Aphid populations and status of resistance (RR Value)			
	Arbaminch	Werer	Goffa	Dubti
Carbosulfan 250 EC	22.17MS	18.67 MS	(-)S	18.0 MS
Furathiocarb 200 EC/ULV	14.08 MS	13.50 MS	(-)S	16.94 MS
Deltamethrin 2.5 EC	17.14 MS	12.14 MS	(-)S	16.96 MS
Dimethoate 40% EC	2.94S	(-)S	2.36 S	3.62 S
Endosulfan 35% EC	3.65 S	3.51 S	(-)S	3.42 S
Pirimicarb 50 DP	3.75 S	4.41 S	(-)S	5.08 S

S = susceptible, MS = moderately susceptible(Ermias, 2006).
RR =

Management measure studies

In order to develop integrated pest management measures against pests of cotton in Ethiopia, different studies such as cultural control, host plant resistance, botanicals and chemicals screening experiments were conducted and results of these studies are summarized as follows.

Cultural methods

Plant population (spacing)

Effect of plant population on cotton leaf worm and whitefly infestations was studied at Werer and Dubti, and it was found that in the pre-spray counts higher number of cotton leaf worm larvae were recorded on widely spaced (35 and 45 cm) plants. After insecticide application, the larval population was reduced below the threshold level in all of the treatments. However, the difference in infestation between the high and low plant population levels was not significant, although the spray penetration was good in the lower plant population (IAR, 1990).

Berhane (1987) reported that high plant density of more than 62,500 plants/ha (at 70 cm spacing between rows) had increased both whitefly population and relative humidity in the canopy (Table 5). The increase in whitefly population in the narrowly spaced cotton fields could be due to the creation of favorable micro-climatic conditions for the development of the pest.

Table 4.Effect of plant spacing on number of white fly adults and relative humidity at Dubti in 1984.

Spacing between rows (cm)	Equivalent plant population/ha	Mean number of adults/5 leaves	Relative humidity (%)
70	71,429	52a	90a
80	62,500	24b	83b
90	55,500	14c	66c
100	50,000	11cd	58cd

Means followed by the same letters are not different at 5% level (DMRT).
Source: Berhane, 1987.

Evaluation of Different Trap Crops

Studies conducted on the possibility of using trap crops such as alfalfa (*Medicago sativa*), hyacinth bean (*Dolichos lablab*), maize, sorghum, pigeon pea (*Cajanus cajan*), chickpea (*Cicer aretisimum*), okra(*Hibiscus esculentus*), groundnut (*Arachis hypogaea*), sunflower (*Helianthus annuus*) and tomato (*Lycopersicum esculentum*) for the management of the African bollworm on cotton showed that there were no significant differences among the trap crops and the main crop (cotton) in terms of egg and larvae numbers (EARO, 2002). Nevertheless, the number of eggs on hyacinth bean, okra and tomato were higher than that of chickpea; more number of larvae was recorded on pigeon pea, tomato and hyacinth bean (Table 5). In general, African bollworm egg and larva counts were higher on cotton than on the trap crops, indicating that none of the trap crops used could attract female moths more than cotton for egg laying.

Table 5.No. of ABW eggs and larvae on trap crops and cotton at WARC in 2002/03.

Trap crops	Average number of ABW egg and larva on			
	Trap crops		Cotton	
	Egg/plant	Larva/plant	Egg/plant	Larvae/plant
Maize	0.37a	0.08a	0.71a	0.42a
Okra	0.54a	0.09a	0.91a	0.42a
Pigeon pea	0.09a	0.31a	0.90a	0.38a
Sun flower	0.32a	0.11a	1.06a	0.82a
Lablab	0.55a	0.24a	0.99a	0.62a
Tomato	0.48a	0.30a	0.43a	0.83a
Sorghum	0.17a	0.18a	0.85a	0.69a
Groundnut	0.22a	0.16a	0.90a	0.85a
Chickpea	0.03a	0.14a	1.35a	0.50a
Mean	**0.303**	**0.185**	**0.903**	**0.615**

Means followed by the same letter within a column are not different from each other at 5% level of probability (DMRT). Source: EARO, 2002.

Closed season

A closed season by definition is a period of time after cotton harvesting where cotton fields and even cotton stores are kept free of cotton parts (vegetative, stalks or seed). The recommended closed season usually is two and half months and the target pest is pink bollworm. A study conducted on the effect of closed season on the population dynamics of pink bollworm in the Middle Awash area revealed that the shorter the closed season the greater the pink bollworm infestation during the following season and vice versa. The peak infestations were between September and October. Girma (1990) reported that the best way to reduce the population of diapausing larvae was to eliminate the food supply by observing a closed season of 60-75 days.

Host plant resistance

Cotton varieties were screened for resistance to major pests of the crop, whiteflies (Berhane, 1987; IAR, 1987; Ababu and Alemayehu, 1989); jassids (IAR, 1987) and to African bollworm (EARO, 2004). The immature and adult counts of whiteflies were lower on the genotypes Frego Bract, Deltapine Smooth Leaf, DSR, and La-Okra-leaf-2. However the yield performance of these genotypes was lower than the standard cultivar Acala 1517/70. On the contrary, honeydew and sooty mould were higher on the standard cultivar. The tolerant genotypes Frego Bract Del.SL, DSR, and La-Okra-leaf-2 have glabrous and open fingered leaves. The cultivar Albar 637 with more pubescent leaves was susceptible to whiteflies.

The glabrous or smooth leaves of cotton were not favorable for egg laying and development of the immature stages of whiteflies. The genotypes with large canopy and dense leaves had much higher number of immature, while the tolerant genotypes had less number of immature whiteflies. Berhane (1987) reported that Okra-leaf-2 cotton showed significantly lower number of immature stages of whitefly than AMS-1-39-1 and Acala 1517/70 (Table 6). This low number of immature stages was due to the contribution of morphological features of the variety with less or no hairs on leaf surface, but there was no significant difference in seed cotton yield between the varieties. The study indicated the need for replacement of the standard cultivar with whitefly tolerant variety such as La-okra leaf-2. unfortunately, this genotype was found to be susceptible to the cotton wilt disease at Dubti.

Table 6.No. of whitefly immature/leaf and yield of three cotton varieties at Dubti in 1984.

Cotton varieties	No. of immature/leaf	Yield (q/ha)
La-okra-leaf-2	4a	24.44a
AMS-1-39-1	7b	21.39a
Acala 1517/70	8bc	26.11a

Means followed by the same letter with in column are not different at 5% level (DMRT).
Source: Berhane, 1987.

Cotton varieties, Albar 637, Acala SJ2, Werer-1-84, Arba, Deltapine 90, Stoneville 213, Bulk 202 and Bulk 101 were evaluated for jassid resistance at Werer from 1989-1991. The average number of jassids counted for 14 weeks showed significant differences among the varieties tested. The maximum number of jassids was recorded on Werer-1-84 and the minimum was on the standard check, Albar 637 (Figure 2). Except for Werer-1-84, none of the varieties evaluated were different in yield and jassid tolerance (IAR, 1990).

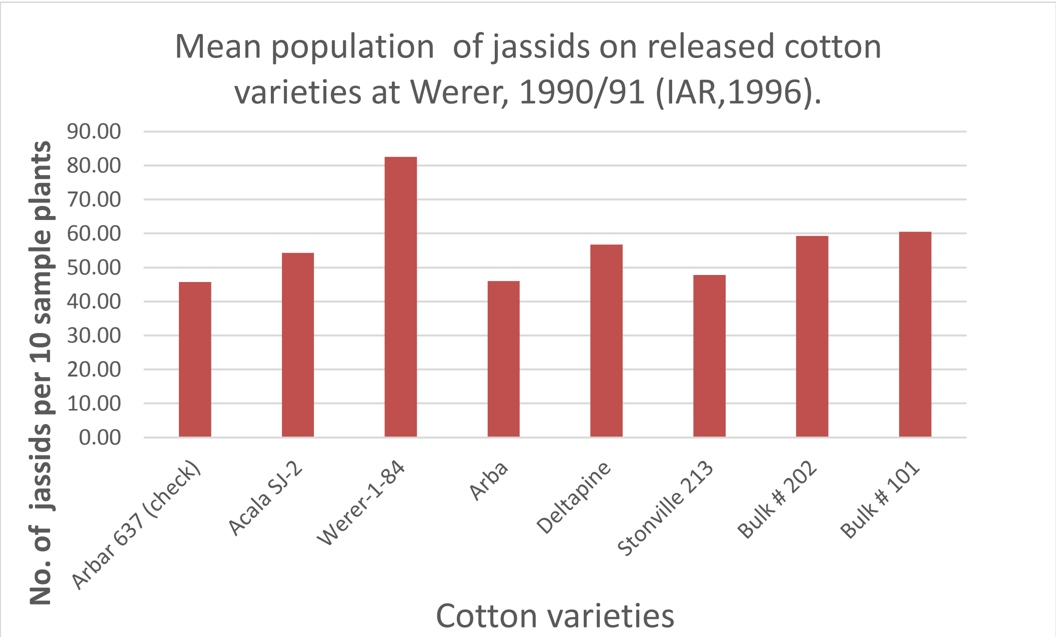

Figure 2. Mean population of jassids on released cotton varieties at Werer, 1990/91 (IAR,1996)

A number of cotton genotypes were evaluated for resistance to ABW in series of experiments conducted from 2000 to 2004. Genotypes Paymaster-145, McNair 235, Dunn 118, Cu-Okra, G-45, Bulk 202, Bulk 101, Pima S-5, Acala 1517V and Sindos-80 had significantly low number of ABW eggs and larvae. On the other hand, genotypes Tomcot Sp-21, Carolina Queen, Stonville-213, and La-frego bract-2 showed higher level of larval infestation, but the yields were also significantly high indicating that these genotypes might have the potential to compensate for damage caused by the pest. Cotton genotypes with lower density of trichomes, higher content of gossypol glands and frego bract leaf type were found to be less attractive, unfavorable for ovi-position and feeding by the African bollworm. The highest larval infestation (about 8.3 larvae per five plants) was recorded from the commercial variety Acala SJ2 that has characteristic closed bract, moderate density of trichomes and low number of gossypol gland (EARO, 2004). Ababu (1987), studied the seasonal susceptibility of the long staple cotton varieties to pink bollworm and found that the Pima-S varieties are more susceptible to pink bollworm towards the end of the crop season, when irrigation is continued and harvesting time is delayed.

Botanical control:

Vegetable oils against cotton aphid and whitefly

Oils of canola, castor, coconut, corn, cottonseed, groundnut, safflower, soybean and sunflower, each at 3% w/v, were evaluated together with a synthetic insecticide Carbosulfan against aphids and whiteflies under field conditions from 1997-1999 at Melka Werer. There were variations in efficacy against the aphids among the treatments. Vegetable oils showed 26-53% aphid population reduction, while Carbosulfan caused 72% reduction. However, different oils varied in their potency, speed of action, and bio-persistence in parameters such as residual activity, spray toxicity, modification of adult's behavior expressed by settling and ovipositiing deterrence. Among the vegetable oils tested, groundnut, castor, and cottonseed oils showed the best performance. However, some of the oils showed phytotoxicity effect (scorching) on cotton 3-6 days after application. Coconut oil was more toxic than canola, while castor oil was none toxic. The order of toxicity was castor < soybean < sunflower < safflower < cotton < corn < canola < coconut. With whiteflies, conclusive results were not obtained due to the low level of infestation in the season (EARO, 2000).

Biological control studies: Studies on natural enemies of African bollworm eggs

African bollworm egg parasitism studies conducted from 1981 to 1986 at Werer showed that egg parasitism and predation increased as the cotton growing season progressed. The overall egg destruction by predators and parasitoids was 34, 55, 70 and 70% in June, July, August and September, respectively (IAR, 1987). Based on these results, ABW egg threshold was suggested to change from 50 in the whole season to 50, 60, 70 and 70% in June, July, August and September, respectively (IAR, 1987).

Effect of sowing date on natural enemies of cotton aphid

Studies on the impacts of insect natural enemies conducted on early and late-planted cotton revealed that aphid population was low and the number of natural enemies was relatively high when cotton was planted early. On the contrary, the aphid population was high and the natural enemy populations were low on late-planted cotton (Table 7).

Table 7. Effect of sowing date on aphid population, natural enemies and seed cotton yield at Werer from 1993 to 1995.

Pest and Natural Enemies	Early sowing				Late sowing			
	B1	B2	B3	Total	B1	B2	B3	Total
Aphid (Pest)	326	411	114	851	427	401	312	1140
Lady beetles	7	14	10	31	5	12	12	29
Lacewing	4	3	2	9	3	2	1	6
Spider	5	10	11	26	2	4	4	10
Yield (q/ha)	39.6	35.9	41.0	38.8	10.1	11.1	8.9	10.4

B1= Natural enemies only, B2= Natural enemies + chemicals, B3 = Aphid free.
Source: (IAR, 1996).

The major natural enemies recorded in cotton fields were lacewings (*Chrysopa* spp.), different species of ladybird beetles (*Coccinella* and *Chelomonas* spp.), syrphid flies and spiders. On early planted cotton, the seed cotton yields obtained from a weekly sprayed (41 q/ha) and unsprayed (39.6 q/ha) plots were not significantly different from each other (Table 10). The plots sprayed at the economic threshold level (B2) gave lower yield than the aphid free and unsprayed plots. Weekly spraying of insecticides did not control the aphid and the seed cotton yield obtained from late planted cotton was low (Table 10). Moreover, the lint quality was poor as it was contaminated with honeydew (IAR, 1996).

Natural enemies of cotton whitefly:

Surveys carried out in cotton growing areas of the country to understand the natural enemies of whiteflies found that the parasitoid wasps *Encarsia transvena* and *Eretmocerus mundis* parasitized the whiteflies (Berhane, 1987; EARO, 2000). The most prevalent and widely distributed predator in cotton fields was the lacewing, *Chyrisoperla carnea*. Different species of ladybird beetles were recorded to be important predators of both whitefly and aphids. Hoverfly (Syrphidae) and unidentified species of spiders were also observed in low numbers (Berhane, 1987; EARO, 2000). During the 1987/88 and 1998/99 seasons parasitism of whiteflies was observed early in June and July in different cotton fields. However, as chemical sprays against the African bollworm started the level of parasitism dropped drastically.

Chemical control:

A series of insecticide screening trials were conducted to control cotton pests (Tessema et. al., 1980). Cypermethrin (Cymbush), cyfloxylate (Bythroid), endosulfan (Thiodan, Thionex, and Ethiosulfan), deltamethrin (Decis), Alpha-cypermethrin (Fastac), cypermethrin (Ripcord), and lambdacyhalothrin (Karate) were recommended for the control of cotton bollworms (MoANR, Pesticide register list, 2016). Pirimiphose-methyl (Actellic), phosphamidon (Dimecron), carbosulfan (Marshal), furathiocarb (Deltanate), suprathion (Methidathion) and diafenthiuron (Polo) were recommended as foliar sprays, while Gaucho (Imidacloprid) and Crusier (Thiamethoxm) as seed dressing insecticides to control the cotton aphid (MoANR, Pesticide register list, 2016). For the control of the red spider mite, oxydemethon-methyl (Metasystox-R), chlorpyrifos (Salut), amitraz (Mitac), dicofol (Mitigan), bromopropyl (Neuron) and dynamic (Vertimec) were recommended. Nurrel-D (cypermethrin + chlorpyrifos), Cybolt (flueythrinate), and Birilane (chlorfenvinphos) were also recommended for the whitefly control (Berhane, 1987; EARO, 2000b, MoANR, Pesticide register list, 2016).

Cotton Diseases Research:

Unlike other parts of the world, cotton in Ethiopia is attacked by a few diseases. In the past, bacterial blight and wilt diseases were considered to be the most important, but since the last one decade these diseases are recorded to be minor countrywide because modern varieties are generally bacterial blight resistant. If however susceptible varieties are grown, bacterial blight might still be an important disease in the wet and humid areas of the country. It is advisable to note that an unidentified wilt disease of cotton (locally known as *Dubti syndrome*) is still important in the irrigated cotton area of Lower Awash Valley around Dubti (Geremew and Dawit, 2009)

Diseases recorded on cotton:

Surveys conducted since 1985 in different cotton growing areas of the country revealed numerous fungal, bacterial and nematode diseases associated with cotton production in Ethiopia (Geremew and Dawit, 2009). Of these, bacterial blight, which occurs in very moist climatic conditions, usually during prolonged rains in the west and northeastern parts of the country, and cotton wilt (the Dubti syndrome) at Tendaho are considered important cotton diseases (Geremew, 1990).

Disease Management Studies;

Cotton resistance to bacterial blight

Bacterial blight was severe on irrigated cotton in the Middle Awash in the late 1960s. It caused losses ranging from stand and vigor losses of seedlings to total crop failure. However, heavy yield losses were attributed to leaf blight (which caused leaf defoliation) and black-arm (which caused losses of fruiting branches) (IAR, 1983). With the introduction of resistant cotton varieties such as Acala 1517/70 in the late 1970s the significance of bacterial blight declined in irrigated cotton, although it remained a problem in high rainfall and humid areas such as Pawe and Gambella (MWRC, 1997). Therefore, trials on screening of cotton genotypes for resistance to the disease were undertaken at Pawe from 1996 to 1998, and differences among the genotypes ranged from moderately resistant to highly susceptible. Many *G. hirsutum* varieties of cotton known for their resistance or tolerance to the disease in other parts of the country were found to be susceptible at Pawe. Other diseases were reported to be sporadic and of minor importance that no screening of varieties was initiated.

Basic studies:

Pathogenicity test

Colletotrichum gossypii, the pathogen that causes anthracnose was isolated and inoculated in two commercial varieties of cotton (Deltapine 90 and Acala SJ2) both at seedling and flowering stages under field conditions at Werer and in the greenhouse at Holetta during the 1990/91 cropping season. All of the seedlings developed specific disease symptoms, while inoculation at flowering resulted in only 60% infection. It was therefore concluded that anthracnose could be a severe disease when infection occurs at the seedling stage. Since then, however, the incidence of anthracnose on cotton declined (IAR, 1996).

Wilt diseases

Cotton wilt diseases are caused by two soil-borne vascular pathogens, *Verticillium dahliae* and *Fusarium oxysporium.* The diseases are known to occur occasionally in Tendaho (because of flood or basin irrigation), less frequently in Arbaminch and sporadically in the Middle Awash cotton farms. Verticillium wilt is recorded only from Sile farm (Semen Omo Agricultural Development Enterprise), while fusarium wilt was common in most farms of the Middle Awash and rain-fed cotton areas (Geremew, 1990).

Studies on the cause of *Dubti syndrome:*

Plant tissue analysis

The cotton wilt that occurs at Tendaho Plantation is called *Dubti syndrome*. In the efforts to identify the causal pathogen(s) experts from different countries in the world (United Kingdom, Germany, Yemen, and India) were involved and over 2000 isolations were prepared from the plant tissues from which *Sclerotium bataticola*, *Fusarium solani*, *Rhizoctonia, Aspergillus, Rhizopus, Penicillium* species, and other weak soil fungi were identified. However, none of these fungal isolates induced similar disease symptom on inoculated plants under controlled conditions (Geremew, 1992).

Soil assessment

From 1988 to 1990 soil assessment study was conducted for microsclerotia of *Verticillium dahliae* and *Fusarium* sp. Soil samples were taken from three depths (0-30, 31-60, 61-90 cm) at Dubti, Asaita, Senbeleta, DBirrahry and Tangayekuma cotton farms found in the Lower Awash Valley and from Ambash farm in the Middle Awash Valley. Samples were cultured on four different growth media (PDA, PDA with streptomycin, Zchapek Dox Agar and Zchapek Dox liquid medium) under diffused light and total darkness at $24 \pm 2^{o}C$. After 7 days of incubation only saprophytic fungi, such as *Aspergillus* sp. were identified. Thus, it was concluded that the disease is non-pathogenic (IAR, 1996).

Effect of temperature on wilt development

To study the impact of air temperature on wilt development, meteorological data of more than 20 years was obtained from Dubti and Werer meteorology stations. Cotton production years were divided into wilt and non-wilt years. On years with wilt incidence, night temperatures in October and November were between 10 and $13.5^{0}C$, but in non-wilt years it ranged from 13 to $15^{0}C$. The slight difference ($1.5^{0}C$) in the minimum temperature between wilt and non-wilt years suggested that the Dubti Syndrome was not associated with temperature changes (Geremew, 1992).

Effect of soil pH on cotton wilt development

The soil pH at Tendaho has alarmingly changed from 7.6 to 8.4, and this was related to the wilt problem (Steven, 1974 pers. com.). Studies conducted at three fields in each of three farms, Melka-Sadi, Melka-Werer and Ambash in 1992, indicated that high pH was not a factor in wilt development (Geremew, 1992).

Loss assessment due to wilt disease

Cotton yield losses caused by wilt diseases are reported to vary with years and locations. At Tendaho up to 90% of the cotton plants in some fields wilted, while at Middle Awash Melka-Sadi and Ambash farms the percentages of wilted plants were 1-2% in 1987 and 3-5% in 1992. As the diseases appeared late in the season, in most cases after the third and fourth irrigation periods, losses in lint yield were minimal (Geremew, 1992). However, quality losses, especially maturity ratio, fiber strength, and fineness could be much higher than the yield loss. A study conducted in 2004 with Deltapine 90 variety at Melka-Sadi farm showed a yield loss of 76% due to wilt disease. Differences between healthy and diseased plants in boll number, boll weight per plant and seed number per boll were observed to be 74.62%, 12.96% and 13.28%, respectively (Geremew, unpublished data).

New disease recorded

An unknown disease was observed on cotton plants at the Nura-Era and Awara-Melka farms of the Upper Awash Agro-industry Enterprise in 2001 and 2002. Diseased plants had abnormal leaf morphology (i.e. pointed, leathery and hard) and root swelling just below the ground surface expressed the disease symptom. Flowers and squares could not open normally and rather developed in to capsule shapes. The disease was temporarily named Nura-Era syndrome, and later identified to be caused by *Agrobacterium* sp. However, this identification is still to be confirmed. The disease occurred in about 60 ha of land and affected all plants in the field uniformly. Bacterial diseases are known to spread slowly and do not infect all plants in a plot at least at once like this disease. It is from this contention that it is less probable for *Agrobacterium* sp. to be the cause for the Nura-Era syndrome.

Cotton Weed Management Research

Quantitative and qualitative surveys were conducted in the Middle Awash, Lower Awash, Humera and Metema cotton farms in 2000 and 2001 by Werer Agricultural Research Center (WARC). During the survey, a total of 88 weed species belonging to 28 plant families were identified (Kassahun et al., 2009). Most of the species were erect annual herbs and grasses and the rest were perennial climbers and shrubs.

The frequency of occurrence of individual species ranged from 0.3 to 51.5%, while the infestation level ranged from 0.6 to 47.8%. Weed species with frequency and dominance levels below 5.0% and 0.05%, respectively, occurred rarely and at low density. There was a positive and significant relationship among the weed species frequency, abundance and dominance. The dominance level of individual weed species varied across locations and crop growth stages. Some weed species with high infestation levels at some localities were not important weeds at other localities. There were variations in weed species composition across locations and crop growth stages (Table 8). Survey results indicated that there were changes in the weed flora over 10 years period (1974 to 1984). The occurrence of new weed species was suggested to be due to the dissemination of weed seeds by the water used for irrigation.

Table 8. Similarity index (%) of weeds occurring in different cotton growing Areas.

Locations	Middle Awash	Lower Awash	Metema	Humera
Middle Awash	100	46	36	31
Lower Awash	46	100	30	44
Metema	36	30	100	42
Humera	31	44	42	100

Source: Abraham and Esayas, 2002.

Weeds were also found to harbour insects and diseases of crop plants. The broad leaf weeds *Gynandropsis gynandra* and *Portulaca oleracea* were found to be alternate hosts to the African bollworm (*Helicoverpa armigera*). Nematode gall was also observed on the roots of *Gynandropsis gynandra*, *Launea cornuta* and *Cyperus* species (Kassahun, 1989).

Basic studies

Studies conducted for three consecutive years to determine the critical periods of weed competition in cotton at Werer Research Center showed that the critical period of weed competition was between 30 and 60 days after crop emergence (DACE). The study also indicated that early weeding was important but not adequate (Tadesse and Ahmed, 1985). Early weeding up to 35 DACE was recommended to increase yield and reduce cost of weeding. The study also showed that late weeding reduced yield of seed cotton, while no weeding resulted in yield loss of 73%. Similarly, studies at the Abobo Research Centre (Gambela) indicated that the critical period of weed competition for cotton was between 30 and 60 DACE, and when no weeding was done an average yield loss of 74% was recorded as indicated in Table 9 (Aderajew and Mesele, 1993). A recent study conducted in 2001 and 2002 at WRC indicated cotton yield losses of 35-88% and 56-94% when weeding was delayed for 60 and 75 DACE, respectively. The loss ranged from 62-96% when no weeding was done. The critical period of competition was between 20 and 60 DACE (Abraham and Esayas, 2002; Esayas and Abraham, 2003).

Table 9. Effects of time and frequency of weeding on cottonseed yield and economic benefit at Abobo, Gambella (1988-1989).

Weeding (DACE)	Seed yield (t/ha)	Cost of weeding	Gross return	Net return
		Birr/ha		
Un-weeded	0.72	-	723	723
15	1.75	81	1746	1665
30	2.64	76	2643	2567
45	2.61	96	2599	2503
60	2.45	145	2453	2308
15 and 30	3.01	89	3014	2925
30 and 45	2.89	163	2895	2732
45 and 60	2.95	132	2954	2822
15, 30 and 45	3.18	209	3175	2966
30, 45 and 60	3.18	159	3117	2958
Weed free check	3.19	443	3192	2749
Mean	2.59	144	2592	2447
C.V %	13.71			

DACE = days after crop emergence

Source: Aderajew and Mesele, 1993.

Esayas and Abraham (2003) found that cotton fibre quality parameters such as fibre fineness (which is read as the micronaire value), fibre maturity percent and 50% span length were affected when the cotton crop was subjected to different weed infestation periods of 15, 30, 45, 60, 75 and 90 DACE. Acceptable values for these quality parameters were recorded when the cotton crop was kept weed free for up to 45 DACE. Fibre span length (2.5%), fibre strength and fibre uniformity ratio were not affected.

Studies on Cotton Weed management methods

Cultural weed control

The value of appropriate cultural practices for weed control cannot be overlooked particularly in light of the high costs involved in the use of labour and herbicides and their unavailability (IAR, 1998; 1999; 2002). In the Middle Awash Valley, the tradition of herbicide use was not common, and weed control was mainly based on manual or mechanical inter-row cultivation and hand pulling. According to Esayas and Abraham (2003), trials conducted for three consecutive cropping seasons (2002-2004) to evaluate cultural practices that can control cotton weeds at WRC indicated that dry planting or pre-planting irrigation combined with machine or manual cultivations at about 15 to 20, 35 to 40 and 75 DACE provided effective results. Moreover, one manual weeding close to harvesting stage may be necessary to remove weeds that may spoil lint quality.

Chemical weed Control

Experiments conducted between 1995 and 1998 to evaluate pre- and post-emergence herbicides for the control of weeds in cotton showed that Propaquizafop at 2.0 L $ha^{-1}$and Select at 0.4 L ha^{-1} product were effective on grasses, and Metolachlor 960-EC at 2.5 L $ha^{-1}$and Trifluralin at 2.4 L ha^{-1} were effective on both grasses and broad leaved weeds except *Cyperus* spp. (Abraham and Esayas, 2002; Esayas and Abraham, 2003; IAR, 1998; 1999; 2002; Kassahun, 1989; 1998). The cotton seed yields were high in the weed free check and two times hand-weeding treatments (Table 10).

Table 10. Effects of herbicide and hand weeding on weed infestation and cotton yield at Werer Research Center (1993-1994).

Treatment	Rate (kg/ha)	GWCS*		Yield (t/ha)
		20 DACE	45 DACE	
Codal 400 EC	6.0	1.0	1.5	4.3
Metolachlor 960 EC	2.5	1.0	2.5	3.9
Trifluralin	2.4	2.1	3.1	3.7
Fluometuron	4.0	2.8	4.2	3.2
Fluzifop-butyl	2.0	6.3	2.2	2.9
Hand weeding 1x (30 DACE)	-	0	5.1	2.2
Hand weeding 2x (30, 55 DACE)	-	0	1.1	4.4
Unwedded	-	9.0	9.0	1.4
C.V				9.8

*GWCS = general weed control score (1-9 scale): 1= effectively controlled, 9 = no effect.
Source: Kassahun, 1998.

Soil And Water Management

Irrigation

Investigation into irrigation system has been one of the priority areas in cotton research. The main focus of research activities were in determining frequency of irrigation and water closure dates, experiments to determine optimum combination of irrigation frequency and depth of application, and experiments to evaluate sensitive stages of growth for moisture stress, moisture depletion patterns and the effect of water logging on yield.

It was reported that the water requirement of cotton planted in mid-May was 1009 mm while that planted in mid-July was 915 mm. It was also found that cotton in the Middle Awash can be irrigated by one of two irrigation regimes, i.e. once in two weeks interval with 75 mm of water per application, or once in three weeks interval with 120.5 mm of water per application. Water budget method has been also studied and it was found that with 70% irrigation efficiency, gross irrigation requirement for cotton in Middle Awash region is found to be 120 mm (Kandia 1982). Studies on cotton–water yield relation confirmed that irrigation of 150 mm water at squaring, flowering and boll formation stages are best for optimum production. Irrigation interval studies for cotton grown on salt-affected soils revealed that one to two pre-planting irrigations can enhance cotton yield. Leaching as a salinity reclamation method for salt affected soils revealed that intermittent leaching practice with 150 mm of irrigation water is effective in removing soluble salts from the root zone of cotton crop in the Middle Awash.

Soil fertility

In semi-arid agro-ecology rain fall is limited to support plant growth. Because of this, plant growth is often restricted and less plant tissue is produced to contribute to the organic matter supply, hence less total N content in the soil. Such soils are in need of nitrogen when brought under cultivation.

Several studies were conducted at Middle Awash and Arbaminch areas including long-term exhaustion trial, fertilizer and cover crop studies, soil types and their fertility status and potassium forms, release dynamics and its availability. The results of the studies revealed that there were no remarkable depletion/changes in soil nutrient levels due to mono cropping of cotton at Middle Awash areas in the past two to three decades. Cotton was non-responsive and consistent to fertilizer application in most of the previous studies. However, according to some recent studies nitrogen was found to be the first and most limiting nutrient being very low both at Middle Awash and Arbaminch soils and its application resulted in significantly higher yield and economic benefit particularly on older cotton farms. Incorporation of cover crop also showed potential benefit in improving cotton yield. Studies on K also revealed that readily available as well as reserve forms of potassium were found to be well above the critical limits in all sites throughout the soil layers. Moreover, the main soil types, which include Salic Fluvisols, Eutric Fluvisols and Eutric Vertisols, were investigated, of which Eutric Fluvisols occupies the largest portion of the cultivated land of the Awash River Basin.

Socioeconomic characterstics of cotton producers in selected areas

Household characteristics

The study conducted during the 2014 production season at of Amibara and Gewane districts in Afar Regional State and Arbaminch in SNNPRS shows that almost all the total sampled households (96.8%) were men headed while 3.2% of the respondents were women headed households. The marital status of the sample respondents were married (77.5%) and single (2.9%) single as shown in Table 11. The average age of the respondents was 46 years with minimum and maximum age of 22 and 67 years, respectively.

Types of varieties and source

There are 19 cotton varieties released by Werer Agricultural Research Center, 15 for irrigated area and four for rain fed agricultural production system but the results of the survey depicted that out of the total farm households under the study, 35.5% used local/ their own variety, while 61.6% used Deltapine90 and 1.5% used Acala and Cucurova varieties. Private companies (investors) are the main sources of cotton seed for the small scale producers in the study area. Table 12 below indicates that out of the total households considered in Amibara and Gewane district 50.0% and 51.7%, respectively, accessed planting seed from private investors in their districts while 47.8% and 46.2% of the households in Amibara and Gewane obtained seed from the research system, respectively. The remaining few households purchased cotton seed from local markets. On average, 78.9% of the farmers in both districts purchased their seed on credit and 19.6% accessed with cash. It is notable from Table 12 that Deltapine 90 made up bulk of the seed supply in both Amibara and Gewane districts.

Table 11: Household characteristics of the study area.

Characters	Amibara	Gewane	Arbaminch	Total	χ²
Gender Men	98.3	98.1	94.1	96.8	
Women	1.7	1.9	5.9	3.2	
	100	100	100	100	12.2***
Marital status					
Single	3.3	4.2	1.1	2.9	
Married	86.7	75.0	70.9	77.5	
Polygamous	8.9	20.8	19.0	16.2	
Widow	1.1	-	9.0	3.4	
	100	100	100	100	4.5
Education					
Illiterate	40.0	60.4	74.7	58.4	
Informal	24.4	6.3	20.9	17.2	
Primary	16.7	10.4	2.4	9.8	
Secondary	18.9	16.7	2.0	12.5	
Diploma	-	4.2	-	1.4	
Degree	-	2.1	-	0.7	
	100	100	100	100	15.0***

***Indicates significance at the 1% probability level.
Source: Socio-economic survey data, 2014.

Table 12. Types of varieties and source

Characters	Amibara	Gewane	Total	χ²
Variety				
Local seed	35. 6	35.4	35.5	
Deltapine90	60.0	64.6	61.6	
Acala	2.2	-	1.5	
Kukrova	2.2	-	1.5	
	100	100	100	6.2**
Source of seed				
Agricultural office	1.1	-	0.7	
Local market	1.1	-	0.7	
Research institutes	47.8	46.2	47.0	
Private investors	50.0	51.7	50.9	
Kin/families	-	2.1	0.7	
	100	100	100	8.7*
Means of access				
Purchased in cash	24.4	10.4	19.6	
On credit	75.6	85.4	78.9	
Gift	-	4.2	1.5	
	100	100	100	7.3**

*, ** Indicate significance at 5% and 1%, respectively.
Source: Socio-economic survey data, 2013.

Access to extension, Technology Scaling-Up, and impacts

Improved cotton technologies were demonstrated and scaled-up for different agricultural experts and farmers in the districts of Amibara and Gewane (Afar Regional State) and Arbaminch (SNNPRS) in order to promote and popularize proven cotton varieties and management practices. The smallholder survey at the time of pre-scaling out reveals that extension agent contact with in the production season yet is low according to the producers key informant discussions. From plenary survey 74.4%, 72.9% and 92.4 of the interviewed had had contact with an extension agent prior to the survey in Amibara, Gewane and Arbamich districts while 25.6%, 27.1% and 7.6% of the producers did not have access to extension services. On average, 42.0%, 14.2%, 18.5%, 15.1% and 10.2% of the farmers in the three surveyed districts had extension service contacts weekly, bi-weekly, monthly, whenever needed and during season basis, respectively, though Arbaminch's contact is limited to weekly and bi-weekly contacts only. Again, on average, the proportion of farmers trained on land preparation, crop protection, post-harvest and credit is 39.7%, 23.4%, 19.7% and 17.2%, respectively (Table 13).

Table 13: Access to extension service in three cotton-producing districts, 2014.

Characters	Amibara	Gewane	Arbaminch	Mean	χ^2
Access Access to Ext. service	74.4	72.9	92.4	79.9	
No access to Ext. service	25.6	27.1	7.6	20.1	
	100	100	100	100	7.8**
Ext. contact frequency					
Weekly	15.9	18.8	91.3	42.0	
Biweekly	19.3	14.6	8.7	14.2	
Monthly	28.4	27.1	0	18.5	
Whenever I want	20.5	24.9	0	15.1	
During production .Season	15.9	14.6	0	10.2	
	100	100	100	100	5.1*
Training					
Land preparation	30.6	30.3	58.2	39.7	
Disease and pest control	22.8	23.9	23.4	23.4	
Post-harvest	23.8	23.9	11.4	19.7	
Inputs use	22.8	21.9	7.0	17.2	
	100	100	100	100	5.4**

**, * Indicate significance at 1 % and 5% probability levels, respectively.
Source: Extension survey data, 2014.

The effect of agricultural extension service for enhancing productivity of cotton, income and poverty reduction on small-scale irrigation users, and the major constraints encountered in the use of the extension service for improved cotton technologies have beed assessed.

The absolute poverty head count ratios of user of extension service and non-user households were 7% and 43%, respectively (Table 14). The moderate poverty head count ratios of extension service user and non-user households were 10% and 50%, respectively. In the study area of the sampled population who live below the absolute poverty level, 88% are non-user households and only 12% are extension service user households. This suggests that extension scaling up of technologies have a significant impact on rural poverty alleviation.

Table 14: Poverty comparison in percent

	Absolute poverty line		Moderate poverty line	
	Head count ratio (P_0)	Poverty gap (P_1)	Head count ratio (P_0)	Poverty gap (P_1)
Ext-service-users	0.07	0.01	0.10	0.01
Non-Ext-service-users	0.43	0.09	0.50	0.10

Source: Socio-economic survey data, 2013/14.

For user households, the gap was only 1%, but was significantly larger for non-user households with 9% and 10% for the absolute and moderate poverty thresholds, respectively. Thus, the poverty gap is much larger for non-user households, which again suggests that technology access may play a role in poverty reduction (Table 14).

Land holding and allocation for cotton production

From the survey, land holding in Amibara (4.50 ha) is larger followed by Gewane (3.45 ha) and Arbaminch (2.75 ha) with an average of 3.57 ha. The fraction of land allocated to cotton is quite large in each district with a mean of 61.3%; this indicated the importance of cotton as a major source of income for the households (Table 15).

Table 15: Average total land holding, part for cotton and experience with technology.

Characters	Amibara	Gewane	Arbaminch	Mean	χ^2
Average total land holding (%)	4.50	3.45	2.75	3.57	79.2***
Average land for cotton production (ha)	2.92	1.89	1.75	2.19	90.6***
Proportion of land for cotton (%)	64.9	54.8	63.6	61.3	
Experience with technologies (yrs)	3.1	1.92	4.1	3.04	14.6*

***, * Indicate significance at 0.001and 0.05 levels, respectively.
Source: Socio-economic survey data, 2014.

Challenges and Opportunities for Cotton Research in Ethiopia

Challenges

Germplasm Enhancement

Locally cotton has a narrow genetic base. Variants of early introductions by the Italians and other foreigners do exist in some parts of the country and also perennial types are cultivated as backyard crop mainly for home use and partly for local markets (Bedada, personal comm.). Modern cultivars have been introduced from different sources; records indicate that commercial varieties which were used in the late 1950s, in the 1970s and 1980s were introduced from Newmexico, Arizona, Israel, West Africa, East Africa, Egypt and The Sudan. In recent times, cotton varieties have been introduced or imported from Turkey, Israel and Greece, mostly through informal contacts, but often with challenges and not smoothly. Because cotton has no international research centers such as for maize, wheat, rice or potato, for cotton germplasm introduction through FAO might help; FAO has collections of cotton germplasm from different countries.

Limited capacity (human, facility and financial) at the research center

There is no interest from donors to support cotton research financially and technologically; since cotton is considered as a cash crop/ government interest crop. Therefore, its research is fully supported by the limited public money. Moreover, the crop is grown and researched in harsh environment; there is high turnover of skilled manpower in the research system. This is aggravated by lack of incentive mechanisms to retain the skilled human resource especially for those working under harsh conditions in the research system/ center.

Lack of cotton seed production, supply and delivery system

Cotton seed for planting has always been a constraint. There is no single legally certified cotton seed producer enterprise in the country and the production of basic and pre-basic seed, though not large enough, is shouldered by Werer Research Center. As cotton is open pollinated, cotton seed production requires proper isolation to prepare pure and quality seed for planting. In absence of cotton seed producers, most commercial cotton producers use their own uncertified seed. May be cotton seed production business is not profitable and attractive. The cost of cotton seed production is high and demand and utilization by cotton farmers are low at the moment. Therefore, development of hybrid cotton varieties locally is indispensable and certainly increase demand for high yielding quality seed.

Weak cotton research-extension (RE) linkage system

The extension system is highly devoted for the promotion of food crops (cereal, pulse and root crops) and the cotton sector is highly neglected. Cotton is traditionally grown on marginal lands by small scale farmers (on exhausted fields with low soil fertility, stress prone areas, etc.) with poor ICM practices (land preparation, fertilizers application, pest control) and poor post-harvest handling. Most small scale cotton farmers use unimproved varieties, low inputs and poor management practices resulting in low productivity and poor quality lint. Compared to other major crops, extension service on cotton development has been discouragingly low. With the development of National Cotton Research and Development Strategy on the horizon, cotton-research-extension will be stronger and will be one of the priority areas.

Shortage of sub centers and testing sites in different Agro-ecologies

During the early days of cotton research in the mid 1960s and 1970s, testing sites had good coverage over the country. The popular sites were Arbaminch, Belle, Abella in the south; Beles, Bir, Dedessa, Asossa and Gambella in the west; Kobbo and Humera in the north; and Amibara, Gewane, Gode and Dubti in the east. Of course, all trials for both irrigated and rained areas were coordinated from the then Melka Werer (now Werer) Research Center. Collaborators were MOA, MSF, private farms and NGOs who were interested in cotton culture for their enterprises and for the surrounding farmers. Research results from all testing sites have been recorded in Progress and Annual Reports of Melka Werer Research Station at the times. Gradually, however, it was notable that linkages based on good will and the non-binding collaborations have been weakened. Nevertheless, there is hope that the current policy, the National Cotton Research and Development Strategy in the making and EIAR's Cotton Research Strategy will strengthen cotton research, development and industrial use focuses nationally.

Existence of Poor Seed Cotton Marketing System

Since there is no well-defined functional cotton value chains, farmers are price takers as prices are determined by brokers and the middle men. The existence of poor and inadequate mechanisms of quality control at the different stages of cotton value chains resulted in discouraging price difference between the three (A, B and C grades) quality standards of cotton lint. Even though, there is a large volume of cotton lint with optimum quality produced locally, cotton lint is imported from other countries to satisfy the increasing demand of the expanding textile industries locally. Therefore, this is highly affecting the market system and discouraging to the local cotton producers and negatively impacting the uptake of improved cotton technologies from the research system.

Unpredicted Biotic and abiotic stress factors

Climate change is becoming a threat as a cause for emergence of new pests such as mealy bug. Also a dynamic shift of some minor pests such as white fly, thrips and spider mites to major pests in the cotton ecosystem is a big concern. Unrestricted spread of these pests is highly challenging to cotton production and requires the attention of the research system. On the other hand, cotton grown in drought prone areas will be subjected to the effects of climate change and research is expected to address the abiotic constraints.

Shift of production system

Farmers are shifting from cotton production to high-value crops such as sesame, sugarcane, etc. because of poor productivity and low market price for seed cotton. Low market price is due to:

- Existence of stiff competition from imported lint leading to reduced price for local cotton lint thus discouraging farmers.
- Some countries (India, China, USA, etc.) are competing with our local farmers being producing cotton under subsidy, in-put availability at low price (machineries, sprayer, pesticides, fertilizers, etc.).(Looks unsubstantiated, it may be true for some countries; it is presumed that the competition is at country level, it is just a marketing choice.)
- The oil quality and content of locally produced cotton varieties were not determined and therefore, there is a high risk of distribution of cotton oil for human consumption that contains high gossypol (toxic to human consumption).(unrelated to "shift to production system")
- No or very limited collaboration with international research centers/organizations/associations.(unrelated to "Shift to production system")

Opportunities

- The culture of producing, processing, marketing and utilization of cotton and cotton by-products dates back to the time of agricultural civilization and is deeply rooted in Ethiopian's traditions.
- Existence of diverse agro-ecologies and vast low laying arable land which is suitable for cotton production.
- The existence of diverse potential agro-ecologies and arable lands suitable for growing cotton (> 3,000,810 ha).
- High potential and demand for cotton production and productivity in Ethiopia which is not yet fully exploited
- Presence of policies and regulations on biotechnology, GMO and bio-safety standards
- Presence of policies and regulations on germplasm exchange, introduction of foreign plant material and plant quarantine
- The ratification of local GMO policy and allowing the introduction and utilization of Bt cotton, highly encourages the research and development of our own Bt cotton locally
- Government focus on transformation of the agriculture sector (ADLI, GTP, PASDEP, PIF….) through diversification and market-led production of high-value, industrial raw materials strategic and import substitution crops like cotton

- Encouraging Government policy and support for the establishment and expansion of textile, garment manufacturing, oil milling, ginneries and cottage industries. Establishment of industrial parks and manufacturing industries in main cities across the country
- Cotton lint and garments import substitution & support for exports' of the same is high priority agenda for Government of Ethiopia.
- The presence of quality standards and associated price for cotton lint currently introduced by Ethiopian Textile Industry Development Institute (ETIDI)
- High demand for seed cotton from the rising textile and garment manufacturing industries that are currently operating only at < 70% of their capacities.
- High demand for lint cotton and cotton fabrics due to increase in the number of textile and garment manufacturing industries in the country and change in lifestyle of Ethiopian people and world population. The opportunities (*AGOA) given by USA to SSA for garments export free of tax and levy.
- Cotton production is good sources of cash/income and means of livelihood for farmers, processors, traders and exporters creating huge job opportunity along the cotton value chain for the citizen.
- Growing interest of other countries to import Ethiopian cotton products.
- The presence of large number of cotton farms, ginneries (21), textile-garment manufacturing and cottage industries and oil milling factories.
- The presence of research centers and experimental testing sites for different agro-ecologies in the country.
- High possibility of producing branded cotton (organic cotton, BCI, Cambia, fair trade) for niche markets that promote sustainable cotton production.

Future Proposed Research Directions

Currently, the National Cotton Research Commodity is a high priority crop for the Government of Ethiopia and has been promoted to a National Cotton Research Program (NCRP).The NCRP has developed a 15-year strategic plan in three phases: short term (5yrs), medium term (10yrs) and long term (15yrs). Accordingly, the program has identified diverse strategic issues and intervention options in the following 12 thematic areas: (1) Genetics and Breeding, (2) Agronomy and Physiology, (3) Crop Protection (cotton entomology, pathology and weeds), (4) Agricultural Research Extension and Gender mainstreaming, (5) Agrucultural Economics, (6) Plant Biotechnology, (7) Post Harvest Handiling and Agricultural Mechanization (8) Soil fertility, Health and Irrigation Water Management,(9) Seed Technology, (10) Cotton Fiber Technology, (11) Food and Nutrition, and(12) Crosscuting Issues such as Climate Change, GIS and Geo-Spatial.

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Achievements, Challenges and Future Prospects Edible Oilseeds Research and Development in Ethiopia

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Introduction

In Ethiopia, oilseeds are the third important crop in acreage after cereals and pulses. Noug, sesame, linseed, groundnut, safflower and Ethiopian mustard are the most common oilseeds grown in Ethiopia. The country has also great potential to grow soybean and sunflower. Edible oilseeds are sources of calories, essential fatty acids, proteins, vitamins and micronutrients (Vollmann and Rjcan, 2010). Oilseeds can be used as row material for agro-industries not only for extraction of edible oil but also for other industrial products such as paints, soap and lubricants. They play a significant role both in rural economy as cash crop and for the national economy as export commodities. The meal remaining after oil extraction of oil crops are good sources of livestock feed. In 2014/15 the total oilseeds production reached to 7.6 million quintals with area converge of 856 thousands hectare excluding soybean which is usually considered as pulse (CSA 2014/15).

Most of the national production of oil crops comes from the local landraces, which have low productivity and poor quality due to both biotic and abiotic factors. Oilseeds production is characterized by labor intensive, low-input and rain-fed cultivation that result in low yield. The national productivity of most oilseeds except soybean and Ethiopian mustard are below one tone per hectare. Growing of oilseed crops on marginal lands, limited access of oil crops technologies such as improved varieties along with improved production packages are the major production constraints of oilseeds sectors. The presence of insufficient information on socio-economics realities such as market linkages along the various actors in the oilseed value chain is also another challenge for the oilseed sector.

According to the five year Growth and Transformation Plan (GTP II: 2015 - 2020) of Ethiopia, the agriculture sector should be transformed into industrializations stage by stage although it is still the leading sector of the country. Oilseeds could contribute much for such transformation since they are sources of raw materials for the expansion of agro-industries both for edible oils and various industrial chemicals. Oilseeds based agro-industrial development even at small and cottage industry levels, is critically important to the expansion and diversification of the agricultural sector in Ethiopia. Such agro-industrial development could also make a significant contribution to the transformation and commercialization of agriculture.

The poor productivity and lack of sufficient amount of oilseeds by oil millers or oil factories result in the dependence on the import of large amount of edible oil, mainly palm oil. Apart from insufficient supply, most of the domestic oil cursing and refining industries produces semi-refined oil or crude oil of poor quality. The declining of oilseeds productivity time to time along with the trade imbalance of exported oilseeds and imported edible oils are factors that pose great pressure for getting stable income for farmers which in turn challenges for food secure and oilseed based –agro industry development (Wijnands, J et.al., 2007).

Research on oilseeds started in earlier years before the beginning of systematic research in multidisciplinary manner in1960's (Getinet and Nigussie, 1992). During those years a number of researches have been carried out for the last five decades to develop high yielding and better quality varieties along with their crop management practices. Since 1976 a number of varieties have been developed along with crop management practices. Agronomic recommendations such as seed rates, weeding frequencies, fertilizer rates, sowing dates and harvesting stages were developed for major oilseed crops. Besides, major economically important diseases and insect pests were identified and recommendations were made for their control methods.The principal aim of oilseeds research is generally to increase the productivity and quality of the crops through multidisciplinary and participatory research approach.

Ethiopia's oilseed sector is, however, found below its full potential due to various bottlenecks along the value chain. Some of the major challenges identified are: i) weak extension system to enhance use of improved technologies of oilseeds by farmers, ii) limited capacity of cooperatives to supply demanded inputs and to facilitate the marketing of output, iii) poor harvest handling and value addition, iv) limited production of oilseeds for agro-processing and lack of incentive for agro-industries, v) weak market information and promotion as well as quality control system. There is, however, a possibility for improvement of oilseeds productivity which can be doubled through the use of improved crop management practices at smallholder level. There are also of potential areas of cultivated lands that offer organic and sustainable oilseeds production. The presences of high demand of oilseeds locally and high potential for export market are good opportunities of oilseed sector. The overall aim of this paper is to review major research achievements of oilseeds, indicating the challenges and opportunities of oilseed sector and suggest the prospects of the oilseeds sector.

Oilseeds Research in Ethiopia

Research on oilseeds in Ethiopia reportedly started during the Italian invasion linked with the few preliminary investigation on noug conducted in Eritrea (Getinet and Nigussie, 1992). During 1960's, yield observation trials were carried out on noug, linseed, safflower, sunflower and castor at Debre Zeit and the then Alemaya University. Similar research efforts were conducted at Hawassa for oilseeds such as sunflower, rapeseed and Gomenzer and during those time Gomenzer varieties such as S-67, S-115 and S-67 and sunflower variety namely Russian Black have been released or registered (Getinet and Adefris, 1992) This was further strengthened with the establishment of the Institute of Agricultural Research (IAR) in 1966. Systematic and coordinated oilseeds research program emerged in 1981 with the support of the International Development Research Center (IDRC) of Canada. The research program had two major projects namely Ethiopian Highland Oil-crops Research Project (EHOCP), which focused on the improvement of linseed, noug, Ethiopian mustard, rapeseed and sunflower, and Ethiopian Low Land Oil-Crops project (ELLOP), which was mandated with the improvement of sesame, groundnut, safflower and castor. The two projects were implemented by interdisciplinary team consisting of breeding, agronomy, weed science, plant pathology, entomology, soil and water science, agricultural economics and research extensions. Holetta Agricultural Research center was the coordinating center of Highland Oil-crops Research Project, whereas Lowland Oil-crops Research projects were coordinated by Werer Agricultural Research Center. During the operation time of the two projects (1981 and 1989), several improved varieties and crop management practices were released, demonstrated and popularized on farmers' fields. In 1989, the two projects were amalgamated into Ethiopian Oilseeds Research Program and coordinated at Holetta Agricultural Research Center. Until 2004/5 the oilseeds research were executed as a program by formulating two projects, namely highland oilcrop project covering noug, linseed, oilseed brassica and lowland oildcrops research project covering sesame, groundnut and sunflower. The research on sesame and groundnut was coordinated by Werer research center, and sunflower was at Hawassa Agricutural Research Center.

Since 2005/6 and till now, noug, linseed and gomenzer including sunflower and safflower are considered as one research commodity coordinated by Holetta Agricultural Research Center while sesame and groundnut are coordinated at Humera Agricultural Research Center, and Haramaya University, respectively. Soybean is introduced to Ethiopia in the 1950s and its research started in 1956 at the Jimma Agricultural Research Center. There had been some research on soybean at Debre-Zeit Experimental Unit (Asrat. et. al 2004). Soybean research is currently coordinated at Pawe Agricultural Research Center.

Major achievements of oilseeds research

Variety development

Provision of improved varieties of oilseeds along with suitable production practices are the major research agenda of oilseeds research in Ethiopia. Although a number of varieties of oilseeds are developed from the previous breeding efforts, their dissemination and popularization to the farmers and other beneficiaries is limited. This implies that most of the national production of oil crops comes from the local landraces, which have low productivity and poor quality due to both biotic and abiotic factors. The overall objective of oilseeds research is thus to develop high yielding, better quality and market-oriented oilseeds technologies, which are useful to the farmers, traders or exporters agro-industries. In line with the above overall aim of the research, a number of varieties and agronomic recommendations were developed for the last five decades. The major achievements of oilseeds research along with their brief descriptions are discussed hereunder.

Noug (*Guizotia abyssinica*): is an oilseed crop, indigenous to Ethiopia, where it is the major source of edible oil. In addition to its oil, the crop offers an important source of seed proteins carbohydrates, vitamins and fiber that significantly contributes to the human dietary intake of resource-poor farmers. The noug seed is consumed after being processed in various forms for its unique nutritional, medicinal and cultural values (Geleta et al. 2002). In terms of utilization, seeds of noug are crushed to be used directly as food locally or exported to North America, UK and Singapore for bird feed market (Quinn and Mayer, 2002). Nevertheless, noug still is less productive as compared to other oilseeds and its national average seed yield is not more than 7 qt/ha (CSA 2013/14). Self-incompatibility, seed shattering, lodging, uneven maturity of heads are the major factors for noug low productivity. Biotic factors such as parasitic weeds (dodder), insect pests (eg. noug fly), diseases such as shot hole and leaf blight are limiting noug productivity. Increasing seed yield followed by oil content are the major breeding objectives of noug. Since noug is highly out-crossing species with self- incompatibility mechanisms (Sujatha, 1993), breeding procedures used for cross-pollinating such mass and half-sib recurrent selection were used as breeding methods. A number of research activities were carried out for the last four decades to alleviate the above challenges and so far, five varieties were released by these methods (Table 1). Besides, it was possible to screen noug accessions with high oil content up to 46.9% from local early collections (Getinet and Adefris, 1994) and up to 66% from recent collections (Bioversity International, 2011). Modern tools of plant breeding such as molecular characterization of noug germplasms using RAPD and AFLP markers by Mulatu Geleta (2010) and SSR (Dempewolf et.al., 2015) have been carried out that showed the presence of high genetic diversity of noug, which was more pronounced within the population than among the population. Besides, it was possible to develop another culture protocol by Misteru Tesfaye (2008) that enables easy development of noug lines, which are useful to improve the selection efficiency of quantitative characters by incorporating them in recurrent selection cycle or used in development of synthetic cultivar of noug population with desirable traits.

Table 1. Seed yield and oil content of noug varieties currently under production

Variety name	Year of release	Maturity days	Seed yield (q/ha)		Oil content (%)
			Research field	Farmer field	
Fogera	1988	147	9.0	3.97	39.6
Esete	1988	147	8.9	4.13	39.6
Kuyu	1994	145	10.9	-	38.0
Shambu	2002	140	9.5	5.6	38.5
Ginchi	2010	149	10.0	7.0	39.8

Sesame (*Sesam umindicum*) is strategically important to Ethiopia specifically in terms of its contribution in agricultural export. Until recently, Ethiopia was among the world's top five sesame exporters, supplying to China and Turkey. Although, Ethiopia has strong position in the global sesame market, the country only reaches lower value markets, with ~95% of its' sesame exported without value addition, in raw form. Moreover, Ethiopia is not leveraging diversified export market strategies and engaging in agro-processing unlike its major competitors, India and Nigeria. In order to transform the sesame sector, Ethiopia should work focusing on i) continuing to supply to the existing conventional market through increasing the volume along with quality, ii) diversifying towards higher value conventional market, and iii) enter premium markets through value addition. There are, however, several challenges that hinder to address the above issues such as weak sesame improvement efforts in terms of variety development as well as crop management and limited efforts to strengthen sesame growers or cooperative in access of input and in capacity building.

Regardless of the release of a considerable number of sesame varieties (Table 2), most of the varieties released are not adopted widely as they do not address the specific constraints of the respective agro-ecology and needs of farmers. Humera-1, Setit-1 and Adi are the most common varieties grown at Humera areas while Obsa, Dicho and Abasena are varieties adapted to Wellega areas. Sesame varieties are labeled and marketed based on the area where they are produced as Humera, Gonder and Wellega types.The Humera variety is appreciated world-wide for its aroma and sweet taste, which is applicable for bakery, tahini and confectionary. The Gonder type is dull white used for bakery while the Wellega type is well –known for its high oil content and suited for cooking oil.

Table 2. Released varieties of sesame and their characteristics

Name	Days to maturity	Altitude (m)	Rainfall (mm)	Seed color	Yield (qt/ha)		Oil content (%)
					Irrigation	Rain fed	
Adi	85-90	300-750	Ir	White	16-20	5	42-48
Abasena	110-120	500-1200	>700	Gray	12-14	9	44-48
Kelafo-74	110-120	<500	Ir	Blackish	10-12	6	42-46
Mehado-80	100-110	300-750	Ir	Gray	15-22	6	41-44
Argene	90-100	350-750	Ir	Deep gray	15-18	-	42-48
Serkamo	90-100	360-750	Ir	White-brown	15-18	-	42-51
E	90-100	300-750	>700	Dull white	12-14	7	42-47
S	100-120	300-750	>700	Light brown	12-16	7	40-46
T-85	100-115	400-650	400-650	Dull white	8-10	7	42-45
Tate	110-120	600-1200	600-800	Dull white	15-18	7	47-49
Ahadu	105-115	1400-1600	750-950	Brown	-	7-10	49-51
Borkena	105-120	1400-1600	750-950	Brown	-	6-8	47-48
Obsa	130-150	1250-1650	700-1100	White-tan	-	8-10	52-54
Dicho	120-140	1250-1650	700-1100	white	-	8-10	51-52
Humera-1	110-120	600-1100	400-650	White	-	8-10	54-56
Setit-1	100-110	600-800	400-650	White	-	7-10	52-54
Barsan	80-90	500-700	<450 + Ir	Brown	7-8	-	46-47
Lidan	80-90	500-700	<450 + Ir	Brown	7-8	-	45-46

Note: *1 quintal (qt) = 100kg; Source: MoARD, crop variety register book, 1990-2010, Ir = Irrigation*

Linseed/flax (*Linumus itatissimum* L.) is one of the oldest oilseeds cultivated for its seed and fiber in the world. Linseed has long history of cultivation by smallholders in Ethiopia as source of oil and traditional foods. It is usually cultivated in higher elevations where frost is a threat for other oilseeds. It is widely cultivated in higher elevations of Arsi, Bale, Shewa, Gojam, Gonder, Welo and Wellega. The quality of Ethiopian linseed complies with fatty acid criteria of large European importers and crushers. The C18:3 value of Ethiopian linseed is within a range of 45-60%, an essential omega-3 which has beneficial effects on health and the auto immune system (Payne, 2000; Moris 2004). Linseed oil has been mostly used for industrial purposes (Lay &Dybing, 1989; Rowland *et al.*, 1998) in making varnishes, paints and the like due to its high linolenic (polyunsaturated) fatty acid, which is known for its fast drying quality because of its auto-oxidative three double bonds. Smallscale farmers have been producing linseed with little application of chemicals (fertilizers, herbicides, pesticides) or other external inputs. Hence, it is popular cash crop for resource poor farmers and is often used in rotation with cereals and pulses.

Despite its multiple uses, linseed national productivity is still low (not more than 1 ton/ha). This is due to low genetic potential of the local landraces, diseases such as wilt and pasmo, insect pests (eg ball-worm) and parasitic weeds (dodder) and some abiotic factors such as frost and waterlogging. The primary objective of linseed breeding in Ethiopia is thus to increase its yield especially through developing varieties resistant to diseases, insect pest and weed, and tolerance to abiotic stress. The second objective is breeding for oil content and quality especially through modification of fatty acid. So far 11 linseed vanities have been released from the local breeding program (Table 3) and one variety namely Biltstar is registered from introduced linseed material from Netherlands.

Table 3.List of released varieties of linseed by EIAR and their seed and oil yield

Variety name	Year of release	Maturity date	Seed yield (Q/ha)		Oil content (%)
			Research field	Farmers field	
Cl-1525	1984	146	14.30	8.10	38.5
Cl-1652	1984	146	13.60	8.80	38.6
Chilalo	1992	140	16.70	9.00	35.2
Belay-96	1996	141	16.80	9.00	36.3
Berene	2001	140	16.17	9.10	37.0
Tolle	2004	143	16.90	10.00	36.0
Kulumsa-1	2006	147	17.85	11.00	36.1
Jeldu	2010	150	15.40	11.23	37.0
Kassa-2	2012	140	12.59	-	37.45
Biltstar	2013	142	19-20	16	37.0
Furtu	2013	145	17.6	15	38.0
Bekoji 14	2014	147	15.47	12	38.6

Oilseed brassica: In Ethiopia, two species of the oilseed brassicas, namely Ethiopian mustard (*B. carinata*) and rapeseed (*B. napus*) are being cultivated for the production of edible oil. Ethiopian mustard is the predominant species of Ethiopian origin, which has been grown in Ethiopia since antiquity both as an oilseed and as vegetable crop. Crushed seed of Ethiopian mustard is traditionally used for many purposes, such as greasing traditional bread-making clay pan (oven), curing certain ailments and preparing beverages. Despite its anti-nutritional chemical constituents (high erucic and glucosinolate level), which can be amenable through breeding, Ethiopian mustard seed have been also used as raw material for edible oil extraction. The current interest of exploiting the non-traditional use of Ethiopian mustard as bio-fuel and for synthesis of bio-products such as lubricants, hydraulic fluids and polymers will bring an advantage of increasing the income of farmers in addition to its use for food security. In 1976 the first rapeseed variety namely Target was released from introduced rapeseed lines. Such research effort was continued and two rapeseed varieties (Pura and Tower) were released in 1980's which were assumed to be canola types (double zero) along with useful merit in terms of oil content, earlier maturity, uniformity and suitability for machine harvest as compared to Ethiopian mustard. In the early 1990's, however, the farms were compelled to abandon the species due exclusively to the breakout of blackleg. Until very recently, research on rapeseed was brought into a halt altogether due to outbreak of the diseases black leg especially on the state farms. It is now being revived due to its demand for better oil quality (high oil content, low erucic acid and low glucosinolate). Research on rapeseed has been underway along with Ethiopian mustard research searching for technological means of curbing the disease than simply giving up on the crop. Currently there are three Ethiopian mustard found under production and recently two rapeseed varieties are registered (Table 4)

Table 4. Varieties of Ethiopian mustard under production and registered varieties of rapeseed

Ethiopian mustard varieties				
Name of varieties	Year of release	Yield (Q/ha)	Oil content (%)	Remark
S-67	1984	30.30	40.5	
Yellow Dodolla	1986	30.20	44.1	
Holetta -1	2005	30.29	39.1	
Rapeseed				
Name of varieties	Year of release	Yield (Q/ha)	Oil content (%)	Remark
Axana	2015	18.0	45.5	Canola type *
Belinda	2015	20.5	45.2	Canola type

*canola type = low erucic acid (< 5%) and low glucosinolate(<15µ moles/g of seed)

Groundnut (*Arachis hypogaea* L.): is an important monoecious annual legume used for oilseed, food and animal feed all over the world (Upadhyaya*et al.*, 2006). It is the principal source of digestible protein (25 to 34%), oil (44 to 56%), and vitamins like thiamine, riboflavin, and niacin (Savage and Keenan, 1994). Groundnut can be utilized as cooking oil and confectionary. Processed groundnut is used in diversified ways including groundnut butter which is used as spread for bread or biscuits, in cookies, sandwiches, candies and frostings or icings. Groundnuts are also a significant source of cash income in developing countries that contribute significantly to food security and alleviate poverty (Almayehu*et. al.*, 2014). As a legume, groundnuts improve soil fertility by fixing nitrogen and thereby increasing productivity of the semiarid cereal cropping systems.

Despite its diversified importance, groundnut production is challenged by both biotic and abiotic stress and its national productivity is not more 16 q/ha (CSA 2014/15). Diseases such as leaf spot and rust, insect pests (beetles), drought are the main production constraints. Aflatoxin, metabolic by-products of the moulds of different *Aspergillus* spp., is a major problem in many tropical countries including Ethiopia. The moulds are common saprophytic fungi found in seeds and soils that contaminate the seed and endangers health of humans and animals and lowers market value (Abdalla, 2009). Since 1976, thirteen groundnut improved varieties were released by Melka Werer Agricultural Research Center, which gives 12-35 and 32-80 qt/ha under rain fed and irrigation conditions, respectively (Table 5.)

Table 5.List of released varieties of groundnut by EIAR and their yield and oil content

Varieties	Year of Release	Yield q/ha unshelled	Oilcontent % of dry seed
Shulamith	1976	50-65	44-49
NC-343	1986	40-60	45-50
Werer-961	2004	26-28	44-45
Werer-962	2004	29-30	46-48
Werer-963	2004	20-22	45-46
Werer-964	2004	20-21	45-47
ICGV-94205	2008	26-70	Confectionery
ICGV-94222	2008	20-80	Confectionery
ICGV-93164	2008	26-80	Confectionery
ICGV-93370	2008	60	Confectionery
Fetene	2009	60-62	50-52
Eta	2010	20-22	Confectionery
Fanta	2010	18-21	42-43

Soybean (*Glycine max (L.)*Merr):- is the most popular oilseed crop produced in the world (Wilcox, 2004) in addition to its use as source of protein like other pulse crops. The seed of soybean possess 40% protein and 20% oil and thus used as both for oil production and protein processing (Elroy R., 2009). Besides, the whole soybean as well as partially or fully defatted cake or meal can be used for making various food items. Soybean products currently are used as a means to solve malnutrition problem especially for children in developing countries due to its rich protein and essential fatty acids in the oil (Nagaraj G, 2009).The majority of soybean is grown in North and South America, China and to a smaller extent in many other countries on every continent (Elroy R., 2009). In Ethiopia, soybean can grow in the mid-altitude and lowland areas of the country. Depending on the varieties, the crop grows in altitudes ranging from 700-1800 m.a.s.l, and rainfall ranging from 450-1500mm/annum, and temperature from 23-25 ^{o}C. An altitude 1100-1700m.a.s.l. and a minimum rainfall of 500 mm/annum are required during the growing period for soybean production. Soybean grows well on highly fertile, well drained and light clay loam, sandy loam and alluvial soils. The crop yield up to 31 quintal/ha at potential areas like Goffa with oil content of 23.2% and protein content of 40.8 (Fekadu et al, 2010). Although soybean has been used as source of protein especially in processing baby food in Ethiopia, currently oil pressing industries have emerged to produce edible oil. Research in soybean started in 1956 at Jimma College of Agriculture and consequently at Debre Zeit Experimental station and Chilalo Agricultural Units (Asrat et. al 2004). Currently, soybean research is coordinated by Pawe Agricultural Research Center and so far 10 varieties were released/registered (Table 6). The varieties are grouped in three-maturity groups namely early, medium, and late maturing and the majority of the soybean varieties are medium maturing types.

Table 6. List of released /registered varieties of soybean in Ethiopia

Variety name	Maturity groups	Productivity (Q/ha)		Protein content (%)	Oil content (%)
		Research	On-farm		
Gizo	Medium	20.06	17.63	31.39	19.71
Gishama	Medium	17.96	15.21	31.37	20.06
BOSHE	Medium	16-30	14-28	35.95	19.86
Dhidhessa	Medium	20-33	14-28	34.97	20.35
Awassa-95	Early	18-26	17-25	-	-
AFGAT	Medium	14.8	13	-	-
ETHIO-YUGOSLAVIA	Late	17-35	16-30	-	-
Tgx-13.3-2644	Late	25-30	15-20	-	-
Korme	Medium	12-38	12-32	39.33	20.53
KATTA	Medium	14-32	13-28	38.73	18.82
AGS-7-1		26.29	15-25	37.29	19.52
Nova	Early	22.48	12-20	33.13	20.05
Wello	Medium	19-32	17-22	30.4	17.9
Belessa-95	Late	17.24-29.8	20.85	-	-
Wegayen	Late			-	-
Clark 63k		25-30	15-20	-	-
Coker 240	Medium	25-30	15-20	-	-
Williams	Early	25-30	15-20	-	-
Davis	Medium	25-30	15-20	-	-
Cheri	Medium	22	15	-	-
Jalele	Medium	22	15	-	-
Crowford	Early	25-30	15-20	-	-

Safflower (*Carthamustincorius L*): is among the well-established oil crops in Ethiopia and the country is considered as secondary center of variability for safflower (Seegler, 1983). Although the crop is widely distributed, previous reports indicated that Harerge, Sidamo, Shewa, Arsi, Welo, Tirgay and the adjoining areas of Gojjam and Gonder are the major production areas of safflower (Yabio, 1985). Recent evidences, however, indicates that tef and maize growing districts of Amhara and Oromia regions of the country have become the dominant producers of safflower through intercropping safflower with tef and maize.

Safflower is rarely used as source of edible oil rather than consumed locally as beverage during the month of fasting and as a nut mixed with chickpea. Though safflower was traditionally grown for its local consumption, the current shortage of edible oil and its export demand for petal color is becoming an opportunity for both small scale farmers and for private investors to grow in large scale farms. Lack of high yielding varieties is the major constraint to safflower production in Ethiopia. According to research progress report, most of the national safflower production comes from the local landraces which are susceptible to diseases such as leaf blight (*Alternaria carthami*), root-rotting (*Phytophtora* and *Fusarium spp*) and insect pests mainly safflower fly (*Acanthiophilus helianthi*). Improved varieties resistant to the above diseases and pests need to be developed along with the optimum crop management practices.

A B

Fig 1. Seeds of spineless safflower variety (A) and local variety (B)

In Ethiopia, research on safflower started in early 1970s by the then Institute of Agricultural Research (IAR) with a few adaptation tests (Yabio, 1985). Systematic research on safflower continued through collecting 166 accessions by then Institute of Biodiversity of Ethiopia (IBE) in collaboration with Melka Werer Research Center. Promising accessions were tested in advanced yield trials and so far five varieties were developed namely Aklilu, Bako-red, Bako-white, Kulumsa-Thornless and Bozinan. These varieties, however, were not as such multiplied and distributed for production. Currently, new spineless variety namely Turkana was tested under adaptation trial in six locations and registered as variety for production. This variety has big seed size as compared to the local landraces (Fig 1.) with better oil content (30%) and comparable yield as local variety.

Sunflower (*Helianthus annus L.*): is one of the major sources of oil in the world and assumed to have originated from southern United States where its progenitor or wild *H.annuus* was found (Heiser 1978). It is a wide spread oilseed crop of the world and it is almost grown in all continents. Evidences suggested that sunflower was introduced to the North Horn of Africa including Ethiopia by the Italians some 160 years ago. Despite small area coverage of the crop, the country possesses large agricultural land suitable for sunflower production. According to adaption trials by Holetta Agricultural Research Center, sunflower can be grown in a wide range of agro-ecology in Ethiopia. Currently, the crop is grown as a border crop and sometimes as sole crop in Central Highlands of Shewa (eg. Bishoftu and Adama), West Gojam (eg.Finote Selam, and Achefer), East Wellega (eg. Anger Guti) and some districts of Arsi Zone.

Although sunflower varieties are classified as oil, confectionary and ornamental, most cultivated sunflowers are applicable for extraction of oil. The oil from sunflower is healthful with great acceptance from consumers and it is considered premium oil for salad, cooking and margarine production (Nagaraj G, 2009). The seeds of confectionary sunflower are used as snack food as well as for feeding birds and small animals. Despite the fact that sunflower production was not significant in the country, currently some private farms have started to grow the crop due to high demand for raw material, for oil-millers and thus its coverage is expected to increase.

In Ethiopia, sunflower improvement started in the late 1960's and during that time three varieties namely *Russian black, Hesa and Pop-158* were recommended for production at national level. These varieties were late maturing, tall type and are less uniform. Systematic research on sunflower has been conducted since 1980s at Hawassa Agricultural Research Center, which was a coordinating center till 2004 to release open-pollinated varieties with desirable agronomic traits. Later in the 1990s, two early and shorter candidate varieties namely *NSH-2* and *NSH-25* for lower-rainfall and warmer areas and another full-season type variety *Argentario* were in pipelines for release from Synthetic Variety Development Program. None of these varieties, however, were successful for release and the state farms also lost interest in producing the crop due to partly i) the severity of bird damage in the production areas, ii) disease occurrence such as downy mildew and sclerotina, and ii) lack of strong research program and follow up. Due to the above challenges the then IAR-management decided to cease the research program altogether and all germplasm materials had been kept in safe at the then PGRC/E (now Ethiopian Biodiversity Institute-EBI). Since the last few years it seems that there is a growing interest from private sector to produce sunflower and thus Ethiopian Institute of Agricultural Research (EIAR) has started to reinitiate the research on sunflower by assigning Holetta Agricultural Research Center (HARC) to coordinate the research program. The breeding efforts started by acquiring and evaluation of germplasms from Ethiopian Biodiversity Institute (EBI). In 2005 the first open-pollinated variety namely *Oissa was* released from local breeding program. Since 2010 a number of hybrid sunflower varieties have been registered through conducting adaptation trial at various locations in collaboration with different private companies. According to the reports from variety evaluation committee, the registered hybrid varities were found to be adaptable to wide agro-ecology and gave better productivity and their oil content ranged from 17-31 Q/ha and oil content 37-51 %, respectively (Table 7).

Table 7. Hybrid varieties registered in Ethiopia and their yield and oil content potential

Varieties	Year of registration	Average seed Yield (Q/ha)	Oil Content (%)	Sources of varieties	
				Country of Origin	**Collaborative company**
PR63A98	2015	17-18	45	France	Pioneer Seed Co.
PR63LL06	2015	18-19	40	France	Pioneer Seed Co.
Camara II	2014	20-25	42.5	America	Minerva PLC
NLN11037	2014	17-20	40.4	Serbia	Minerva PLC
Vicenzo	2014	18-22	38.7	Serbia	Minerva PLC
X6859	2014	21-25	38.0	America	Minerva PLC
Hysun 33	2013	25-30	45.0	Australia	General Chemicals and Trading Company
NfDelfi	2012	17.6	44.0	France	Red Speckled Global Trading PLC
Neoma	2012	19.4	46.0	France	Red Speckled Global Trading PLC
VSFH-2074	2012	18.0	37-40	India	Vibha Seeds, India
VSFH-1006	2012	21.0	37-40	India	Vibha Seeds, India
Kazanova	2011	31.0	48-51	Serbia	Ashiraf Agricultural and Industrial PLC
NS-H-45	2011	18.0	45-50	Serbia	Ashiraf Agricultural and Industrial PLC
NS-H-111	2011	19.0	48-50	Serbia	Ashiraf Agricultural and Industrial PLC

Crop management

Improvement of the performance of the crop can be attained either by manipulating the genotype or by optimizing the environment or both. The environment could be either directly linked to the crop (eg. irrigation, fertilizer and pest control) or indirectly linked to the crops such as plant arrangement and time of sowing. In simple terms, agronomic practices and pest managements are the most common crop management practices that need to be considered along with genetic improvement. Despite the fact that improved varieties showed better performance as compared to the local varieties, they fail to express their genetic potential due to poor crop management practices.

In Ethiopia, farmers usually grow oilseeds under poor conditions that would not allow the crop to perform better even compared to local varieties. To alleviate this problem, research on crop management practices especially on agronomic and weed management have been carried out in collaboration with the respective disciplines. Recommended crop management practices of each oilseed are discussed below despite the fact that some of them need to be refined due to limitations to be applicable to different agro-ecologies and outdated due to the current change in edaphic and climate factors.

Noug

Noug is usually planted in mid-May to early July in areas where ‘Abat’ noug is grown and harvested in December. ‘Bungne’ noug is planted in July and harvested in October while the growing season for ‘Mesno’ noug is from September to February. A seed rate of 6-10and 12-15 kg ha^{-1} were found to be optimum rates for row and broadcast planting, respectively. Though noug is assumed to be less responsive to fertilizer, according to previous studies around West Shewa Zone (Dendi District) on less productive soils, 30 kgha^{-1}Urea and 50kgha^{-1}DAP are recommended for initial establishment of the crop. Noug is traditionally used as a break-crop for cereals since crop following noug will give higher yield. Right time of harvesting noug is an important practice in reducing shattering. Harvesting noug when the bud moisture content is about 40%, which is expected to be three weeks after 50% petal drop resulted in higher yield and minimum shattering without affecting the oil content (Hiruyand Nigussie, 1986). Survey of diseases on noug showed that blight, shot hole and powdery mildew were important (Yitbarek Simane, 1992). However, seed loss due to shot hole was not significant probably because noug produces too many leaves per plant or the disease comes lately. Noug fly is the major insect pest that feeds on disk flowers (Tadesse and Bayeh, 1992) and the breeding populations have been screened for resistant to noug fly in collaboration with entomologists. The parasitic weed namely Dodder is the main problem in noug production. The use of dodder-free seed is the best recommended management practice .

Sesame

Sesame requires a warm, moist, weed-free seedbed and a high temperature for germination. Availability of moisture, length of the rainy season and temperature are the three major factors, which determine sesame planting time. Research recommended dates of planting for rain-grown sesame is mostly between mid-Junes to mid-July while mid-June for the main season and late November for the off-season is optimum planting dates for sesame production under irrigation. The recommended planting space for sesame in Ethiopia is 10 cm between plants and 40 cm between rows making 250,000 plant populations per hectare and such population will be attained at seed rate range of 2-5 kg/ha depending on seed size. If the space between plants could not be attained during sowing, thinning is required when the seedlings reaches at height of 10 to15 cm. Although fertilizer recommendation study is very limited, application of N and P_2O_5 at the rate of 38/29 around Bako areas and 120 kg/ha NPK (19:19:19) + K_2SO4 50kg/ha + urea 50kg/ha for Humera areas significantly increased sesame production. Since sesame is poor competitors against weeds, it is very important to eliminate weeds from sesame fields as early as possible. Weeding can be done manually or using herbicides depending on its economic advantage. According to the study conducted at Werer, Humera, Pawe, Metema and Bako, sesame requires twice hand weeding during 1-2 and 4-6 weeks after sowing. If the weed cannot be managed by only hand weeding, application of herbicide Metholachlor 960 EC at 2.5 l ha^{-1} is recommended with supplement of hand weeding to be conducted at 30-35 days after crop emergence. A wide range of insect pests and diseases attack sesame around the world. In Ethiopia, sesame webworm, seed bug, gall midge, termites are the major insects that challenge sesame production while bacterial blight, phyllody and wilt are economically important diseases of sesame. Integrated pest managements that involve cultural, biological and chemical measures can be used for management of the above diseases and insect pests. Field sanitation, crop rotation and use of clean seeds are the major cultural practices employed for sesame pest managements. Diseases can be managed by the use of resistance varieties. Biological controls such as the use of predators for insects like webworm. Use of pesticides such as Malathion 50% EC, Diametheolate 48% and Diazinone 60% EC at the recommended rates are used as the last resorts. Harvesting of sesame at the appropriate time is very important to avoid seed shattering. Harvesting should start when 75% of the pod/capsules are ripe, leaves and stems tend to change from green to yellow and to dark red in color and the leaves begin to fall off.

Linseed

Since linseed is a small-seeded as well as poor competitive to weeds, a finely prepared, weed and clog free seedbed is essential for successful crop establishment. Plowing twice or three-times can serve this purpose. Although the seed can be broadcasted by hand, row planting by seed drilling is recommended at seed rate of 25 kg/ha with row spacing of 20 cm, that will give plant density of about 500 plants/m^2. The optimum sowing date generally varies from early to late June on red soils of Holetta, Kulumsa and Adet, while early to mid-July was for black soils (Nigussie and Yeshanew, 1992). Sowing too early reduces germination and seedling establishment, predisposing the crop to weeds competition while late sowing may cause desiccation of crops at flowering and seed filling stages, exposing to them to frost damages. According to earlier studies at Holetta, Kulumsa and different linseed testing sites, linseed was found to be less responsive to fertilizer (Balesh et.al 1992). Later preliminary studies around West shewa region at a rate of 23/23 of each N and P_2O_5 was found to be the optimum rate especially in less fertile soils. Seedlings of linseed are too weak to compete with weeds and thus it is necessary to weed the plant at appropriate time. Hand weeding twice at early and mid season is recommended for weed control (Rezene Fessehaie, 1992). Although pre-emergence herbicides such as Linuron (1 Kg a.i. /ha) and Metabromuron (2 Kg a.i/ha) are recommended by the above author, a recent study on pre-emergence herbicide namely, Pendimenthaline at the rate of 1.0 L ha^{-1} has also recommended as alternative herbicide. The optimum time for harvesting linseed is when most of the capsules are fully matured and turned brown. At this stage, the seeds make a rattling sound in their capsule and seed moisture content will range between 10-15%. Survey and identification of diseases and pests of linseed have established facts that wilt and pasmo are important diseases so far (Yitbarek Simane, 1992). The use of resistant varieties is best recommended for the control of the above diseases. Linseed is relatively less attacked by insect pests and currently only African boll worm is found sporadically threatening the crop.

Oilseed Brassica (Ethiopian mustard/rapeseed)

Optimum sowing dates for both species in the central and lower altitude (<2500 m) areas of Southern and South Eastern Zones where oilseed brassica is potentially grown are three weeks after the commencement of steady rain, which is expected during late-May to mid-June; and for high altitude (>2500 m) areas, in the South East, late-May is appropriate. Both broadcasting and row-sowing can be applied but the latter allows ease in movement and less crop damage during hand weeding. Based on the agronomic studies conducted by Nigussie and Yeshanew (1992), a seed rate range of 10-15 kg ha^{-1} was found optimum for different climatic conditions. Recent preliminary studies, however, showed that lower rates (2.5 -5 kg/ha) seemed to be appropriate when the row planting method was properly implemented. Fertilizer trials conducted at various sites showed that yield of rapeseed and mustard depended largely on soil fertility. In most sites, a rate of 46 kg of N and 69 kg of $P_2 O_5$ kg ha^{-1} was optimum. Weeds can be effectively controlled by hand weeding once during early stage of growth or by pre-emergence application of alachlor at the rate of 1.5 kg a.i. kg ha^{-1}. Survey and identification of diseases and insect pests on rapeseed and mustard showed that Alternaria leaf spot, white rust and black leg are important. Leaf spot reduced seed yield of mustard by 8%, on average. Black leg has been found to be a serious threat on rapeseed almost in all the state farms where the crop was grown. The use of resistant varieties is the best option for management of such diseases. Among insect pests, cabbage aphid, cabbage whit fly, flea beetles and diamond back moth are considered important.

Groundnut

The planting time of groundnut around Babile, Gursum and western Hararge usually ranges from the beginning of April to end of May. Mid-June and mid-July are the optimum planting dates for groundnut around Dihdessa and Bissidimo, respectively. Groundnut is planted at Gambela in late May while mid-May at middle Awash. Seed rate of 80 kg/ha for small seeded and 120 kg/ha for big seeded varieties with 60 cm and 20cm inter and intra row spacing is recommended for groundnut. The critical period of crop-weed competition in groundnut starts from crop emergence and extends to 30 to 35 days of crop establishment (Kassahun *et. al*., 1992). Early hand weeding at 2-4 weeks after planting is recommended with supplement weeding at 7-8 weeks. If hand weeding is found to be expensive, application of herbicides such as vernolate 3.96 kg a.i/ha, nitralin 1.32 kg a.i/ha before emergence are recommended for management of both broad and grass weed. Yellowing of leaves, resemblance of the new seed to old ones, smoothness of the inner surface of the shell coupled with brownish /darkened veins are good indicators of groundnut maturity. Pods should not stay in the field after optimum maturation, which may increase the infestation by *Aspergillus*. Leaf spots and rust are the most economically important diseases of groundnut and the use of resistant varieties and cultivation of varieties especially those with erect stem types are recommended for management of the above diseases. Fungicides such as Benlate 50% WP and chlorothalonil 85% WP at the rate of 3-3.5 kg /ha are recommend for management of rust and leaf spots, respectively. Stripped blister and pollen beetles are the major insect pests attacking groundnut and integrated insect management can be applied for the control of the above insect pests.

Soybean

Poorly prepared fields affect soybean seed germination and results in low yield/harvest at the end and hence, good land preparation is crucial for soybean production. Usually soybean requires three times tilling, fine land preparation, and free from any weed seed and other crop debris for optimum productivity. Although time of land preparation varies in different locations, first tilling starts in April immediately after harvest of the previous crop. The Second and third plowing can take place one month after the first plowing. Based on the results of different studies on planting date on different varieties and locations, the appropriate planting dates for early maturing varieties (matures less than 120 days) is mid-June to first week of July; for medium maturing varieties (mature from 121-150 days) is Mid-April to first week of June; and for late maturing varieties (mature in more than 151 days) is first to last week of May. The appropriate row spacing for early maturing varieties is 40cm; while 60cm for both medium and late maturing varieties and the spacing between plants is 5cm for all groups of varieties for optimum growth and yield. The sowing depth varies depending on the type of soil. Therefore, the recommended sowing depth for heavy soil is 2.5-4cm, and 4-5cm for light soil. It is important to maintain the optimum sowing depth in soybean for uniform germination and vigorous seedling growth. Regardless of soil type, type of variety and environmental conditions, 100 kg ha^{-1} DAP is commonly used on soybean. It is recommended to use 125gm of Rhizobia bacteria for 25kg of soybean seed. No additional nitrogen fertilization (from the N that is applied in the 100kg DAP for one hectare) is required, if the inoculation is applied properly.

Sunflower

Planting sunflower from early- to late-June at inter- and intra-row spacing of 75 and 25 cm resulted in a higher seed yield. Fertilizer application did not have significant effect on sunflower yield. Assessments on yield losses from weed competition indicated that one hand weeding at 25 days after emergence is enough to reduce full-season weed competition effect of 58% yield loss to economically negligible level. In Ethiopia, downy mildew, sclerotinia head and stem rot, leaf spot and rust were identified as important diseases of sunflower. Higher incidence of downy mildew was noted with excessive delays in sowing dates beyond the established-optimum for a particular region. The disease can be controlled by dressing the seeds of sunflower with metalaxyl at the rate of 120 g a.i per 100 kg of seed. Sclerotinia causes tremendous yield losses as noted in the former state farms. Despite limited research on the sunflower diseases, crop rotations with sufficiently long enough periods are perceived to be better preventive measures. Surveys made in the South and South Eastern parts of the country enabled to identify more than 28 species of insect pests on sunflower. Of these, however, only African boll worm was found economically important.

Safflower

Agronomic studies on safflower are limited except some scattered research findings. Experimental evidences indicate that late June to early July is recommended planting date for areas around Debre Zeit (Bishoftu) and Nazreth (Adama) while early June, just during the onset of rain, is recommended for areas such as Gursum and Babile. According to previous preliminary study, a seed rate of 20 kg/ha sown by drilling method with 45 cm between rows was found to be better for optimum plant population. Currently, further studies on agronomic and pest management is planned to be conducted along with variety development efforts.

Challenges of oilseed sector and possible interventions

Despite the presence of various oilseeds technologies, the oilseed sector has still several challenges to its growth. Such challenges are reflected in all routes along the value chain. Few oilseeds are merged and considered as one commodity (eg. noug, linseed, oilseed brassica, sunflower and safflower) and the most popular oilseeds in the world namely soybean has not been as such considered as oilseeds rather as pulse crop. Little attention has been given to the research efforts of oilseeds as compared to cereals and pulses. Most of the national production of oilseeds come from the local landraces due to weak research extension linkage. Despite funding the oilseeds research by the government, the support from international and private companies is very weak.

Limited accessibility of inputs particularly improved seeds have been the major challenges. Currently, seeds for most of the oilcrops are not produced by the public seed enterprises including by the Ethiopian Seed Enterprise. It is, therefore, difficult for farmers to obtain high-quality seed and most oil-seed producing farmers are forced to save their own seed or buy from local markets. This might be due to poor capacity of public seed enterprises to multiply oilseeds in addition to major staple crops. Farmers or growers also lack credit facilities to purchase inputs such as seeds, fertilizer and pesticides.

Oilseeds production has become stagnant due to several factors, which are i) the nature of the oilseeds themselves (indeterminate growth habit, lodging, shattering and self-incompatibility); ii) biotic stresses that involve diseases, weeds and insect pests; iii) abiotic factors which are aggravated mainly byclimate change; and iv) weak research extension and socio-economic studies that bring insufficient popularization and lack of socio-economics information on the crops.

Post harvest loss and backward agro- processing technologies are also the challenges for the oilseeds sector. Most of oilseeds have shattering problems and farmers usually fail to harvest the crops at the appropriate time, and thus there is a huge lose of post harvest from oilseeds. The majority of the local edible oil processing industries are working under low capacity due to lack of raw materials and poor oil-crushing method. The local oil-millers do not have any incentive mechanism give the huge import of palm oil in some instanses tax-free. This situation discourages oil-millers and they are obliged to cease their business.

Market information and promotion is not widely available for oilseeds. The input market is not stable and fluctuate year to year that disturb the production plan of agro-processers or oil-millers. This is linked with the dominant role of brokers in oilseed market. They deliberately distort the prices, which lead to volatile and unpredictable price hikes. The export market is still not exploited due to lack of market information and poor linkage with potential importers.

There should be a strategy to tackle the above challenges of oilseeds sector with the involvement of different stakeholders who are actors or enablers along the value chain of oilseeds. In line with this, way forward or possible interventions for the above challenges are presented in Table 8.

Table 8.Challenges and possible interventions in oilseeds sector along the value chain

Challenges	Possible intervention
I. Research and development	
• Insufficient research efforts	Establish system that enables to focus on oilseeds
	Capacity building
• Oilseeds varieties grown under sub-optimal agronomic practice	Develop agronomic recommendations based on agro-ecology
• Limited research on quality improvement	Develop target for quality improvement.
• Weak research extension linkage	Strengthen research extension for technology demonstration and popularization.
• Neglected by agricultural research community	Supporting the research through PPP approach
II. **Input supply and distribution**	
• Lack of proper estimation of improved seed demand	Leverage the existing farmers extension system for proper seed demand estimation
• Poor attention from the formal seed system	Enhance the capacity of ESE/RSE
	Introduce community based seed system
• Poor capacity of FCUs to supply inputs	Build the financial capacity of FCU
• Limited access to input credit for farmers	Establish & strengthen RuSACOS& microfinance
III. **On-farm production**	
• Weak extension service	Provide sustainable extension service through training and demonstration
• Oilseeds grown under poor crop management practices	Training on oilseeds
• Occurrence of pests (disease, insect and weed)	Introduce integrated pest management
	link producers /FCUs to agro-chemical supplier
• Climate change	Avail technologies resilient to climate change
IV. **Post-harvest technology**	
• Lack of awareness on post-harvest loss (eg. sesame and noug)	Awareness creation on post-harvest loss
• Lack of infrastructure (storage and road)	Make available & develop appropriate infrastructure
• Limited post-harvest technology	Introduce best practices & post-harvest technology (eg . Groundnut Sheller
V. **Agro-processing**	
• Inadequate supply of inputs	Growing oilseeds in cluster and specialization approach
• Lack of incentive for agro-industries ,especially local oil millers	Support in system development (eg., cluster approach) and encouraging policy
• Limited technology and expertise in agro-processing	Introduction of agro-processing technologies and training
• Very low scale of value addition (eg., sesame)	Awareness creation
	Encourage those who could engage in value addition
VI. Marketing	
• Low quality and insufficient volume	Enhance the quality of oilseeds along with understanding the market demand
	Scale up oilseeds in other potential areas
• Under developed traceability and organic certification	Introduce traceability mechanism and organic certification
• Weak market information and promotion system	Access to market information using different technologies
	Strengthen market promotion
• Limited access to infrastructure and logistic facilities	**Make available and develop appropriate infrastructure and logistic facilities.**

Note :PPP=public private partnership, ESE=Ethiopian Seed Enterprise, RSE=Regional Seed Enterprises, FCU= Farmer Cooperative Union, RuSACos = Rural Saving and Credit organizations

Opportunities and prospects

In Ethiopia, there are different agro-climatic zones and a range of altitudes from below sea level up to more than 4000 meters above sea level. This enables the country to grow a wide range of oilseeds, in which it has a long tradition (Wijnands et. al., 2007). Ethiopia has an attractive portfolio of oilseeds with great diversity especially for noug, Ethiopian mustard and linseed. The existence of large area of uncultivated and fertile land offers good opportunities for organic and sustainable oilseeds production. The domestic demand of vegetable oil and fats has also been rising rapidly at an increasing rate due to increase in per capita income and standard of living. Oilseeds namely safflower, linseed and Ethiopian mustard can be used for export because of their specialty for petal color, high omega-3 and high erucic acid, respectively. Increasing interest in and attention to the oilseeds value chain by the Ethiopian government offers another opportunity for the sub-sector to grow. Such attention is due to the sector's contribution to the growing export earnings, source of food and energy and ingredients of animal feed and there is also an interest to promote import substitutions for oilseeds. Taking into consideration the above opportunities, the following recommendations are suggested with respect to research, development and policy perspectives for the improvement of the sector:

Research: Oilseeds research is not a matter of priority- but mandatory for its role in food security, raw material for agro-industries, income generation and export earning, which implies the need for due emphasis to the oilseeds research sector. The research should be strengthened through utilization of modern tools of plant breeding. In addition to generating high yielding and quality varieties, development of effective agronomic practices and understanding of the integration of oilseeds with other crops is very important.

Development: There should be strong linkage between research and extension to enhace access to technologies to users and this could be achieved through the establishment of sustainable Public Private Partnership (PPP) for oilseeds. Such partnership enables to link public research and extension institutions/organizations with private companies. Promotion of oilseed cultivation in new potential areas is very important for the availability of oilseeds for agro-industries and export. Though Ethiopia exports oilseeds especially sesame, still the country does not exploit the entire potential. Sesame export should be strengthened not only in raw form but also through value addition. The country could also benefit from the export of linseed, Ethiopian mustard and safflower through assessing the potential importers.

Policy: Most local oil-millers are discouraged for oilseeds production due to shortage of raw materials and lack of incentive as compared to those involved in import of palm oil. The need of incentive scheme to those who are involved in oilseeds cultivation. This may include land provision, tax, and fertilizer subsidy. One of the challenges of oilseeds market is maintaining quality linked with weak quality control system for edible oil in the country. Due attention should be given for quality control system for both oilseeds and edible oil.

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Review of Coffee and Tea Research Achievements and Prospects in Ethiopia

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Introduction

Unlike coffee producing countries in Latin America and Asia, the coffee sector is constrained by the prevailing ineffective and inefficient policy frameworks in promoting coffee production, processing and marketing systems in several African coutries (ICO, 2014). Ethiopia is a leading *arabica* coffee producer in Africa and ranks fifth in the world. On the other hand, because of its high local consumption, it ranks tenth coffee exporter with 4.79 percent share of the world total. Coffee plays a very important role in the national economy. About 4.7 million smallholders are directly involved in producing coffee and 20-25 million people directly or indirectly depend for their livelihoods on the coffee sector (CSA 2015).

Ethiopia is endowed with enormous genetic diversities and unique natural coffee forest environments. However, the country has not fully exploited these valuable resources due to several factors, including inadequate access to finance and poor input distribution mechanisms for small-scale coffee farmers, predominant use of traditional varieties (local landraces) and management practices, poor harvesting and post-processing techniques, and lack of quality differentiated marketing system. The current climate change has also been noted to affect field performance of coffee plants in some areas in the country.

Ethiopia has set a goal to become the second leading *arabica* coffee producer and exporter in the world. To this end, national coffee development strategic plan has been developed by aliening with the ambitious GTP-II (2015-2020) targets for coffee production and export earnings. This requires, *inter alia*, strong national coffee institution, awareness creation to all stakeholders and capacity development of the key actors in the coffee value-chains. This may require supporting farmers' organizations, cooperatives, and unions to exercise their full power in creating ideal environments and supporting the farmers in building their capacity. Furthermore, it is of paramount importance to exert concerted efforts to disseminate improved coffee technologies and best practices through designing different research and development options targeting all groups (small, medium- and large-scale producers). This may promote active participation of each primary producer to boost their coffee productivity and production.

Ethiopia is endowed with high genetic diversity and favourable ecological conditions that warrant sustainable production and supply of the finest quality coffee types. The major coffee areas are concentrated in the southwestern, southern, western, eastern and southeastern parts of the country. Limmu, Gimbi, Yirgacheffe, Harar are the most recognized brands that fetch relatively premium prices in the international market. Coffee is produced under different production systems, including forest, semi-forest, garden, medium/large-scale plantations and semi-garden/forest plantations. Accordingly, more than 90% of the total volume of coffee production comes from small-scale farms, whose average land size is less than one hectare with low average yields of 200-250 kg /ha (Workafes and Kassu 2000). The fact that these small-scale farmers are resource poor and cannot afford to buy inorganic fertilizer and chemicals, the Ethiopian coffee is commonly considered *de facto* organic even though the farmers did not benefit from such quality product.

Since its inception, Jimma Research Center (JRC) has played crucial roles for the outstanding past research achievements and development of the coffee sector in the country. The use of geographical indicators and empowering of small-scale farmers should be given due attentions to ensure high quality, traceability and consistency. Likewise, developing new brands, promoting the production of quality forest products and provision of consistent services are very important for sustainable management and conservation of forest ecosystems.

The country's coffee production has shown consistent increase from year to year with an average of 6,737,000 bags per annum and 4.79% share of world total for the period between 2010 and 2014 (ICO 2014). The total productive coffee area is estimated at 561,761.82 hectares with annual average production of 419,980 tons and productivity of 748 kg/ha (CSA 2015). The annual coffee production has shown an increasing trend over the last ten-years (2005 – 2014) and the national coffee volume has increased from 348,981 to 439,836 tons (3.8%). At regional level, the increasing trend of annual coffee production was also very vivid specially in Oromia (4.6%), SNNP (1.5%) and Gambella plus others (14.9%), indicating the attentions given to both the traditional and emerging coffee growing areas in the country. The achieved GTP-I results showed an increased coffee production (13%) due to increasing land area (14%) and productivity (2%) (**Figure1**).

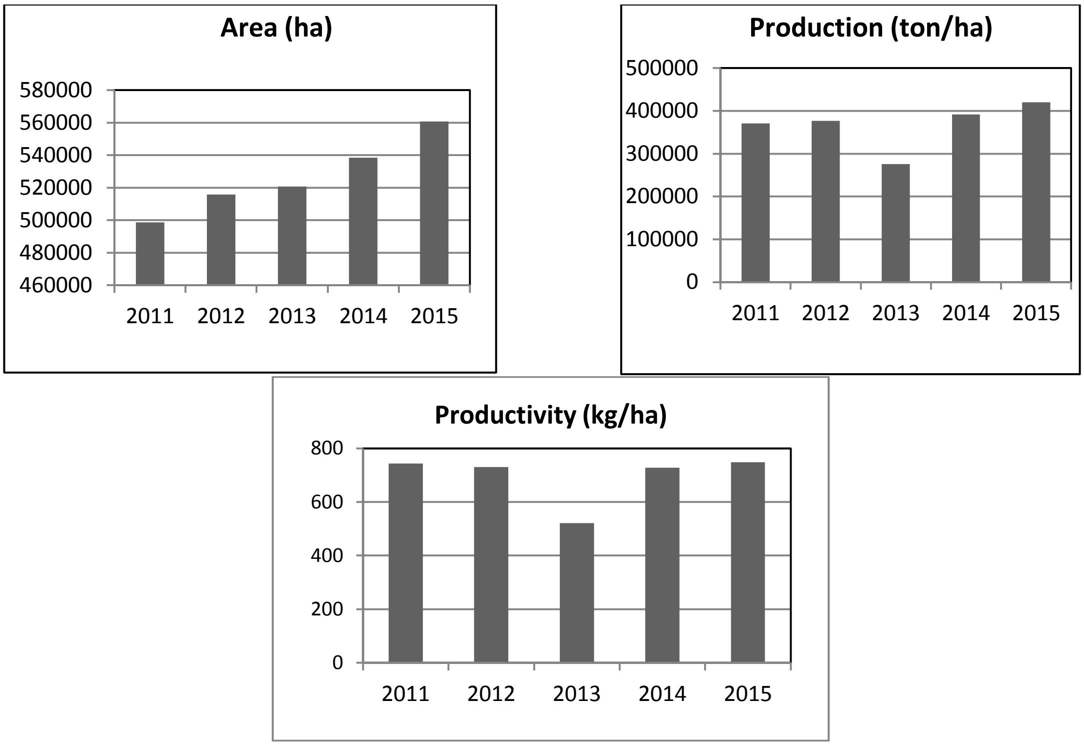

Fig. 1: Trends of cultivated coffee area, annual production and productivity in Ethiopia

Coffee is still a leading export commodity and source of foreign exchange, though the share of coffee export for the same period revealed declining patterns due to fluctuating world coffee prices and trade diversifications (agricultural, industrial and mining products). To maximize the revenue from coffee, significant improvement has been made to increase the proportion of washed coffee export. Currently, the share of traded coffees for washed and natural sundried is 41% and 59%, respectively. The average annual growth rate to central market was 3.53% for washed and 1.12% for sundried coffees (CSA 2015). About half of the total volume of coffee produced is exported, while 40-45 percent is estimated to be consumed locally with per capita consumption of 1.33 kg. The data for coffee production and consumption showed increasing trends over years, though export can be affected by the world coffee prices. Since the recent past, domestic consumption has sharply increased, largely due to population pressure, the booming outdoor coffee services and change in the life style. Consequently, there is an increasing trend in the domestic coffee consumption (**Figure 2**). This can ensure the sustainability and profitability of local market and calls for the need to strategize the improvement of coffee production and productivity in the country.

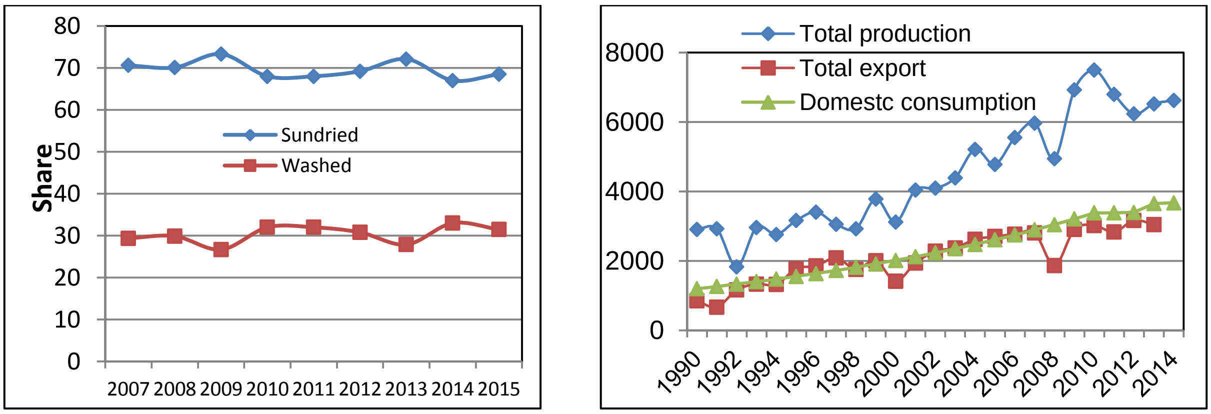

Fig. 2: Percent share of coffee arrival at the central market (left), total production and domestic consumption trends of Ethiopian coffee (thousand 60 bags)

In Ethiopia, tea is also an important commodity for domestic and export markets. It has ample opportunities for development in meeting the global competitiveness. These include, among others, the favorable agro-ecological zones offering excellent opportunities for the production of best quality tea types, the existence of vast areas of suitable land for expansion, and the favorable government policy of the country that encourages agricultural investment in export commodities. Despite these, the production and productivity of tea remained very low as compared to other producing countries like Kenya (Melaku 2008). There are very few tea genetic materials in the country from the introductions made in the past (less than 15 tea clones of Assam type). Tea productivity is low hardly exceeding 33.3 Qt/ha at Wush Wush and 33.9 Qt/ha at Gummero. This is in contrast to Sirilanka, where tea productivity is as high as 60 Qt/ha, witnessing the need for strong support to generate and promote appropriate technologies in the country. This is attributed mainly to technology limitation and direct adoption of all production packages from abroad, as tea research in Ethiopia is at its infant stage. Nearly all the tea processing is in black form, except some attempts made to produce green tea in recent times. Therefore, there is a need for launching an extensive research and development program in the country in order to exploit the available potential.

Histrory of coffee and tea research in ethiopia

Establishment of Coffee Research

In Ethiopia, coffee research first started at the Jimma Agricultural and Technical School in the 1950th through the assistance of the Food and Agricultural Organization (FAO) of the United Nations that provided a technical expert from 1952 to 1958. However, the real coffee research program was initiated only after the Institute of Agricultural Research (IAR) established a research station at Jimma late in 1967 (Van Der Graaff 1981). The Jimma Research station began its operation in 1968, but most of the land for establishment of sub-stations was acquired in 1970. In those early years, efforts were made to introduce coffee varieties from other countries, and these were tested for their adaptation at the Jimma Agricultural and Mechanical Arts School and later at the then called Jimma Research Station. Coffee accessions/varieties were introduced from India, Latin America, Africa, some other countries. However, none of the varieties showed better performance compared to the local collections as tested under different agro-ecologies. Only few of them exhibited desirable character for certain traits.

The establishment and development of coffee research in Ethiopia has been reviewed by Paulos (2008). He pointed out that much more attention and strong support should be given to coffee research and that it should be made demand-driven and market-oriented. The systematic location of each of the established coffee research substation in 1970 was mainly targeted to represent the major coffee growing areas in the country (**Table 1**). These were also augmented by various on-farm coffee adaptive research and demonstration sites established around each coffee research center. Coffee research was originally aimed at the improvement of existing forest coffee and selection of new coffee types. Specifically, the research activities consisted of studies to define optimum management for both forest and plantation coffee, weed control, shade tree identification and observations,processing studies to improve the rather poor quality of Ethiopian coffees and a limitted amount of entomological and pathological studies (Van Der Graaff 1981). After the identification of CBD in 1971 and its subsequent spread to all coffee areas, the emphasis gradually shifted to the control of the disease. In particular, the development of resistsnt cultivars gained first priorityrelative to cultural and chemical control methods.

Table 1: Coffee research centers in the major coffee growing areas of Ethiopia

Center	Establishment year (GC)	Total land holding (ha)	Elevation (m.a.s.l)	Mandate Areas
Jimma***	1967	183	1753	Jimma/Limu
Gera**	1974	280	1900	Jimma/Gera highland
Agaro*	1973	15	1630	Limu/Jimma
Metu*	1974	32	1550	Illu Ababora
Haru**	1998	76	1750	West Wellega
Mugi*	1973	27	1553	Kelem Wollega
Tepi**	1976	100	1200	Tepi/Bebeka
Mechara**	1986	50	1800	West Hararghe
Awada**	1994	31	1740	Sidama
Wenago*	1974	10	1850	Yirgacheffe

***, **, * *Indicates Main Center, Sub-Center, and Station, respectively.*

The Jimma national coffee research coordinating center has a vision to be a leading center of excellence for *arabica* coffee research and training in the world. Since its inception in late 1967, several research activities have been carried out at the Jimma Research main Center (JRC) and its sub-centers and stations to generate and promote improved technologies, scientific information and knowledge on coffee in the country. The major areas of research include coffee genetics and breeding, coffee agronomy and physiology, Protection (pathology, entomology and weed science), soils and water management, coffee processing/quality, socio-economics, and extension. Accordingly, a good number of coffee resereach recommendations, including high yielding, disease resistant and top quality coffee varieties, improved management and post-harvesting technologies have been generated and transfered to various end-users and beneficiaries in the country (Taye, 2013). However, the impact for increasing coffee productivity and enhancing high quality standards remain too low due to multiple constarints and challenegs. Among others, limited research capacity, lack of efficient technology transfer system and weak linkages among stakeholders along coffee value-chain actors were indicated as crucial bottlenecks that need due attentions (Girma *et al*. 2008) and these constraints remain the same today.

Establishment of Tea Research

In Ethiopia, although the commercial production of tea has the history of more than five decades, tea research in Ethiopia started in 1997/98 at Jimma Agricultural Research Center (JARC). The research program was nationally coordinated by JARC until 2011 and since then the national research coordination moved to the Jimma University College of Agriculture and Veterinary Medicine (JUCAVM)

Major research achievements

Coffee Research

Genetic Resources

Despite the persistent problems threatening the maintenance of the Ethiopian coffee genetic resources, there are still different *arabica* coffee cultivars and local landraces possessing variations for desirable agronomic traits. There are a number of local landrace coffee types that are known by different vernacular names and growth characteristics in different geographical areas, localities or origin in the country designated by the respective local communities. Based on their branching habit, the Ethiopian coffee materials can also be broadly categorized into three canopy classes, including open, intermediate and compact types (Yacob *et al*., 1996). They could also be of the bourbon or typica types, which are quite different in their shoot and root growth systems, as well as their adaptations to specific localities and/or respective management inputs. The local coffee types vary in their frequency of occurrence along rainfall gradients and soil profile depths, indicating their long-term adaptations to specific environments. Taye (2015) reported a total of 11691 *arabica* coffee germplasm accessions that have been collected from the different parts of the country and *ex situ* maintained at field genebanks of the Jimma Research Center and its sub-centers (5960 accessions or 51%) and conservation genebanks of the Ethiopian Biodiversity Institute (5731 accessions, 49%). Recent inventory report (JARC 2015a), indicated a total of 6923 original collections and 5853 live (85%) accessions are being conserved at different coffee research field gene banks (**Table 2**) for research purpose, though it requires high costs for establishment and long-term farm management operations.

Table 2. Status of coffee germplasm collections at research field genebanks

Program/Type	Year (GC)	Original collection	Present number	% conserved
National collection	1966-1990	1633	1431	88
Exotic collection	1968-1984	190	78	41
CBD selection	1973-1987	868	825	95
Local landrace	1994-2015	4232	3519	83
Total		**6923**	**5853**	**85**

Development of coffee trees under forest ecosystems is impaired due to high biotic and abiotic stresses, including diseases, insect pests, low sunlight interception and high humidity (Arega *et al*. 2008). These problems are particularly witnessed in the forest, semi-forest and homestead and/or garden coffee systems, indicating the need for incentives like premium prices through sound certification program to maintain the available genetic diversities thriving under these production systems. Arabica coffee germplasm accessions are seriously affected by the major coffee diseases, including coffee berry disease (CBD), coffee wilt disease (CWD) and coffee leaf rust which are seriously threatening coffee production and maintenance of genetic resource in the country. Hence, on-farm participatory promotion of local coffee landraces and development of disease resistance coffee varieties are among top priority areas to alleviate these problems.

The wide yield gaps across coffee production systems demonstrate the intensity of management levels to boost productivity. The forest and garden systems would provide unique opportunity to meet the sustainable development goals, including environment friendly, biodiversity conservation, food security, and ecosystem services. Nonetheless, conservation and management of the wild coffee populations and farmers local types require urgent collaborative actions at global, national, regional and local levels (Bellachew and Sacko 2009; Taye 2015). The proclamation on access to and benefit sharing of genetic resources and indigenous knowledge need to be reinforced and effectively implemented. There seems to be a reluctance and lack of concern from most public and private institutions in protecting and safeguarding Ethiopia's coffee genetic resources (Girma*et al*. 2008). Policy framework and regulations on farmers' and researchers' property rights should be urgently put in place and implemented. There is also a need to strengthen coordination among the stakeholders in the coffee sector and the public as a whole in awareness creation and shared vision regarding the serious consequences of informal and illegal transfer and use of arabica coffee genetic resources that could jeopardize the nation's benefits from its unique natural coffee gene pools.

Coffee Variety Development

Coffee berry disease resistant variety development (1967-1981): The then called Jimma Research Station (JRS) commenced variety development activities in 1966/67. The first few years were the formative period, constructing offices, laboratories, greenhouses, and over all station development and establishment of infrastructure. During this period, some observation trials, which were more of agronomic, crop protection, processing studies, and adaptation trials were conducted. Basic research, was also started soon in 1968 and continued from there onward the study, on the occurrence, biology, epidemiology and control measures of coffee berry disease (CBD) which, first observed in Ethiopia in 1971, was the major component of this program. The period between 1968 and 1973 was a remarkable period where considerable national and international collections were made for variety improvement, the outbreak of CBD was observed and deeply studied, and research and extension linkage was established for a concerted effort. Hence, during this period, a large number of CBD resistant selections and collections were made and evaluated. This was the period where all professionals (research staff), support staff, National Coffee Board and expatriates worked together day and night through FAO and the EEC technical and financial support. During this period 18 CBD resistant selections were released and most of these are still under production (**Table 3**). Five of them were withdrawn after few years of release owing to various drawbacks the selections exhibited under field condition.

Table 3: Coffee varieties released between 1977/78 and 1980/81 with target production areas

Variety	Year of release	Clean coffee yield (Q/ha)		Altitude (masl)	Quality status	Suitable areas
		On-station	On- farm			
741	1977/78	12.2	6-7	1550-2100	Acceptable	Jimma, Gera, Agaro
744	1979/80	16.6	8-9	1550-2100	Acceptable	Jimma, Gera, Metu, Wonago
7440	1979/80	16.2	8-9	1000-2100	Acceptable	Gera, Jimma, Tepi
7454	1980/81	18.3	8-9	1000-2100	Acceptable	Gera, Tepi
7487	1980/81	23.8	9-10	1550-2100	Hardly acceptable	Gera, Wonago
74110	1978/79	19.1	9-10	1550-2100	Acceptable	Gera, Jimma, Metu
74112	1978/79	18.1	9-10	1550-2100	Good & acceptable	Gera, Jimma, Metu
74140	1978/79	19.7	9-10	1550-2100	Hardly acceptable	Gera, Jimma, Metu
74148	1979/80	18.0	6-7	1550-2100	Hardly acceptable	Gera, Jimma, Metu
74158	1978/79	19.1	9-10	1550-2100	Acceptable	Gera, Jimma, Metu
74165	1978/79	17.3	8-9	1550-2100	Acceptable	Gera, Jimma, Metu
754	1980/81	14.8	7-8	1550-2100	Acceptable	Gera, Jimma, Metu
75227	1980/81	17.9	8-9	1550-2100	Acceptable	Gera, Jimma, Metu

Hybrid Coffee Variety Development: Since the beginning of hybrid variety development program in 1978, a number of experiments on hybrid vigor studies in crosses among indigenous selections/cultivars and hybrid variety development were conducted. Based on the on-station and verification evaluation data; three hybrids; namely, Aba-buna, Melko CH_2 and Gawe were released in 1998 and in 2002. Mean yield of the hybrids ranged from 24-26 q/ha on research station and 13-20 q/ha in farmers field (Bayeta *et al*. 1998). They are suitable to the low- and mid- altitude (1000-1750 m.a.s.l) in the southwestern coffee growing areas of the country (**Table 4**). The observed heterosis and hybrid vigor revealed in the relatively higher yield advantages of coffee hybrids over their pure-line parents (18-20%) had necessitated the research work to give peculiar emphasis to the development of more coffee hybrids (Behailu *et al*. 2008a). The coffee hybrids were moderately resistant to CBD and their yield performance under farmers' condition is about 1600 kg/ha to 1800 kg/ha, their quality being commercially acceptable comparable to the local Jimma/Limmu coffee quality profile. Thus, it is imperative to expand the released technologies and develop more coffee varieties that best suit the varying agro-ecological conditions of the country.

Local Landrace Development: From years of experience and existing realities, the conventional method of breeding was noted with a number of drawbacks. Some of these were: (1) difficulty to develop adequate number of varieties for each environmental condition, in the shortest time possible, (2) low preference of the released varieties by the local farmers in different areas, (3) adulteration of the typical quality of coffees in each specific and known area by introducing improved varieties originated from other areas. Cognizant of these and other drawbacks, a new breeding strategy has been designed while preparing ten years development plan in 1991. This new selection and breeding strategy is known as **'*Local Landrace Development Program (***Bellachew and Labouisse 2006; Bellachew and Sacko 2009). According to the new program, varieties are developed for each major agro-ecology or coffee growing area independently using local landrace collections of the respective areas. The basic assumptions are that (1) local landraces have better adaptation in their areas of origin than cultivars introduced from other geographical and ecological origins, (2) farmers show more preference for local cultivars than those improved varieties introduced from other areas, (3) it is possible to maintain the typical quality of each locality,(4) it is market oriented in a sense that consumers preference for single-origin specialty coffee is becoming more pronounced than bulk coffee and (5) it enables to effectively utilize the available high genetic diversity in each locality or agro-ecology. Below are some of the specialty coffee areas included under this new approach:

Sidama/Yirgacheffe Coffee: Variety development program for Sidama/Yirgacheffe coffee growing areas started in 1997 with the establishment of Awada Coffee Sub-center in Sidama zone of Southern region. Series of screening and variety trials were conducted using germplasm collections from Sidamo/Yirgacheffee surroundings that were previously collected and maintained at Melko and those collected and maintained at Awada since 1994. A total of about 590 coffee accessions were evaluated at Awada and its sub center Wenago and other testing sites since 1997. Among the varieties tested in variety trial, one variety known as Angefa (1377) was first released in 2006. The variety is high yielder, moderately resistant to CBD and posses the typical Sidama/Yirgacheffee cup test. In addition to the released variety, after promoting 12 Sidama/Yirga Cheffee origin coffee selections at Konga (Gedio Zone) and Korke (Sidama Zone) and tested for yield, disease resistance and quality attributes over years in series of trials, three more pure line varieties were released (Table 4).

Wellega/GhimbiCoffee: This is one of the known quality coffee types in the international market that fetches premium price. In order to promote its production and productivity and thereby benefit the farmers and the nation, a new coffee research center known as Haru Sub Center was established in Haru district, west Wellega, in 1997 through the financial assistance of the European Union. The primary task of this center was to develop improved varieties from the local land races and release to the area in the shortest time possible. In effect, a collection program was started in 1998. About 559 Wellega coffee types were collected from the surrounding areas. The collections were evaluated for yield, growth performance, CBD and other diseases and insect pests over 3-years and promoted 14 promising selections to variety verification trial and field planted at three sites; namely, Iretcha and Dutchi (Haru sites) and Mugi Center. Based on yield, disease resistance and quality performance, 4 selections (Haru-1, Challa, Sende and Manasibu) were released to Wollega areas in 2010 (Table 4).

Harrarghe Coffee: Following the establishment of Mechara coffee research sub-center in Harrarghe in 1986, a large number of Harrarghe coffee collections were collected and planted in the center. However, the collections were all destroyed during the civil unrest in the country in1990. A new collection program was started in 1998 and about 1914 accessions were collected and planted at Melko, Jimma Research Center. Detailed evaluation was made on 226 promising collections selected from 1013 accessions collected in 1998. Using a modified crash program, 13 promising Harrarghe accessions were prompted to variety verification. The genotypes were field planted in 2004 at two trial sites, Mechara and Micheta, in Harrarghe. Based on stringent evaluation for yield, CBD and CLR resistance under field and laboratory conditions, and other desirable growth/agronomic characters, four Harar coffee varieties *viz.*, Harusa, Mocha, Mechara-1 and Bultum (**Table 4**) were released in 2010. The varieties are currently under commercial production in different parts of Harrarghe.

Limu/Jimma Coffee: Variety development program for Limu specialty coffee area started in 2001. The aim was to boost the production and productivity of Limu coffees in order to meet the increasing international demand as it is already popular in the international market. A total of 203 coffee accessions were collected from Limu coffee growing areas and planted at Gera and Agaro in four different sets and evaluated for various desirable agronomic traits. Eleven promising selections were identified and advanced to co-ordinate variety and verification trials. Evaluation of these selections for yield performance, resistance to diseases and insects and quality attributes is under way and at least 3 - 4 varieties are expected for release in 2017.

Moreover, in addition to what has been released so far, several promising coffee genotypes have been identified and these materials are currently in pipe line (under verification) for additional release to the known specific localities of Hararghe, Sidama, Yirgacheffe, Limmu, Illuababora, Kafa and Tepi areas, among others. In effect, a total of 86 promising selections (23 hybrids and 63 pure lines) were planted for coordinated variety trial at the respective production areas in the country. Among these, three coffee hybrids have been presented to the national crop variety release committee and accepted for official release.

Table 4: Coffee varieties released between 1997 and 2010 and their recommendation areas

Variety	Year of release	Elevation (masl)	Clean coffee yield (Qt /ha)		Quality status/Overall quality (typicity/standard)	Suitable areas
			On-station	On-farm		
Dessu	1997	1000-1750	18.2	13-15	Good & acceptable	Jimma, Metu, Goma, Tepi
Catimor J-19	1997	1000-1400	16.6	9-12	Hardly acceptable	Bebeka, Tepi
Catimor J-21	1997	1000-1400	19.4	13-15	Hardly acceptable	Bebeka, Tepi
Me'oftu	2002	1550-1750	21.4	14-20	Acceptable	Jimma, Metu
Geisha	2002	1000-1400	23.4	10-12	Hardly acceptable	Bebeka, Tepi
Merdacheriko	2006	1750-2100	15.4	17.1	Acceptance	Gera, Kota, Sedi
Buno Washi	2006	1750-2100	23.5	15.6	Acceptable	Gera, Kota, Sedi
Yachi	2006	1750-2100	19	15.2	Acceptable	Gera, Kota, Sedi
Wushwush	2006	1750-2100	16.4	16.2	Acceptable	Gera, Kota, Sedi
Angefa	2006	1550-1750	20.4	16.2	Good & acceptable	Sidama and Gedeo
Ababuna	1997	1000-1750	23.8	15-16	Average	Jimma,Metu, Tepi
Melko-CH2	1997	1000-1750	24.0	13-15	Acceptance	Jimma, Metu, Tepi
Gawe	2002	1550-1750	26.1	24	Acceptance	Jimma, Metu, Tepi
Haru-1	2010	15500-1950	15.7	9.0	Spicy (66%)*	West, Kellem and East Wellega
Challa	2010	1550-1950	15.6	8.4	Fruity (61%)	West, Kellem and East Wellega
Sende	2010	1200-1550	16.1	9.2	Fruity (67%)	West, Kellem and East Wellega
Manasibu	2010	1200-1550	16.4	9.6	Fruity (66%)	West, Kellem and East Wellega
Harusa	2010	1550-1750	16.0	8.7	Mocha (70%)	West Hararghe
Mechara-1	2010	1650-1850	11.9	8.2	Mocha (76%)	West Hararghe
Bultum	2010	1650-1850	17.0	9.3	Mocha (74%)	West Hararghe
Mocha	2010	1550-1750	13.5	7.2	Mocha (82%)	West Hararghe
Fayate	2010	1750-1950	19.5	9.6	Spicy/flora (71%)	Sidama and Gedeo
Odicha	2010	1500-1750	20.2	10.2	Spicy/floral (70%)	Sidama and Gedeo
Koti	2010	1750-1950	21.1	9.9	Spicy/floral (69.5%)	Sidama and Gedeo

**Percentage figures in parenthesis represent the overall quality standard for the respective released coffee varieties*

Coffee Management and Cropping Systems

The coffee growing agro-ecologies in Ethiopia are highly variable in terms of climate, soil type, and elevation that ranges from 550-2,400 masl. The ideal coffee soil is characterized by a brown red color of clay origin, having an average depth of one meter or more. Well distribted rainfall with an annual average of 1400 mm or above and aveage mimimum and maximum air temperatures of 10 and 24^0C, respectively, are required for successful arabica coffee cultivation in Ethiopia (Paulos, 1994; Bayeta *et al*., 1998).

Coffee production and productivity can be improved by using improved agronomic and best management practices. Existing coffee stands suffer from poor returns, primarily due to old age of the coffee trees, poor management and processing practices. Both the coffee plants and its natural shade trees are often found being old and irregularly spaced, suggesting the need for rejuvenation and adjustments of the plant population using recommended techniques (Anteneh *et al*. 2008). However, while undertaking such practices, it is essential to take the utmost care not to spread the coffee wilt disease, which had recently become the most devastating coffee disease in the major coffee production systems of the country.

Besides coffee varieties, the use of improved or best agronomic practices has been found to increase the rate of stand establishment, coffee yield and quality performances and even tolerance to some diseases and insect pests as demonstrated under both on-station and on-farm trials. For example, the specialty coffee varieties multiplication and distribution initiative by JARC has shown an encouraging yield and quality improvement in the major coffee growing areas of the country. The result clearly indicated the need to develop strategies to scale-up all the available coffee research findings/technologies to increase coffee production, productivity and quality in each agro-ecological zones of the country. The available technologies may include suitable coffee varieties, nursery management, plant density, pruning and training, rejuvenation methods, water harvesting and conservation, soil fertility management, application of plant nutrients and control of coffee pests, harvesting and processing methods, among others (Alemseged *et al.*, 2015). The pre-scaling up of coffee nursery and field management practices carried out around coffee research centers in Jimma, Illubabor, West Wellega and Kelem Welega zones on a total of 120 farmers (JARC, 2015a) clearly showed the significant improvement that can be achieved using these package technologies and the high demand by coffee farmers for these improved technologies at all the intervention areas.

Since the recent past, climate change has become a new challenge to coffee production that requires special attention. There is unbalanced vegetative and reproductive growth, continuous flowering, reduced flower setting and several other anomalies due to change in climate. Davis *et al.* (2012) has established a fundamental baseline for assessing the consequences of climate change on wild coffee populations of *arabica* coffee that may be applied on cultivated coffee as well. The study underlines the possible irreversible losses of the indigenous *arabica* coffee gene pools from their original places due to severe stress from climate change. This indicates the need for strong actions to support climate-smart mitigation and adaptation options, while increasing coffee production and productivity in the country. On the other hand, complementary *in-situ* and *ex-situ* conservation and management approach is needed to mitigate the effect of climate change and preserve coffee genetic diversity for future breeding works (Bayetta *et al*., 2008).

Coffee Technology Promotion

The important role of research-extension linkage in enhancing productivity and quality is highly considerable. Negusie *et al*. (2008) have indicated the attempts made by the JARC in this regard to foster links between research and coffee stakeholders (coffee platforms) to facilitate dissemination of improved coffee varieties, pre- and post-harvest management practices. Admassu *et al*. (2008) have also elabortaed the major factors affecting the adoption of research technologies, taking adoption of CBD resistant selections in the country as a case study.

In coffee, various technology transfer mechanisms were employed to promote wider use of improved technologies across the country. These include pre-scaling of improved technologies, supplying improved seeds and seedlings, training and advisory services, field-days, farmers' research group, partners' council forums, distribution of various types of publications, use of communication media, etc. There is a great need in capacitating small-scale farmers, cooperatives and unions, private investors and others involved in the value-chains through training services and knowledge sharing events. In this regard, it is of paramount importance to build the capacity the main training centers such as JRC and Gomma-II to provide efficient training services to farmers, experts, private investors and other stakeholders on skill upgrading and all other required areas including certification, pest control, maintenance of traeability etc.

Improved coffee seeds and seedlings: There is an acute shortage of seed agents and this has considerably hampered the scaling-up of the released coffee varieties in the country. Neither private nor public enterprises are engaged in producing and trading certified coffee seeds and seedlings. The results of a simple supply and demand assessment indicate that the demand for improved coffee seeds significantly surpasses the supply from coffee research centers and the gap is increasing over years (**Figure3**). Despite the increasing mismatch between demand and supply, an integrated informal and formal coffee seed system is lacking at regional and national levels (Taye *et al*., 2012). This calls for immediate action to establish and support sustainable coffee seed system in the country. There is still lack of apropriate technologies in both traditional and non-traditional coffee producing areas..

Jimma Agricultural Research Centre (JARC) is the only public institution that had taken the national responsibility of multiplying and supplying basic coffee seeds. So far a total of 243,600 kg of seeds and ten million seedlings have been multiplied and distributed from the released adaptable local varieties (JARC 2015b). Hence, JARC has made considerable contribution to adoption of improved coffee technologiesin the country. Taye *et al.* (2012) also indicated the existing experience and capacity of other private and public sectors in this regard.

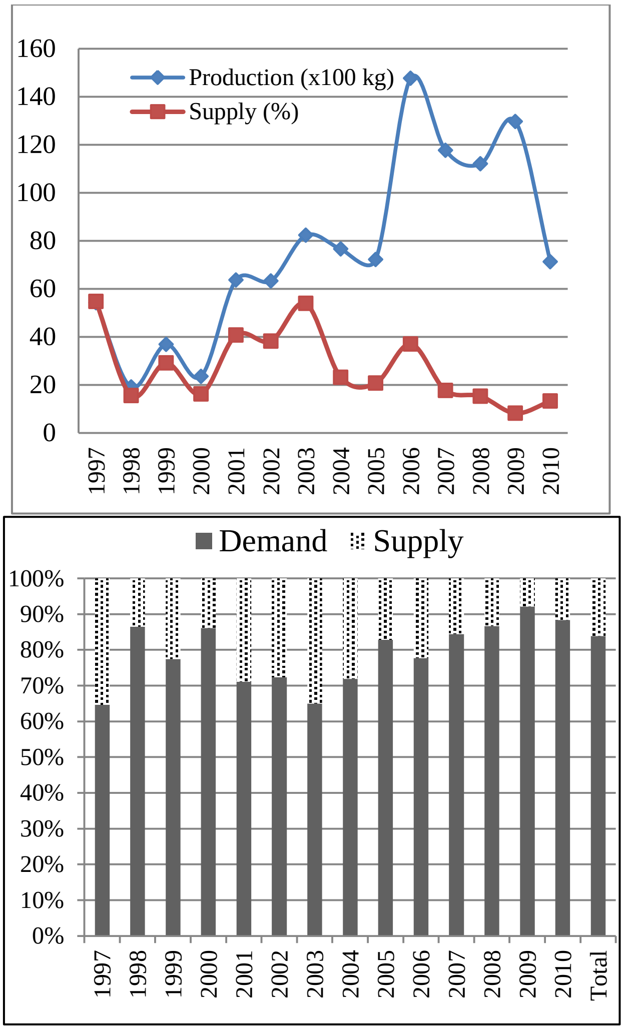

Fig.3: Trends of improved coffee seeds produced and supplied by JARC (1997-2010)

Cognizant of the demand for single-origin specialty coffees in the global markets, JARC had initiated a local landrace development program through which 11 varieties were developed for four specialty coffee areas in the shortest time possible. Altogether, a total of 3.6 million coffee seedlings were produced from these varieties and distributed to growers in the four specialty coffee growing localities; *viz*., Limmu, Sidama/Yirgacheffe, Wellega and Harraghe. This is estimated to cover about 1,422 ha of land and these farms may serve as seed sources if properly maintained and regularly monitored by JARC staff for its purity (Taye *et al.* 2012). Moreover, a total of 22 seed orchards and 18 farmers' research-extension groups were established as future coffee seed sources (**Figure 4**), awaiting for urgent action to be accredited as legal and accountable coffee seed sources for each locality.

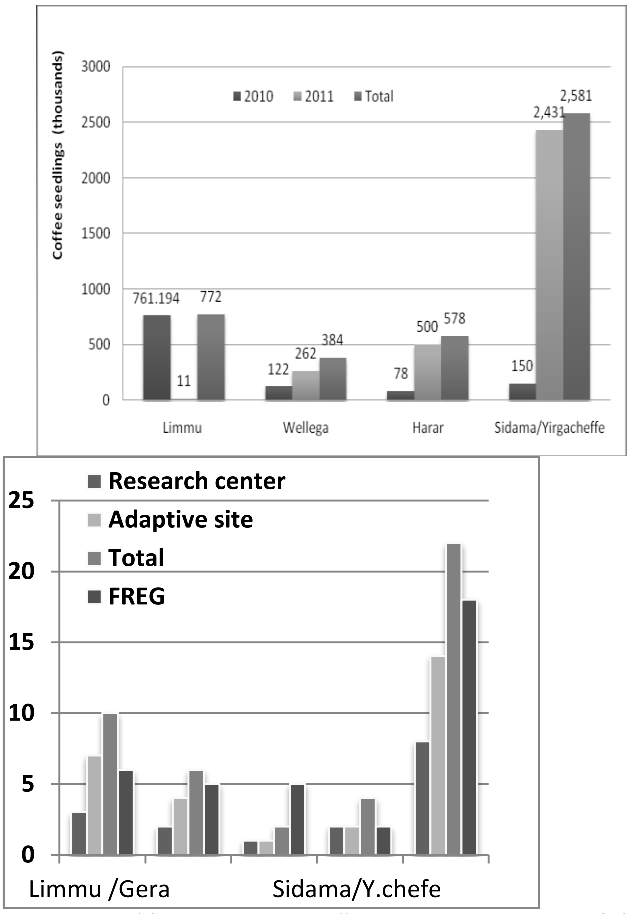

Figure 4: Seedlings of coffee varieties distributed (a) and established coffee seed orchards and FREG (b) in the four major coffee growing areas

Apart from the pure line varieties, there are three high yielding and disease resistant hybrid varieties that were released before a decade. Despite their significant yield advantages, these hybrid coffee varieties were not effectively distributed due to difficulties in multiplying true-to-type seedlings. Through hand pollination and rooting of cutting, about 50,180 hybrid coffee seedlings were distributed to 64 growers in the target areas of Jimma and Kafa zones largely for clonal garden establishment.. Wondyifraw *et al.* (2008) reviewed the historical background of large-scale clonal propagation of coffee through tissue culture and the progress of protocol optimization efforts at JARC for *in vitro* propagation of coffee hybrids. The preliminary results of embryo proliferation, plantlet development and *ex-vitro* acclimatization and hardening-off activities were encouraging to warrant subsequent commercialization of the technology. About 153,600 and 1200 seedlings were produced from coffee hybrids using cuttings and tissue culture techniques, respectively. These seedlings were field transplanted at JARC and on-farm sites in Jimma zone and are currently under good conditions in the field. The use of hybrid coffee technologies through micro-(tissue culture) and macro- (cutting) vegetative propagation techniques need strong support and coordinated actions to scale-up the dissemination of the technology.

Coffee research publication: In the past 50-yeras, several technical coffee publications have been produced and distributed to promote technology transfer and exprience sharing in the country and elsewhere. Eventhough it is difficult to access and analyse all the published and distributed information sources,attempts have been made to present some coffee publications presented at various forums. It is apparent that attention should be given to establish and support proper filing and data-base management to improve accessability and distributions of technical and scientific coffee information including those papers pblished in proceedings, journal articles, handbooks, leaflets, newsletters, reports and others. The newly established ***Ethiopian Coffee Science Society*** is a good opportunity to serve as main source of information on coffee science in Ethiopia**.** Besides, in the past,four national coffee conferences and workshops were organized and these could be other sources of information eventhough proceedings were not produced for two of the events. Reflections from the annual coffee-day being celebrated at regional and federal levels annually have become the best platforms for the deliberation of practical coffee issues which needs to be properly docummented as an important source of information.

In conclusion, the past outstanding achievements of coffee research have made significant contributions to coffee germplasm collection and conservation, CBD resistant varieties development, supply of improved coffee seeds, promotion of hybrid coffee technologies through the initiative of research for development in 1998, local landrace variety development and establishment of coffee seed orchards and producer groups, pre-scaling-up of improved agro-practices, among others. The present development of the national coffee industry is the direct contribution of technologies generated from coffee research. To this end, JARC has received a number of awards including the first International Gold Mercury Medal (1986), award of the Federal Science and Technology (2012) and several other recognitions.

Tea Research

In Ethiopia, tea research was started seven-years back at JARC and promissing findings have been recorded in the areas of performance evaluation of tea clones under diverse environments, propagation techniques, weed control, plant nutrient and post-harvest management practices.

Constraints and challenges

Coffee Genetic Resource and Research

- **Land degradation and genetic erosion:** Due to expansion of unplanned land uses (e.g., tea and coffee), shift of cropping system (e.g. coffee to chat), less awareness about the consequences of the problem, deforestation, over exploitation of forest resources and biotic (e.g. coffee wilt disease) and abiotic stresses (e.g. global climate change), the coffee genetic resource is to day greatly endangered and at risk more than any time in the past;
- **Conservation and sustainable utilization strategies of germplasm:** There are limitations in putting in place a viable conservation and sustainable utilizations strategies (*ex-situ* and *in-situ*) and implementation due to shortage of skilled personnel in the area and lack of adequate budget. Our coffee germplasm is also currently vulnerable to looting by foreigners due to lack of coordinated system of plant genetic resources protection system.
- **Germplasm exchange and equitable benefit sharing:** There are a number of conventions issued at global level such as Convention on Biodiversity (CBD), proclamation on access and benefit sharing of genetic resources and indigenous knowledge and many others but these conventions are not effectively implemented the principle of material exchange and equitable benefit sharing. Ethiopia is the primary victim in this regard particularly with regard to *arabica* coffee genetic resources. In addition, there is serious lack of public awareness about germplasm protection and its value.
- **Policy framework for conservation and use:** Lack of strong policy framework and integrated effort for biodiversity conservation and utilization among key stakeholders at all levels (GOs, NGOs, private sectors, universities, colleges).

Coffee Research

- Limited or lack of improved technologies with regard to coffee varieties (both pure lines and hybrids), agronomic practices, soil and water management, crop protection, coffee processing and quality improvement for all the different coffee growing agro-ecological zones and specific localities of the country;
- Lack of package recommendations and complete descriptions for each of the known Ethiopian coffee brands that would enable to build trust among the clients and facilitate setting of specific market niches for premium price;
- Inadequate technology multiplication and distribution capacity, for example, multiplication of seeds and seedlings of improved coffee varieties) due to problems of budget, human power and multiplication facilities;
- Limited research focus on coffee quality improvement and breeding for unique coffee qualities for special market;
- Limited research in integrated approaches to prevent and control coffee diseases and insect pests;
- Participatory research approach and stakeholders involvement in on-farm research and technology generation is minimal and at early stage;

- Farmer’s indigenous knowledge in disease and pest management, landrace development or local variety selection, soil and water management practices and others did not get due attention and well exploited;
- Effective characterization, conservation and sustainable utilization of natural resources and diversification approach in the coffee based farming systems of the country are not well emphasized;
- Inadequate research fund, laboratory and field facilities, number of trial sites and trained human power are serious bottlenecks to strengthening national coffee research program;
- Lack of coffee database and networking to assist the national coffee research system;
- Lack of comprehensive research on value addition and by-product utilizations; and
- Weak institutional set-up to coordinate the coffee industry in general and the national coffee research program in particular.

Tea Research

In Ethiopia, although the commercial production of tea has the history of more than five-decades, tea research is at its infant stage. Tea development is also restricted to few private sectors in the southwestern parts of the country. There are several limitations in tea research development and the major ones include narrow genetic base population that limits selection and breeding program for variety development, low productivity and quality of the limited number of tea clones available in the country, limited capacity to initiate and execute sound tea research programs, weak linkage among the stakeholders in the country and inadequate support by the government and private sector (Melaku 2008).

Recommendations and resarch directions

It is of paramount importance to work towards achieving the national GTP –II targets for the coffee sector to remain competitive in global coffee market. In effect, challenges from increasing population pressure, declining natural resources and the demand for increased crop productivity demands for new research and development interventions. Generally, top priority should be given to realize the recommendations given on coffee conservation, research, extension, quality and marketing as well as linkages among stakeholders (Girma *et al*., 2008). The national coffee research center has also developed 30-years of strategic plan with the following key research issues.

- Collection and development of wide genetic base population for breeding programs against biotic and abiotic stresses and improvement of productivity;
- Assessment of impact of released coffee varieties under optimum environments in the farmers field;
- Developing mitigation and adaptation technology options to climate change and variability;
- Soil moisture conservation, watershed management and irrigation systems;
- Integrated soil fertility and plant nutrient management technologies;
- Demonstrate/validate improved agronomic practices in the traditional coffee growing areas;
- Molecular characterization and identification of coffee and tea genotypes for unique traits;
- Pre-and post-harvest management, mapping quality profile to benefit from single-origin specialty coffees;
- Value-addition and marketing studies for coffee and tea commodities;
- Sustainable conservation and use of coffee genetic resource and ecosystem services;
- Legal framework on access to and equitable benefit sharing of genetic resources and awareness creation at all levels;
- Capacity building of national coffee research (manpower, field and lab facilities, transport, finance…);
- Technology generation and dissemination to traditional and non-traditional areas;
- Design and plan for full benefit from the unique opportunities and potentials-mainstreaming
- Support shade-grown coffee landscapes as major driver for green economy development strategy;
- Promote private and model farmers in commercial coffee farms at potentail areas
- Estabilsh and support national training center to train key actors involved in the coffee sector
- Build strong linkages and networkings among relevant stakeholders at regional, national and international levels;
- Promotion of small-scale tea producers through formal linkage with private sectors in terms of capacity development and technology transfer;
- Generation and adoption of tea technologies suiting to each agroecology by launching a well designed introduction and evaluation of more germplasm from abroad;

- Creation of variability through hybridization and modern biotechnological approaches and testing for performance under different environments is of paramount importance for identification of suitable tea types for specific ecologies;
- Investigation on sustainability of tea plantations and conservation of the remaining forest areas taking into account the economic, social and environmental aspects;
- Studies on identification and management of economic diseases, insects and weeds associated with tea need to be undertaken
- Adaptation and generation of suitable technologies on tea agronomy, irrigation, plant nutrition and soil fertility management for improved production and productivity of top quality tea types;
- Adequate information on the costs of production, processing, marketing systems, value-addition and agro-processing need to be researched in the country.

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Fruit Crops Research in Ethiopia: Achievements, Current Status and Future Prospects

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Introduction

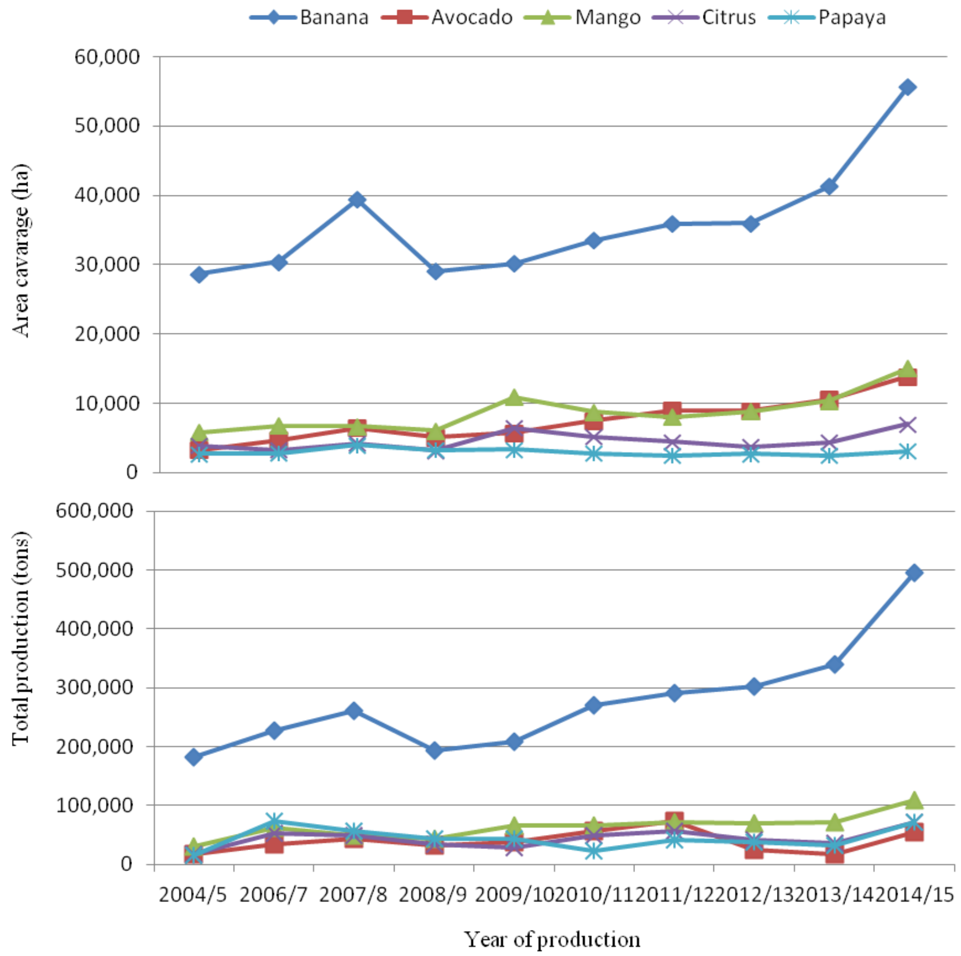
The agro-ecological conditions of Ethiopia favor the cultivation of various fruit crops that span from highland (like apple) to lowland (such as dates and cashew nut) fruits. Abundant and suitable land with different ranges of altitude, huge irrigation potentials, and ample labor-force in the different parts of the country provide opportunity to produce tropical, sub-tropical and temperate fruits (Seifu, 2003; EHDA, 2012).

Fruit crops cultivation in Ethiopia had been a routine practice from time immemorial to the present day. The introduction of grapes in the form of raisins is believed to be in the fourth century with introduction of Christianity (Asfaw and Derbew, 2013). Since then, imported raisins have been in use in the all Christian Churches as ‘sacred’. It has been also reported that various fruits varieties such as citrus, strawberry, passion fruits and mangoes were introduced in the late 1960s and the early 1970s (Godfrey-Sam-Aggery and Bereke-Tsehai, 1987a, b).

The area coverage and total production of major fruit crops during the last decade showed increasing trend in small-scale farms (Figure 1). In the 2013/2014 production year, 499,183.76 tons of fruits were produced in the country (CSA, 2014). The overall production increments were 172.87, 227.85, 262.92, 294.15 and 381.57% for banana, avocado, mango, citrus and papaya, respectively. Whereas, the percent increment in total area coverage for these fruit crops were 87.22, 321.13, 118.33, 14.30 and -11.82 , respectively. Among the major cultivated fruits, banana has been the leading fruit crop and covered about 57.84%of the total area (41,356.88 ha) followed by avocado (14.81%) and mango (14.47%). Banana was top in production increment, while avocado covered the highest total area increment. The production of apple fruit is relatively of a recent development in Ethiopia. The annual production of fruit in Chencha was about 15 metric tons during its establishment years. However, the overall annual production in the country is estimated about 50 metric tons (Timoteos, 2008).

Fruit production is highly intensive, and the fruit industry creates employment opportunities, particularly for farming communities. According to CSA, (2014), about 3.6 million peasant holders were engaged in fruit production in Ethiopia where the main producers of fruit are smallholder farmers primarily for home consumption and supply the nearby local markets. There are also medium and large commercial fruit production farms in the country, most of which are concentrated in the eastern parts of the Rift Valley (Seifu, 2003). The production of avocado has become greater source of income for those involved in the value chain (Zakarias, 2010). In addition to good source of income for farmers, fruit growing in gardens helps to reduce family budget on purchase of fruits. Well managed fruit orchards can bring better returns than many of the field crops even though. , It is however compensated by its higher productivity per unit area of land and the high value of the produce (Seifu, 2003).

Both fresh and processed fruits have huge potential domestic and export markets. Fruits with a high potential for export markets include avocado, apple, banana, citrus, grape, guava, mango, passion fruit, pineapple, papaya and strawberry (Joosten, 2007; EIAR, 2012). The demand for Ethiopian wine is also high for both domestic and export markets. The major export market destinations for fruits from Ethiopia are the neighbouring countries like Djibouti, Sudan and Somalia. The United Arab Emirates, United Kingdom, the Netherlands, Belgium, Yemen, Saudi Arabia, and the Russian Federation are among the dominant export market destinations (EHDA, 2012).



(in ,000 for Y axis)

Figure 1. Area coverage and total production of major fruit crops for smallholders during the last 10 years (CSA, 2005/5 to 2014/15)

Ethiopia has very limited number of agro-processing enterprises. Awash Winery and Castel Winery, with other few growers are engaged in the production of grapevines for the production of wine, fresh table and raisin grapes (Asfaw and Derbew, 2013). Merti Processing Plant processes orange concentrate, marmalade squash, and guava nectar (Seifu, 2003). AfricaJuice Tibila, Share Company produces blended concentrate from mango, passion fruit and papaya (Asmare and Derbew, 2013). At present, introduction of processed fruit products are quite significant in Ethiopia. Some fresh fruits have also been imported. For instance, about 350 metric tons of apple fruits were imported annually from South Africa, Iran, China and Israel (Timoteos, 2008).

Owing to the importance of fruits in Ethiopia, research on fruits started in 1967 with introduction of citrus scion wood cultivars grafted on different rootstocks, which were imported as budded materials and planted at the former Melka Werer Research Station (now Werer Research Center) to form the nucleus of foundation/ mother block. Another foundation block was established at Koka (Godfrey-Sam-Aggery and Bereke Tsehai, 1987a). In 1970/71, adaptation trial was conducted on four strawberry varieties introduced from Germany, USA and England at IAR research stations and Horticulture Development Corporation (HDCA) farms (Seifu and Lemlem, 1994; Seifu, 2003). Adaptation study of passion fruits was also conducted at Melka Werer, Nazaret, Jimma, Methahara, Kulumisa, Awassa and Bako Research Stations, and at Tseday Farm in 1972 (Seifu and Lemlem, 1994). Tropical and sub-tropical fruits, scions and rootstocks of many deciduous fruit crops were imported from California in 1970/71 and planted temporarily at Nazareth research station; but they were transferred to other trial sites like Koka, Holleta, Melka Werer and Bako research stations (Godfrey-Sam-Aggery and Bereke-Tsehai, 1987b). After the establishment of Melkassa Agricultural Research Center, all the fruit materials from Nazareth and Koka research stations were transferred to the new center. Hence, in the past four decades, introduction and adaptation of commercial varieties of many tropical, subtropical, and deciduous fruit crops have been made by the research system. Many tropical and sub-tropical fruit crops have also been collected locally. Demonstrations of various fruits have been made and contributed to the current fruits production throughout the country. This review paper highlights the major achievements, the status and future prospects of fruit research in Ethiopia.

Research achievements

Ethiopian Institute of Agricultural Research is the leading research institute in the country in the generations of improved fruit production technologies (varieties and crop management practices). The fruit research programs were employed for the adaptation and generation of improved fruits varieties, developing innovations and best management practices including nursery propagation, postharvest and crop protection aspects on various fruits at many research centers during the last few decades. In the following section, the achievments made are presented.

Variety Improvement and Germplasm Enhancement

Since the establishment of Werer, Holleta and Melkassa Agricultural Research Centers, local collections of major fruits were made and improved fruits varieties were introduced from major fruit crops producing countries. These materials were tested at multi-locations and verified. Some fruits varieties were released, some were registered and others were recommended during the past many years (Herath *et al*., 1994; Seifu, 2003; Edossa *et al*., 2008; Asmare and Derbew, 2013). Until present, more than 66 varieties of improved fruits were released, registered and/or recommended (Table 1). All varieties of improved fruit crops are now available at federal, regional and agricultural universities' research centers and in many private farms and nurseries in the country based on their agro-ecological requirements.

Table 1. Number of released, registered and recommended varieties of fruit crops with their performance at the research fields in comparisons with CSA data in Ethiopia

No.	Fruits	No. of varieties	Yield range (q/ha)		Year of released/ registered varieties
			National average (smallholders) (2014/5)	National average (commercial) (2014/5)	
1	Banana				
1.1	Dessert [a, b]	8	89.4	93.8	2006
1.2	Cooking [a]	4	NA	NA	2006
2	Avocado [a]	6	39.6	81.3	2008
3	Mango[a]	4	72.3	80	2007, 2013
4	Papaya[b]	3	171.9	449.5	2015
5	Citrus				
5.1	Scions[c]				
5.1.1	Sweet Orange	7	96.5	133.5	1976
5.1.2	Mandarin	4	64.1	NA	1976
5.1.3	Lime	2	64.1	NA	1976
5.1.4	Lemon	3	64.1	75.7	1976
5.1.5	Grapefruits	4	NA	NA	1976
5.1.6	Tangor/Tangelo	3	NA	NA	1976
5.2	Rootstock[c]	4			1976
6	Grapevines				
6.1	Wine [a]	6	NA	NA	2004
6.2	Raisin [a]	3	NA	NA	2013
7	Pineapple[a]	1	NA	13.6	2008
8	Apple				
8.1	Apple Scion[c]	4	NA	NA	1987
8.2	Apple Rootstocks	1			1987
9	Figs[a]	2	NA	NA	2012
10	*Ziziphus*[a]	2	NA	NA	2013
11	Peach scion [a, c]	5	NA	NA	2015
12	Peach Rootstock	2			1987
13	Plum scion [c]	5	NA	NA	1987
14	Plum rootstock	2			1987

Note: a= Registered, b= Released, c= Recommended, and NA= Not available. Adapted from CSA (2015); MoA Variety Registry Book (2000-2015); IAR, EARO and EIAR Reports.

In addition to introduction and generations of commercial varieties of major fruits, many germplasm collections and introductions of citrus, banana, grapes, mango, avocado, papaya, pineapple, guava, passion fruit, strawberry, date palm, *Anona*, macadamia nut, olive, noni and Casamiroa have been made and are being conserved in the research centers (Table 2). Some new fruit crops such as Litchi (*Litchi chinensis* Sonn.), longan [*Dimocarpus longan* (Lour.) Steud], chest nut, pummelo, cashews and pomegranate have been introduced into the country and are currently maintained at Melkassa, Holleta, Deber Birhan and Werer Research Centers.

Table 2. Fruit crops germplasm/ accessions available for research

No.	Fruits	No. of germplasm	Germplasm maintenance center
1	Dessert Banana	62	Melkassa, Tepi, Jimma, Werer
2	Cooking banana	26	Melkassa
3	Avocado	33	Melkassa, Debre Ziet
4	Mango	51	Melkassa
5	Papaya	115	Melkassa
6	Citrus scion	71	Melkassa
7	Citrus Rootstock	7	Melkassa
8	Table Grape	34	Debre Ziet, Melkassa
9	Wine Grape	80	Debre Ziet, Melkassa
10	Raisin Grape	6	Debre Ziet, Melkassa
11	Pineapple	6	Jimma
12	Figs	8	Melkassa
13	*Ziziphus*	7	Melkassa
14	Dates	24	Werer, Semera
15	Passion fruits	6	Melkassa
17	Apple (Scion)	20	Holleta and Deber Birhan
18	Apple (Rootstock)	6	Holleta and Deber Birhan
19	Peach (Scion)	15	Holleta and Deber Birhan
20	Nectarine (Scion)	9	
21	Peach (rootstock)	2	Holleta
22	Plum (Scion)	14	Holleta and Deber Birhan
23	Plum (rootstock)	2	Holleta
24	Almond	4	Holleta
25	Chest nut	3	Holleta
26	Walnut	2	Holleta
27	Olive	8	Holleta, Melkassa
28	Pear (Scion & rootstock)	11	Holleta and Deber Birhan
29	Apricot	2	Holleta
30	Cashew nut	1	Pawe
31	Guava	8	Melkassa
32	Longan	1	Melkassa
33	Pomegranate	7	Melkassa
34	Litchi	1	Melkassa
35	Pummelo	5	Melkassa
36	Wild chest nut	1	Melkassa
37	Rambutan	1	Melkassa
38	Noni	2	Melkassa
39	Macadamia nut	1	Jimma
40	Kola nut	1	Tepi
41	Casamiroa	12	Melkassa

Propagation Techniques

Almost all fruit crops are propagated vegetatively. Great efforts have been made in developing improved multiplication techniques for avocado, mango, citrus, apple and peach. *In vitro* micropropagation protocols were developed for banana at Melkassa (Asmare *et al*., 2009), grapevine at Holetta (Beza, 2010), and pineapple at Jimma (Zerihun *et al*., 2009). Subsequently, rapid multiplication of banana and pineapple through tissue culture has become successful. The knowledge and skill of fruit propagation techniques from research centers has been transferred to fruit growing communities through trainings. Currently, there are many private and public nurseries in major regions that propagate grafted fruit seedlings. Horizon Plantation PLC at Nura Era is involved in multiplying thousands of improved grafted mango and citrus varieties annually. Furthermore, there are also some private tissue culture laboratories in the country that could multiply fruit crops.

Crop Management

Various crop management activities have been conducted to generate best nursery and field management practices. Grapevine agronomy such as pruning and training system, and physiology such as dormancy and bud break studies were conducted at Melkassa and Merti (Tessema *et al*., 1994). Trials were conducted to identify low cost nursery potting media formulation from locally available materials (Seifu, 1995). Factors affecting seed viability and germination for papaya and mangoes, grafting techniques with greater grafting success for better seedling growth and vigor in mangoes were detected (MARC, 2008). Optimum number and size of banana suckers per hill at Melkassa and Werer (MARC, 2008; WARC, 2010), and K and N requirements of banana at Melkassa (MARC, 2008) have been determined to improve yield and quality of fruits. Nutrient status of sweet orange at Nura Era was studied through field observation and laboratory analysis of soil and leaf samples to determine macro- and micro-nutrients status of the plant (Dejene, 2009). An experiment was conducted to identify appropriate mulch type, mulching percentages and sucker management and the response of pineapple fruit to organic and inorganic fertilizers in Sidama Zone of SNNP was also determined (Daniel and Gobeze, 2012 and Daneiel 2013).

Postharvest

Utilization and quality of citrus, banana, papaya, and grapevine varieties were evaluated (Senayit *et al*., 1994). Postharvest and mechanization studies/researches were conducted. Solar drying of banana slices using Modified Local Kawanda Solar Cabinet Drier was conducted at Jimma University (Mulatu *et al*., 2012). An experiment was conducted to evaluate the effect of bunch bagging and male-bud removal on various yields, quality characteristics and maturity time of banana at Ziway (Abiyot *et al*., 2012). Influence of 1-Methylcyclopropene and polyethylene packaging on postharvest ripening and shelf life of mango (*Mangifera indica* L.) fruit was evaluated (Lemma *et al*., 2012).

Crop Protection

Diseases, insect pests and nematodes of major fruits crops were studied by many researchers. An overview of pest ecology and management of fruit crops in Ethiopia was studied (Tsedeke 1994; Ferdu *et al.,* 2009). A diagnostic survey on the occurrence and distribution, infestation level and extent of damage caused by a new insect pest, and identification of the pest on mango was conducted in western Ethiopia (Mohammed *et al.*, 2014). Management options recommendations were made to manage fruits insect pests such as fruit flies, woolly white flies, red scales, white mango scales, and false codling moth on citrus, mango and guava. Cultural practices, bait sprays and attractants, a number of insecticides, parasitoids and predators, and botanicals have been recommended for the management and control of major fruit insect pests (Tsedeke 1983, 1991; Firdu *et al*. 2009).

Review of research results including surveys, identifications and control measures of diseases on fruits were documented (Lemma, 1994; Mohammed *et al.,* 2009). Viruses and virus-like diseases including psorosis, tristeza and greening were reported to be of great economic importance in fruit production in the country (Tesfaye and Habtu, 1985; Lemma, 1994). Eshetu and Sijam (2007) reported the occurrence of citrus canker disease on Mexican lime and sour orange in some citrus orchards. Various fungal pathogens including *Phytophtora*, *Penicillium*, *Colletotrichum* and *Phaeoramularia* species affected citrus trees (Mohammed, 2007). Asmare *et al*. (2014) conducted a survey of citrus orchards in the country and based on their field observations, most citrus orchards have suffered from complex of diseases. Management options for some fruit crops diseases were developed. Cultural practices, host plant resistance and heat treatment have been suggested for the management of fruit diseases. A number of fungicides have also been recommended for the control of citrus leaf and fruit spot, papaya anthracnose and powdery and downy mildews of grapes (Mohammed *et al.*, 2009).

Capacity Building, Technology Multiplication and Promotion

Capacity Building

Since the establishment of fruit research at most centers, tremendous trainings have been given to subject matter specialists, development agents of the MOA, model farmers, private nursery owners, and others every year. These capacity building activities were provided by Holleta Research Center on highland fruits; Jimma Research Center on pineapple and avocado fruits; Melkassa Research Center on banana, avocado, mango and citrus; Werer Research Center on dates; and Deber Ziet Research Center on grapevine production. Following these trainings and private nurseries were established across the country and multiplied grafted fruit seedlings (avocado, mango and citrus). Thus, research centers have contributed to the establishment of many nurseries through the provision of trainings and initial planting materials. Many private fruits orchards and vineyards, and small-scale wineries have also been established.

Technology Multiplication and Promotion

Providing access of proven crop production technologies to producers is one of the mandates of the national agriculture research system. Improved fruits technologies have been disseminated through various methods including trainings, pre-extension demonstration, scale-up/ popularization and Farmers Research Group (FRG) approaches as well as field demonstration and visits. Large number of planting materials (scions, rootstock seeds, grafted fruit trees, suckers, cuttings, slips and others of various fruits) were multiplied and distributed to the growers through various research centers (Table 3).

Table 3. Summary of planting materials of fruits distributed from Melkassa, Holleta and Deber Ziet Agricultural Research Centers

Fruit Crop	Units	Total planting materials distributed	
		1998/9 to 2007/8	2008/9 to 2014/15
Mango	No. of grafted seedlings	49,107	92,815
Banana	No. of suckers	19,826	29,047
Avocado	No. of grafted seedlings	10,771	88,304
Citrus (oranges, lemon, mandarin, grape fruits)	No. of grafted seedlings	20,892	21,948
Papaya	No. of seedlings	7,016	10,327
Papaya	Gram	1,730	18,065
Citrus rootstock seed	Seeds (gm)	7,600	5,000
Grapes	No. of rooted cuttings	1,850	70,000
Apple	No. of grafted seedlings		9,431
Peach	No. of seedlings		645
Plum	No. of seedlings		355
Pear	No. of seedlings		150
Total		118,792	276,087

Different training programs have been organized for farmers, development agents and experts, and for junior researchers from different institutions in the country on production, management and utilization of various fruit crops. Various trainings of trainers have also been organized for experts working in different organizations in collaboration with stakeholders. Pre-extension demonstration of improved fruit crops varieties together with the recommended crop management practices were carried out in the different parts of the country. Public nurseries and farmers' training centers of MoA, state and private farms, schools, churches, mosques and home gardens have been used for demonstrations. Fruit crops popularization has been done by "a one fruit tree per family" approach to reach more urban communities, households and farm families. The approach has caused significant awarness and hence created more demand for fruit crops. Moreover, the FRG approach has been used in establishing fruit based model backyard agro-forestry practice through the participation of farmers. The research centers have hosted a number of visits vinifera from different institutions. Research centers have also participated at different exhibitions (Asmare and Derbew, 2013).

With the help of the research system, many public nurseries were established in collaboration with Bureaus of Agriculture in Tigrai, Amhara, Oromia and SNNP regions (Table 4). Improved fruits varieties have been planted as mother stocks in these nurseries. Commercial farms such as Horizon Plantation and many private micro-enterprises are also involved in fruits multiplications.

Table 4. Number of public nurseries established in major regions

Region	Fruit nurseries	
	1999 - 2000	2001 - 2014
Tigrai		Seleklaka, Mehoni, Wukiro, Hwuzin and RayanaAzebo
Amhara	Kurar, Finote Selam, Chagni, Bicolo, Bebeks, Addis Zemen, Enfranz, Zarima, Aradom, Habru (Mersa), Harbu, Warabit, Sitir	Efratana Gidim, Kamisse, Finote Selam and Chagni
Oromia	Sodere	Arsi Negelle, Wondo Oromia, Ziway, Bako, Godino (Adaa'a), Ziway Monastry, Huruta St Gabriel Church
SNNP		Lantee-Arba Minch, Shebedino, Wondo Genet ARC

Regional and International Collaborations

Collaboration and institutional linkage has been created with many international and regional partners especially in germplasm introduction, capacity building and technology promotion. Some of them are BARNESA, INIBAP (Bioversity International), ASARECA, World Vision, SG2000, FAO, ICRISAT, MASHAV, and ISAAA *Africenter*.

Impacts Observed

- Demand for improved fruits varieties increased steadily
- Farmers engaged on fruit production, total amount of production and productivity increased
- Fruit nurseries established in many parts of the country
- Many public and private nurseries adopted vegetative propagation such as grafting
- Mother trees for scion sources established in many fruit nurseries
- Locally produced fruits of improved varieties became common in local retail markets and supermarkets in many cities of the country.

Potentials and opportunities

Increasing the production and productivity of fruit crops is an important factor in ensuring food and nutrition security, and livelihood and health improvement of the nation. In addition, export potential for horticultural crops is enormous, which shows the possible contribution of the sector for the country's aspired economic growth and poverty reduction agenda.

The current fruits production in Ethiopia does not satisfy the domestic consumption. The country imports large quantity of mango, passion fruits, and purees, processed and fresh fruits. Although Ethiopia has favorable climate for the production of fruit crops, production has been small compared to other crops. With the prevealing market oriented agricultural policy (export promotion and import substitution), the government has identified five major horticulture development corridors, each with registered land bank, identified potential crops and possible out-growers. Oromia and Addis Ababa corridors have an estimated area of 30,000 ha; Bahir Dar, Abay valley and South Gondar have about 25,000 ha; Awash, Dire Dawa, Harar and Somali horticulture corridors have an estimated area of 21,000 ha; Hawassa and Arbaminch corridor has an area of 29,000 ha; and finally Mekele-Raya and Kobo Alamata horticulture development corridor has an estimated area of 25,000 ha (EHDA, 2012).

The country has huge irrigation potential with major river basins and thousands of tributaries, which can irrigate throughout the year. It has also good market proximity and niche to supply its horticultural produce to Europe, Mid-East, and Eastern African countries. The population growth of the country is so high and the living standard is improving. The horticultural produce consumption is increasing in all urban, pre-urban and rural areas. With good research for development planning, the country would benefit from producing diversity of horticultural crops in diverse agro-ecologies. Almost all fruits crops give high yield per unit area as compared to other crops.Thus, the possibility of producing large quantity of fresh fruits is high (Table 2). Most of the fruits such as banana and papaya give yield year-round and are also suitable for agro-processing. Hence, with intensification and advanced commercial production techniques, the possiblity of making available fresh and processed fruits throughout the year is unprecedeted.

Challenges and research gaps

The potential of producing sizable fruit products appear to be influenced by several constraints. However, the main challenge is related with the horticultural seed system of the country. The absence of organizations that are involved in multiplication of improved quality and certified fruit seedlings is a serious problem. Propagation activities are mainly handled by public nurseries, which often lack even basic amenities for proper propagation of fruit tree seedlings in sizable quantity, and high quality. Moreover, the few private nurseries operating in the country that produce seedlings of different fruit crops of known pedigree follow traditional methods and lack adequate infrastructure. The other constraints include inferior quality propagules, unavailability of standardized rootstocks that are resistant/ tolerant to biotic and abiotic stresses and lack of healthy scion of elite varieties are common problems for both commercial and small-scale fruit growers in the country.

Further unavailability of nucleus seed/ propagule, inadequate supply of mother plant, unavailability of propagation tools, lack of well adopted plant protection measures, non-existence of virus indexing system, and the use of diseased scion woods are some of the major constraints. Although public seed certification schemes are established for seed production of grain crops in the country, there is no enforced legislation to regulate and standardize production and sale of vegetatively propagated planting materials. Lack of strong and sustainable international linkage from where improved fruits varieties and germplasm can be obtained.

Fruit development requires implementation of modern production technologies and management practices for the production of competitive and quality produce to satisfy the different processors and/or consumers. Lack of modern production techniques including planting systems and implementation of improved tree management practices for different growing environments, poor agronomic (these are the same as improved tree management) and irrigation practices, poor postharvest, processing, utilization, handling and management (packaging, storage, processing techniques, value addition), limited agro-processing industry and variety poor transportation and marketing systems, limited resource capacity (human power, facility, infrastructure and financial support), lack of suitabile map of the major fruits growing area are the major drawbacks of the Ethiopian fruit production sector. Moreover, key information on the determinant of physiological processes in fruit trees, are often coupled with changes in growing environments that are at infant stage in the research, and often lack practical and informative knowledge for commercial growers and fruit processing industries in the country.

Consumers are increasingly demand safely produced quality foods, sustainably. To meet the challenges retailers demand certification from their producers. They face a tricky situation when working with emerging producers who may not be able to achieve GlobalGAP certification. Producers without certification for their products have difficulties to access the local and regional markets. T**he LocalGAP** innovative product is a cost-effective solution developed locally for emerging markets. It helps producers gain gradual recognition by providing an entry level to GlobalGAP certification. It also helps retailers gain access to quality foods, support their local and regional producers, and promote good agricultural practice.

Future direction

Improving Organizational Structures of Fruits Research

The organizational set up of fruit research in general is so minimized that many important fruit crops are merged into one project, which have squeezed the availability of all required resources. This has significantly hampered research capabilities and minimized the expected outputs. Many fruit crops that have significant importance have been merged into two commodities, that is tropical and temperate fruits and lack multidisciplinary commodity approach (variety, crop management, IPMs, agricultural mechanization, postharvest and extension) leading to uncoordinated and poorly communicated research system with visible lack common vision.

Fruits research should be organized with at least one research program/ case team followed by at least eleven research projects (Figure 2). Horticulture research in Ethiopia should be promoted to Ethiopian Horticulture Research Institute like in many other African countries. There should be a strong platform among horticulture development actors in the country, which is almost absent now. In addition, there should be strong coordination system established among national horticultural crops research, Smallholder Horticulture Directorate of MoA and partners such as the Horticulture Development Agency with sufficient annual budget allotted for fruit research. The proposed structure is as follows:

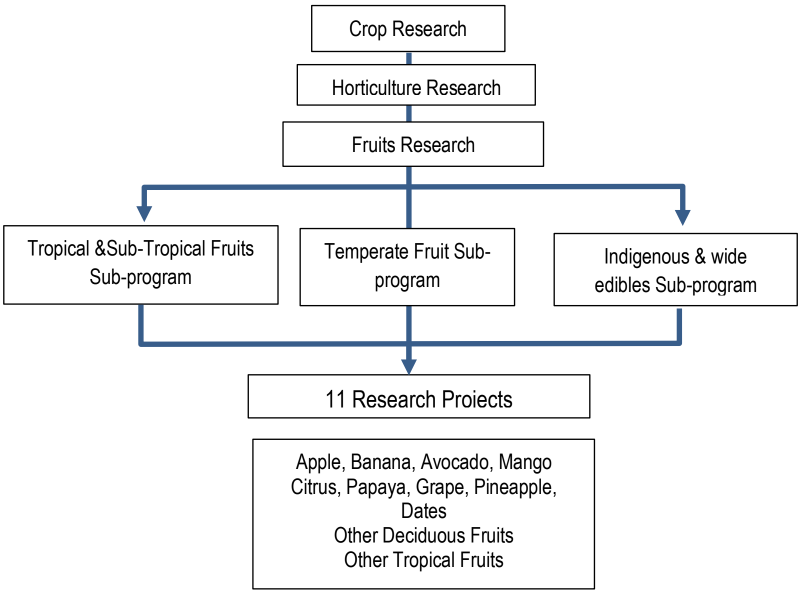


Figure 2. Proposed fruits research program and corresponding projects

Effective Research Coordination

Weak coordinated fruits research by Federal and Regional Research Institutes, and Universities in the sector may not yield the desired results. In the absence of proper national institution set up that can take care of all aspects of research, development, regulation and promotion of standards and trade faces several key constraints. The existence of many actors and stakeholders in the fruits value chain desires strong and dedicated institutional set up for successful development of technologies, innovations and management practices (TIMPs) of fruits. Moreover, the actions taken to create, implement and strengthen the linkages with local and international partners along the value chain of fruit research and development has been weak.

Improving Research Capacity, Facilities and Infrastructure

The development of competent human resource is one of the key activities for implementing effective fruit development strategy under the current challenging global business environment in the production of fruit. . Lack of trained and skilled human power is one of the important limiting factors in fruits research and development efforts in the country. Therefore, , due emphasis should be given to capacity building of various stakeholders in the sector viz., researchers, farmers, field level workers, officials and entrepreneurs.

Fruits research requires high standard facilities and infrastructure including multi-purpose building; mechanized chemical sprayers; harvesting equipment/machines; quality and tissue culture laboratories; sorting, grading and packaging facilities; refrigerated transportations; and irrigation facilities and structures. Thus, it is imperative to improve and organize fruits research activities to achieve the required knowledge and capacities based on the GTP II horticulture development objective /vision.

Pre and Post-Harvest Technologies

Efficient pre and post-harvest technologies for different fruit crops are lacking. There is a need to develop best managements of pre-harvest and post-harvest handling, storage, cold chain, value added products and processing system, product diversification, and export of fruits based on market intelligence is highly unequivocal. However, under the current situations these technologies are lacking for fruit crops production.

Disease and Pest Management

The prevalence of serious diseases and pests in the country requires the utmost management practices so that production and productivity of fruit crops becomes among the top priorities of development of . Therefore, the premature decline of most fruits plantations in the country caused by disease and insect pest complexes, poor quarantine legislation and enforcing control mechanisms are the main challenges for sustainable commercial fruit production. These problems are aggravated by inadequately updated an Integrated Disease and Insect Pest Management options. There is also little or no irrigation information for the current fruit production technologies with sufficient scientific studies involving different disciplines to obtain complete packages that include proper disease and pest management practices.

Multi-stakeholders Networking

To enhance development of fruit crops production in Ethiopia, a multi-stakeholder consortia engagements of integrated fruits research for development is required and is an opportunity to promote linkages in research for development between knowledge centers (universities), public, private and consumers practitioners as well as research institutes to address the practical aspects of applied research for innovation (Table 5).

Table 5. Some important actors and their roles in the fruit value chains

Stages of value chain	Actors	Role
Supply of inputs	Private merchants, Unions, BoA, BWME, NGOs,etc	Supply inputs for the producers
Production	Research, private leasers, individual farmers, government enterprises, commercial farms	Involved in production and supply of planting materials for irrigated fruits' orchards for end users and processors
Research	Research institutes/ research centers, universities	Generation and popularization of technologies, trainings on best production practices, provisions of solutions for existing and emerging problems
Coordination	Ethiopian Horticulture Development Agency, national horticulture coordination	Link all actors along the value chain
Transporting and storing	Farmers, private land leasers, commercial farmers, refrigerated truck owners , whole salers , central cold storage	Deliver and store until the product reaches end users
Processors	Private firms and government enterprises commercial processors	Value addition to the product
Marketing	Producers, middlemen / brokers, merchants (retailers and whole salers), SMI, Coops	Distribute the product, decide on prices
Consumption	Urban and rural communities	Buy and utilize quality products with reasonable price

Improving Market Issues and Information on Tropical Fruits Value Chains

Develop market orientation to integrate fruit farm production with national and international markets to enable farmers to undertake market oriented and demand driven production plan and adoption of modern marketing practices.

Address Environment Issues, Intensification, Water Smart Agriculture and Climate Resilience and Mitigation provide brief discussion for each

Fruits crops production includes wide agro-ecology coverage from extreme highland to extreme lowland of the country. There is a possibility of planting multipurpose fruits such as *Ziziphus* in the dry land. Many fruit crops can be used as shade trees for coffee and spices. Some fruits are selected crops for planting on the rugged sloppy mountainous areas of the country and are best trees for conservation. Many fruit trees by products are also used for animal feed.

NOTE: The above title is not adequately covered. Suggestions: a. reduce the major topics'; b. good as it is but only with sufficient elaboration

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Vegetable Crops Research in Ethiopia: Achievements and Future Prospects

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Introduction

The vegetable sub-sector is one of the important sub-sectors of the Ethiopian economy. High productivity and short growing period of vegetables, as compared to cereals and other annual crops, enables upto three production cycles per year thus making vegetables the most preferred crops for irrigated agriculture. Consequently, the return from vegetables per unit area is several folds higher than major cereals. The sub-sector also plays a great role in reducing unemployment as it is labor intensive and needs special skills and knowledge. It is also the major sources of income for growers and for those who are involved in all aspects of the business: propagation, production, harvesting, transporting, trading and processing of vegetable products. Indigenous vegetables such as Ethiopian kale, okra, pumpkin, etc are part of the culture of the Ethiopians and contribute to food and nutrition security and survival of the rural population during adverse drought/food shortage.

The country produces 1.32 million tons of vegetables on 238,607 ha of land involving about 11 million smallholder farmers (CSA, 2013). Production of most vegetable crops has more than double (Table 1) with the maximum growth recorded in pepper, which quadrupled in the period between 2004 and 2013 (CSA, 2004-2013). Moreover, production under commercial farms increased from 108.6 thousand tons in 2010 to 221.1 thousand tons in 2015 while area and productivity increased from 34.3 to 35.2 tons and from 9711.2 to 108631, respectively, during the same period (Table 2).

Table 1: Total production ('000 tones) of major vegetable crops in Ethiopia between 2004 and 2013

Crop	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	% increase (2004-13)
Ethiopian kale	213.6	262.5	180.8	159.2	238.4	281.6	274.2	331.6	323.2	371.0	173.7
Red pepper	66.9	72.5	179.0	101.7	122.4	183.4	159.3	209.9	239.5	316.6	473.1
Garlic	135.4	196.7	107.2	68.3	103.5	156.0	179.7	128.4	124.0	222.5	164.4
Onion	216.7	229.7	175.9	178.5	175.1	148.9	169.3	236.9	328.2	219.2	101.2
Green pepper	41.4	44.3	40.1	37.5	62.3	65.9	61.5	57.8	65.8	85.5	206.7
Tomato	54.9	36.2	35.4	na*	33.8	41.8	40.4	55.6	81.7	55.5	101.2
Head cabbage	8.6	15.2	12.9	10.1	11.8	24.1	20.4	19.5	43.5	23.2	270.8
Beet root	14.1	16.5	16.3	14.4	16.9	20.1	10.1	14.4	24.5	16.8	119.5
Carrot	10.0	17.9	6.9	6.7	na	13.5	18.2	12.3	13.6	5.1	50.9
Swiss chard	1.1	0.7	na	na	na	0.7	0.6	1.0	1.7	0.3	30.6

Source: CSA 2004-2013
*na = data not available

The increase in production trend of some of the major vegetables, however, was attributed mainly to expansion of irrigated land. The increase in productivity is still slow and lags way behind that of major producing countries such as China and India (Table 3).

Table 2: Estimate of crop land area and production of commonly grown vegetables in Ethiopia by commercial farms between 2010 and 2015.

Crop	Area (ha)			Production (t)			Yield (t/ha)		
	2010	2011	2015	2010	2011	2015	2010	2011	2015
Lettuce	201.5	825.1	225.9	5853.7	16319.9	5452.6	29.0	19.8	24.1
Head cabbage	204.7	88.5	620.6	4749.4	2058.3	18770.2	23.2	23.3	30.3
Ethiopian kale	17.9	31.1	40.4	175.6	204.6	457.9	9.8	6.6	11.3
Tomato	1645.0	1370.9	3427.3	5496.2	33872.2	102348.1	33.4	24.7	29.9
Green pepper	150.4	16.5	315.8	2964.6	136.6	3432.7	19.7	8.3	10.9
Red pepper	4529.6	1893.1	2660.1	19646.9	8153.7	9572.1	4.3	4.3	3.6
Swiss chard	41.9	108.3	19.2	133.3	1692.2	289.9	3.2	15.6	15.1
Beet root	3.3	5.0	2.9	32.1	68.1	49.7	10.2	13.6	17.3
Carrot	13.2	115.9	82.9	82.9	1665.3	1189.8	6.4	14.4	14.4
Onion	866.3	1160.0	3500.4	19306.7	173,18.9	79093.4	22.3	14.9	22.6
Garlic	35.2	42.1	42.1	532.2	495.8	289.7	15.1	11.8	6.9
Total	**9711.2**	**7659.7**	**12944.4**	**108639.1**	**82186.1.13**	**221146.6**	**376.8**	**357.5**	**387.0**

Source: CSA 2010-2015

The lag in productivity is mainly due to lack of technological advancements in research and production such as traditional way of production, unavailability of high yielding germplasms, infestation due to pests, poor agronomic practices, insufficient number of trained human power and lack of advanced facilities for variety development and propagation among others.

Table 3: Comparison of productivity of major vegetables of Ethiopia with major producers and the world

Crop	Countries				World average
	Ethiopia	China	India	Kenya	
Onion	10.5	22	16	11.2	19.4
Tomato	9.6	50	20.7	20.5	33.8
Cabbage	7.1	33.5	22.9	31.6	29.4
Garlic	11	24.6	5.1	6	16.9
Dry chillies	2.3	6.8	1.7	1.2	1.8

Source: faostat 2014

Vegetables are also used as raw materials for the agro-processing industries. Currently, Melge Wondo, Gondar, Merti and Green Star food processing factories produce tomato paste and canned vegetables both for local and export markets thus creating job opportunity and generating foreign currency.

The export of fresh and processed (frozen, canned, dried and ground) vegetables has been increasing considerably. In the period between 2010 and 2014 the amount of vegetables exported increased from 51.3 thousand tones to 153.3 thousand tones while the value generated increased from 32.4 million USD to 353. 6 million USD (Table 4). Somalia, Djibouti and Indonesia are the major importers of Ethiopian vegetables and vegetable products accounting for 68%, 15% and 7% of the export value (Fig. 1,2 &3). Despite the promising trend of export and the potential of the sector owing to the proximity of the country to non-agricultural oil producing countries, the sector has yet to improve production, productivity and quality to be able to satisfy local demand and export at competitive price with suppliers from South American countries.

Table 4: Summary of export of fresh, dried and value added/processed vegetables

Year	Weight (tones)	Value (,000 BIRR)	Value (,000USD)
2010	51286.4	471,358.1	32,363.5
2011	83742.6	2,305,028.2	135,075.8
2012	100643.9	4965376.4	277929.5
2013	102657.4	5,482,065.1	291,597.7
2014	153696.1	7123102.4	353616.2
Total	492,026.5	20,346,930.2	1,090,582.6

Source: www.erca.et.com

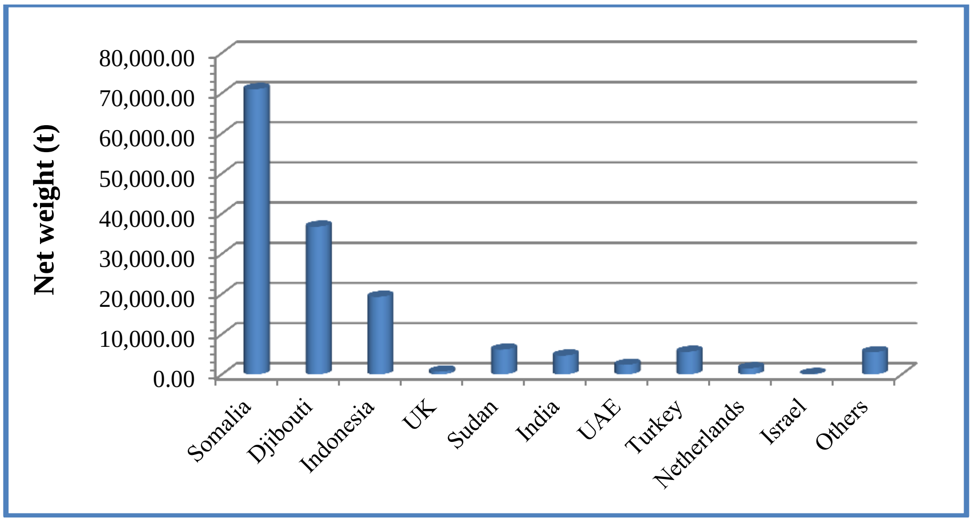

Fig 1. Quantity of vegetable export to major importing countries
Source: www.erca.gov.et

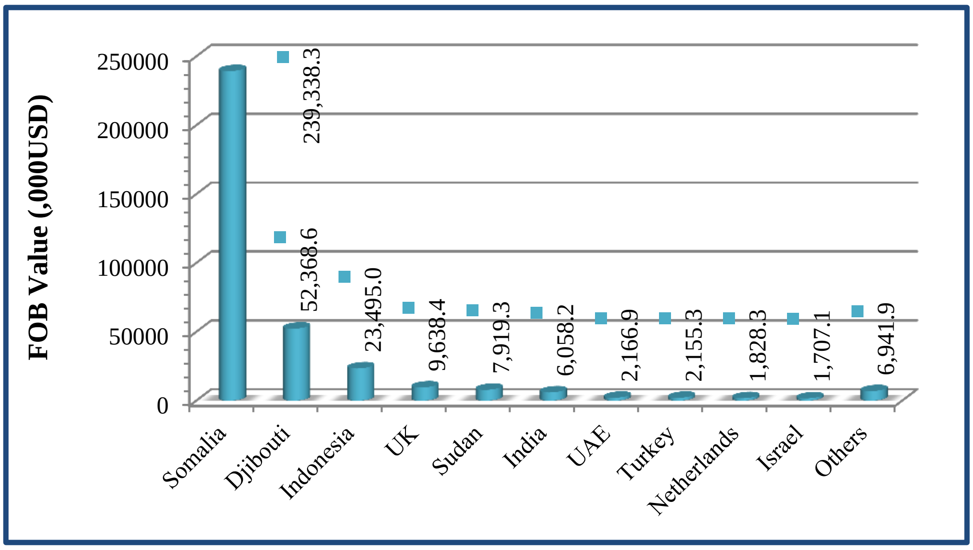

Fig 2. Export value of vegetables (, 000 USD) generated from major importing countries
Source: www.erca.gov.et

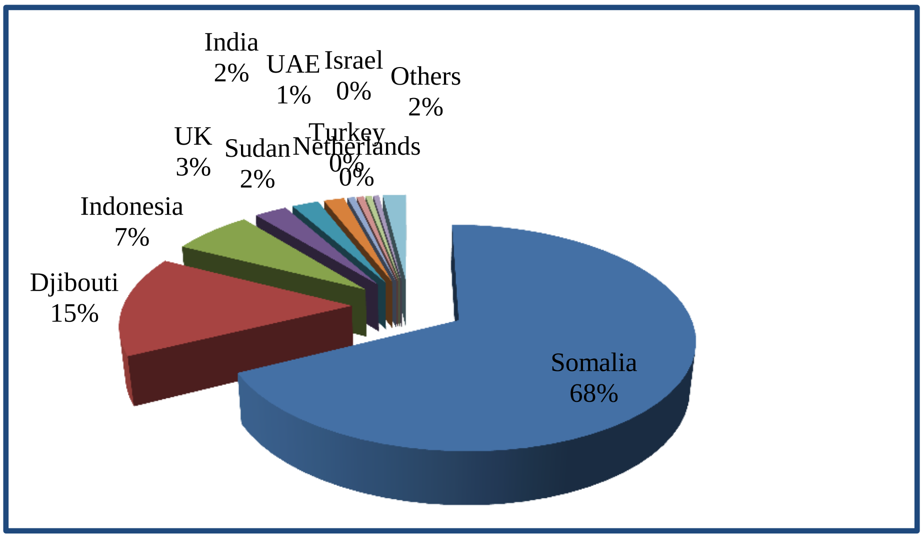

Fig 3. Percent of vegetable export income obtained from different countries
Source: www.erca.gov.et

Vegetable research

Historical background

Research in onion was started at various centers of the then IAR with thirty-two cultivars introduced in the early 1970's resulting in the recommendation of the two popular cultivars: Bombay Red and Adama Red (Mermiru White and Mermiru Brown) especially for the use by State Farms. However, consumers were very reluctant to adopt them initiall, because of locally available more pungent shallot varieties. However, later onion has become one of the major vegetables in Ethiopia after several years of effort in research and popularization awareness created among public.

The recommendation of these onion varieties accompanied with information on agronomic information such as production of bulbs from sets, planting time (sowing date of seeds and planting of bulbs) for seed production, irrigation interval and amount, fertilizer rate, pruning and trimming of leaves and roots, planting methods, bulb size and spacing (Hort. Depart. Ann. Prog. Reps. 1981/1982). Although research in shallot began in 1978 with the local collections 28 accession from Nazareth market and other areas, variety was not released. Later in 1986, research on shallot resumed at Debre Zeit and released bulb propagated cvs Huruta, Negele and Minjar. Later, "Yeras" a seed propagated variety was introduced from Malaysia and was recommended but its light red color and high bolting at seed to bulb phase reduced its acceptance. Currently, promising seed propagated varieties are under verification at Debre Zeit and Melkassa.

Research in garlic started in 1986 at Debre Zeit and five varieties have been released so far. Similarly, research in hot pepper began in late 1960's with accusation of sixty-seven varieties from local and foreign (Turkey, India, Tanzania and Kenya) sources resulting in the release of two popular varieties, Mareko Fana and Bako Local. Sowing date and transplanting method (direct seeding vs transplanting), fertilizer rate, harvesting frequency, spacing and seeding rate of the recommended varieties were studied as of early 1970's.

Research in tomato started with the variety screening of introduced cvs in early 1970's resulting in the recommendation of varieties such as San Marzano, Roma VF, Money Maker, Marglobe, and Heinz 1350. Sowing date, spacing, staking and pruning, mulching, planting method, seedling production, hardening, seed extraction, organic and inorganic fertilization were studied (Godfrey-Sam-Agrey et al., 1987).

Green beans research was started in the early 1970's with experiment consist of some twenty two varieties from which Premier and Tendergreen identified as promising ones. From other set of experiments variety B.C 4.4 released for production. Currently one promising snap bean variety has been identified for release.

Coordination

The research in vegetable has been coordinated at various levels since the establishment of IAR in the1970's. It operated under department of crop science and horticulture section. The various sections of departments of crop protection, mechanization, and food science participated to have multidisciplinary approach. The Horticulture Department of Melkassa Agricultural Research Center was given the responsibility of coordinating horticulture research in general while serving as center of excellence in onion, tomato and pepper. Kulumssa, Holleta and Debre Brehan centers were focused on cool season vegetables while Debre Zeit was conducting research on garlic and shallot. Other IAR centers (Werer, Bako, Sirinka, etc) and Alemaya, Hawassa and Jimma agricultural universities have been collaborating to undertake activities and vice versa(Fig 4). State farms, Extension Project Implementation Division (EPID) centers of the Ministry of Agriculture also served as testing sites for multi-location variety trials, and adaptation and demonstration of vegetable technologies. After the reorganization of IAR to Ethiopian Agricultural Research Organization (EARO), vegetable crops research was recognized as one of the research programs with tomato, alliums, capsicum and indigenous and other vegetable crops considered as independent projects.

Then when the organization was reduced as an Institute, the vegetable research was reduced to the level of commodity. The establishment of Regional Agricultural Institutes (RARIS) in 2000's did not bring change in the structure of vegetable research program organizational structure. The vegetable research in RARIS mainly limited to adaptation of released verities; recently they have been developing some varieties for their regions. In general after nearly half a century of existence, the vegetable research in Ethiopia is at commodity level consists of many crops under the Horticulture case team of the crop research process.

Different organizations collaborate in financing, backstopping, dissemination of technologies and offering feedback to the vegetable research (Fig.5). However, the collaboration among government organizations involved in vegetable sub-sector such as Ethiopian Horticulture Development Agency (EHDA) and Ethiopian Horticulture Producers and Exporters Association (EHPEA) is not strong as it should be.

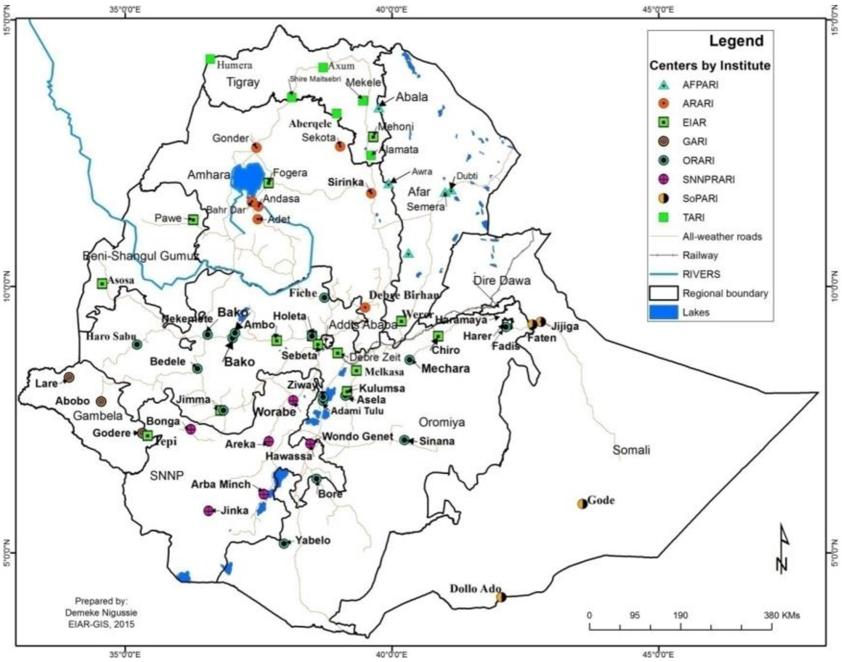

Figure 4. Agro-ecology based research centers

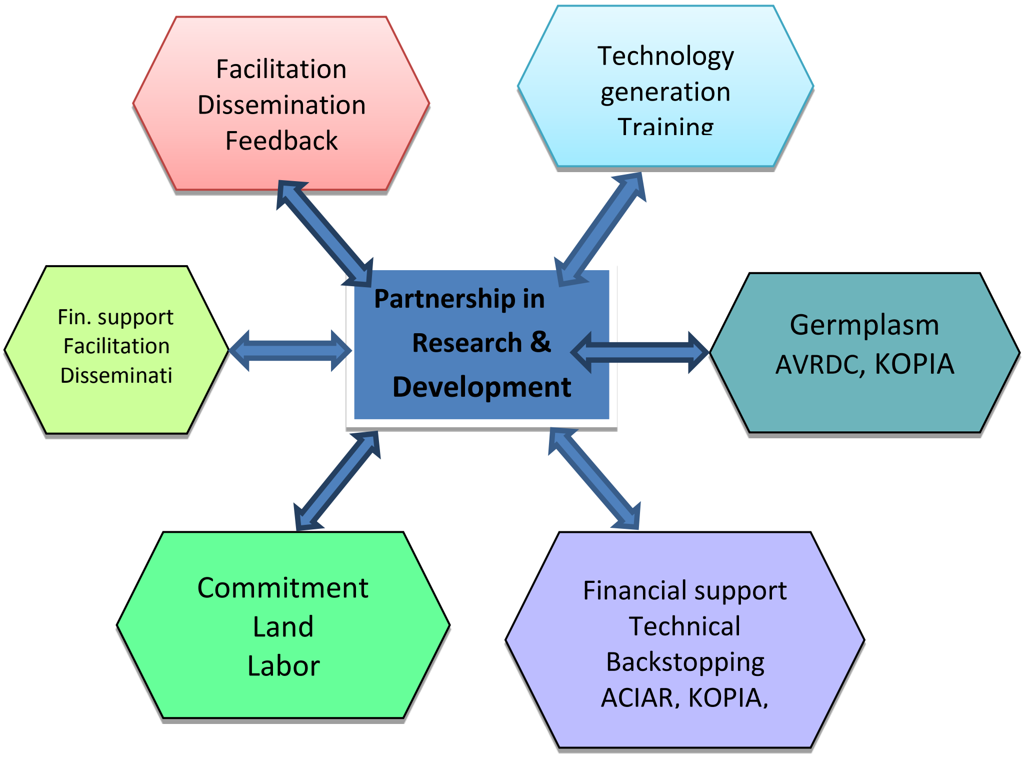

Figure 5. Different organizations collaborate in financing, backstopping, dissemination of technologies and offering feedback to the vegetable research

Achievements

Research has been conducted over years to develop technologies in the areas of variety development, crop management, crop protection, food science, socio economics and research extension with the major out comes in the variety development mainly in tomato, onion, capsicum, shallot and garlic.

Table 5: Released/ registered varieties of different vegetable crops

Crop	Number of varieties		
	Research	Commercial seed Companies	Total
Tomato	15	19	34
Garlic	6	-	6
Onion	4	14	18
Shallot	4	-	4
Hot pepper	4	7	11
Sweet pepper	2	-	2
Cabbage	-	8	8
Carrot	1	1	2
Lettuce	1	10	11
Snap bean	1	-	1
Snow pea	-	2	2
Fine bush	-	4	4
Snap pea	-	2	2
Water melon	-	5	5
Corrugate	-	2	2
Sweet corn	-	1	1
Okra	-	1	1
Brocoli	-	2	2
Red beet	-	1	1
Cauliflower	-	2	2

Source: MoA, 2014

Germplasm enhancement*:* Germplasms of exotic and indigenous vegetables have been collected from different sources to strengthen the genetic pool for further breeding works. Currently a total of about 1174 germplasm of major vegetable crops is available at Debrezeit and Melkassa Agricultural research centers. As can be seen the available germplasms are very narrow especially for the exotic ones and this needs strong collaboration among international institutions for germplasm introduction/exchange.

Variety development*:* Variety development mainly focus on major vegetable crops in the country; tomato, onion, capsicum, shallot and garlic. From 1997/98 to 2015, a total of 38 improved varieties of tomato, onion, capsicum, shallot, garlic, carrot, snap bean and lettuce were recommended/released mainly from federal research centers (Table 5). In addition to the varieties released by the research centers, commercial varieties introduced by different international companies and adapted in collaboration with EIAR and MoA. During 2009 to 2015 period a large number of commercial hybrid vegetable varieties introduced, adapted and well performing 119 varieties were registered (Table 5) (MoA 2009-2015). Although the involvement of these companies/private sector in registering varieties is very recent phenomenon in Ethiopia, its contribution to the private growers has been significant especially in vegetable crops that there is no responsible organization in the production of improved seed.

Agronomic practices*:* Planting date and method, spacing, fertilizer rate, seed rate, spacing, harvesting date, irrigation scheduling for onion, tomato and pepper, pruning of leaf and root in onion, effect of bulb size on bulb yield and quality of onion, effect of shading and chemical spray in hot pepper, mulching and seed extraction method in tomato and so on were determined. More over seed production technology in onion and seed production potential of carrot, beet root, cabbage and Swiss chard have been tested in potential growing regions of the country and found to be effective to produce seed of most of the presently imported vegetables in the country.

Crop protection: The proceeding on two decades of crop protection research in Ethiopia (Abraham, 2009) provides information on insect, disease and weed pests research conducted on vegetable crops. Major achievements include the following

- Survey and identification major diseases, insect pests and weed species in tomato, onion, garlic and snap bean.
- Chemical, cultural and host resistance recommended for major diseases and insect pests of tomato, onion and shallot, garlic, capsicums.
- Management practice for vegetable damping off recommended.
- Arthropod pests associated with vegetable crops produced in Ethiopia are catalogued.
- Predators and parasitoids of some arthropod pests are identified and catalogued.

- Economic importance/yield losses due to major arthropod pests determined: cabbage (36 -91 %), onion thrips (26-57%), fruit worms (PTM and ABW) in tomato (30%).
- Ecology of some key vegetable arthropod pests and natural enemies determined (eg. Diamondback moth on brassicas).
- Critical period of damage on tomato due to the fruit worm African bollworm determined.
- Effective pesticides against major arthropod pests identified and registered for use.
- Efficacy of some botanical and microbial insecticides assessed against thrips on onion, fruit worms on tomato, and aphids and diamondback moth on cabbage.
- Sources of host resistance against fruit worms in tomato identified and utilized in fruit worms IPM.
- Classical biological control of Diamondback moth using a hymenopteran parasitoid *Diadegma semiclausum* implemented in highland brassica production areas of western Arsi.

Table 6. Major pests (insect pest and diseases) on common vegetables in Ethiopia

Crops	Major insect pest	Major disease
Tomato	*Potato tuber moth (Phthorimaea operculella)*	Powdery mildew (*Leveillilataurica*)
	African boll worm (*Helicoverpaarmigera)*	Late blight (*HPhytophthorainfestans)*
	Red spider mites *(Tetranychus*spp.)	Early blight *(Alternariasolani)*
	Tobacco white fly (*Bemisiatabaci)*	
Onion Shallot	Onion thrips*(Thripstabaci*)	Downy mildew *(Perenospora destructor*)
		Purple blotcht*(Alternariaporri)*
		Basal rot (*Fusariumoxysporumf.sp. cepae)*
Garlic		Garlic rust (*Pucciniaallii/P. porrii*)
		White rot (*Sclerotiumcepivorum*)
Hot pepper	African boll worm *(Helicoverpaarmigera)*	Powdery mildew (*Leveillulataurica*)
	Tomato erinose mite *(Acerialycopersici*)	Fusarium wilt (*Fusariumoxysporum*)
	Termites (*Macroterms spp.and Microrerms spp.)*	South blight (*Sclerotiumrolfsii*)
		Bacterial wilt (*Ralstoniasolanacearum*)
		Phytophthora blight (*Phytophthoracapsici*)
		Frogeye leaf spot (*Cercosporacapsici*)
Cabbage	Diamondback moth *(Plutellaxylostella*)	Soft rot (*Erwiniacarotovora*)
	Cabbage aphid *(Brevicorynebrassicae*)	Black rot (*Xanthomonascampestris*
	Cabbage flea beetle (*Phyllotretaatra, P. mashonana, P. weisei)*	
Studies	Biology, EcologyIPM (Abraham 2009)	Yield loss assessment, ,characterization of pathogens, IDM

Source: Abraham, 2009

Post-harvest handling

- Storage structure to maintain onion bulbs for 45 days with about 10% loss in weight
- Pre harvest ComCat® treatment, modified atmospheric package, storage in evaporative cooling, as well as disinfecting with chlorinated water, decreased postharvest decay of tomato and extended shelf life and improved quality (Tilahun, 2008).
- Harvesting time and curing techniques for onion and pepper developed
- Duration of garlic bulb dormancy (120 days after harvest) identified
- Value added products such as tomato paste, catch-up, relish developed
- Tomato, hot pepper and onion preservation (dehydration) methods for small-scale and commercial production identified.

Socio-economics

As most vegetable crops were of foreign origin, they were not easily accepted by Ethiopian consumers. Relentless efforts were made to demonstrate/popularize the major vegetable crop varieties along with their production packages. These include:

- Small-scale farmers and private growers are successfully producing onion seed (1.2-2.0 t/ha) for their own use and for sale which significantly improved their lives (Lemma and Chemdo 2006).
- Pre-basic seeds have been multiplied and distributed to producers. For example, between 2010and 2015 about 1821 kg of onion, tomato and capsicum was produced and 90% of it was distributed to growers.
- Farmers were trained to apply the production packages.
- Production guidelines, leaflets, and research reports have been produced and distributed to small-scale farmers and other stakeholders.

- Cost of production of tomatoes and onion determined.
- Vegetables production status surveyed and possible interventions suggested.
- Vegetable IPM components demonstrated on farm

Publications

So far the vegetable research commodity has published research results in peer reviewed journals, proceedings and chapters in a book. Moreover, research reports , production guidelines, leaflets were also published to raise awareness farmers in technology adoption and popularization.

Capacity building

Human resource

Currently, the human resource of the vegetable crops research project from different discipline is eight PhD, 20 MSc and 22 BSc researchers devoting either full or part of their time conducting research; eight others are on study leave. They are of different professions and distributed at thirteen research centers and three universities (Haramaya, Hawassa and Jimma). Considering the number of crops and centers involved, this number barely satisfies the multidisciplinary team required to run full-fledged research on major vegetable crops.

Facility

Vegetable commodity at different research centers are not sufficiently equipped with office, field and laboratory facilities; some have fields with furrow irrigation and diffused light stores. Pathology, entomology, nutrition and soil labs are commonly used among the different commodities.

Potentials and opportunities

- Conducive policy framework
- Irrigation potential
- Market proximity and niche
- High labor force
- Agro-ecology and diversity of horticultural crops (temperate to tropics)
- High yield per unit area as compared to other crops
- Suitable agro-processing (fresh, semi-processed, etc)
- High demand of vegetables in local and export markets.
- Availability of improved varieties and technologies

Challenges and research gaps

- Knowledge and skill gap
- Limited improved varieties and germplasm
- Shortage of quality and healthy seed/planting materials
- Diseases and insect pests
- Postharvest, processing, utilization, handling and management (packaging, storage, processing techniques, value addition,)
- Limited agro-processing industry and variety for processing
- Poor agronomic (spacing, fertility, pruning, training,) and irrigation practices
- Poor transportation and marketing
- Limited capacity (human power, facility and infrastructure)
- Limited financial support
- Lack of local seed system.

Future direction

- Reorganization of vegetable research commodity as suggested
- Capacity development (Human, lab and field facilities)
- Create awareness across the value chain through demonstration, popularization and pre-scaling up vegetable crop technologies.
- Broaden the genetic base and develop varieties suitable for fresh market, processing, export and different production system(protected, home garden and organic cultivation).

- Employing biotechnology tools to enhance and speed up variety development, genetic manipulations and introducing desirable traits for yield, quality and stress tolerance.
- Develop technologies that can minimize risk of pests and absorb climate change
- Develop appropriate crop management technologies for different agro-ecologies and production system.
- Develop technologies that minimize postharvest losses such as small scale vegetable preservation techniques, processing, low cost and effective storage technologies, handling techniques and packaging technologies.
- Exploit the genetic potential of indigenous vegetables
- Develop gender sensitive technologies
- Improve vegetable seed system
    - Development and promotion of harvest and post-harvest seed management techniques(developing appropriate seed extraction, drying, packing and storage methods).
    - Facilitation and establishment of farmers associations and providing technical support for quality and sustainable seed production.
    - Establishment of innovative platform for production and marketing of vegetable seed production.
    - Development of appropriate vegetable seed production, delivery and marketing models.
- Create strong linkage with nation and international institution
- Create strong capacity (human power, facility and infrastructure)
- Create strong coordination system among national vegetable crops research and development
- Enhance data base on horticultural crop technologies and information

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Root and Tuber Crops Research in Ethiopia: Achievements and Future Prospects

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Introduction

Root and tuber crops, including Enset *(Ensete ventricosum)*, potato (*Solanum tuberosum*), sweetpotato (*Ipomoea batatas* Lam.), taro (*Colocasia esculenta* Schott.), yam (*Dioscorea* spp.), anchote (*Coccinia abysinica*), 'Ethiopian dinich' (*Coleus edulis*), cassava (*Manihot esculanta*) and tannia (*Xanthsoma* spp.) are among the most important food crops for direct human consumption in Ethiopia (Gebremedihn *et al.*, 2008). They are grown in diverse agro-ecologies and production systems ranging from densely populated highland regions to lowland drier areas prone to droughts or floods.

There are many compelling reasons for encouraging these humble root and tuber crops for sustainable food production in Ethiopia. They are versatile staples to address food and nutrition security for millions of people, as they produce more food per unit area of land than most other food crops. Potato and sweetpotato, short cycle crops with three to four months cropping cycle, are well suited to double cropping particularly in rain-fed systems and have significant advantage over grain crops which require relatively longer time to mature. Their short growing cycle allows for flexible planting and harvesting times and also permits quick production of foods to augment "hunger months "of October to December before grain harvests when people lack sufficient food to meet their basic caloric and nutritional requirements. Yam, taro and cassava, though with longer cropping cycles, are vital for annual cycle of food availability. Their broader agro-ecological adaptation including marginal environments, diverse maturity period and suitability for under-ground storage permit flexible harvesting periods which aids sustained food availability. These crops are also capable of efficiently converting natural resources into a more usable product, caloric energy in the growing season, which is the most productive of all major arable crops. Root and tuber crops are cheap but nutritionally rich staple foods that contribute protein, vitamin C, vitamin A, zinc, iron etc. towards the dietary demands of the country's fast-growing towns and cities. Another advantage of these crops is that they are largely traded locally and nationally, as opposed to internationally. They are far less susceptible to large-scale market shocks and price speculations experienced by more widely traded staples, such as grains, during international market crises. As such, they contribute to a more stable food system, maintain nutritional and food security, and are a predictable source of income (Nteranya Sanginga, 2015).

The Ethiopian Agricultural Research Institute (EIAR) through its implementing federal and regional research centers has been conducting several research activities since its establishment in 1966 under its former name Institute of Agricultural Research (IAR). Since then several technologies have been released, demonstrated and popularized for the larger farming community in the country. The objective of this paper is, therefore, to review research outputs obtained in the last four decades.

Historical background and trends in production, export and import

Historical background

Most root crops were introduced to Ethiopia. Potato (*Solanum. tuberosum* L.), originating in the highlands of the Andes in South America was brought to Europe in the 16th century. It was introduced to Ethiopia in 1859 by a German Botanist called Schimper (Horton 1987 and Pankrust 1964). For many years since its introduction, potato production was limited to homesteads as a garden crop. Cassava was introduced to the African continent by Portuguese traders in the late 16th century. It is grown on an estimated 80 million hectares in 34 African countries (AIC, 2002). The Democratic Republic of Congo is the largest consumer of cassava in Africa, followed by Nigeria. Although it was not very well documented when cassava was introduced to Ethiopia, some evidences indicated that it dated back to 100 years ago.

The exact date of introduction of sweetpotato to the continent of Africa is unknown. However, evidence indicates that slave traders brought it and since its introduction, it has been displacing true yam in tropical Africa (Low *et al.*, 2009) given that it has been in the food system for several hundred years.

Little is known about its exact place of origin, production and distribution, the yam species D. *rotundata* and *D. cayenensis* are native to West Africa (Coursey 1976). Yam had limited eastward movement reaching only as far as East Africa including Ethiopia and the region is generally considered as 'an isolated center of yam cultivation' outside the 'yam belt' of West Africa (Norman *et al*., 1995). It is widely believed that *D. abyssinica* Hochst. Ex Kunth is native to Ethiopia (Coursey 1967, and is currently distributed in the savanna regions of Africa. The other species were believed to be introduced before 1000 AD.

Various evidences suggest that taro originated in South Central Asia, probably in India or the Malay Peninsula and believed to arrive in the east coast of Africa around 100 BC (Purseglove, 1972). Conversely enset, anchote and Ethiopian Dinich are native to Ethiopia as evidenced by the presence of wild relatives and other facts.

Research establishment and Coordination: Research on various root and tuber crops has been going on since the establishment of IAR in 1966 under horticultural crops research division at different research centers and higher learning institutions (HLIs) in a fragmented manner. In 1997, after realization of the contribution of the root and tuber crops towards household food security, local industries and natural resources base conservation, research on root and tuber crops was reorganized as a program at the national level with projects on Enset, potato, sweet potato and other root crops. The projects were coordinated by different regional and federal research centers: Enset South Agricultural Research Institute, Hawassa Agricultural Research Center, potato and sweetpotato and other root crops by Areka, Holeta and Hawassa, respectively. Later, the potato project coordination has been transferred from Holeta to Adet since 2005 (Gebremedhin *et al., 2008*).

Importance

Root and tuber crops are most important in south, southwest, eastern and northwest parts of Ethiopia in terms of production area, distribution and consumption. They are also grown almost all over the nation. Small-scale subsistence farmers grow the crops, under resource-poor conditions. In general, root and tuber crops are part of traditional foods of Ethiopia. Their contribution to family food-self-sufficiency, income generation and soil-based resource conservation is indispensable. Currently, most root and tuber crops are grown as security crops against crop failures and/or to bridge the food deficit periods, as they are ready for harvest during "hunger months." These crops are also tolerant to termites, which might be attributed to their higher moisture content, and thrive well on poor soils and under moisture stress conditions. These crops can grow from extreme lowland to extreme highland agro climatic conditions of the country. Potato thrives well at mid to high altitudes whereas other root crops perform well at low mid altitudes. They are good source of food nutrients such as carbohydrate, protein, vitamins and minerals which alleviate the problem of malnutrition in subsistence farming areas. Root and tuber crops have attracted attention as industrial raw material. Starch extracted from root and tuber crops is used in many applications including pre-gummed papers, tapes, labels, stamps and envelopes. They have a great potential to substitute import in the textile, pharmaceutical, soft drink, beer and ethanol/alcohol industries (Tesfaye *et al*., 2013).

Area, production and productivity

Root crops cover more than 1.42% of the area under all crops and contribute 6.15% to the total crop production in the country. Nevertheless, potatoes, sweet potatoes and Taro ('Godere') account for about 29.8%, 25.7% and 19.9%, respectively of the total area under root crops. The area coverage of these crops showed an increase compared to the 2012 figures of 28.45 %, 23.35 % and 18.87 %, respectively (CSA, 2012). Ten year "Meher" production data indicated that the area covered by major root and tuber crops in the country ranges from 111,434.00 to 175,450.00 ha with an average productivity of 7.2 to 29.8 t/ha (CSA, 2005-2015).

Production system

Root crops can be planted as standalone crops or cultivated alongside other crops like maize, vegetables and cover crops. They can be intercropped and rotated with different crops for different merits such as insect pest and disease management, maintenance of soil fertility, increase in land productivity and others. Compatible crops with root and tuber crops for intercropping and rotation purpose are pulses, cereals, oil crops, vegetables and coffee. Coffee is majorly intercropped with enset for which the latter provides shade for higher yield. It is noticed that root and tuber crops never follow other root and tuber crops and/or intercropped with them as they have almost similar nutrient requirements. Potatoes are often grown in rotation with other crops such as maize, linseed, rapeseed, faba beans, or haricot beans following the last cultivation of potato in May or June. A 1997 survey of 420 farmers in the Amhara region indicated that about half of the interviewed farmers intercropped potatoes with other crops. Factors affecting their decisions included late blight pressure, poor market outlets, insufficient seed availability, competition with other growers, and periodic food shortages (GebreMedhin *et. al*. 2001).

Export status of root and tuber crops

Export of root and tuber crops is either non-existent or very negligible. The potential of export markets within east and central African region is not fully exploited. Despite the presence of different opportunities to export row and processed root and tuber crops products to different African, Asia, European and other countries, only Irish potato is being exported to the neighboring countries such as Somalia, Sudan, United Arab Emirates and the like. Fig.1 shows three years (2009-2011) export data for potato.

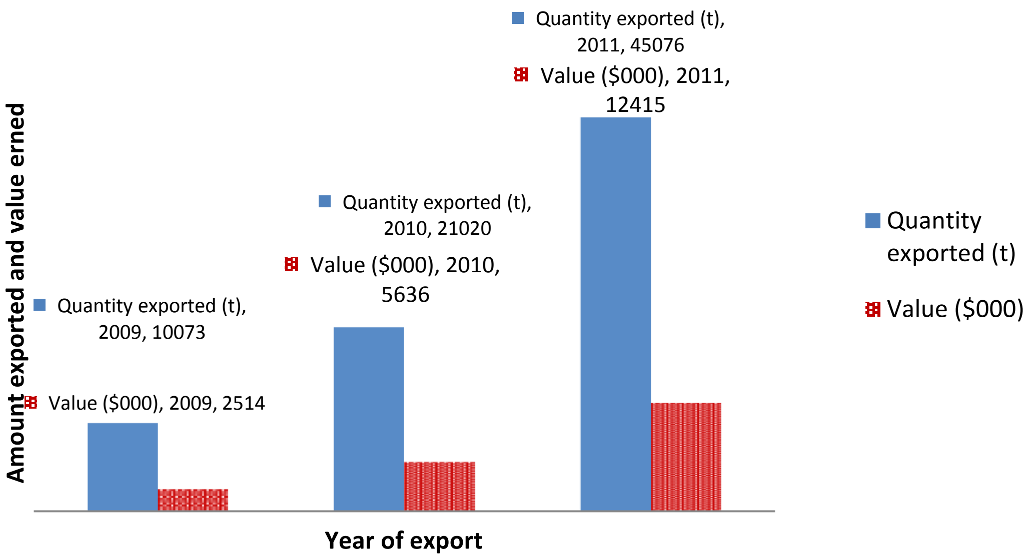

Fig. 1 potato Export quantity and value obtained

Achievements

A number of technologies have been selected, developed, released, adopted, and popularized since the establishment of research system in the country. Among which variety development for different agro ecologies, crop pest management technologies, crop husbandry, post harvest management and food quality appraisals are the major ones.

Potato

Ethiopia is among the top potato (*Solanum tuberosum* L.) producers in Africa, with 70% of its arable land in the high altitude areas above 1500m being suitable for potato production (FAOSTAT, 2008). Currently, potato is produced mainly in the north western, central and eastern highlands of Ethiopia (Berhanu *et al.*, 2011). Its production is constrained by a wide range of factors that result in low yields. These include shortage of high yielding varieties tolerant to late blight, marginal soils, inadequate seeds, deficient cultural practices, storage problems, high cost of farm inputs, and insect pests and diseases (Gebremedhin, 2013).

Varieties developed: The local varieties introduced earlier may be of the same parentage (Haile-michael, 1979). This intensely shows that the genetic base of the local varieties are narrow; making any progress in improving the productivity of the crop unsatisfactory. To make such a progress possible by widening the genetic base of potato, a selection program with a large number of seedling populations started in 1973 at the College of Agriculture in Alemaya in cooperation with IAR and International Potato Center (CIP). A more coordinated improvement work on potato started in 1975. National potato research programs in sub-Saharan Africa have continuously focused on selection of high-yielding varieties with resistance to late blight (LB) disease (E1-Bedewy *et al*., 2001).

Introduction and evaluation of broader germplasm and commercial varieties, and generation of local population and recently introduction of advanced materials are some of the strategies that have been followed to develop varieties wide adaptability, resistant/tolerant to different pests and stresses (Berga *et al*., 1994a). Accordingly a number of variety trials have been conducted in different corners of the country to address different agro-ecologies of the potato growing areas. From these experiments widely adaptable, late blight resistant and high yielding (25-40 tons/ha) potato varieties were released and are under production. So-far, about 33 improved potato varieties have been released and recommended by the National Potato Improvement Program (MoA, variety registry, 2014). Most of the potato genotypes that have been developed and released in Eastern Africa before 2008 either had genes for vertical resistance to LB or horizontal resistance to LB in the presence of unknown resistance (major R) genes, thus named population "A" clones (Landeo *et al*.,1997). A particular feature of this breeding population is that horizontal resistance was improved in the presence of undesired, unknown major (R) genes for vertical resistance (population A). Their presence made the recognition of true horizontal resistance and effective gene frequency upgrading more difficult rather than contributing to the overall resistance, (Landeo *et al*., 1997). Although the Ethiopian Potato Improvement Program has shown progress over the years, further improvement is still needed, particularly in accelerating varietal selection and release schemes and increasing adoption and diffusion rates (Gebremedhin, 2013). Diffusion of new varieties has been sluggish and limited; thus old potato varieties are still produced by a significant number of farmers in large land areas. In other words, new varieties are struggling to reach larger areas or replace the old ones. Farmers would like to replace their old varieties with new ones because of diminishing productivity, but they usually are not aware of the release of new ones and even if they are, limited availability and farmer's access to seed of such varieties are prohibitive. Therefore, the lacks of quality seed in sufficient amount and at affordable prices are the major limiting factors for varietal diffusion.

Agronomy: The suboptimal agronomic techniques practiced by potato growers in Ethiopia are undoubtedly one of the contributing factors to the existing low average national yield. Agronomic studies have been undertaken by different research centers to develop a package of optimum management practices, for the improved cultivars.

Therefore, research on planting dates, planting depth and method of planting, fertilizer rate, method and time of application, as well as number of hilling during the growing period for seed and ware potatoes, plant population for seed and ware potato productions comprise the major components of the agronomic research.

Time of planting: Planting time varies with location, variety and the growing season. It influences incidence of late blight and has significant impact on tuber yield and quality. To secure maximum yield, potato should be planted during the time favorable conditions prevail for better growth and development of the crop. Planting from, early June was recommended as optimum planting time for Emdiber (Gurage zone), Holetta (central Ethiopia) and other similar agro-ecological areas (Berga *et al.*, 1994). Similarly, May first to mid May and from May first to June first are recommended as optimum planting dates for late blight susceptible and moderately tolerant/resistant potato cultivars around Adet and similar agro-ecologies. Abdul Wahab and Semagne (2008) recommended that last week of May to mid June as an appropriate planting time for optimum potato production in the high lands of Ankober (North Shewa) and other similar agro-ecologies.

Depth of planting: Even though optimum planting depth varies with soil moisture content, soil temperature etc., under Holetta condition planting at 15cms depth followed by 10 and 20 cm are best for yield and minimum insect pest attack.

Seed tuber size and plant population: Seed tuber size and population density are among the most determining factors of the production and productivity of potato. A potato tuber may at the end of dormancy grow one or more sprouts, and after planting variable proportion of these sprouts develop into main stems. A plant may have variable number of stems depending up on the tuber size, number of eyes per tuber and storage conditions of the planted seed tuber. The stem numbers per tuber in turn affects the number of tubers set, the growth and longevity of the haulm and therefore yield (Gebremedhin *et al*., 2008). Closer intra-row spacing of 10 or 20cm in rows of 75cm apart would be beneficial for seed and larger seed tubers (45-55mm) do better than the smaller ones. Wider intra-row spacing of 30 or 40cm are better, again on rows 75cm apart, for ware. Similarly, considering the amount of seed tuber required type of output and synergism with other cultural practices, seed tuber size of 35-45mm diameter, 60cm inter-row spacing and ridging once at 3-4 weeks after crop emergence is recommended for seed potato production. However, 35-45mm diameter seed tuber, 75cm inter-row spacing and ridging once after 3-4 weeks from crop emergence is found optimum and recommended for ware potato production at Adet and its surroundings (Tesfaye *et al.*, 2008). Generally, use of 75 cm inter-row spacing is found suitable for ware potato production and 60cm inter-row spacing is found ideal for seed tuber potato production.

Fertilizer rate: Potato, as a high yielding crop is a heavy consumer of nutrients. Many factors may affect the total nutrient consumption of the potato crop. Reports indicate that the effects of season, variety and rate and time of N, P and K fertilizer applications resulted in the removal of mineral nutrients in fresh tubers in the following ranges: N, 2.28–3.57; P, 0.40–0.62 and, K, 3.70–5.41 kg/t (Gunasena, 1969). However, the diversity of soil types, moisture and nutrient regimes, cropping sequences, fertilizer uses and climatic conditions as well as biotic factors such as weeds, pests and diseases all may affect the state of soil nutrient flux and use by the growing crop. The extent of use of fertilizer may also be dictated by factors like market prices and the economic status of a farmer (Gebremedhin *et al.*, 2008). Considering these problems, area specific and economically feasible fertilizer rates were recommended by different research centers for different potato growing areas across the country. According to Tesfaye and co-workers *(* 2008) fertilizer rates of 108/69 and 81/69 kg/ha N/P_2O_5 are economically feasible in South Gondar and Gojam areas, respectively. Similarly, 110kg/ha nitrogen and 70.5kg/ha P_2O_5 are recommended for optimum potato tuber yield in nitosol and light vertisol in the highlands of North Shewa (Abdul Wahab and Semagne, 2008). Berga and co-workers (1994) also reported that 165/90 N/ P_2O_5 recommended as feasible rate for the central Shewa area and this recommendation is still in use in the central and Southern part of the country as a blanket recommendation. By the same token, 146/138 N/ P_2O_5 was recommended for the highlands of Hararghe. These recommendations may not work for the current market, soil fertility status and other climatic variables. Therefore, considering the variability of the input-output market and soil fertility status, detail soil test based fertilizer rate studies should be carried out.

Ridging: Ridging, which refers to the practice of hilling or earthing up the soil around the potato plant, is a normal practice in potato production. Ridging is practiced to obtain sufficient earth or soil around the potato plant and form a well-shaped ridge that helps to loosen the subsoil for good aeration and/or to cover the tubers set with sufficient layer of soil. On lighter soils ridging presents no difficulty, and it is very useful if the soil depth is shallow. However, on heavier soils, ridging may present a problem unless it is done under low soil moisture conditions. Proper ridging increases tuber yield by creating favorable condition for tuber initiation and development. Poor ridging in potato may expose the tuber to sunlight, high temperature, disease and insect damage. Studies show that a yield loss as high as 8% have been registered due to poor ridging. The frequency and optimum of ridging may depend on variety, soil structure and workable soil depth (Gebremedhin, 2013). The highest yield was obtained from plots with four and three times ridging. Generally, increasing ridging frequency substantially reduced green tubers from 53.3% in no ridging to 29.5% at four times ridging. In a similar study conducted at Adet, ridging frequency had no significant effects on parameters like tuber size, marketable and total yields. The results under Holetta conditions showed that yield and tuber quality can be affected by ridging and at least twice ridging is very necessary. Light soil and heavy rainfall areas require more frequent ridging. Whereas, in light red soils care has to be taken to reduce insect damage and greening by modifying planting distance and increasing frequency of ridging. In ware potato production, good cover-up of soil does substantially increase marketable tuber yield due to less greening (Gebremedhin *et al*., 2008)

Intercropping: Intercropping of potato with maize is a common practice in northwest Amhara region. Consequently, an experiment was conducted at Adet for two consecutive years (1997-1998) to identify economically feasible intercropping pattern. The result was also statistically analyzed using total monetary value (TMV) of the system and economic yield of each component crop. Moreover, the land equivalent ratio (LER) of each intercropping system was calculated. From this work intercropping of potato with maize in 2:1 and 1:1 (potato: maize) row spatial arrangement are found superior in their order and recommended for potato production at Adet and its surroundings (Tesfaye *et al.,* 2008). In addition, intercropping study of potato and maize was made at Bako for three cropping seasons. Maize and potato were arranged in 1:1 ratio alternating within a row (15 x 75cm) and between rows (37.5 x 30 cm) including sole planting (75 x 30 cm). The yield of potato in an intercropped field was as high as sole potato in one of the three study seasons. Intercropping was found economically advantageous than sole cropping as the maize grower could get potato yield as bonus in addition to maize yield (Gebremedhin *et al*., 2008).

Crop protection

Potato Disease Management: The potato is prone to many diseases caused by either bacteria, fungi, viruses or mycoplasma. Late blight, caused by *Phytophthora infestans*, remains the most devastating disease in potato resulting in economic costs that sum up to 5.2 billion euros, globally. The use of resistant varieties is a powerful, viable and environmentally friendly alternative or supplement for the current, commonly deployed chemical control strategies (Haesaert *et al*., 2015). Late blight is generally the most important disease wherever potatoes are grown in the country. Traditionally the crop is grown during the off-season using the short rain that falls during February–April and sometimes with supplementary irrigation when available. The main reason for not growing potato during the long rainy season, despite the high yielding potential, is the severe threat posed by late blight. The local varieties do not cope with the disease pressure in the main rainy season and often are wiped out particularly in the highlands. Viruses and bacterial wilt are also very important diseases affecting potato production (Bekele and Eshetu, 2008). Among these, late blight (LB), followed by bacterial wilt (BW), potato leaf roll virus (PLRV), and potato virus Y (PVY) were the most important diseases. Late blight was widely distributed where the crop is grown under rain fed conditions (Bekele and Yayinu, 1994). In this report, BW was detected and found restricted to the mid-and low altitudes. Currently, however, it has also been recorded in high altitudes (>2400 masl); virus diseases were more prevalent at mid and low altitudes than at higher. Studies on host-plant resistance, loss assessment, cultural control measures, and integrated management have been conducted on many diseases. Promising results have been obtained. The level of economic loss of late blight has been determined for some varieties. Furthermore, the use of integrated pest management (IPM) in reducing blight damage has been emphasized. The result showed that early planting of moderately late blight tolerant varieties with one or two fungicide applications significantly reduced the disease, thereby, highly increasing the tuber yield. Attempts have been made to determine the physiological races of *P.infestans*. Results of chemical control trials indicated that a fungicide (Ridomil MZ 63.5% WP) containing Mancozeb and Metalaxyl was very effective in controlling late blight (Bekele and Yayinu, 1994). In a host resistance study, potato varieties that are tolerant to late blight, early blight and bacterial wilt have been identified (Baye and Gebremedhin, 2013).

An integrated bacterial wilt control research was conducted in a farmer participatory approach, where different options were compared. The options were (a) an improved package (IP) that consisted of clean seed, a less susceptible variety, and improved cultural practices, (b) a farmer package (FP), which consisted of a farmer's variety and farmers' seed, planted under the farmers' cultural practices, (3) clean seed of a less susceptible variety planted in farmers' cultural practices (CSFCP), and (4) farmers seed planted under improved cultural practices (FSICP). All the options significantly reduced wilt incidence and increased potato yield as compared to FP; with IP performing best. The options were all economically beneficial and resulted in marginal rates of return of 1034% for IP, 805% for CSFCP and 634% for FSICP (Berga 2001; Berga *et al*., 2005).

Potato is naturally infected by over 36 viruses. About 50% of these viruses are dependent on potato for their survival and spread, while others usually have major hosts apart from potato. Viruses and virus diseases constitute a major constraint to potato production in developing countries including those of SSA. The diseases are often overlooked because the symptoms are usually not as striking as those incited by fungi and bacteria. The virus diseases cause reductions in yield quality and quantity (Salazar and Accatino, 1990). Berhanu and co-workers , (2011) described that, evidence of the occurrence of potato viruses in Ethiopia was first reported in studies conducted in central, south and southeast Ethiopia during the 1984 and 1985 crop seasons. The results of these consecutive studies indicated the presence of *Potato virus X* (PVX), *Potato virus S* (PVS), *Potato leaf roll virus* (PLRV), *Potato virus Y* (PVY), *Potato virus A* (PVA) and *Potato virus M* PVM). The effect of viruses on potato production is primarily due to their accumulation on seeds causing degeneration within short period of production cycles. There is a need, therefore, to strengthen the tissue culture laboratory in order to supply disease-free seed to producers and minimize the effect of viruses on potato yield. In addition, the existing sites for seed production should be strengthened. It is also crucial to forge strong linkages between potato seed producers and the research system. The potato plant can become systematically infected with viruses following transmission either mechanically or through vectors. Whereas, nearly all of these viruses are transmitted vegetatively through seed tubers. PVY and PLRV, the two economically most important potato viruses, PLRV and PVY are horizontally transmitted by aphid vectors under natural conditions. Green peach aphid (*Myzus persicae*) is the most important vector of these two viruses worldwide, while other aphids like potato aphid (*Macrosiphum euphorbae*) are less efficient vectors.

Potato Insect Pest Management: Potato is attacked by a number of insect pests. In the past over two decades, the major insect pests that stay on potato did not shift and have included: cutworms (*Agrotis* spp. and *Euxoa* spp.), red ants (*Dorylus spp.),* potato aphid (*Macrosiphum euphorbiae*), green peach aphid (*Myzus persicae*) and the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) (Bayeh and Tadesse, 1994). Among these insects, potato tuber moth (PTM), cutworms, and aphids are the most important ones. Research has been conducted to generate information on management options against these economically important insect pests. Many survey reports indicated that PTM was known to damage potato only in warmer areas, though major production areas are mainly in the highlands. Monitoring of PTM was conducted using PTM sex pheromone trap at Holetta. The result showed that the peak months were January, February, and June. Unlike the field situation, monitoring in the store showed no obvious peak record (Bayeh and Tadesse, 1994). Aphids in potato, though, were more important as vectors of virus diseases than as pests. Monitoring work was conducted using yellow water traps at Holetta, and during the monitoring different aphid species were recorded.

The peak months were January, April, and November–December. According to Bayeh and Tadesse, (1994) the dominant species were Brassica aphids, green peach aphids, and potato aphids. In this work an attempt was made to correlate the population fluctuation with some abiotic factors, temperature, (minimum and maximum), rainfall, and wind speed. The result showed that rain fall and low temperature had negative effects, whereas the influence of the other two factors was non-significant.

Seed/planting material production: The Ethiopian Potato Improvement Program, with almost 35 years of CIP's technological support through its regional office in Kenya and its headquarters in Peru, has been able to release more than 31 varieties; however, the rate of adoption and diffusion has been quite limited. Of the released varieties, Belete, Jalenie, Gudenie, Guassa, and Gera are the most widely grown potatoes at present. In most cases, the main limiting factor for variety diffusion was insufficient amount of clean seed due to limited formal seed system. Currently the national mean yield in Ethiopia is low which is about 10.8 t/ha (CSA, 2014) but could easily be doubled or tripled. Moreover, the adoption and coverage of 25.2% of the total potato area in the country with improved varieties has partly contributed for the witnessed productivity gain (Labarta *et al.*, 2012). Potato's production value is estimated at 403 million USD (CSA, 2014). Perhaps the most significant constraint to increasing productivity and overall production is the chronic shortage of good quality seed tubers of the productive varieties.

A pre-requisite to a successful and sustainable seed scheme is a continuous supply and maintenance of pathogen free early generation seed potato. This is the responsibility of research institutions in the country. To provide these disease free planting materials, a number of research activities have been conducted. Evaluation of some rapid multiplication techniques (stem cutting and aeroponics) were made under local conditions. Tuber yield increased with increasing number of stem cuttings per hill from 1 to 3 and with closer spacing. Stem cutting results revealed that the rooting abilities of stem cuttings differed with cultivar and media, where as fine sand was found to be the best locally available medium (Berga *et al.*, 1994b). Currently, Millions of mini-tubers are being produced under rapid multiplication for experimental and pre-basic seed in our TC labs and aeroponics structures at Bahirdar and Holetta. The conventional multiplication rate of potato (1:3) is promoted to 1:30 by rapid multiplication techniques (RMT) especially by using aeroponics system (Abebe *et al.*, 2014).

Postharvest Management: In Ethiopia potatoes are basically stored for two purposes: ware and seed, but mostly in inappropriate storage facilities. Farmers use different traditional potato storage systems depending on the use. However, these storage facilities are not proper to keep the quality of tuber for more than 1–2 months (Endale *et al*., 2008). Since potato tuber is a living botanical organ, it loses weight and quality during storage. Farmers keep potatoes in the ground for a long period or forced to sell their produce at low prices during harvesting and buy seed tubers at high prices during planting. A study on extended harvesting period in Alemaya revealed that yield of marketable tubers was reduced by 60% when tubers were harvested at 210 days after planting as compared to a harvest at 120 days (Berga, 1984). Similarly Gebremedhin (1987) reported that significant yield reduction (70-100%) was obtained as harvesting was delayed from about 125 days to 230 days at Holetta.

Therefore, the low-cost diffused light store (DLS) for seed tubers developed by CIP has been evaluated under the Ethiopian condition. It was found to be very useful and efficient storage technique. Consequently, it has been adopted by many potato farmers' in many parts of the country. Agajie and coworkers , (2008) reported that, 87% of the central part and 25% in the north and west are using DLS to store their improved variety seed potato. Thus, practical training was given to farmers in different parts of the country and they are aware of the new seed storage technology that is, DLS. Generally, better quality seed tubers are obtained with storage in DLS than in traditional dark storage, resulting in increased productivity in the country.

In DLS tubers can be stored 8-9 months without much loss. They also produce 3-4 sprouts, which are green and strong consequently giving high yield. If possible seed store should be covered with aphid proof screen to avoid insect entrance.

Scio-economics and research extension: Technology transfer is both a technical and nontechnical process, and it should be carried out in collaboration with stakeholders. The main objective of technology transfer is to improve peoples' welfare steadily gradually and continuously. In Ethiopia, there are still some drawbacks of technology transfer such as inappropriate channels, applicability of the technology, and lack of integration. A number of potato technologies were promoted through participatory seed multiplication and scaling-up from production to utilization in different parts of the country. These promotional activities sought to facilitate the diffusion and adoption of potato technologies that will improve potato production. To transfer these new technologies, activities were conducted in two phases.

In the first phase, participatory seed multiplication was conducted over the last 10 years. During this time, researchers, farmers' research groups (FRG), development agents (DA), subject matter specialists (SMS), development project workers, nongovernmental organizations, and other stakeholders were involved in planning, technology dissemination, awareness creation, monitoring, and evaluation. This was to promote adoption of new technologies by producers.

In the second phase, before launching the actual activity, an inception workshop was held with all stakeholders. Researchers played a catalytic role. On the basis of group consensus, the seed, which is maintained during the evaluation and seed multiplication phase one, was distributed to all members of the FRG, bringing the productive seed (a technology) closer to farmers. Currently, potato farmers are using almost all components of the potato production package. Throughout the whole process of evaluation, seed multiplication, and scaling-up of improved technologies, participation of farmers and stakeholders was useful to promote the diffusion and adoption of improved technologies, knowledge, and skill of quality seed production, and postharvest handling. This established the farmer-to-farmer seed exchange and information dissemination system. In the process, a number of field days were organized to demonstrate the production, postharvest handling, and utilization of potato. In general, technical backstopping and creating good public-private partnership and technology transfer system are the most important issues that need more attention.

Sweet potato

Varieties developed: To date, a total of 24 sweet potato varieties have been released in Ethiopia, among which six are orange fleshed. Among the 24 varieties, Awassa-83 is the most dominantly grown variety in most of the sweet potato growing areas of the country. Farmers prefer to grow this variety due to its high yielding potential, high total biomass and high dry matter content as compared to other varieties.

Available Germplasm: The major source of germplasm for sweet potato improvement has been the International Potato Center (CIP). Most of the sweet potato varieties that have been developed in Ethiopia are of CIP origin. Currently, more than one thousand improved seeds with different characters were introduced from CIP and are under screening. Crossing of sweet potato in Ethiopia started in 2013 and currently some clones with better yield, beta-carotene and dry matter contents have been developed and are being evaluated under multi-location trials. The released varieties are maintained at Hawassa Research Center to serve as source of planting materials.

Agronomy: In sweet potatoes, like in all other crops, agronomic factors/management practices are among the crucial factors that highly influence crop yield and quality. However, sweet potato farmers in Ethiopia usually use traditional management practices. In most cases, farmers' practices cannot effectively and efficiently address the different agronomic challenges and problems faced by growers. The production and productivity of the crop has thus remained low due to poor management, among other major reasons (Girma *et al., 2008*)

The sweet potato improvement research program undertakes different works that can help alleviate the existing production and productivity barriers of the crop through the use of not only improved varieties but also appropriate management practices. Good management would enable farmers to exploit the potential of improved or local sweet potato varieties for higher yield and quality produce.

Seedbed Preparation: Different seedbed preparation methods are used in sweet potato production at different localities based on the soil type, moisture holding capacity, depth and workability. However, the most common methods are mounds, ridges and planting on the flat. Flat planting is recommended for areas like Hawassa where the soil type is more of sandy that can easily percolate water. But, generally in moisture stress areas or during non-rainy season, tied ridge is the most universally recommended method of growing sweetpotato (Girma *et al*, 2008).

Spacing: Spacing may vary depending on soil condition and crop variety. In root and tuber crops, spacing directly affects the root size grades for domestic use as well as market. Spacing experiments at different locations showed different results and as a result spacing combinations of 60 cm x 30 cm for Hawassa and Areka, 100 cm x 30 cm for Tepi and 60 cm x 35 cm for Jima were recommended. The recommendations have considerable difference in spacing between rows varying from 60 up to 100 cm. This difference has an implication on quantity of planting material and cost of production. There might be a need to further look in to the problem and identify the reasons behind and see the possibility for cost effective recommendation (Girma *et al,* 2008).

Soil Fertility Management: Soil fertility decline is noted as the principal cause for crop yield reduction in Ethiopia. This has happened due to continuous cultivation, removal of crop residue for livestock feed and fuel wood, insufficient fertilizer supply, erosion and poor soil management. This aspect may assume serious dimension in root and tuber crops production, particularly sweetpotato as the crop is a heavy feeder of nutrients. Therefore, it is essential to replenish soil fertility to sustain crop growth and high yield. The nutrient requirement of the crop depends on the type of the soil and expected yield. Efforts have been made in Bako on farm, Hawassa, Areka, Loko and Nedjo to mitigate low soil fertility problems. But the recommendations from such experiments are not in use currently by farmers. Another experiment conducted in SNNPR at Halaba special district indicated that application of 46 kg P_2O_5 and 92 kg Nitrogen gave better yield. However, this result has to be verified at similar locations before recommendations are given.

Crop protection: The major insect pests of sweetpotato in Ethiopia are sweetpotato weevil *(Cylas puncticollis L.)*, sweetpotato butterfly (*Acraea acerata)*, sweetpotato hornworm (*Agrius convolvuli)*, tortoise beetles (*Aspidomorpha spp*.,) and virus transmitters such as Aphids (*Aphis gossypii)* and white fly (*Bemisia tabaci)*. Among these insect pests, the most serious ones are the sweetpotato weevil and sweetpotato butterfly which can cause a yield reduction of 60-80% (Temesgen *et al.*, 2008). The sweetpotato weevil larvae and adults feed on the roots, causing extensive damage, both in field and storage, in many parts of the world. Roots may be initially attacked during storage or may be contaminated with eggs or larvae from the field. Such contaminations may not be readily visible to the naked eye and apparently healthy roots may be stored only to be attacked when eggs hatch and larvae begin to feed. Previously uninfected roots are also exposed to attack. The weevil may go through several life cycles during a prolonged storage period. Weevil damage produces quantitative losses and aesthetically unappealing roots which may be discolored and have bitter taste. The weevil also stimulates the production of phenolic compounds, leading to brown discoloration of the flesh and also phytoalexins such as ipomeamarone (Woolfe, 1992). In Ethiopia, losses due to the insect pest range from 20-75% (Emana, 1990) and 70-80% (Temesgen *et al.*, 2008). Studies had been made on cultural control methods such as planting date, time of harvesting, crop rotation, variety screening and integrated pest management. The second most important insect pest of sweetpotato is the sweetpotato butterfly (*Acrea acerata*) which was reported to cause over 60% defoliation (Temesgen *et al*, 2008). A study was made at Hawassa and Areka to investigate the effect of planting date on the yield of sweetpotato and infestation of sweetpotato weevil. The findings of the study indicated that early planting, besides increasing yield through plant growth vigor, is associated with significant reduction in sweetpotato weevil infestation (Temesgen *et al*, 2008).

Among the pathogens, viruses, fungi and bacteria are responsible for economic losses of sweetpotato worldwide. Different types of viral, fungal and bacterial diseases have been recorded in Ethiopia. However, the most devastating sweetpotato disease in Ethiopia is the sweetpotato virus (Tadesse et al., 2013; Mekonnen et al., 2014). In east Africa in general, over 90% sweetpotato yield reductions have been associated with viruses (Gibson et al., 1998). Since late 2004 to 2011 four types of viruses namely, Sweetpotato feathery mottle virus (SPFMV), Sweetpotato chlorotic stunt virus (SPCSV), Sweetpotato virus (SPVG) and Sweetpotato virus 2 (SPV2) were identified and recorded in the country.) In 2012 other six viruses, namely, C-6 virus, sweetpotato caulimo-like virus (SPCaLV), Sweetpotato chlorotic flecks virus (SPCFV, Sweetpotato latent virus (SPLV), Sweetpotato mild speckling virus (SPMSV) and Cucumber Mosaic Virus (CMV) were identified and recorded (Mekonnen *et al*, 2014).

Planting material production: Foundation planting materials of sweetpotato are primarily produced by Hawassa Research Center. The center has been producing pre-basic and basic planting materials of the crop and selling to various vine multipliers. Multiplication of the planting materials starts with cleaning of the planting materials from diseases, especially viruses in a tissue culture laboratory at Arkea Research Center. Then the cleaned materials are produced in insect proof net tunnels as pre-basic seeds. The vines derived from the net tunnels are then multiplied in open field as basic seeds. The vines from the basic fields are sold to private vine multipliers for further multiplication in order to meet the huge demands from various organizations. Currently, there are registered private commercial sweetpotato vine multipliers in Ethiopia such as Jara Agro-industry, Ezera PLC, Muluneh Boru farm PLC, Mulualem farm, Ayzman PLC, Wamole seed enterprise and Hulume seed enterprise. Almost all of these multipliers mainly focus on multiplication of sweetpotato vines and sell to governmental organizations (GOs) and non-governmental organizations (NGOs). Then the GOs and NGOs distribute the vines to farmers, especially during severe and prolonged drought.

In 2014/15 alone, more than two million basic sweetpotato seeds/cuttings have been sold from Hawassa Research Center to various organizations such as Ayzman PLC, Agri-Service Ethiopia, Lutheran World Federation, KOGOVED PLC, Jara Agro industry and FAO. Similarly, the multipliers were selling millions of cuttings to various GOs and NGOs. Through the collaborative project between SARI and CIP, considerable amount of cuttings were distributed to different districts in SNNPR and Oromia regions. Accordingly, 5,135,000 vines in 2011, 6,190,166 vines in 2012, 225,000 vines in 2013, 1,088,000 vines in 2014 and 4,420,000 vines in 2015 were distributed to different districts of SNNPR and Oromia.

Postharvest handling: Duration of harvest is a function of variety, soil type (nutrient), availability of other foods, household size, disease and pest infestation and weather conditions. Sweetpotato roots are ready for harvesting from 3 months after planting. Varieties such as Awassa 83, mature in 6 months after planting, Guntute 5 months and Belela 3 months. If the crop is harvested too early the roots will not be fully developed;

too late, the roots may be fibrous and possibly pest-infested thus reducing yields. Harvesting can be done on a piecemeal basis and whole crop harvesting. The practice involves harvesting small quantities and normally starts as early as 2 months after planting for some varieties. Varieties with longer maturity period are usually more suitable for piecemeal method than early maturing ones which have all their roots maturing at almost the same time. Sweetpotatoes should be handled with care after harvesting to prevent cutting, skinning, and yellowing. The roots must also not be exposed to the sun for more than an hour or so after digging. To prevent infection by disease-producing organisms, the roots should be kept in ventilated area until used or sold. There is no storage facility for sweetpotato in Ethiopia and therefore the shelf-life of the crop is very short.

Sweetpotato is among crops that have short shelf-life since the roots contain about 70% water. Limited knowledge about sweetpotato processing and preservation, and lack of processing equipment makes sweetpotato postharvest handling among the major constraints of sweetpotato as described by farmers in the major sweetpotato growing areas of the country (Gurmu *et al.*, 2015).

Therefore, there should be a postharvest handling technology to prolong the shelf-life of the crop. In most of the growing areas, sweetpotato root is consumed boiled and there were no postharvest handling technologies. Sweetpotato can be processed into numerous traditional products by mixing its flour with cereals and legume crops. The root can be processed to make bread, enjera, flour, cookies, wot (stew), local beer and juice. Given proper training, and access to appropriate equipment, farmers could make a range of food items from sweetpotato. This would reduce the postharvest losses of the crop and help maximize its utilization.

Scio-economics and research extension: A survey by Gurmu *et al.* (2015) showed that the major pre-harvest production constraints of sweetpotato constitute: heat and drought (21.6%), shortage of planting materials (20.1%), shortage of land (15.7%), diseases (10.0%), insect-pests (9.4%), a shortage of draft power (8.1%), shortage of money to purchase inputs (7.9%), a shortage of labour (5.1%) and weeds (2.0%). Similarly, poor access to markets (22.6%), poor market prices (19.1%), low yields (14.2%), low preferences due to low root dry matter content (13.6%), a lack of knowledge on processing (11.7%), a lack of processing equipment (11.1%) and transportation problem (7.7%) were identified as the major postharvest constraints. The major farmers' selection criteria for sweetpotato varieties were resistance to heat and drought (19.6%), dry matter content (16.4%), taste (14.3%), root yield (13.6%), resistance to disease and insects (13.3%), earliness (11.6%) and cooking ability (8.9%). Similar results were reported by Tadesse *et al.* (2006) that farmers prefer sweetpotato varieties based on characteristics like resistance to diseases/pests, marketable tuber size and colour, and ease of intercropping and palatability.

Since most farmers (98.4%) store the roots *in-situ* in the soil and practice piece-meal harvest, the roots are affected by insect pests (mainly weevils), diseases and rodents and the quality deteriorates (Gurmu *et al.*, 2015).

According to Million *et al.*, (2008) the sweetpotato marketing system was relatively not well developed because of various reasons. Although the sweetpotato marketing channel was very long, the volume of transaction and the incremental profit margin that traders obtained was very low. From the total number of sample traders interviewed, 86% were retailers and 6% wholesalers, while the remaining 8% were assemblers. Except for the wholesalers, almost all retailers and assemblers were operating within production areas. The same study indicated that sweetpotato consumption increases during May and June mainly because during these months, household grain reserves were usually finished and the price of cereals mostly tends to rise. Hence, people consumed more sweetpotatoes. Due to increased demand during this period, farmers who had irrigation facilities were encouraged to produce sweetpotato and got better prices. Nevertheless, the major supply of sweet potato remained to be influenced mainly by price of other crops and its own price, availability of moisture or rainfall, and occurrence of insect pests. Lack of high yielding varieties was also one of the important factors influencing the market supply of sweetpotato.

Cassava

Varieties developed: Variety trials for yield and other agronomic trials had been started at Hawassa, Jima, Bako, and Melka Werer research centers since 1975 on some introduced germplasm of cassava. Through the effort of national and regional research institutes, more than 80 germplasm were introduced as integral parts of cassava variety development. Some of these were tested at different agroecological locations from 1996-2001 in Ethiopia and two most promising varieties (Qulle and Kello) were officially released for production. They give 27 and 28 t/ha, which is by far higher than the world average 9.4 t/ha (MoA, 2006).

Available Germplasm: Different cassava germplasm were locally collected and introduced from cassava growing countries (Uganda, Kenya and Tanzania) in the form of botanical seeds. More than 500/five hundred/ germplasm with different morphological and nutritional traits are maintained at Hawassa and Jima agricultural research centers with the objectives of evaluating them for higher storage root yield, low hydrogen cyanide content, high dry matter content, earliness, biomass yield and adaptability to local agroclimatic conditions. Among the germplasm orange fleshed clones with higher beta-carotene content, which is a precursor for vitamin A, are found to be maintained for further evaluation.

Agronomy: Low soil fertility, nutritional imbalances, soil salinity, crop field management like weeding are among the factors that reduce cassava yield in addition to the inherent genetic potential. Cassava is a crop that extracts large amounts of nutrients from the soil, especially N, P and K. A study showed that cassava required about 200kg/ha of Nitrogen, 100kg/ha Phosphorus and 100kg/ha potassium to give an average fresh storage root yield of 23.9t/ha (Bernando and Hernan 2012). The presence of weeds during the first 60 days of the crop cycle was observed to reduce yields by about 50% compared with cassava that was free of weeds throughout the cropping cycle (Bernando and Hernan 2012).

In Ethiopia, little cassava agronomic research has been conducted. Spacing trials were conducted at Amaro and Hawassa during 2004-2005 cropping seasons. For optimum cassava production a spacing of 80cm X 80cm was recommended for Amaro while a spacing of 100 cm x 80cm was recommended for Hawassa and similar agroecologies (Gobeze *et al.*, 2005).

Intercropping cassava with haricot bean, cowpea, soybean and mung bean, reduced cassava yield by 27, 37, 52 and 50%, respectively. However, intercropping cassava with haricot bean, cowpea, soybean and mung bean resulted in 82, 49, 48 and 62% greater land use efficiency than for either crop grown alone. (Legese and Gobeze , 2013)

The HCN content as affected by the soil nutrient amount especially that of potassium(K_2O) was studied and concluded that at lower doses of potassium application, root HCN content was relatively high. It substantially decreased at higher rates of potassium, which indicates the need for further experimentation with more cultivars and other sources of potassium. Although potassium is found important in reducing the HCN content of cassava roots, other locally available and cheap sources of potassium such as wood ash can alternatively be used by the mainly subsistent farmers who usually cultivate the crop (Endris,S. 1977).

Nitrogen and P fertilizers effect on storage root yield was conducted in different agroecologies of the country (Hawassa, Jinka, Goffa and Bonga) and had shown a significant yield increase as compared to the untreated check with some exceptions at Hawassa where no significant difference was among the tested N & P rates. The highest storage 31.8 t/ha was obtained from application of 100 kg/ha urea & 50 kg/ha DAP. The result is by far higher than the control which received no fertilizer (Personal communication).

Crop protection: The main diseases affecting cassava are cassava mosaic virus (CMV), cassava bacterial blight, cassava anthracnose, and root rot. Pests and diseases, in combination with poor agronomic practices, combine to cause high yield losses in Africa (AIC, 2002). Although there is no tangible evidence on the occurrence of viral diseases, cassava root rot blight and leaf spot were observed in Ethiopia. In the same way, cassava white flies (*bemisia tabaci*), cassava green mite *(mononychellus tanajo),* cassava mealy bug *(phenacoccus manihoti),* cassava white scale *(aonidmytilus albus)*, elegant grasshoppers (*zonocerus spp*), termites and vertebrate pests (monkeys, wild pigs, goat's rats, and birds) are the most important pests.

The most important insect pests attacking cassava in the production areas in Ethiopia are cassava scale insect (*Aonidoytilus albus),Cassava green mite (Mononychellus tanajoa) and Red spider mite (Tetranychus spp) (*Ermias *et.al.*, 2012). Among these, cassava scale insect was the most serious one. Cassava scale *(Aonidomytilus albus) (*Cockerel) (Hem: Diaspididae) was reported for the first time in 2001 at Amaro. It was affecting the production and productivity of cassava in southern Ethiopia, Amaro especial Wereda (Mesele *et al*., 2007).

Very few research activities have been conducted in Ethiopia to manage cassava scale insect damage. To study the biology, field abundance and seasonal patterns of cassava pests (scale insect) pot and field experiments were conducted. But the results have not been released for farmers to apply. Chemical and germplasm screening for cassava scale insect were also conducted. Accordingly clear variation among the germplasm for the reaction against cassava scale insect was observed. A total of 11 promising germplasm were found and promoted to further evaluation (Mesele and Ermias 2014, unpublished).

Moreover chemicals screening including untreated control were evaluated in insect hot spot areas under natural infestation. Two chemicals, dimethoate and Deltanate were found to be very effective. The management options have not been popularized by the researchers to be utilized by cassava farmers (Mesele and Ermias 2014, unpublished).

Seed/planting material production: One of the most important problems of cassava production is the lack of quality planting materials and formal seed production system in the country beyond breeder and pre-basic seed multiplication by research centers. Two improved varieties are multiplied on more than 8ha of land at Hawassa, Dilla, Arbaminch, Areka, Goffa and Jima for different purposes. From these multiplications a number of cuttings (more than 4 million cuttings) were distributed for further multiplication, research and production.

In the year 2014/2015, Hawassa agricultural research center sold more than 950, 000 cuttings and generated more than ETH Birr 325,925.

Postharvest management: Upon harvesting, cassava starchy storage root suffers a rapid deterioration that renders it unpalatable and unmarketable within 24 -72 hrs depending on the environmental conditions. Except farmers' preservation methods of cassava after harvesting and/or leaving in the ground after maturity no other postharvest methods have been designed in Ethiopia despite its significant and critical value. Farmers preserve cassava roots through extended harvesting after maturity, chopping and sun drying, converting chips into flour and store in ordinary jute sack under low temperatures (Tesfaye *et al.*, 2013).

Though research on postharvest handling of cassava is lacking, a number of anti-nutritional and nutritional analysis of cassava varieties were conducted. Mulugeta and Eskindr (1999) studied effect of storage methods and cooking practices on the total hydrogen cyanide content of cassava cultivars. They obtained a high reduction of 98.6-99.3% in total hydrogen cyanide in sun dried flour compared to roots stored underground trench (19.9-23.5%), and refrigerator (-33.6%). They also tried to show that cooking reduced the total hydrogen cyanide from 61.0 to 98.2% depending on cultivar and practice of cooking.

An experiment on detoxification of cassava was conducted and interesting results were obtained. Processing methods such as washing, boiling, drying and fermenting with flour of cereals were evaluated to increase nutritional content and reduce cyanide levels. They concluded that peeling, solar drying and fermentation were found to be the best methods to removing the cyanide content of cassava by 99.7% and blending with cereal flours improved nutritional quality of cassava-based foods (Aweke *et al*., 2012).

Analysis of HCN, moisture and fiber content of garri produced from different cassava varieties were conducted by Hawassa College of Agriculture. The total moisture, cyanide and fiber contents varied from 26.1-40.0 %, 1.5-2.8 mg HCN/100 g and 1.8- 2.4%, respectively. The Kello44/72 and MM96/5280 varieties with the lowest cyanide and comparable fiber contents are most suitable (Enidiok *et al.* 2008). From this study it could be concluded that moisture content of cassava roots are inversely related to the total cyanide content.

Scio-economics and research extension: Status, Potentials and challenges of Cassava production, processing, marketing and utilization assessment of cassava in selected SNNPR was conducted. The assessment result indicated that cassava stands first in both production and productivity followed by sweetpotato and maize in Belg (short rainy season) while during Meher (long rainy season) the reverse was observed (at Amaro, Kindo Koisha, Debma Gofa, Konso and Arbaminch) (Tesfaye et al., 2013).

In the study area, the Area allocated for improved and local cultivar cassava on average is 0.19 and 0.30 ha, respectively. Land preparation for all crops under cassava farming system was carried out using outdated and labor intensive tools such as hoe (66%) and oxen plough (33%) of sample farmer's average for the five districts. Cassava is used to generate income by selling fresh cassava root from the farm and/or the nearby local market. In the same way, processed cassava products especially cassava chips and flours were consumed and sold in the study areas. Most of the farmers obtain planting materials from their own savings but a few had gotten from relatives, friends and other sources. The two improved varieties introduced to the farmers were kello (44/72 red) and Qulle (104/72 Nigerian red). The adoption rate for the improved varieties by the sampled farmers in the study area on average was only 30%. Major constraints to cassava production include insect pest attack , lack of early maturing varieties, shortage of land, low moisture stress and low market demand and/or price. Thus it was recommended that labor saving farm implements, management of cassava scale insects and existing post-harvest processing equipment need to be employed to improve cassava production and productivity. Development of early maturing cassava varieties is a pertinent solution to solve problems related to long maturing cassava varieties (Tesfaye et al., 2013).

Demonstration and pre-scaling up: The adaptation of high yielding, disease resistant and low HCN containing varieties released in Ethiopia is being practiced at different agroecological locations (Somale, Gambela, Mytsemri, Asayta, Tepi, Gambella, Pawe and Alamata). Varieties Qulle and Kello have shown an excellent performance in some of these areas beyond their recorded yields at Hawassa and other centers in the south. The case in point is Pawe, where they yielded 54.6 and 66.3 tons per ha. In North western Tigray A total of 10 male and five female farmers participated in the demonstration and popularization of cassava varieties released so far. For this purpose 374 cuttings from Qulle, 319 cuttings from Kello and 50 cuttings from local varieties were distributed to the selected farmers. Pre-scaling up of cassava varieties using two released cassava varieties, was carried out at Silte, Hossana and Burji. Totally 220 farmers participated in the pre-scaling up activity. The farmers found that the improved varieties were better than their own cultivars in root yield, earliness and palatability.

Enset (*Ensete ventricosum*)

Enset is the backbone of the southern, central and south western parts of Ethiopia. This perennial crop mostly covers the densely populated areas. Had it not been for enset, the livelihood of the inhabitants would have been greatly threatened in the past many decades. The high yield per unit area coupled with its ability to withstand drought makes enset an ideal and strategic crop for the populace (Mesfin *et al*, 2008).

The enset Improvement Program has focused on variety improvement, agronomy, crop protection, storage technology, food science (utilization), seed production techniques, socio-economic studies and research-extension. In the genetic improvement high priority was given to the development of high yielding, bacterial wilt tolerant varieties, with wide adaptability and desirable horticultural characteristics and culinary qualities. The agronomic research, on the other hand, emphasized the development of appropriate cultural practices such as planting dates, plant density, fertilizer rate and time of application, and depth of planting.

Variety development: So far six high kocho yielding enset varieties with early to late maturity cycle adapted to low, mid and high altitude areas have been released. Morphological characterization of enset clones based on phenotypic traits has been done at Areka Agricultural Research Centre (Tabogie, 1997; Yeshitila and Diro, 2009; Bekele *et al*., 2008). However, morphological characterization of the clones is rudimental and a well-established taxonomic classification and descriptor list are lacking. In addition, attempts have been made to document and analyze clonal identity using farmers' classification. In these cases, clonal names reported in the literature are associated with only limited phenotypic data provided by farmers (Shigeta, 1991). Molecular characterization of enset clones was conducted using AFLP (Tsegaye, 2002; Negash, 2001) and RAPD techniques (Birmeta, 2004). However, enset accessions considered in their studies were from limited growing areas. Efforts were also made to genotype some enset clones using molecular markers developed for *Musa* with the assistance of Generation Challenge Program (GCP)

Available Germplasm: Since 1994, enset clones were collected from their major growing areas of SNNPR and Oromia regions, and more than 652 enset vernaculars are collected and conserved *ex situ* by Areka Agricultural Research Center, the Southern Agricultural Research Institute

Multiplication of disease free planting materials of enset through tissue culture provides opportunity to manage the spread of bacterial wilt disease, which is threatening enset production. Attempts have been made to optimize protocols for *in-vitro* propagation of enset (Zeweldu and Ludders, 1998; Tesfaye, 2002; Diro, 2003). Recently, enset in vitro propagation protocol has shown the possibilities of obtaining about 50 shoots per shoot tip explant (Girma, 2009, Personal communication).

Agronomy and Physiology: Agronomic practices (spacing, fertilizer, propagation methods and nursery management). Most of the research on enset has concentrated on agronomic studies (Bezuneh 1996). Agronomic research was developed mainly by Areka, among which propagation (seed/vegetative), planting time, spacing, frequency and rate of organic and inorganic fertilizer application and frequency of transplanting are the major ones (Diro,1997; Belehu, 1996; Tabogie *etal*.,1996; Haile *etal*.,1996; Diro *et al*.,1996).

According to the recommendations, during sucker production from the corm to propagation, splitting the corm in to two at equal position and planting the two half corm independently, on 1m x1m spacing on 30-40cm deep hole at 45^0 tilted on upright position by covering 10cm deep with top soil provide strong and large number of suckers. In addition to that, direct transplanting of suckers in to main field on 1.5m between plant and 3m between rows spacing give better yield and shortened maturity time of the crop; compared with multiple transplanting. In the main field application of 10kg compost or 45g DAP and 117.5g urea per year per plant also increases the yield of the crop and shortens its maturity time.

Crop Protection: Various diseases of enset have been reported. Some of these are leaf damaging fungal diseases, corm rot, sheath rot and dead heart leaf rot of enset with unknown causal agents. Root knot, root lesion and black leaf streak nematodes are also known as enset production constraints (Quimio and Mesfin, 1996). There are also viral diseases of enset known as mosaic and chlorotic leaf streak diseases. However, based on the distribution and extent of damage, Enset bacterial wilt disease caused by *Xanthomonas campestris pv. musacearum* is the most destructive and highly invasive disease that is considered a threat to enset production system.

Most of Fungal diseases of enset are not as such threatening to crop production relative to bacterial wilt. Foliar fungal diseases largely affect the crop at the early growth stage by causing leaf spot and blight. These later coalesce and severely affect the photosynthetically active leaf area of the crop. As the crop gets older, it resists most of the fungal pathogens. Among the fungal diseases, corm and root-rot diseases were found as devastating especially on young seedlings (Mesfin *et al*.,2008).

Seed/planting material production: In the last five years, on average 10,000 to 15,000 suckers/year of released enset varieties and bacterial wilt tolerant enset clone (mazia) have been multiplied and distributed to more than 727 farmers and to universities (Wolkite University, Wachemo University) by Areka Agricultural Research Centre. In collaboration with different organizations, like Concern Ethiopia and FAO hundreds of thousands' of planting materials were distributed to farmers.

Postharvest handling or management: Little research is done on enset towards improving postharvest handling and management. Traditional enset fermentation increases types and numbers of microbs and contributes to the reduction of nutrients in Kocho and its spoilage (Tariku, 2012). The traditional postharvest managements are also tedious and highly labor intensive, unhygienic and associated with great yield losses. According to Atnafua and coworkers (2008), the use of white plastic sheet is recommended as good storage material for kocho. But, the effect of chemicals released from plastic sheet in the process of fermentation on the human health needs investigation.

Scio-economics and research extension: Survey has been done on bulla Value chain and the result shows that rural retailers, assemblers, whole sellers and urban retailers are engaged in bulla transaction and trade. They rarely add value to this product, but make available to consumers in their locality. Moreover, baseline survey on enset production constraint and disease mapping were conducted on major enset producing areas. Enset bacterial wilt disease is the number one constraint to enset production followed by moisture stress and mole rat attack.

Demonstration and pre-scaling up: Efforts have been made on promotion and dissemination of Enset production technologies. Hundreds of thousands of improved enset suckers, 32 processing devices and 180 scrappers are among technologies disseminated in the past. On the other hand, attempts have been made by Awassa and Areka Agricultural Research Centers to introduce and demonstrate improved enset decorticator and squeezer and reports showed that the technologies were accepted by the participant farmers.

Recommendations and the way forward

Root & tubers crops will continue to play a significant role in the Ethiopian food system because: 1) they contribute to the energy and nutrition requirements over the next two-three decades; 2) they are produced and consumed by many of the world's poorest and most food insecure households; 3) they are an important source of employment and income in rural, often marginal areas, including for women; and 4) they adapt to a wide range of specific uses, from food security crop to cash crop, from food crop to feed crop, from the latter to raw material for industrial uses, and from fresh food to high-end processed product. To realize the potential of root and tuber crops, a combination of new technologies and improvements in the institutional and policy environment will be required.

A set of constraints along the R&T crops value chain has to be considered simultaneously, to ensure higher yields, better income and a significant contribution of R&T crops farming to food security and improved livelihoods in the country. For example high yielding varieties have to be released that have good resistance to the major disease of the crops and low degeneration rate as well as good table and processing qualities. These varieties should have wide adaptability, with a potential to produce well in the different agroecolgies of the various regions. If seed of these varieties is made available to growers, using rapid multiplication technologies such as aeroponics and farmers learn to keep the quality of their seed/planting materials for a longer time through on farm seed maintenance technologies and suitable seed storage, there is a great potential to boost R &T productivity and production, especially if these are coupled with best cultural practices like soil fertility management and disease control measures as well as storage technologies.

To achieve the required /planned in research and development of root and tuber crops the following area should get more focus:

- Working in partnership to avoid duplication of efforts and promote complementarities
- Strengthening the capacity at all levels (Human power, Laboratory and Budget).
- Empower farmers through continuous training, follow up visits and M&E
- Give emphasis to Quality Declared Seeds (Standards for disease and insect pest limits, Packaging, Prices, Marketing and Seed certification).
- Highly decentralized seed/planting material multiplication schemes allow farmers in remote areas to gain access to affordable quality seed.
- Quality seed needs to be clearly separated from ware products through branding, labeling, and the creation of separate seed value chains.

- Targeted Research (agroecology based research, drought, climate change, nutrition, industrial use)

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Spice Production and Future Research Demand in Ethiopia

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Introduction and back ground information

Economic value of spices in Ethiopia

Ethiopia, with a population of more than 90 million people, was on the ancient spice trail from India and was visited by Arabian and Persian spice traders, who left their mark on the cuisine. It has become one of the largest producer and consumers of spices in Africa. People use spices to flavor bread, butter, meat, soups, and vegetables. And they use them to make medicines and perfumes. Similar to India, the majority of spices produced in Ethiopia (80 %+) are absorbed domestically (AIA, 2010). At the same time, export of spices has been developing and bringing increased foreign exchange (ERCA, 2014). The share of spices export in total export earnings of Ethiopia has in general remained negligible. That is, except for the year 2012/13 and 2013/14 in which the share of spices exports in total export earnings was 1.1 and 1.3 %, respectively. The major export spices from Ethiopia are ginger, turmeric, black cumin, and chili products. There are however, spices like saffron, cardamom, cloves, and cinnamon that are not produced that much in the country, however, the data shows that the country re-exporting these spices after importing (ERCA, 2014). The major export destinations for Ethiopian spices are Sudan (40.1 % of the total export volume goes to Sudan), India, Yemen, Saudi Arabia, Djibouti, Singapore, South Africa, and other African, European, Asian and American countries.

Though the country has a positive trade balance in spice, most of the imported spices can grow in the country given the existence of diverse and suitable agroecology. When we see the suitability of the country for growing of those spices it can make the country covering its demand and become one of the major competitors in the export market. In 2012, spice exports reached 23,518 tons with equivalent value of 28 million USD and the country ranked ninth in world production and export of spices (FAO, 2012/13).

The economic importance of spices can be elaborated more by the status of black cumin production and marketing in Ethiopia in the period 1997-2001. During this period, a total of 35,508 quintals black cumin seed at a value of 46,229 million USD has been supplied to the world market. At the same period, a total of 58,870 quintal of black cumin seed was produced in Ethiopia and of this, 453 quintal was exported annually (Ministry of Trade, 2001). This indicates that Ethiopia has about 12% share in the world market, while 99% of the produce was consumed locally. In terms of share on household expenditure, on average, 1.79% of the total household expenditure goes for spices with major expenditure going to pepper whole and flour, followed by ginger, fenugreek, and then cinnamon, chilies, long pepper and mixed spices (CSA 2005).

In addition, Ethiopia has experience of producing and exporting oleoresins and essentials oils for more than 50 years. Due to the refined nature and extremely minimised volume, essential oils are widely used in the world in substitute for the original plant material from which they are derived. Particularly, they are in common use in different industrial firms of the developed world. However, the sector remain untouched due to the limited capacity of processing in the country. Countries like India import row turmeric and ginger from other countries like Ethiopia for production of oleoresins, which is exported to USA and Europe with premium price.

Spices production in Ethiopia

Production and productivity as well as area coverage of spices increased since the start of research intervention. The average land covering by spices is approximately 222,700 ha with an estimated production of 244,000 ton/annum (Masresha Yimer, 2010). Total area, production and productivity levels for different years of the different spices produced in the country is presented in Table 1.

Table 1. Area, Production and yield of spices in Ethiopia

Crop	Area in ha.	Production in quintal	Yield quintal/hectare	Yield in research field	Year
Fenugreek	24, 426.24	456,266.15	18.68	12-22	2006/2013/14
Black cumin	21550	170720	7.9	9-16	2005-2007
White cumin	350	1400	4		
Coriander	942.0	2372	2.5	10-24	2010/11
Ginger	21732.49	4660139	51.2	75	2010/11
Turmeric	2070	227500	35	200-300	2010/11
Black pepper	2000	24600	12.8	21-30	2014/15
kororimma	9233.30	56252.50	6		

Source: CSA, 2015 & Masresha, 2010

Given the importance of the different types of spices for local farmers' livelihood and export, the research system has been focused only on seven types of spices. Accordingly, there are spices for which there are no any improved variety released like for Kororimma and White cumin.

Spices research development in Ethiopia

The spices research program in Ethiopia starte in 1975 with the collection and/or introduction of germplasm. During that time, spice crops got special consideration as alternate cash generating commodities linked with the policy direction on the need for coffee diversification. Because, they have significant untapped potentials to augment the foreign currency earnings, withstanding the impacts of the commonly observed drastic fluctuations of world coffee market.

Consequently, the spice research team was established in 1980 to run and co-ordinate extensive research activities at a national level. During this time, however, the program was forced to encompass only those spice crops with highest export demand till 2010. This was one of the basic reasons that resulted in the restricted activities of the program on very few crop species and under limited agro-ecology zones (AEZs) (mainly in Jimma, Tepi and Bebeka).

As the Institute gave a due consideration to this research program, recently, the previous Tepi research Sub-center was upgraded to a full-fledged research center (Tepi National Spices Research Center) as a center of excellence for spices research. Currently, the research program was capacitated in human and physical facility. In the meantime, the program has been thriving a lot on collection and /or introduction a number of accessions of varied types of spices, evaluation under different agro ecologies for yield and quality attributes. As a result, the program succeeded in releasing a number of varieties along with recommended agronomic practices.

Research achievement

Breeding: So far the national spices breeding research team release 15 improved spices variety (table 8). In Ethiopia a number of improved spices varieties increasing the production and productivities of spices as well as farmer's income and the country have been benefited by hard currency generated from exporting of spices

Table.8. Spices variety released.

Type of spices	Variety	Yield (Q/ha)	Agro-ecology
Vanilla	Yeki 1	2.29	Hot humid low land
Black Pepper (*Piper nigrum L.*)	GACHEB (Pan. 4/80)	30.5 (dry)	Hot humid low altitude
	TATO(Sril.3/80)	21.7 (dry)	
Ginger (*Zingeber officinale Rosc*)	YALI (Miz.180/73)	200-250 (Fresh)	Low and mid altitude
	BOZIAB (Mau.37/79)		
Turmeric (*Curcuma domestica*)	DAME (Ind. 48/72)	200-290 (Fresh)	Low and mid altitude
Cardamom (*Elettaria cardamomum*)	GENE (Tan. 82/72)	1.4-1.8 (dry)	Low and mid altitude
Black cumin *(Nigella sativa)*	DERSHYE	9-16 (dry)	High altitude
	ADEN	9-16 (dry)	
	Darbera	15-19 (dry)	
Coriander *(Coriandrum sativum* L.)	INDIUM 01	10-24 (dry)	Mid and high altitude
	Walta-I	10-24 (dry)	
Fenugreek (*Trigonella foenum-graecum*)	Hunda-01 (FG-18)	12-22 (dry)	Mid and high altitude
	Chala (FG-47-01)	9-16.5 (dry)	
	Ebissa		

Agronomy/crop management: Suitable land preparation, planting material selection/preparation, seed storage, seed rate, suitable nursery activities and appropriate planting time for rhizomatous and perennial spices were recommended. Selection of suitable planting material and nursery management, field transplant and management are attained and recommended for users. Compatible intercropping of major spices (ginger, turmeric and cardamom) with coffee are recommended. Suitable shade levels (55 to 63 %) were identified for optimum production of shade loving plants such as cardamom and Korarima. Suitable live support trees such as Korch and grilicidia were identified and recommended for black pepper and vanilla production.

Crop protection: Important diseases, pests and weeds of major spices were surveyed and registered. From the result major diseases on black pepper was fungus (*Pytophthora capsici*), on ginger bacteria (*Ralstonia solaneacerem biovar 3 race 4*) on turmeric rhizome rot fungus (*Phythium spp.*).Major weeds of Black pepper and Cardamom were *Gramineae*, *Malvaceae*, *Composite*, *Amaranthaceae*, and Cyperaceae. The most frequent and dominant weed were *Commelina benghalensis* in black pepper field whereas, the most frequent weed were *Galinsoga parviflora* and the most dominant weed were *Cerastium arvense* in cardamom field. Major weeds of turmeric and ginger were families *Gramineae*, *Compositae* and *Amaranthaceae.* The most frequent weed was *Sida alba* where as the most dominant weed was *Galinsoga parviflora*. Major insect pest of black pepper were *Orsodacne sp,* Brown sting bug- *Euschistus sp, and* Biting black ants -*Tetramorium aculeatum.*

Management of spices pests, the critical time of weed competition of ginger and turmeric were found between 30 and 45 days after planting. When weeding was totally ignored yield loss amounted to 100%. Weeding must be practice between 30 & 45 days. Mulching of ginger when applied after one or two hand weddings applied at 30 and 45 days after planting found good agronomic practice, Screening of black pepper accession against *P. capsici* reviled that all the thirteen accessions at Tepi were found susceptible..

Harvest and postharvest: Assessment of the suitable harvesting time and harvesting and drying practices of ginger, turmeric and black pepper were conducted targeting to improve quality of the extraction. Accordingly, harvesting 7 to 9 months after planting for ginger and turmeric, and 4 and half to five months after 75% fruit setting of the stand were suitable to achieve high quality extractions (essential oil and oleoresins) black pepper. Good experience of processing of cardamom capsule, cinnamon barks and vanilla pods have also been achieved. Major harvest and postharvest management and processing of highland seed spices are also recommended.

Preliminary exercises were made on harvesting and product preparation of cinnamon barks (quills, quilling and chips), ginger rhizome (dred whole, clean peeled, half scraped, sliced and split) black pepper (white and black), and turmeric (boiling curing and polishing). As flavor and aroma determine the quality status of spices, such characteristics as flavor, pungency, essential oil and oleoresin contents of the available cultivars of black pepper, cardamom, ginger, turmeric, korarima and cinnamon were analyzed and compared with the specific standards used at the international market. Determination of loss during harvesting, drying, processing, transportation and storage of spices also determined. In addition, evaluation of chemical compositions for the elite promising materials had been undertaken and those variety/ management practice meet the international quality standards were recommended for users or officially release

Future research demand

Enhacing Spice Export and its Diversification: Spices are one of the major export commodities in Ethiopia. However, given the potential and diversity of spices produced in the country, the export remain limited and only for few types of spices. The major exported spice is ginger with average share of more than 75% both in tersm of volume and value. From 1997 to 2001, a total of 35,508 quintal at a value of 46,229 million USD black cumin seed has been supplied to the world market. At the same period, a total of 58,870 quintal of black cumin seed was produced in Ethiopia and of this, 453 quintal was exported annually. This indicates that Ethiopia has about 12% share in the world market, while 99% of the produce was consumed locally. This is due to inferior quality of the product due to inappropriate postharvest handling and processing. In this regard, the research system is expected to address these challenges by providing packages of practices that make the different types of spices more competent in quality and quantity in international market and to ensure diversificatied spice export.

Import substitution: Ethiopia imports considerable volume of several types of spices and the imported spices are those that the country can locally produce. The key challenges of local production is linked with lack of appropriate varieties, agronomic practices and skill to produce. Thus, the national research system is expected to promote the introduction and adaption of different varieties of these spices along with adequate demonstration, popularization and empowerment of the respective value chains. This is expected to enhance domestic production thereby promoting import substitution.

Raw material supply for domestic industry: Spices are used as raw materials for pharmaceutical, body care, perfumery, food flavoring and coloring industries. Many of the substances those spices constitute are also used as antioxidant while adding a rich, sunny color to creams, lotions and shampoos. For instance, turmeric is used as a preservative; licorice as a medicine; garlic as a vegetable and nutmeg as a recreational drug, and Annatto oil is an emollient. However, the emerging industries that can use spices as an input are forced to import due to the limited domestic production and supply. Thus, it is important to ensure enhanced spice production and improved linkage with domestic industries.

Conclusion and recommendation

This review paper presents the status and prospects of spices research and its linkage with research. It also presents the research efforts along with the achievement as well as the demand for future spices research. It is well recognized that the research achievements recorded are so meager as compared to the volume of research problems related with the need to exploit the country's potenitals and the production and marketing challenges especially linked with biotic and abiotic constraints. In addition, the limited technologies and practices that are in the hands of the research systems did not yet reach adequately end users, which demands the need to strengthen the research-extention linages in spices sectors. Given the the aggravating climate change challenges and expanding biotic and abiotic challanges, and the ever increasing world market completion, there is a need to strengthen the national spices research capacity both in terms of human and physical facilities, if the country is to expoliot the potential its endowed with.

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Early Generation Seed Production and Supply: Status, Challenges and Opportunities

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Introduction

The Government of Ethiopia (GoE) has developed an integrated five-year economic Growth and Transformation Plan (GTP) to ultimately achieve the Millennium Development Goals and become a middle income country by 2025(NPC, 2015). The agriculture sector will remain an integral component of the economic growth and development plan. The GoE has demonstrated strong commitment to agriculture and rural development through allocations of over 10 per cent of the total annual budget (PIF document, 2010). The total public spending on agricultural research and development (R&D) in Ethiopia is growing significantly after 2000 as a combined result of government and donor support(Kathleen et al., 2010) increased from BIRR182.9million in 2011 to BIRR 416.8 million in 2015.

Ethiopia faces fundamental challenges in achieving the food and nutritional security of its ever increasing population(CSA, 2013). Among these the limited use of new improved agricultural technologies is one of the main factors(Mann and Warner, 2015; Kotu and Admassie, 2016). For example, while it varies depending on the crop type(Alemu et al., 2010), the certified seed use from improved crop varieties covers only 8.5% of the total crop area in the country(CSA, 2015a).Apart from increased public investment in agricultural research and development a widespread adoption of new agricultural technologies including improved crop varieties is critical.

The development of the national seed system has been identified as one of the key components of the agricultural transformation agenda of the country. A new seed sector development strategy has been formulated by ATA where systemic bottlenecks have been identified and key interventions have been formulated. Among these availability and access and low quality of early generation seed (EGS) has been identified as major weaknesses of the national seed sector and given a priority for intervention. Early Generation Seed (EGS) refers to variety maintenance and production of seed classes such as breeder seed and/or pre-basic seed(van Gastel et al., 1996). EGS multiplication is a distinct step in seed production and should not be confused with large-scale certified seed production for end users (Tripp, 1997). Specific circumstances, crop types, and seed production costs and requirements present complexity into solving the problem of early generation seed (EGS supply) and getting quality seed of improved varieties available to smallholder farmers in Ethiopia.

The aim of this paper is, therefore, to review the status, challenges and opportunities of EGS production and distribution with particular reference to the public national agricultural research system of Ethiopia.

Definition and Purpose of EGS

Newly released crop varieties need to be multiplied and made available to farmers so that they can access and benefit from the genetic gain of the crop improvement programs. Seed production is a key component of a functional seed system and is expected to produce sufficient quantity and quality within the national prescribed rules, regulations and standards. Formal seed production follows a limited generation system although the number of generations that are allowed after breeder seed depends on the mode of reproduction of the crop, risk of contamination, multiplication ratio and quantity of the seed required (van Gastel et al., 2002).

Different national seed production and certification schemes use different names for generations or seed classes.Ethiopia adopted the Organization for Economic Cooperation and Development (OECD) nomenclature with some minor modifications : breeder seed, pre-basic seed, basic seed and certified seed (Desalegne et al., 2013). Accordingly, breeder seed is the seed of first generation produced under the supervision of the plant breeder. Pre-basic seed is the progeny of the breeder seed and used for crops with low multiplication factor. Basic seed is the progeny of pre-basic seed and usually provided to certified seed producers and suppliers. Certified seed is the progeny of basic seed and produced for sale to farmers. Certified seed can be recycled for one or more generations (Certified 1 and C2);and in Ethiopia C3 and C4 are recognised which deviates from the OECD seed scheme.

There are two critical stages in seed multiplication, where a small quantity of ‘parental material’ (‘nucleus seed’)of new variety received from breeders is systematically multiplied into large quantity certified seed for distribution to farmers (Bishaw and van Gastel, 2007):small-scale early generation seed multiplication and large-scale certified seed production. Early generation seed (EGS) production constitute the maintenance breeding of improved variety and regular multiplication and supply of high quality breeder, pre-basic and basic seed for large-scale certified seed producers. Breeder seed is expected to be of the highest varietal purity and seed quality. All seed classes are related to breeder seed through one or more generations and subject to certification (except the breeder seed itself) and must meet the prescribed field and seed standards (ESA, 2012).

Lavarack (1994) defines variety maintenance as ‘the perpetuation of a small stock of parental material through repeated multiplication following a precise procedure’. Parental material, often called ‘nucleus seed’, is the initial seed obtained from bulking breeding lines to constitute the new variety by the breeder (Bishaw and van Gastel, 2007). It is the original stock of a new variety and can be used as a reference material for varietal maintenance, seed production or seed certification. It is used to produce breeder seed and later generations. Different variety maintenance procedures have been described by various authors for both self-and partially cross pollinated crops (Bishaw and van Gastel, 2007) and cross-pollinated crops (Maize Program, 1999) which need to be followed strictly by NARS.

EGS production applies only to the formal sector which relates to the development and release of new varieties (Van-Gastel et al., 1996; Bishaw and Louwaars, 2013; Teklewold and Mekonnen, 2013). The main purpose of early generation seed multiplication is to ensure that the genetic potential of newly released variety is maintained and regular supply of high quality pre-basic and basic seed is produced and supplied for the entire seed program.

EGS in Ethiopian seed system

Legal framework for EGS production

IAR and ESE were the sole source of new varieties and seeds, respectively in the early formative years where there was no systematic generation control. IAR provides source seed, which is multiplied into commercial seed by the ESE and distributed to the state farms, cooperatives, and farmers. However, to overcome the limited availability and quality of source seed from NARS, the ESE established two basic seed farms for highland and lowland crops in the late 1980s. Later on, the development of the national seed industry policy in 1993 streamlined the seed sector and the Seed Proclamation 2000 introduced systematic generation control and prescribed field and seed standards for different seed classes (FDRE, 2000; ESA, 2012

The Seed Proclamation 2013 recognizes four seed classes, which conform to the OECD nomenclature (Table 1) except the Quality Declared Seed (QDS). The proclamation defines the seed classes and explicitly elaborates the production and access to breeder seed. It gives, MoANR the authority forregistering varietiesin National Variety Register and appointingpersons responsible for maintaining varieties in the event of failures by the breeders. Moreover, the proclamation states that any seed producer holding a certificate of competence may, subject to any other applicable legislation, access breederseed, pre-basic seed and basic seed of registered varieties. This opens new opportunities for both public and private sector to enter early generation seed production to overcome the seed shortage.

The Ethiopian Plant Breeder’s Right Proclamation (No 481/2006) accepted unequivocally the notion of intellectual property protection of new plant varieties and its purpose is manifold (Bishaw and Atilaw, see chapter xx). It provides the rights of plant breeders or breeding institutions to protect their varieties. The protection can be enforced using a licensing mechanism and/or by developing a royalty collection system on seed use. This may provide economic incentive for an effective EGS production and supply.

Table 1: Seed classes for production and certification inEthiopia

No.	Seed class	Certification tag
1	Breeder Seed	White, violet mark
2	Pre-basic Seed	White violet mark
3	Basic Seed	White
4	Certified Seed 1st generation	White, Blue mark
5	Certified Seed 2nd-4th generation	White, Red mark
6	Quality Declared seed (QDS)[1]	Green background

Note[1]TQDS is not part of OECD seed scheme and may not require strict generation control

Technical procedures in EGS production

EGS multiplication

Early generation seed is expected to meet high standard of varietal purity and seed quality attributes prescribed by the national seed regulations (ESA, 2012). This includes field standards to maintain varietal purity and identity and seed standards in terms of physical, physiological and health quality. The former is ascertained by field inspection while the latter through laboratory seed testing. Applying the recommended technical procedures and agronomic management practices (Bishaw et al, 2006) during variety maintenance and seed production would ensure producing EGS of highest varietal purity and identity and seed quality. Apart from breeder seed, expected to be of the highest seed quality standards, the subsequent generation of pre-basic and basic seed need to be inspected, tested and approved by the seed certification agency.

Demand for EGS

Demand assessment is an essential component in seed production planning. Seed demand can depend on many factors, including the prices of seed available from alternative sources, farmers' incomes, preferences, and crops (Alemu et al, 2008; Louwaars and Boef, 2012; Rubyogo, Sperling et al, 2010; Tripp, 2006).

In Ethiopia, demand assessment for certified seed is carried out by the Ministry of Agriculture and Natural Resources (MoANR) through Bureaus of Agriculture (RBoA) of Regional States on the basis of the area sown under different cropsand the seed replacement rate achieved in each region without accounting for other factors. Demand assessment for certified seed is first collated from individual farmers at peasant association by development agents and summarized for each district by BoA. Aggregated data from the districts will pass on to zonal and then on to regional offices. The demand for regional state will be submitted to the federal MoANR. Currently the process for assessing seed demand from farmers and subsequent seed production targets areoften inconsistent and inaccurate, leading to under or overestimation of demand(Dawit and Bishaw, 2016).

The MoANR facilitates to ensure the certified seed requirement is met to the maximum extent possible. The Seed Production and Distribution Technical Committee (SPDTC), drawn from MoANR, EIAR and ESE at the Ministry fixes a production target (part of total requirement) based on the capacity of formal seed sector. At the national level,the SPDTC will discuss the demand and planning of production and distribution with senior policy makers of MoANR, public and private seed-producers, Agricultural Extension Directorate and EIAR.During the meeting, a decision ismade on what percentage of the total seed requirement should be producedfor the specificyear, and the required amounts are calculatedfor each seed class, i.e., breeder seed, pre-basic, basic seed,and certified seed.

The quantity of breeder seed production is based on the required amount of pre-basic and basic seed derived from crop area estimates using backward calculation based on the total certified seed requirement of the country. Certified seed is calculated based on crop area and production targets set by estimated seed replacement rates.

The availability of early generation seed (EGS) is also ascertained by the Ministry on the basis of production of seed by public and private seed producers. In addition, the demand for EGS is set as the basis of Growth and Transformation Plan (GTP) targets.

Planning EGS production

According to certified seed demand, the actual need of EGS to be multiplied by different federal agricultural research centres is planned and communicated to EIAR by the NSMDTC. The TMSRD facilitates the allocation of EGS production ofa crop to the centres based on the capability and the availability of breeder seed of a variety. Based on the demand set by the MoANR, a memorandum of understanding (MoU) is signed between EIAR and seed companies one year ahead of the production season. After the seeds are multiplied by each research centre, the quantity and type of seed is compiled by TMSRD, and then communicated to NSMDTC. Part of the breeder and pre-basic seed is reserved for further multiplication of pre-basic and basic seed, and for demonstration and research purpose by respective centres.

A similar procedure is followed for EGS planning at the Regional Agricultural Research Institutes, though the planning process starts from the Farm Management Team at ARCs and discussed and reviewed with the management of the centers. Furthermore the plan is reviewed and discussed at the regional level for final approval. The planning is based on the demand collected from regional bureau or seed users in the previous year.

Currently factors considered in planning EGS and certified production is shown in Table 2. It consider losses of area due to natural phenomena such as drought and erratic rain and seed losses during processing and failure to comply with prescribed field and seed standards during seed production. Hence, it is important to take these factors into consideration for planning and to calculate net yield of cleaned seed obtained from the quantity of seed used to plant.

Table 2: Factors considered in planning EGS and certified production

Factors	Class of seed			
	Breeder	Pre-basic	Basic	Certified
1. Loss of area due to				
• Drought, pests, etc.	10%	10%	10%	10%
• Field rejection	0	0	5%	20%
2. Loss of seed during				
• Processing	5%	10%	15%	20%
• Laboratory testing	0	0	5%	10%

Source: ESE, 1994

Multiplication factor

Planning EGS production also considers the seed multiplication factor. The ratio between normal gross yield per unit area and seed rate for same unit of area is defined as gross multiplication factor. It differs not only among crops, but also differs between seed classes of the same crop. In general it is higher for initial generations (breeder, pre-basic and basic) as lower seed rates and higher yields are assumed(Van-Gastel et al., 2002; Kalsa et al., 2015). The multiplication factor for sorghum, tef, maize, rapeseed and sesame is higher than other crops. Therefore, it is easy to multiply and supply EGS of these crops in a limited size of land. However, the multiplication factor for faba bean, field pea and chickpea is high. So, EGS supply for these crops is difficult in smaller size of land and the breeder seed supplied by the breeder is generally not enough to produce the seed demanded by growers. The multiplication factor may also have to be calculated for a variety particularly if there are significant differences in seed rate and yield of varieties of the same crop.

EGS reserve stock

Apart from EGS production otherfactors that influence timelyprovision of quality seed is the maintenance of reservestocks.Keepingenough reserve seed to guardagainst losses from crop failures iswell recognized in a seedproduction program. The reserveseed stocks will help ensure the continuity of seed production program in case of natural calamities such as drought which may lead to total crop failures. Sufficient reserveseed pf parental material or nucleus seed, breeder seed,and pre-basic seed should bekept under cold storagesufficient for plantingfor at least twoyears.

EGS allocation and distribution

Based on the information from NSMDC, the available EGSfrom EIAR is allotted to seed producers according to the MoU signed between EIAR and Regional Bureau of Agriculture (RBA) and demand from other seed producers. The breeder seed produced is primarily provided to the Ethiopian Seed Enterprise whereas the pre-basic and basic seed is allocated to regional public seed enterprises (Oromia, Amhara, South), Tigray Bureau of Agriculture) and/ or private basic seed producers. Part of the remaining EGS is used for research and demonstration, forfurther multiplication by respective EIAR and regional research centers, NGOs, HLIs, etc. If the EGS is produced with the support of projects, it is provided to the project objectives unless otherwise there is shortage to meet the demands by seed enterprises.

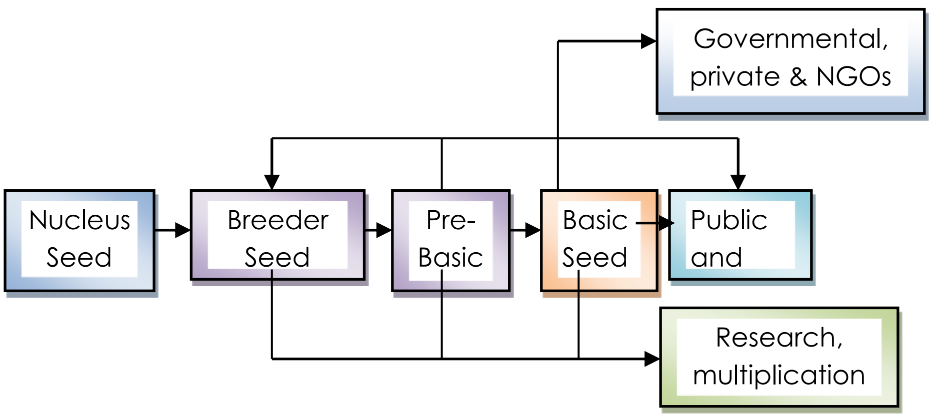

Figure 1: EGS production chain and allocation

Institutional responsibility for EGS production

Historically upon a release of a variety, a designated maintainer is ascertained to ensure regular seed supply. Technically a breeder or a breeding institution is assigned the responsibility. Variety maintenance and EGS production is done by the breeder or under his supervision by a designated agency. In Ethiopia, the national variety register include the name of a variety maintainer, usually those which bred the variety. NARS is responsible for maintenance and breeder and pre-basic seed production of public-bred varieties while the public and/or private seed enterprises are mainly involved in basic and certified seed production. Both public NARS and foreign private seed companies are providing the EGS while small to medium domestic private seed companies, however, rely on public institutions for EGS supply.

EIAR started systematic EGS production after the country has developed the national seed policy in 1992. A major breakthrough in EGS production was achieved with the establishment of the farm management units in EIAR research centres which is involved in growing of seed crop following the seed certification standards of the country.

Currently, the Technology Multiplication and Seed Research Directorate (TMSRD) under the EIAR is engaged in EGS production (breeder, pre-basic, and to some extent basic seed) and carry out research on seed technology to improve seed production and quality. Similar trends can be observed elsewhere in Africa, Asia and South America. In India, companies may produce their own EGS of public varieties, or may acquire it from public research institutes, universities or state seed corporations. In Brazil, the national research institute (EMBRAPA) provides EGS for hybrids and open-pollinated public maize varieties to a group of small private seed companies and co-operatives (Lopez-Pereira and Filippello, 1995). In Argentina, the national research institute (INTA) provides EGS to a co-operative (PRODUSEM) that produces and markets the seed (Jacobs and Gutierrez, 1986). CENTA, the national research institute of El Salvador, provides EGS of maize hybrids to private seed companies and cooperatives (Choto et al., 1996). In Ghana, however the Crops Research Institute is responsible for plant breeding, but another organisation, the Grains and Legumes Development Board, produces EGS and provides to small commercial seed producers (Bockari-Kugbei, 1994).

Varieties for EGS production

The public sector has a national crop improvementprogram for major agricultural (cereals, legumes, oilseeds, industrial (cotton), tuber and roots) and horticultural (vegetables, fruit trees and aromatic(spices, medicinal) crops (Table 3). In the absence of private plant breeding program some joint or private seed companies are collaborating with NARS in introducing, testing, releasing and registration of agricultural and horticultural crop varieties.

Table 3: Public and private sector institutionsin variety development and registration

Institutions	Number	Crops
Federal and Regional ARIs	14?	All crops
Higher Learning Institutions	3	Maize, sorghum, haricot bean?
Federal and Regional PSEs	4	Maize
Domestic private seed companies	7?	Chickpea, vegetables
Foreign private seed companies	17?	Maize, cotton, sunflower, vegetables
NGOs	1	
Total		

Source: MoA,2015

EIAR is the major source of nationally registered improved varieties while RARIs have released several varieties with specific regional adaptations. Until 2014 about 960 varieties were recommended or released (Table 2) though old varieties from 1970s are still multiplied by some seedproducers. This may be due tolimited popularization and demonstration of the newly released varieties and lack of coordinated action in promoting them by the research, extension and seed suppliers (Teklewold and Mekonnen, 2013). Moreover many of the new varieties have low productivityand become susceptible to diseases and pests in shortest period of time (Alemu *et al*., 2010). The absence of adequate and independent varietal evaluation and release proceduresled to lack of,objective decisions making and is liable toinfluence by breeders’ who developed the variety, regardless of the relative merits of the new variety. Such a system discourages the release of competitive new varieties; and also discourages national or international seed business(Tripp and Rohrbach, 2001).

Table 4: Number of varieties released by public and private sector(Source: MoA, 2015)

Crops	Total release	Private sector	% Private sector
Wheat	100	2	2
Rice	29	3	10
Maize	61	18	30
Sorghum	41	1	2
Fox tail	2	2	100
Chickpea	23	1	4
Mung bean	4	1	25
Linseed	16	1	6
Sunflower	14	12	86
Potato	32	3	9
Vegetables	93	63	68
Cotton	26	7	27
Total	**960**	**114**	**11.9**

Variety maintenance

All released varieties are required to be maintained true to their registered characteristics ensuring the genetic purity and identity andseed qualityforregular seed production-supply-use continuum. Maintaining crop varieties in their recommended agro-ecological domains is essential to retain the original genetic integrity and unique characteristics particularly for cross pollinated crops. Therefore it is suggested that the variety maintenance program by NARS should be decentralized based on the recommended agro ecological domains of the varieties and location of research centres to diversify the alternative seed sources. It is recommended to develop avariety maintenance chart and update regularly.

International experiences in EGS production

Kenya

The Kenyan Agricultural Research Institute (KARI)established the Seed Unit (KSU) in May 1997, originally a Foundation Seed Unit. It was registered as a seed trader in December 1999. The goal of Seed Unit is to meet farmers demand for sustainable and reliable supply of high quality seed of open pollinated crops and vegetatively propagated planting materials. The purpose of KSU is to develop a self-sustaining system starting with afew pilot Centers which will provide breeder, pre-basic and basic seed and planting materials to customers on the basis of cost recovery. KSU is also linked with farmers in developing local units referred to as Seed Industry Development Units (SIDU). The SIDUs are strategically placed in areas where individual farmers with irrigation facilities produce seed for the local farmers.

KSU is responsible to develop sustainable organizational structure for producing, processing, marketing and distribution of good quality EGSat KARI. The unit maintains all pre-released and released parental lines, populations and varieties as well as vegetatively propagated planting materials and producing breeder, pre-basic and basic seeds.

The formal seed sector purchases breeder seed from KSU and the informal sector purchases basic seed for further multiplication. Seed companies usethe breeder or basic seed purchased from KSU to produce certified seedstocks/seedlings. KSU also sells seed and planting material directly to farmers through selected seed growers/nursery operators. It is also support the informal seed sector to produce high quality farm saved of open pollinated varieties (OPV) by training seed producers who are assisted by various non-governmental organizations (NGOs).

India

The Indian Center for Agricultural Research (ICAR) andthe State Agricultural Universities (SAUs) and their research centers are producing quality seed for various agro-climatic zones of the country (http://www.dsr.org.in.). The National Seed Program (NSP) under ICAR coordinates overall breeder seed production and seed research and these activities are supervised by a coordinator based at the IARI headquarters. The National Seed Program provides the financial support to establish the necessary infrastructures for breeder seed production and for seed technology research. The programensuresregular supply of breeder seed to the national and state seed corporations for production of adequate quantity and quality of foundation and certified seed. The NSC is also undertakes seed research to the seed industry.

The Directorate of Seed Researchunder the Agricultural Institute for Crop Research Program and National Seed program (AICRP-NSP), coordinates and monitors breeder seed production and supply of field crops to meet the increasing demandof foundation, certified or truthful-labeled seed. The breeder seed production units located at 34 centers of ICAR and agricultural universities produce breeder seed and conduct seed technology research.

DSR conducts and coordinates seed science and technology research to address problems in seed production and certification such as in seed physiology, testing, storage, pathology, entomology and processing. DSR also undertake maintenance breeding to maintain high genetic purity and stability of the varieties and development of quick and reliable molecular detection kit (DNA bar coding) for genetic identification of varieties and hybrids.

DSR also promote awareness about quality seed and use among farming communitiesin tribal areas through its network of Poverty Alleviation projects.

Implications of international experiences for EGS in Ethiopia

The above review indicates that there is a need to institutionalize the roles and responsibilities in variety maintenance and EGS multiplication. In Ethiopia, variety maintenance and breeder seed supply is handled by the breeder while in India and Kenya it is handledby the respective seed units and Directorate of Seed Research (Table 5).

The availability of sufficient and skilled manpower in the research system also ensures effective EGS production. Strengthening the manpower of TMSR is envisaged both at the EIAR headquarters and research centres. Moreover, there should be an incentive to motivate staff involved in EGS production.

Table 5. Ethiopian and international experiencesin EGS multiplication

Criteria for comparison	Kenya	India	Ethiopia
Institutionalization	Seed Unit (KSU) under KARI; SIDUs to support local seed production	National Seed Program under IARI; 34 seed production units of IARI and SAUs	TMSR under EIAR; 16 TMSR units of EIAR
Budgeting system	Operates on cost recovery	Operates on cost recovery	Allocated budget from government
Roles and responsibilities in EGS	Provides breeder, pre-basic and basic seed and planting materials Maintains all pre-released and released parental lines, populations and varieties Sells breeder seed to public or private seed sector and basic seed to informal sector	Provides financial support for infrastructure for breeder seed production Maintenance of varieties Supports seedresearch including development of quick and reliable molecular detection kit for varieties and hybrids	Multiply breeder, pre-basic and basic seed Conducts seed research to support seed production and quality assurance.
Support to informal seed sector	Build capacity of farmers to produce quality farm saved seed	Creates awareness of quality seed among farming communities in tribal areas through its networks	Provide basic seed to development projects involved in local seed multiplication and pre-scaling up
Weaknesses	NA	NA	Poor facility;insufficient staffing and limited seed technology research

Source: Glover, D *et al.,* 2015

Status in EGS multiplication and distribution

EGS production and supply by NARS

EIAR is given the responsibility to produce and supply EGS of varieties that are released by the federal public research system. According to the seed production plan, different EGS classes are multiplied at the respective research centers based on the competency and agro-ecological suitability. Most of national crop improvement programs are coordinated by the EIAR centers and each program at every research center has the responsibility toproduce EGS. Currently, EIAR has 734 ha of land for research and EGS multiplication and a major part of the seed is produced through federal research centers located at the different agro-ecologies of the country (Table 6).

Table 6: Federal ARCs, technologies for multiplication and available land area (EIAR, 2014).

ARC	Commodity group	Crops	Total cultivable land (ha)	Allocated for seed multiplication (ha)	
				Rainfed	Irrigated
Debre Zeit	Cereals, legumes, vegetables, fruit trees	Tef, durum wheat, chickpea, lentil, grass pea, fenugreek; shallot, garlic, grape vines,	148	96.3	30
Melkasa	Cereals, legumes, vegetables, fruit trees	Sorghum, maize, millets, haricot beans, cowpea, mungbean, onion, tomato, red pepper, citrus, apple mango, banana, papaya	200	80.71	48
Kulumsa	Cereals	Bread wheat, faba bean, field pea, rape seed, linseed, forages	376	288.98	20
Werer	Fibers, oilseeds	Cotton, kenaf, sesame, groundnut, Irrigated rice, forages	211	23.3	23
Wendogenet	Medicinal plants	Sweet annie, Stevia, Basil, Oregano, sage, hibiscus, pyrethrum	105	11	2
	Aromatics	Rosmery, nardos, citronella, palmoroza, spearmint,lemongrass, lavender, chamomile			
	Biofuels	Castor bean, Jatropha			
Sebeta	Aquaculture	Fishery			
Holeta	Cereals	Barely, noug, rape seed, potato	104	48.6	5
	Temperate fruits	Apples			
	Livestock	Forages			
Ambo	Cereals	Maize, noug	84.9	52.5	2
Bako	Cereals	Maize	24	8.23	3
Pawer	Cereals	Rice, millet, sorghum, soybean, groundnut, sesame	100	50.95	0
Asosar	cereals	Rice, millet, sorghum, soyabean, ground nut	65	30.63	0
Jimma	Stimulants	Coffee, soyabean, taro, pine apple	206	30.99	10
Mehoni	cereals	maize, sorghum, millet, mung bean, papaya, avocado, mango, citrus, banana	100	13	13
Chiro	cereals	Sorghum			
Fogera	cereals	Rice, onion, tomato	8	3.65	
Tepi	Spices	korarima, ginger, black/white cumin, coriander, fenugreek, chillies, mustard, black pepper, cardamom, turmeric, cinnamon, coffee, taro	24.5	5.6	
		Total	1756.4	744.44	156

Maize

Maize variety development is coordinated from three centres of excellence. Melkassa Agricultural Research Centre, Bako National Maize Research Program, and Ambo Plant Protection Centre are responsible forcoordinating maize variety development for lowland, mid altitude and highland agro-ecologies, respectively. The maintenance of hybrid and open pollinated varieties of maize and breeder/pre-basic seed production is undertaken by coordinating centres. The regional research centers such as Adet, Hawassa, Mekelle and Pawe ARCs as well as, Haromaya and Hawassa Universities are collaborating in maize EGS production. Most of the breeder/pre-basic seed produced by Bako National Maize Project is supplied to Bako (regional) research center for further pre-basic/basic seed production. A total of 610.41 tons of breeder seed, and 2417.82 tons of basic seed was produced and supplied to different stakeholders from 2001/02 until 2014/15 (Figure 2).

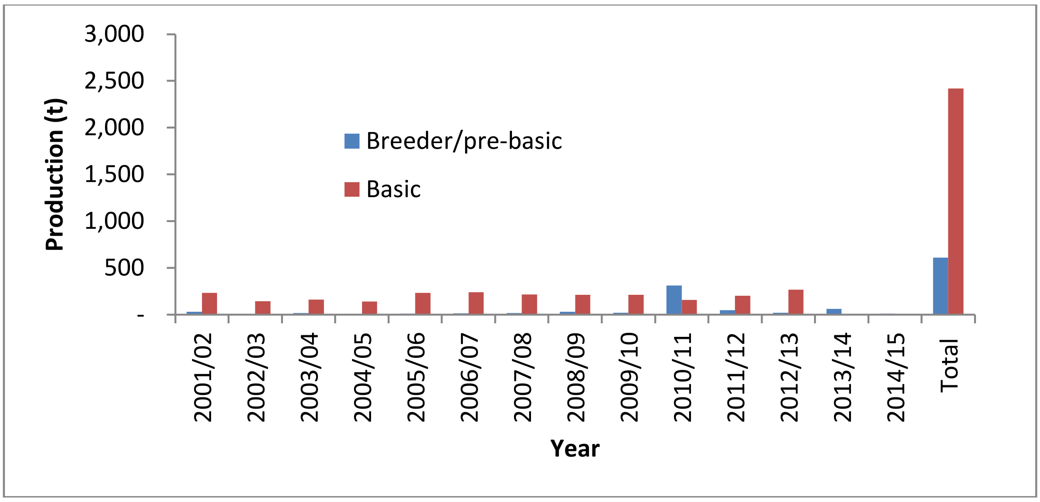

Figure 2: Maize EGS production (t) (Source: --------, Unpublished data)

Wheat

According to NPC (2015), wheat seed occupies more than 65% of the national seed supply. Therefore, the EGS demanded for wheat seed is higher than any other crop seed. Kulumsa Agricultural Research Center is the national wheat program coordinating centre with focus on bread wheat and through DZARC for durum wheat and Werer ARC for irrigated wheat (Figure 3). Accordingly bread wheat and durum wheat variety maintenance and breeder and pre-basic production is undertaken by these research centers where KARC plays the major share of the EGS production. At the regional level, Sinana, Adet, Debre Birhan, Sirinka, Areka, and Mekelle are conducting research and EGS multiplication though their share is minimal. At national level over 100 varieties of durum and bread wheat varieties have been released/ registered. From 1992/93 up to 2014/15 about 11,587 tons of bread wheat and 927 tons of durum wheat EGS (breeder, pre-basic and basic seed) of different varieties was produced and distributed to users.

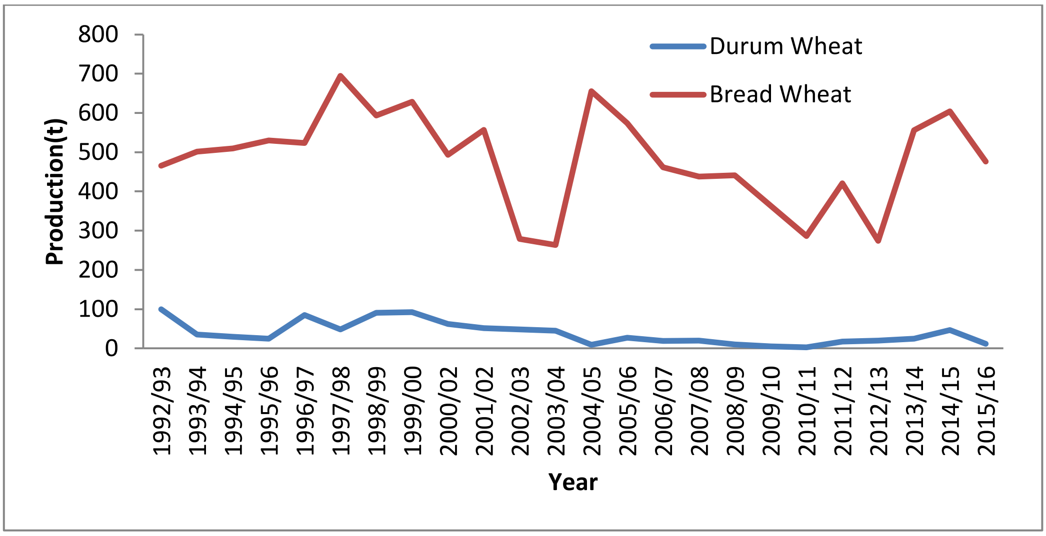

Figure 3: Wheat EGS production (Source: KARC, 2015 Unpublished data)

Tef

Tef is a hugely important crop, both in terms of production and consumption, accounting for about 15% of all calories consumed in Ethiopia. Furthermore, approximately 6 million households grow tef and it is the dominant cereal crop in over 30 of the 83 high-potential agricultural *woredas*. In terms of production, tef is the dominant cereal by area planted and second only to maize in production and consumption (CSA, 2015b).

While Debrezeit Agricultural Research Center (DZARC) is the center of excellence for tef research within EIAR, other federal and regional agricultural research centers are also involved in research and EGS multiplication.Since 1992/93 upto date about 1,376.8 tons of tef EGS was produced and supplied to users (Figure 4).

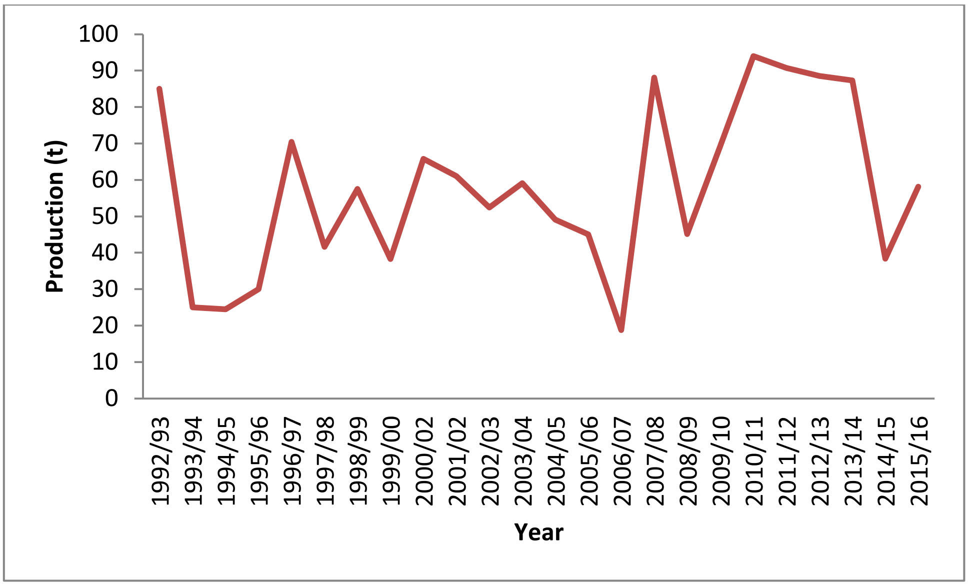

Figure 4: Tef EGS production (Source: DZARC, 2015, Unpublished data)

Sorghum

Sorghum is the fourth important crop in terms of area coverage and volume of production. It is adapted to a wide range of environment, and hence can be grown in the highlands, medium altitudes and lowlands, widely grown than any other crops, in the moisture stress areas.

Melkassa ARCis the center of excellence for National SorghumResearch Program, but other federaland regional ARCs are also involved in sorghumresearch and EGS multiplication.Since 1985/86 up to date about 1098.334 tonnes of sorghum EGS was produced and supplied to users (Figure 6).

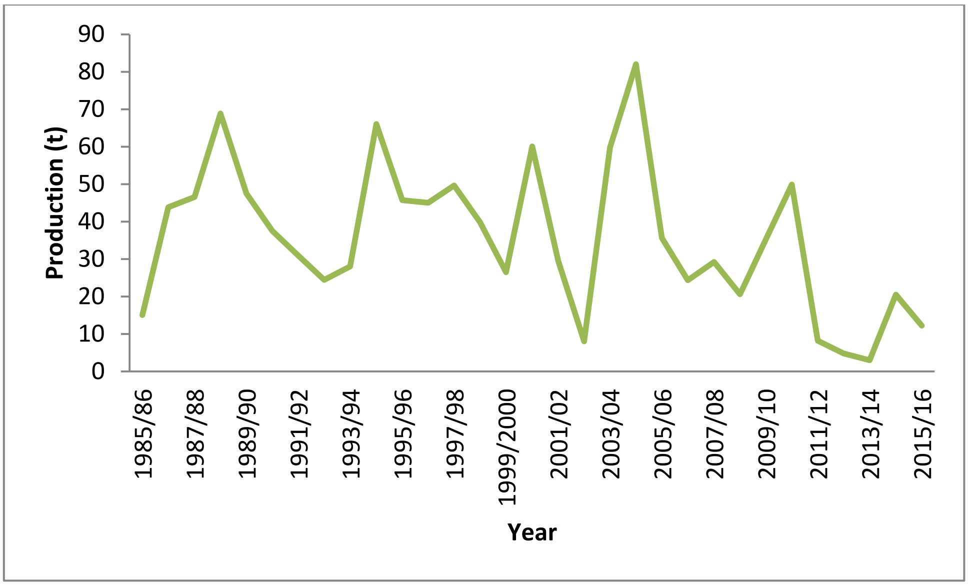

Figure 5: Sorghum EGS production data (Source: MARC, 2015; Unpublished data)

Chickpea and Lentil

Chickpea is the second most important cool season food legume crop after faba bean. The amount of seed produced is as shown below (Figure 6). Lentil is also a major cool season crop in Ethiopia. Lentil EGS supply from the research system very minimal and the from federal research centers from 1002/93-2014/15 was 48.8 tonnes.

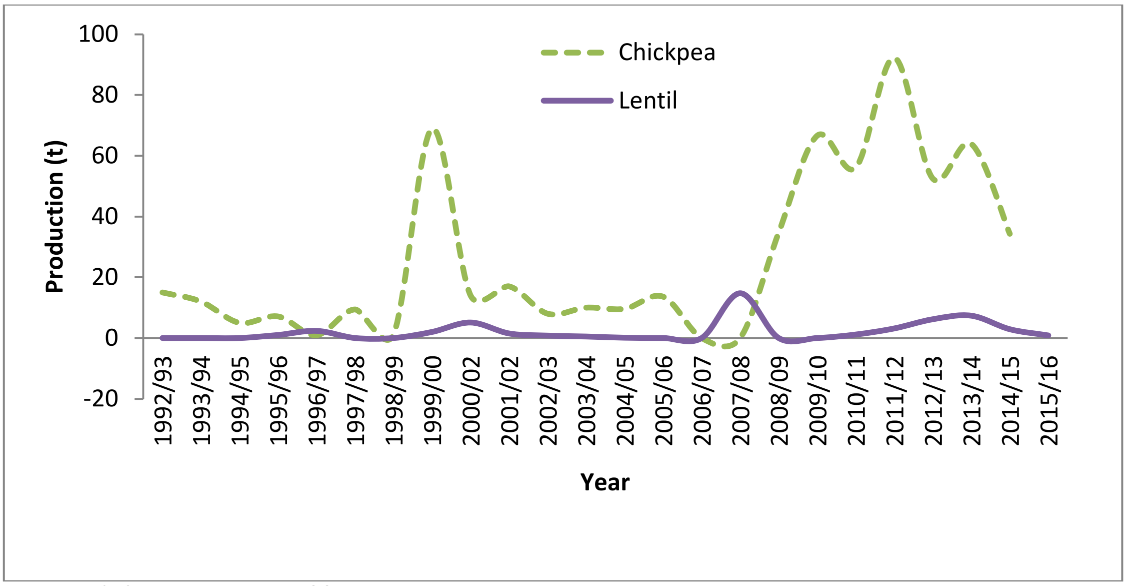

Figure 6: Chickpea and lentil EGS production

Barley, faba bean and mustard

Barley, faba bean and mustard are also major crops that are multiplied by the national research system.Faba bean and rape seed, owing to their out crossing nature, maintaining their genetic purity is indispensable but yet painstaking job. EGS multiplication and supply for faba bean is limited due to the fact that it's low seed multiplication factor (Figure 7).

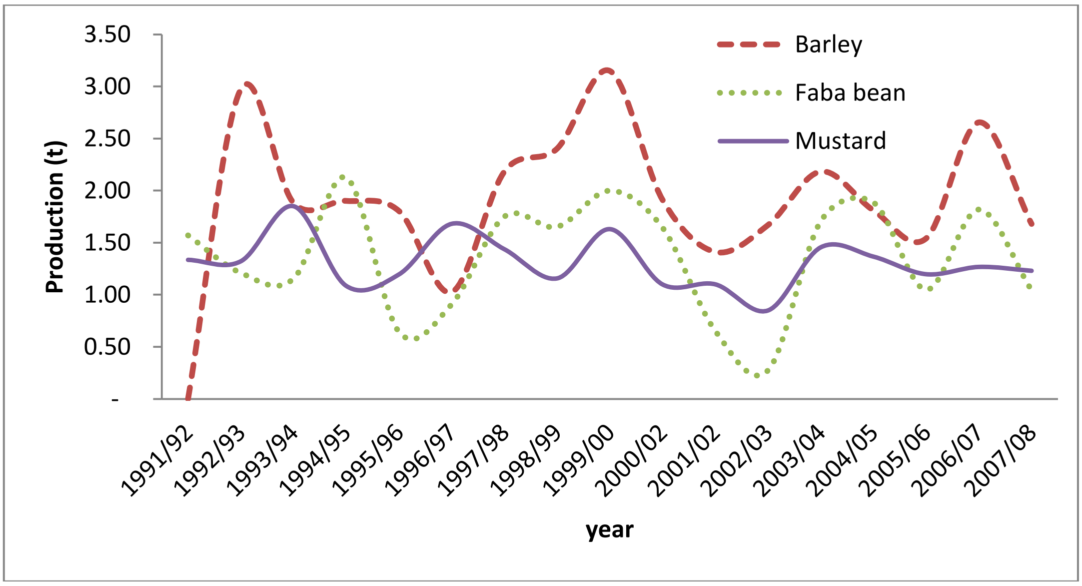

Figure 7: Barley, faba bean and mustard EGS production (t)

Haricot bean

Haricot bean is one of the lowland pulse crops grown in the hot humid regions of the country. It is known as an export crop but can also be grown as a food crop consumed in traditional dishes. Melkassa ARCcoordinates research on haricot beans. The national strategy to develop improved bean varieties has evolved over time and now focused ondeveloping specific cultivars that meet the needs of different bean growing zones and production systems. . Figure 9 below shows the EGS multiplication by Melkassa and other research centers.

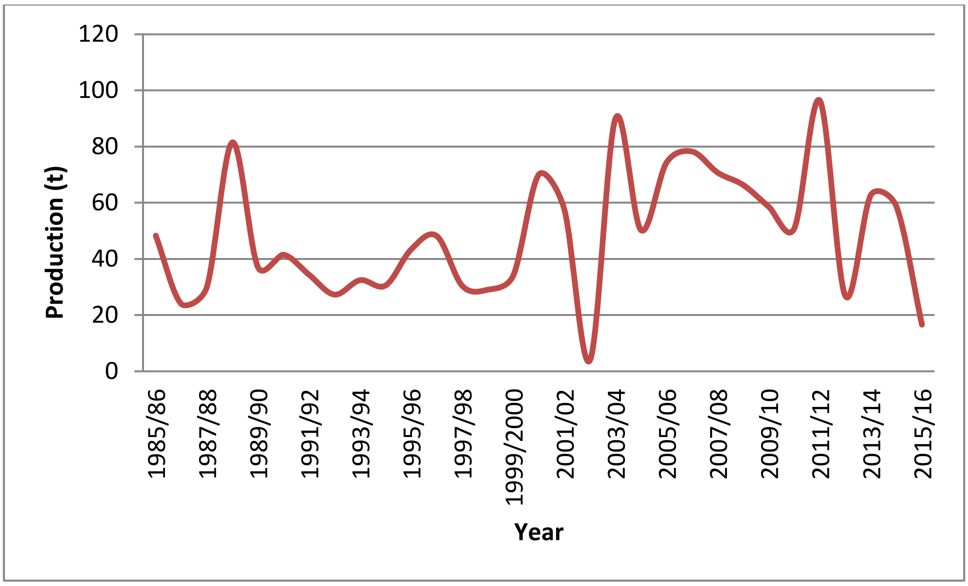

Figure 8: Haricot bean EGS production (t)

In EGS production, the average productivity of crops at both main and collaborating centers is very low compared to the potential of the crops. For example, the average productivity of wheat ranged from 1.8 t ha-1 in Werer to to 2.3t ha^{-1} at Kulumsa, although the potential productivity is about 7t ha^{-1}(MoA, 2015). Such low productivity is ascertained to inadequate agronomic management practices,lack of adequate infrastructuresand lack of skilled and sufficient manpower.

For cereals, the current EGS production is sufficient to meet the projected certified seed replacement of major crops, if the recommended procedures are followed using standard multiplication rates. However, early generation seed demand for pulse crops cannot be fulfilled due to very high seed rates and low multiplication factors. The EGS production also cannot met the demand because of inadequate varietal choices preferred by diverse group of farmers in different agro-ecological domains and socioeconomic settings. In addition, inadequate planning and unregulated distribution and lack of incentives for production/marketing are some of the constraints.

The requirement of EGS is based on the amount of certified seed derived from crop area estimates using backward calculation. The requirement of breeder and pre-basic seed is expected to increase to 5400 t by 2020 with emphasis on the quality and varietal choices.

EGS production and supply by ESE

The Ethiopian Seed Corporation (now ESE)was established in 1979 to produce and distribute quality seed of improved varieties to meet the national seed requirement of state farms, producer's cooperatives and private farmers. From the outset, the enterprise recognized the bottleneck in EGS production and established two basic seed farms at Gonde-Ethaya and Awssa-Shallo for pre-basic and basic seed production. The enterprise multiplies further the basic seed on contract to produce commercial seed for distribution to farmers.

Currently, ESE produces pre-basic, basic and certified seed of 25 crops and 137 varieties. The enterprise produces basic seed in its seed farms located in Gonde/Iteya, Awasa/Shallo, Ardayita, Chagni and Kunzula farms.The basic seed is further multiplied to certified seed on its own farmers or through contractual agreement with state farms, private farms and farmers. The figures below demonstrate the pre-basic and basic seed production of ESE for the last 10 years (Figures 9 and 10). Its contribution to the EGS supply especially basic seed is considerable.

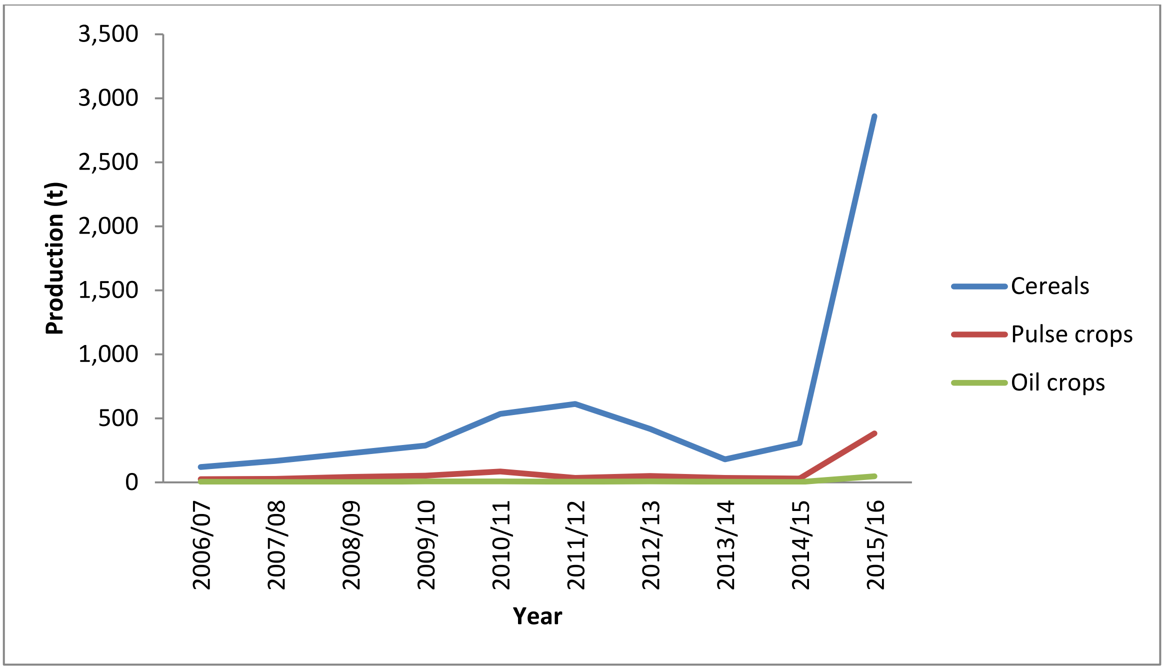

Figure 9:Pre-basic seed multiplication by ESE (2006/07-15/16)

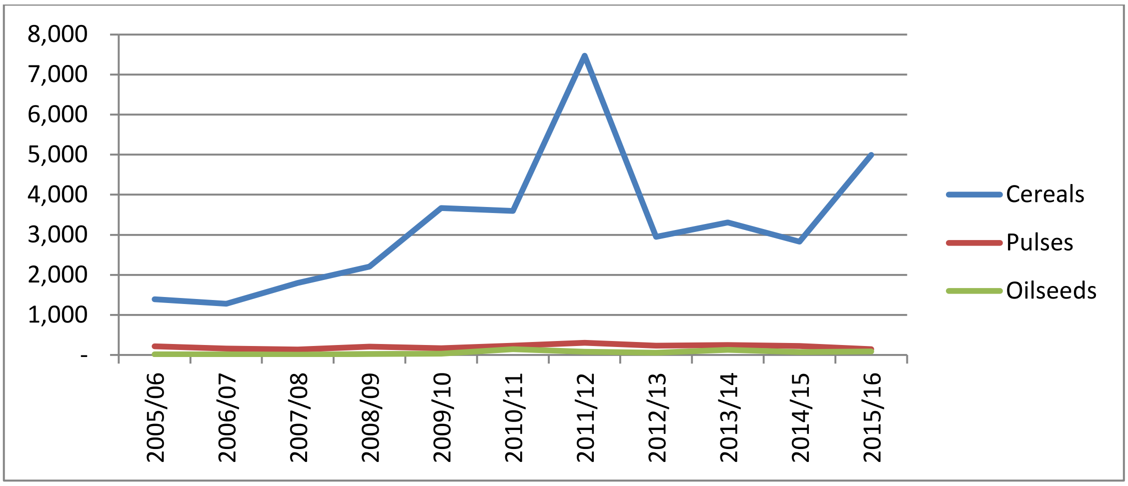

Figure 10:Basic seed multiplication by ESE (2006/07-15/16)

Establishing sustainable EGS production

EGS production is a specialized task and requires adequate provision of physical, financial and human resources. Diversification of seed production for public bred varieties depends on establishing a sustainable strategy for EGS production. In Ethiopia, the responsibility for EGSrests with NARS operating on a limited budgetsupport from the Governmentand bilateral projects. In 2015, aboutBIRR 33.8 million 2015 was allocated for the maintenance, multiplication and distribution of EGS of improved varieties released in the country(EIAR, 2015). If enough quantity seed with high quality to produced and supplied, the incentives for NARS must change. It must become a financially viable operation and develop the capacity to serve a wide range of seed producers.

The technical requirements of EGSproduction also shows that this responsibility may initially have to stay with public institutions. The experiences fromother countries such as Kenya and India however show a strategy of moving EGS into a commercial and competitive system. Currently, NARS are focusing on breeder and pre-basic seed production and the ESEon both pre-basic and basic seed production. It is suggested that in the future

NARS will concentrate on breeder seed production, ESE on pre-basic and basic seed production along with the regional seed enterprises as they develop technical skills (MoA, 2007). Some local private seed enterprises may even be encouraged to specialise on EGS production and distribution.However, any full cost recovery from the program may not be feasible where some government support is desirable for some crops.

With the approval of new seed regulation(FDRE, 2013), the variety release and seed quality control directorate of MoANR should place more emphasis in ensuring that adequate standards are established and the quality of EGS maintained. NARS also could help train the public and private seed enterprises in EGS production and management.

Adequate information exchange and consultation among NARS and seed producers is critical for effective and efficient EGS production and supply. As thedemand for EGS increases, it is worth establishing a forum where seed producers, EGS providers and plant breeders can exchange information. Such an EGS forum for joint annual planning would help in improving the availability of EGS in sufficient quantity and quality and in sustainable manner.

With the increase in certified seed demand from farmers, the EGS demand by seed enterprises is also increasing from year to year. In order to meet the ever increasing demand from the producers, TMSRD has begun to multiply EGS twice a year (during the main and off-seasons). This task requires skills, resources and incentives. One of the principal problems with public seed sectoris lack of appropriate incentives. Seed multiplication in EIAR can be efficient if the technicians provided with appropriate incentives.In order to have sustainable variety development and release good Incentives also must be in place that motivates public plant breeders to address farmers' needs.

Key challenges and opportunities of EGSproduction

Challenges

Despite five decades of development initiatives, availability of and access to good quality EGSat the right time and place has been one of the major constraints in the seed value chain. Bishaw and Atilaw (Chapter xx) identified four principal issues that are important for streamlining EGSproductionby the federal and regional national agricultural research systems: adequate variety maintenance, coordinated breeder seed demand, decentralized multiplication and quality assurance. Some of the major issues and problems that hinder EGS production and supply are outlined in Table 7.

Table 3: Challenges in EGS production

Challenge	Reasons
Limited demand for source seed of newly released varieties	Limited incentive for certified seed producers to create demand for new varieties
	Limited demonstration and popularization of newly released varieties
Limited source seed multiplication capacity	Limited land for multiplication
	Limited facilities (storage, irrigation, equipment and machineries) Lack of sufficient knowledge and staff
Limited options of access to source seed	Limited possibility of multiplication of source seed by other actors (seed producers both private and public)
	No application of provisions like exclusive right, use license etc
Lowquality of EGS produced	Weak capacity of the regional quality control bodies
Weak MoU and enforcement mechanisms	The current MoU is not legally bindings
Lack of incentives for EGS	One of the principal problems with public seed systems has been the lack of appropriate incentives.

Opportunities

Enablingpolicy environment:The National seed policy and regulatory framework provide an enabling environment for the seed sector development. Itprovides incentives for public and private sector, setting standards for seedproduction and quality assurance; and supportingthe development ofinfrastructure, inter alia. Theintellectual property rights provide plant breeders the rights to protect their varieties without contravening farmer' rights to save theirown seed and to register their varieties.

Strong institutional support for quality seed production:The Ethiopian government has strong commitment to support EGS production. Public agricultural research and plant breeding has been reinvigorated and directed towards the needs of farmers. Community initiatives are also made important contributions toseed development.

Modernization of agriculture and increased seed demand*:*An enabling government agricultural policy led tothe development of the agriculture sector and created huge demand for improved seedwhich is increasing from time to time.The development of the agriculturesector determines the range and types of seed thatfarmers' demand and the realignment of government responsibilities in theseed sector.

Favourable opportunities for collaborative research partnership:One of the characteristics of seed provision is the need to link public, private and commercialpartners. Government policies and specific projects are neededto strengthen participating organizations; and

Capacity building initiatives: The provision offacilitiesfor seed laboratoriesat NARS and the initiatives on seed technology training by higher learning institutions such as Haramaya and Bahir Dar Universitiescould benefit EGS system in the country.

Conclusion and recommendations

The diversification of certified seed supply for public bred varieties depends on establishing a sustainable strategy for EGS production. In Ethiopia, to date the responsibility for EGS production is shared between public NARS and public seed enterprises. NARS are involved from variety maintenance to basic seed production while some PSEs produce pre-basic and basic seed. There are also trends to allow private seed companies to get access to breeder seed to produce their own pre-basic and basic seed of public-bred varieties. There are some ambiguities and overlapping responsibilities in EGS production and supply which need to be streamlined based on different options.

First and foremost it is important to clearly define what constitute the EGS in the national seed sector context, and thendetermine the roles and responsibilities of each institution in EGS production at the federal and regional levels among NARS and public and private seed producers.

Second, there is a need to establish an autonomous seed unit within NARS at federal and/or regional levels. The unit should have adequate physical, human and financial resources toundertake the full responsibility for planning and production of EGS in liaison with seed producers. It should have access to farm machinery for field operations and infrastructure for post-harvest operations and should operate in locations with favourable climatic conditions that permit the use of resources on an economic scale. Therefore, to strengthen the seed unit at EIAR in particular orNARS in general the following interventions are needed for EGS production:

- Allocation of additional land as current land holdings for research and EGS production of NARS is very limited and competition for land between research and EGS production;
- Strengthen the infrastructure (irrigation, storage), farm machineries for field operations(tractors, cultivators, combiners, threshers) and equipment for post-harvest operations (cleaners, treaters, seed quality laboratory);
- Strengthen human resources capacityby employing experienced and skilled staff and provide relevant training to enhance capacity of researchers and technicians;
- Allocation of sufficient budget for operations and create a mechanism to retain sales of EGS to ensure sustainability;
- Demand creation for newly released varietiesthrough popularization and demonstration in partnership with other stakeholders;
- Introduce appropriate agricultural technologies (crop diversification, improved cropping systems, integrated crop management, storage management);
- Strengthen the seed quality laboratory to undertake the internal regulatory oversight for EGS production.
- Improve the monitoring and evaluation of EGS systemand undertake a review and reform as desired during the implementation

Different management options for breeder seed production are available, and could be adopted in developing countries (Laverack, 1994). It would be helpful to integrate a breeder seed unit into plant breeding and seed production as in the private sector, or create a separate unit within the breeding institutions or seed producing organizations. Alternatively, an independent unit could be established, with a clear mandate to take over this responsibility.

Third, there is lack of adequate need assessment for EGS production which is critical for national seed supply. Consultation among NARS and seed producers is necessary for effective and efficient EGS production and supply. It is recommended to establish an EGS platform for annual planning among seed producers, EGS providers and plant breeders. Such an EGS forum would help in improving the availability of EGS in sufficient quantity and quality and in sustainable manner.

Fourth, the Plant Breeder's Right Proclamation (No 481/2006), grants breeders or breeding institutions the right to protect their variety and can be enforced using a licensing mechanism and/or by designing an effective mechanism for royalty collection. It is time to take some initiatives and provide implementation guidelines to enforce PVP. This will encourage and provide incentive for both public NARS and the private sector to investment the EGS production and supply.

Fifth, given the criticalrole of EGS, in maintaining high standards of quality is of utmost importance. Seed regulatory and quality control agencies should place emphasis on ensuring that adequate standards and procedures are established and enforced for EGS production through self-regulation or external control.

A recent study commissioned by ATA identified EGS production arch types, priority crops, the economic incentives and the recommended the interventions.It classified crops based on potential options for EGS production by the public, private or a combination of both. It is anticipated that the future strategy for EGS production is to provide economic incentives to become a sustainablecommercial operation. Moving EGS production gradually towards greater financial independence would improve the availability and quality of EGS. However, any full cost recovery from the program at least in the short-term may not be feasible where some government support is desirable.Implementing the recommendations of the EGS study is the way forward to achieve the desired goal.

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Enhancing Agricultural Sector Development in Ethiopia:The Role of Research and Seed Sector

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Historical development of the seed sector

Modern crop varieties are the backbone of a robust seed system showing a strong interface between agricultural research and seed delivery. The emergence of knowledge based agriculture including scientific plant breeding, mechanization, commercialization, diversification and specialization at various stages of agricultural development led to the emergence and progressive development of an organized seed sector in developed countries (Thomson, 1979; Groosman, 1989; Tripp, 2001). Seed remain the delivery mechanism of agricultural innovations.

In Ethiopia, the pattern of organized seed sector development follows that of many developing countries with some local variations due its political and socioeconomic context. At least three stages of seed sector development can be recognized: (a) Stage 1: emergence of organized seed sector characterized by ad hoc seed production and delivery (1940-1978); (b) Stage 2: establishment of organized seed sector and consolidation of public sector (1979-1990);and Stage 3: Diversification and expansion of the organized seed sectorand entry of the private sector (since 1991).

In stage one, from the outset seed activities were started essentially linking crop improvement and extension (Bishaw et al 2008).Early attempts made by JimmaAgricultural Technical School (1942) and Alemaya College of Agriculture (1954) and later on by the Institute of Agricultural Research (1966) and the ChillaloAgricultural Development Unit(1967) were some of the precursors of the organized seed sector in the country.

During stage two , the establishment and consolidation of Institute of Agricultural Research (1966) and attempts in modernization by emerging private estate farms in the 1960s and 1970s culminated with the establishment of the Ethiopian Seed Enterprise in 1979 (Bishaw et al. 2008; Niels and Bishaw, 2012). The expansion and establishment of large public state farms, the formation of farmer producer's cooperatives and theresettlement programsunder socialist government in the 1980s further strengthened the basis for strong centralized public seed sector.

In stage 3, following the socialist government, itwas envisaged to move the agricultural sector from a command and control production and marketing system to market-driven agriculture.Since 1992, both the agricultural research and the seed sector went through several policy and regulatory reforms and institutional andstructural changes to respond to the developmental challenges of economic growth and development.The reforms and liberalisation of the seed sector led to the emergence of substantial number of domestic small to medium scale private seed companies and entry of limited number of foreign private seed companies.

To date we find a mix of federal and regional public seed enterprises,small to medium domestic private seed companies and large-scale foreign private seed companies and a wide range of semi-informal licensed or non-licensed small seed enterprises of different shapes and scales operated by cooperatives or farmer associations which are involved in seed supply.

Current State of Agricultural Research and Seed Sector

According to Alemu (2010), Ethiopia has a strong commitment to a decentralized political-administrative system which translates to decentralized agricultural and rural development under the umbrella of national policy and regulatory framework. The country moved from a centralized to decentralized institutional arrangements in agricultural research, seed delivery and related services.

Developments in Policy,Regulatory and Institutional Frameworks

The Ethiopian agricultural sector is at cross roads supported by various high level government policy support and interventions to bring about transformational change.To date the development of the seed sector occupies centre stage from federal and regional governments to regional and global development partners and donors (Alemu and Bishaw, 2015). The Agricultural Transformation Agency (ATA) was established to address some key systemic bottlenecks in the agricultural sector among which the seed sector is one of the priorities of the country. It is expected that this support will bring greater opportunity for public and private sector investments to achieve the desired changes in the agricultural sector contributing to overall economic growth and development.

Institutional and Organizational Changes

Box 1. Landmarks in Seed Industry Development in Ethiopia (Turner & Bishaw, 2016)

1976	National Seed Council established by the National Crop Improvement Conference
1978	Start of the FAO Seed Production and Quality Control Project
1979	Establishment of the Ethiopian Seed Enterprise under the WB project
1982	National Variety Release Committee established
1990	ESC forms joint venture with Pioneer for hybrid maize seed production
1992	National Seed Industry Policy and Strategy published
1993	National Seed Industry Agency established to handle regulatory matters
1993	Ethiopian Seed Corporation renamed as Ethiopian Seed Enterprise
1995	Policy of regionalisation introduced by the new Constitution
1996	Joint venture terminated; Pioneer becomes independent PLC
2000	Seed Proclamation by MoA (206/2000)
2002	National Seed Industry Agency abolished, responsibilities transferred to newly formed National Agricultural Inputs Authority (NAIA)
2004	NAIAabolished,responsibilities transferred to the newly formed Ministry of Agriculture and Rural Development (MoARD)
2007	Ethiopian Seed Growers and Processors Association established
2008	First Regional Public Seed Enterprise established in Oromia Regional State; (and Amhara RS in 2009 and Southern Nations, Nationalities and Peoples in 2010; and Somali RS in 2014)
2009	Integrated Seed Sector Development Project established with NL funding
2010	SeedCo enters hybrid maize seed market
2010	First regional quality control bodies established
2011	Agricultural Transformation Agency established, with seeds as one key focus area
2013	New Seed Proclamation promulgated by Federal Government (2013)
2014	Strategy and road map for seed sector development published by ATA *(online in 2015*

Since 1990s, the Ethiopian agricultural research has been restructured into federal and regional levels. In addition to the federal agricultural research led by the EIAR, seven Regional Agricultural Research Institutes (RARIs) were established during late 1990s serving the regional states. Moreover, there are agricultural universities/faculties engaged in academic teaching and research of varying degrees in crop improvement.

Similarly, besides ESE at federal level, four Regional Public Seed Enterprises (RPSEs) were also established in Amhara, Oromia, Southern and Somali Regional States and became operational in late 2000s.Furthermore, several small to medium scale domestic private seed companies emerged over a decade or two operating at federal and regional levels. Also technically, financially and organizationally weak about 33 private entities are operating in seed business at regional levels. There are also few foreign companies like Pioneer Hibred PLC and Seed Co which are already involved in the seed sector while some new ones have shown genuine interest to enter the seed market. This pluralism is quite new to the country, but obviously, most of these private companies mainly produce maize seed.

The Plant Variety Release, Protection and Seed Quality Control Directorate (PVRPSQCD) wasreorganized as a separate entity within the Ministry of Agriculture. It became responsible to provide policy direction and coordinate variety release and protection as well as seed quality control and certification at federal level. The regional seed quality control agencies have been formed and have established seed inspection and testing laboratories to implement seed quality control under the Bureaus of Agriculture of respective regions.

Growth and Transformation Plan

In GTP II agriculture remains the major source of economic growth. The accelerated and sustainable growth expected to ensure food and nutritional security, provide adequate raw product to the agro-industry, contributes to foreign exchange earnings and transforming rural livelihoods.Increasing crop production and productivity is one of the main strategic objectives where detailed goals in terms of production and productivity were set for the main agricultural and horticultural crops. The expected productivity changes will not be achieved without strong demand driven agricultural research employing a combination of both conventional and modern biotechnologytools. New crop varieties which are well adapted to diverse agro-ecologies and farming systems that are farmer,industry and consumer preferred are required for competitive domestic and international markets.

Moreover, new integrated crop management technologiesare required which combineconservation of natural resources such as water and soil health.Seed remain a conduit to transfer of new agricultural innovation. There is greater opportunity for convergence and synergy between agricultural research and seed supply for sustainable agricultural development.

Establishment of NARC and Research strategy

The National Agricultural Research Council has been created as an apex body to provide policy guidance and setting the research agenda and coordination at the country level involving both the federal and regional agricultural research institutes. This would enable to bring together somewhat scattered and defused agricultural research system under one umbrella.

Within the national agricultural research for development agenda, EIAR has recentlydeveloped its research strategy and prioritized its national agenda. The RARIs of regional states are expected to follow suit in developing their research strategies and priorities.

Development of Seed Sector Strategy

Agricultural Transformation Agency has developed a strategy document of the national seed system with the broader consultation and inclusive participation of the seed value chain actors. The strategy has classified the national seed sector into three sub-sectors- formal, intermediate and informal- and has identified several systemic bottlenecks, proposed set of interventions and developed a road map for respective areas across the seed value chain. It is envisaged that the strategy is to bring comprehensive transformation of the seed sector and provide blue prints to guide domestic and international development partners in targeting priority investments to address systemic bottlenecks.

The issues raised in the strategy are not new to long-time observers of the Ethiopian seed sector, however and the interventions are related to (i) strengthening the variety development, release and registration; (ii) improving the delivery of early generation seed by NARs, (iii) strengthening the capacity of public and private sector to expand the volume of certified seedsupply, (iv) developing a more reliable demand assessment and supply management system, and (v) establishing a more efficient quality assurance and certification scheme (Alemu and Bishaw, 2016).

What are unique of the proposed strategy are a series of key activities outlinedand the assignment of responsibilities and institutional ownership to undertake the implementation of the strategy. However, the deficiency of the strategy is its lack of implementation plan and the resources required for the proposed interventions, which left its designand implementation tothe stakeholders where its success is dependent on adequate ownership, coordination, and accountability of partners at all levels. The strategy document is available online for public comment before its final approval and endorsement by the MoANR. It remains to be seen how far the stakeholders are engaged and implement the strategy for the target year set in 2018.

National Seed Policy and Regulatory Framework

The National Seed Policy and Strategy (1992) explicitly advocated the role of the private sector in the Ethiopian seed sector. Bishaw and Louwaars (2012) stated that ‘The birth pangs of diverse and pluralistic seed sector are visible with the emergence of the embryonic private sector’. However, despite the optimism the role of the private seed companies remain weak in scope and scale of their operation. On the other hand, the seed sector continues to be dominated by the expansion of the public sector. In general there is lack of clear guidelines addressing the entry of foreign private sector into the domestic seed market.

The revised Seed Proclamation (782/2013) puts the Ethiopian seed system on legal footing. It is the basic seed law of the country addressing the key issues of variety release and registration, eligibility and certificate of competence for seed producers and seed quality control and assurance. Accordingly all varieties, domestic or introduced, should be registered and all seed, produced locally or imported (including exported seed), should meet the national field and seed standards.

The national seed policy also encourages various forms of alternative local seed production by farmer seed producer’s cooperatives or associations to fill the gap and expand quality seed supply. Cognizant of this fact, a Quality Declared Seed (QDS) scheme was introduced and standards developed for 35 priority food, feed and horticultural crops. The move is expected to bring some form of normality to otherwise chaotic scene of project based operations which may undermine the formal sector. While this will provide greater opportunities for less resourced local seed businesses greater effort is expected in promoting the principles and spirits of QDS where it is liable to different interpretation and misrepresentation.

The Bisoafety Law is now revised and is expected to facilitate the introduction, testing and release of biotech crops, contrary to previously very restrictive law which criminalizes research on GMOs. The PBRslaw is under review to facilitate the protection of domestic and foreign plant varieties and expected to build confidence of the private sector investment in the seed sector. Theselawsare expected to provide greater opportunity for diversification of research and seed supply in the agricultural sector.

Performance of Agricultural Research and Seed Sub-sectors

EIAR, since its establishment in 1996, played a pioneering role in generating and transferring new agricultural technologies with significant contribution to the agricultural growth and development of the country over the last six decades. A substantial number of new improved varieties and integrated crop management technologies for major agricultural and horticultural crops were developed, released and disseminated in the country.Some of the achievements of these activities are discussed in the following sections.

Development of agricultural technologies (varieties and hybrids)

New varieties of plants are the backbone of a robust seed system and one of the fundamental technologies for sustainable agricultural development. In 2014, the Crop Variety Register contains an impressive list of 960 improved varieties of 114 crop species including agricultural, horticultural, forage and fruit tree crops (Figure 1 and MoA, 2014). During the last four decades and half there is an increasing trend in varietal releases with the highest peak so far from 2000-2009. Since 1970s, the average annual varietal release per year is7.8 for cereals, 3.4 for legumes and 2.6 for oilseeds. In case of individual crops the varietal release per year was 2.6for wheat which is the highest followed by 1.6each for barley and maize and 1.2 each for rice and haricot beans, the CGIAR mandate crops, where most of the releases are of direct or indirect origin from IARCs. This can be compared to the average annual varietal release of wheat of 14 in SSA during 1994-2014 (Lantican et al, 2015) where Ethiopia is one of the contributors in terms of varietal release.

Given variations in crop area, releases per million hectares of crop suggested as useful indicator for comparison. Accordingly, the number of varieties released per million ha of cultivated land over four and half decades is the highest for oilseeds at 105 varieties followed by legumes with 100 varieties, owing to the smaller total area under cultivationcompared to cereals with 35 varieties. These numbers are slightly higher for horticultural and minor crops. Significant achievements have been registered in terms of increased agricultural productivity and production through adoption of these new crop varieties and associated agronomic technologies by farmers.

The impressive figures in varietal releases however mask serious deficiencies in many ways. First, in terms of varietal mix, cereals and legumes occupy about 36 and 20% of all varietal releases across all crops followed by that of vegetables(12%) compared to some important food security crops. Second, despite the agro-ecological variability and the diversity of farming systems in the country, there is lack of diverse set of well adapted and context specific varieties for different environments, where most released varieties are for favourable highland areas with adequate rainfall compared to moisture stress areas in the lowlands or irrigated areas. Third, grain yield and (a)biotic stress tolerance is an overriding criteria both for breeders and farmers whereas grain quality traits for industrial use (durum, malt barley) and seed size (legumes for export) appeared to be lacking for some crops. Fourth, most of varietal releases are OPPs except for maize (almost 50% for hybrids) and few for sorghum. Fifth, most varietal releases are from the public sector whereas releases from the private sector constitute less than ten per cent not withstanding hybridsof maize, rice, sunflower and cotton andvegetable crops. In total about 93 varieties of maize (15), rice (3), sunflower (12), cotton (7) and vegetables (68) were released by the private sector until 2014. Six, there is a general lack of research on transgenic, leaving aside the controversy onbiotech crops.

Alemu and Bishaw (2016) found that farmers' perceptions of attainment indices, varietal attributes demanded by farmers, is high for improved varieties compared to the local landraces. However, there is a high variability in the attainment indices among improved varieties for different attributes thus implying the need to target varieties for the different environments and circumstances.

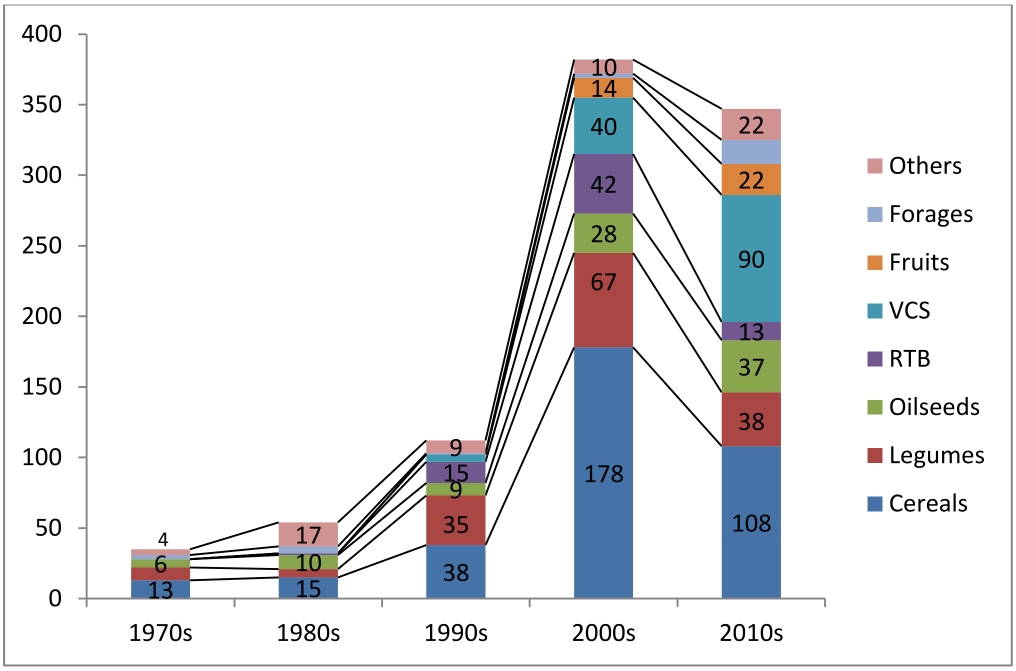


Figure 1. Varietal releases of agricultural crops in Ethiopia (1970-2015)
Note: RTB=root and tuber crops; and VCS= vegetables, condiments and spices

Performance of the seed sector

It is crucial that improved crop technologies reach the majority of farmers to bring about tangible results on the rural livelihoods. Hence generation of technology must be coupled with a robust and diverse seed system which provides farmers with adequate quantity and quality seed at the appropriate place, time and price.

From its modest beginning in the early 1980s the formal sector went through substantial changes in recent years. During the first decade of its operations from 1980 to 1989, the ESE was distributing on average 21,162 tons of seed annually of handful of cereal and few legume crops particularly haricot bean where the major customers were the public state farms followed by MoA and some NGOs for emergency seed relief. Inthe second decade (1990-1999), the average yearly seed supply dropped to 14,012 tons due to reduced demand from the public state farms where the new major customers were the regional Bureaus of Agriculture and the federal Ministry of Agriculture. In the third decade (2000-2009), formal seed supply on averagereached 18,632 tons although in 2010, it was more than doubled reaching 54,000 tons. The major leapin formal seed supply can be witnessed during the fourth half decade (2010-2014) withan average of 67,630 tons reaching over 105,100 tons in 2014, if the statistics is right. This is close to one third of the target planned under GTPI which was aimed at reaching 360,400 tons by the end of 2015(excluding the recycled certified seed as this is not considered seed from formal sector).

Despite over four decades of organized seed delivery in the country, there is no significant shift in the portfolio of crops and varieties in the menu of certified seed provided where cereals predominate and among these wheat and maize occupy the major share of all crops. The proportion of wheat seed supply declined quickly from over 90% at the beginning while that of maize increased rapidly from less than 10% and both crops continue to dominate the formal seed supply. In 2014, wheat and maize occupy 64 and 19% of formal seed supply, respectively but both crops occupy about 13 and 17% of cultivated area in the same order. Moreover, a handful and sometimes old varieties dominate the formal seed supply.

Another important performance indicator is the degree of private sector involvement is seed delivery. The role of private sector in certified seed delivery is limited both in scope and scale of seed supplied. Pioneer Hi-bred Ltd started seed operation in 1990 and was the only private seed provider in the country until the emergence of a number of small to medium domestic private seed companies in 2000s. From 1998-2008, based on available data, the private sector on average provided about 1,388 tons of primarily maize seed which is about 21% of total maize seed supply or 9% of total formal seed supply across all crops. Pioneer Hibredis a major supplieramong the private sector. Its share of hybrid sales increased from a little more than 500 tons in 1996 to nearly 3,000 tons in 20011(Negari and Admasu, 2011). The figure reached 4,214 tons (2012), 7078 tons (2014) and expected to hit the 10,000 tons mark in 2016 (Melaku Admasu, personal communication). Alemu et al (2010) also found a similar situation where the contribution of private sector is focused on maize seed and very limited in other crops.

On the other hand, the vegetable seed sector is dominated by the private sector where the total seed import has increased from about 2 thousand tons in 2012 to 2.5 thousand tons in 2013, and about 3.6 thousand tons in 2014 with the corresponding CIF value equivalent to USD 3.7 million, 4.6 million and 6.3 million, respectively (Alemu??).

There is insignificant or no certified seed supply of certain legumes (except haricot bean), oilseeds, root and tuber crops,forage and pasture crops. Certainly, the current low level productivity of these crops compared to wheat and maize and the relatively higher seed to grain price ratio may have limited or discouraged the demand for certified seed and technology of these crops.

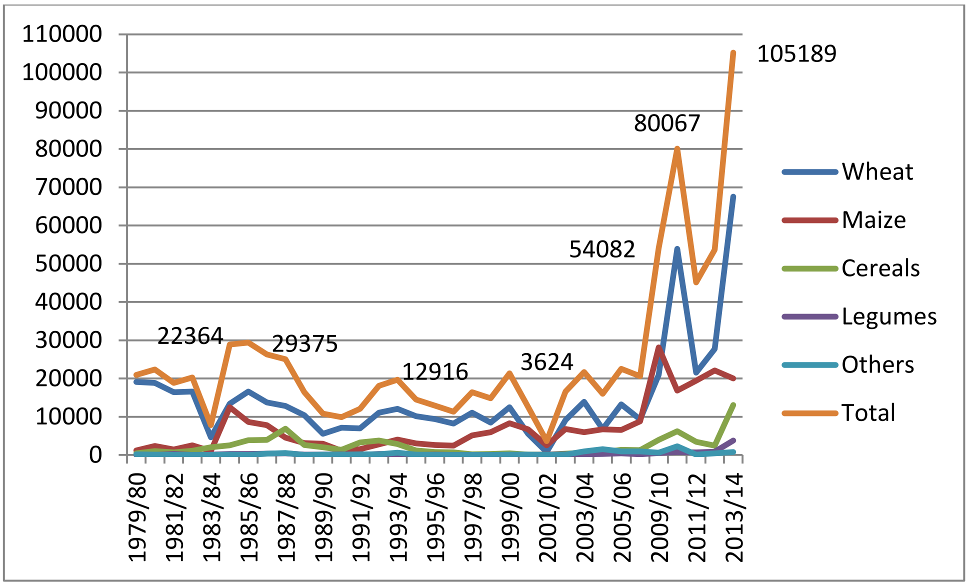


Figure 2. Certified seed supply in Ethiopia (1979-2014)

Varietal and seed replacement rates

Varietal release alone is not the measurement of success for agricultural research unless they are adopted by farmers. Varietal replacement and seed replacement rates help measure the performance of the formal seed sector and determines the extent of spatial and temporal changes in varietal use and the extent of access to quality seed by farmers.Variety replacement is the decision by farmers to change varieties already adopted whereas the decision to obtain fresh seed stocks of the same variety is termed as seed replacement. In both cases the decision to replace variety and/or seed may be due to perceived reduction in productivity of the variety and/or deterioration of seed quality due to continuous use of the same variety or seed.

Varietal replacement: The rate of varietal replacement is estimated by the age of varieties in farmers' fields, measured in years since releases and weighted by the area under each variety (Brennan and Byerlee, 1991).Low average age of varieties indicates higher rates of varietal turnover and earlier access to new crop varieties and associated with better productivity.

In Ethiopia, several studies were conducted on adoption of improved varieties of cereals (wheat, barley, sorghum, etc) and grain legumes (faba bean, chickpea, lentil, haricot bean, etc). Arguably all studies, some at local or regional levels, have found high adoption rates of improved varieties and associated technologies such as fertilizers and herbicides among small-scale farmers in Ethiopia. Yirga et al (2015) found that 65.2% of farmers (0.9% durum wheat) used improved wheat varieties on 59.8% of the area (0.31% durum wheat) across different ago-ecologies and regionsof Ethiopia. They defined adoption as use of seed of improved variety for five consecutive years which is problematic as farmers may access seed from informal sources. However, one of the striking findings was the weighted average age of varieties which was 19.3 years showing the predominance of older varieties and low varietal replacement rate among farmers. Accordingly old varieties such as Kubsa (1995), Galema (1995), Dashen (1984), and Tusie (1997), respectively occupy 19.6%, 7%, 5.4% and 5.3% of the area (62.2% of improved wheat area). This situation may change slightly following the yellow rust epidemics of 2010 and stem rust recurrent in 2013 and 2014 crop seasons.

Yigezu et al (2015) found that adoption of improved varieties varies from 39% for barley, 19% chickpea, 15% for lentil,11% for fab bean to 2% for field pea in Ethiopia. They found significant variation in adoption between geographic regions and high and low potential areas. In case of chickpea, adoption based on national survey showed that 17.4% of farmers planted improved varieties on 19.4% of the cultivated chickpea area.

Among adopted varieties, Arerti, Habru and Shahso occupy almost 89% of area covered by improved varieties (Yirga et al 2015).Muthoni and Andrade (2015) estimated that 44% of bean area is covered by improved varieties in 2010 and among them improved varieties Nasir, Teshale and Awash 1 covered about 12 and 10% of the area under bean production. Adoption of improved potatoes estimated at 22.6% of the area where varieties such as Jalene (7.51%), Gudene (4.9%), Menagesha (2.91%) and Bule (2.6%)collectively cover 17.92% of the area (Labrata, 2015).

Table 1. Adoption of improved crop varieties in Ethiopia

Crop	Varietal adoption		Seed supply	Reference	Remarks
	% of farmers	% of area	% of farmers		
Wheat	65.2	59.8	16	Yirga et al 2015; Alemu & Bishaw	WAA (19.3 yrs)
Barley (malt)	32.8 (96)	40.78	8.4 (39)	Alemu & Bishaw, 2016	Including partial adopters
Maize	57.1	39	58	Jeng et al 2013; Benson et al 2014;Gierend et al 2014	Including partial adopters WAA (15.74 yrs)
Sorghum	<5	8		Gierend et al 2014	
Faba bean	27.5	22.38	6	Alemu & Bishaw, 2016	Including partial adopters
Chickpea	17.4	19.4		Yirga et al 2015	
Lentil		10.4%		DIIVA, 2009	
Haricot bean		43		Muthoni and Andrade, 2015	2009 national data
Potatoes		22.6		Labrata, 2015	National

Seed replacement: For seeds , the rule of thumb requires replacing seed every year for hybrids, two to three years for cross pollinated varieties and four to five years for self-pollinated crops because the extent of yield loss due to use of recycled seed is comparatively higher for hybrids compared to seed of self-pollinated crops.

There is substantial increase in the amount of certified seed supply in recent years. In 2014/15 crop season, a total of 95 varieties of cereals (9 species), 41 varieties of grain legumes (7 species) and 14 varieties (4 species) of oilseed crops were produced during the season. The total formal seed supply was 88,603 tonsfor cereals, 3129 tonsfor grain legumes and 591 tonsfor oilseeds by the federal and regional public seed enterprises and the private sector (Pioneer Ltd with 5,706 tons maize seed). This is sufficient to meet 84.4% of certified seed demand of cereals, 21.2% of grain legumes and 52.5% of oilseed based on actual demand figures from regional states with an overall performance of 76.3% across all crops. Formal seed supply met 96% of wheat, 71% of maize and 23.6% of barley (46% for malt) of actual seed demand.

Table 2.Performance of formal sector in 2014/15: actual demand and supply

Crop	No of varieties	ESE supply	RPSEsupply	Total seed supply	Total seed demand	Gap	%
Bread wheat	21	150707	452861	603569	631031	-27462	95.6
Durum wheat	4	0	894	894	150	744	596.0
Total	25	150707	453755	604463	631181	-26718	95.8
Food barley	7	1275	976	2251	48335	-46084	4.7
Malt barley	9	7209	11590	18799	40966	-22167	45.9
Total	16	8484	12566	21050	89301	-68251	23.6
Tef	11	20316	52368	72684	57681	15003	126.0
Rice	5	20	550	570	2032	-1462	28.0
Maize	26	94996	89982	184978	261792	-76814	70.7
Sorghum	10	478	1340	1818	7388	-5570	24.6
Millets	2	328	135	463	877	-414	52.8
Cereals	95	275329	610696	886025	1050252	-164227	84.4
H. bean	8	6687	9382	16069	83530	-67461	19.2
Faba bean	11	365	2633	2998	32122	-29124	9.3
Field pea	2	324	2758	3082	15378	-12296	20.0
Chickpea	9	1857	1781	3638	14983	-11345	24.3
Lentil	3	1684	2173	3857	1053	2804	366.3
Soya bean	7	1292	343	1635	780	855	209.6
Mungbean	1	9	0	9	0	9	
Legumes	41	12218	19070	31288	147846	-116558	21.2
Ground nut	5	31	0	31	137	-106	22.4
Rape seed	1	4007	0	4007	800	3207	500.9
Linseed	3	88	457	545	1332	-787	40.9
Sesame	5	518	812	1330	8992	-7662	14.8
Oil seeds	14	4644	1269	5913	11261	-5348	52.5
Total	150	292,191	631,035	923,227	1,209,359	(286,132)	76.3

Taking into account the potential seed demand of the country and the recommended seed replacement rates, the overall performance of the formal sector appears satisfactory for some crops than for others. For cereals, the certified seed supply reached 17% seed replacement rate although it varies from 0.2% for food barley and durum wheat to 28.8% for bread wheat and 50% for hybrid maize. For legumes and oilseeds, the seed replacement rate is 15% and 13%, respectively although it differs across crops and does not include some crops where there is no certified seed supply such as grass pea and noug.

The formal seed supply figures however mask some important deficiencies in terms of varietal choices and age of the varieties in the farmers' fields. Interestingly, a handful and sometimes old varieties dominate the formal seed supply. For example, from 21 bread wheat varieties under multiplication in 2014/15, three old varieties Digalu (2005), Kubsa (1995) and Pavon (1982) occupy 30% and two new varieties Danda'a and Kakaba occupy 63% which is collectively almost 93% of formal wheat seed supply. Among 26 maize hybrids/varieties, two old varieties BH660 (1993) and BH540 (1995) occupy 37% and two relatively new varieties BH661 (2011) and Shone (2006) occupy28%which is collectively 65% of formal maize seed supply.From 16 barley varieties Holker (1979) occupy almost 78% of barley seed supply.

During, 2002-2010, the share of hybrids to total maize seed sales reached 86.9% and the three hybrids BH660, BH540 and BH140 covered 95.1% of hybrid seed sales whereas for the OPPs, the two old varieties A511 and Katumani covered 86% of OPPs sales of ESE(Sahlu and Beshir, 2011). For seed production nine local hybrids and seven OPVs were included in the certified seed production by ESE where 85% were hybrids and among these three hybrids, BH660, BH540 and BH140 accounted for more than 92% of the total hybrid seed produced by ESE (Sahlu and Beshir, 2011). All the OPPS were releases from 1970s.

Table 3. Performance of formal seed supply in 2014/15: Potential demand and actual supply

Crop	Cultivated area in ha	Potential seed required (t)	CS required (t)	CS supplied (t)	% CS	% potential (total) seed
Bread wheat	1397630	209645	52411	60357	115.2	28.8
Durum wheat	266215	39932	9983	89.4	0.9	0.2
Total	1663846	249577	62394	60446	96.9	24.2
Food barley	843939	105492	26373	225	0.9	0.2
Malt barley	150000	18750	4688	1880	40.1	10.0
Total	993939	124242	31061	2105	6.8	1.7
Teff	3016063	90482	22620	5768	25.5	6.4
Rice	46832	4683	1171	203	17.3	4.3
Maize	2114876	52872	52872	26179	49.5	49.5
Sorghum	1834651	27520	6880	739	10.7	2.7
Millets	453909	11348	2837	88	3.1	0.8
Cereals	10124115	560724	179835	95528	53.1	17.0
Haricot bean	323327	38799	9700	1607	16.6	4.1
Faba bean	443108	110777	55388	300	0.5	0.3
Field pea	230667	28833	7208	308	4.3	1.1
Chickpea	239755	23976	5994	364	6.1	1.5
Lentil	98869	7415	1854	386	20.8	5.2
Soya bean	35260	2116	529	164	30.9	7.7
Mungbean	14562	728	182	1	0.5	0.1
Legumes	1385549	212644	80855	3129	3.9	1.5
Ground nut	64649	8081	2020	3	0.2	0.0
Rape seed	30083	361	90	401	444.0	111.0
Linseed	82326	2470	617	55	8.8	2.2
Sesame	420495	2102	526	133	25.3	6.3
Oilseeds	597553	13014	3254	591	18.2	4.5
Total	12107217	786382	263944	99248	37.6	12.6

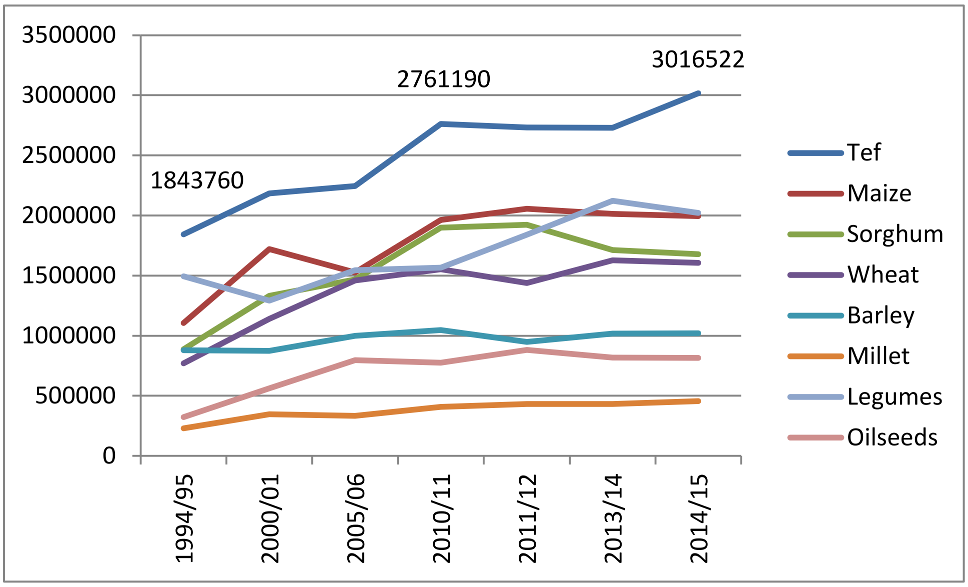
Trends in crop area, production and productivity

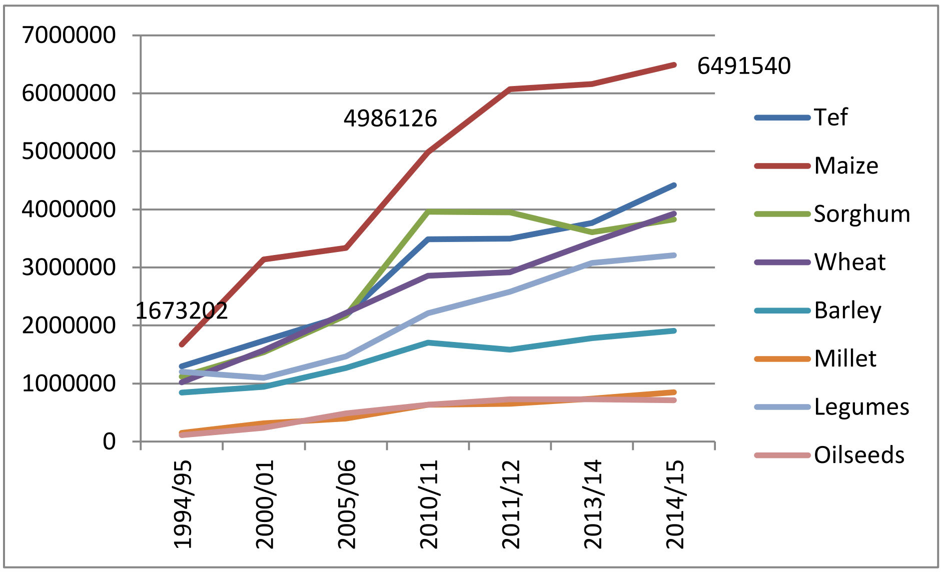
In Ethiopia, the trends in cultivated area, grain production and productivity are as shown in Figure 4a-c. According to CSA data in 2014, the cultivated area of cereals is 10,144,252 ha (80.78%) followed by legumes at 1,558.442 ha (12.41%) and oilseeds at 885,750 ha (6.81%). There is a progressive increase in harvested area, crop production and productivity of major agricultural crops over the last two decades (FAO, 2015; CSA, 2014).

For major agricultural crops- cereals, legumes and oilseeds- area increased from 7.6 million ha in 1994 to 12.7 million ha, an increase of 68% or combined annual growth rate of 3%. Cereal area has increased from 5.7 million hain 1994to 9.8 million ha in 2014, an increment of about71%, an annual growth rate of 4%. Similarly, for legumes, the increment was from 1.5 million ha to 2.0 million ha, about 35% in area(2% growth rate per year) whereas for oilseeds, substantial increment was observed from 0.3 million ha to 0.8 million ha which is more than doubled (an increase of 153% or annual growth rate of 8%).

Agricultural production followed the same trend where total grain production has increased during the same period from 7.5 million tons in 1994 to 25.4 million tons in 2014, an increase of 242% or combined annual growth rate of 12%. Cereal production has increased from 6.2 million tons in 1994 to 21.6 million tons in 2014, anincrement of over threefold (an increase of 251% or annual growth rate of 13%). For legumes, the increment was from 1.2 million tons to 3.2 million tons, more than doubled (an increase of 167% or annual growth rate of 8%) whereas for oilseeds, the increment was from 109 thousand to 711 thousand tons which is more than fivefold (an increase of 552% or annual growth rate of 28%).

While substantial increase in area contributed to significant increases in production, the increase in productivity remains modest due to low average national yield of all crops. However, substantial increases in yield have been reported in localized areas which are an outcome of adoption of improved varieties and associated integrated crop management technologies. Among cereals, maize and wheat, has shown higher productivity during the last two decades. For example plot level yield changes have been reported in the range of 48-63% due to adoption of new varieties in Ethiopia (Zeng et al 2015). Grain legumes have shown the highest productivity increase across the major crops such as faba bean, field, chickpea, lentil and soya bean. Similar results have been observed for oilseeds.





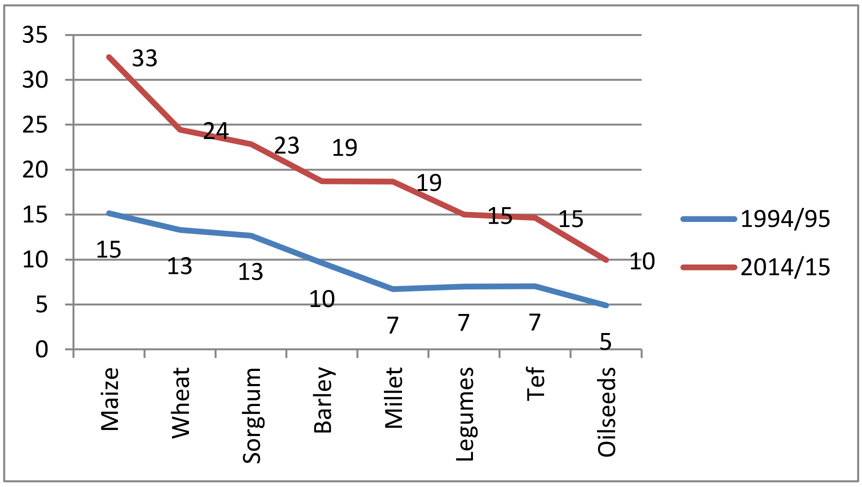


Figure 3. Trends in area (op), production (middle) and productivity (bottom) of major crops in Ethiopia: 1994-2014

Yield gaps in major crops

Whilst there is good evidence that genetic improvement contributes to yield improvement there is good body of literature where contribution of advances in agronomy to increases in yield is well documented. Crop productivity and use of production enhancing technologies such as fertilizers, herbicides, etc are low in Ethiopia by any African or global standards. Ethiopian varietal release lack specific recommendation and generic in terms of agro-ecological adaptation (altitude, rainfall pattern and soil fertility gradient), fertilizer application (urea and DAP), though recent attempts try to address fertilizer application with soil fertility tests.

There is a tremendous yield gaps between yields on research centres, demonstration plots and farmers' fields. For example, this variation in yield gaps can be demonstrated using barley and faba bean. During 2004-2014, the average national yield for barley is 14.9 ton/ha whereas yields under farmers practice on average is 20.18 ton /ha. However, barley yields under improved management practices on the farm can reach up to 2.7 tons/ha whereas yields on research station on average can be 3.8 tons/ha (Alemu and Bishaw, forthcoming). A similar situation can be observed for faba bean where national average yield per ha is 1.5 ton during the same period and this can reach 1.9 ton under farmer management, 3.2 tons in demonstration plots and 3.8 tons per ha on research stations. Agro-ecology based recommendations are required to reduce yield gaps not only in provision of seed of improved varieties but of complementary inputs and information to farmers.

Table 4. Barley and faba bean yield gaps in Ethiopia

Category	Technologies	Average yield in t ha^{-1}			Source
		Food barley	Malt barley	Faba bean	
Research field	• Improved variety • Recommended practices • Researcher managed	3.8	3.3	3.8	MoA, 2011, 2012 and 2014
Farmers' fields	• Improved variety • Recommended practices • Farmer managed	2.7	2.8	3.6	
Farmers' fields	• Local variety • Recommended practices • Farmer managed	2.02		1.9	Assefa et al. 2011; Berhanu et al. 2011
National yield level*	• National production of ten years	1.49	1.49	1.5	CSA, 2004-2014

Source: Alemu and Bishaw (forthcoming)

The Way Forward

The Ethiopian seed sector is highly characterized and subject to many studies and reviews during the last two decades. The challenges and opportunities for the seed sector have also been described and presented in the recently developed seed strategy document of ATA. Bishaw and Louwaars (2012) also presented key policy considerations in order to facilitate the progress of the seed sector development in Ethiopia. They advocated for enabling national policy and regulatory frameworks and institutional innovations to build a robust national seed system. They also raised critical issues to be addressed in promoting the private sector, diversifying the crops and seeds, seed marketing, seed quality control and certification and capacity development. Some of these and other options which are relevant today are presented and discussed in more depth below.

Demand Driven Agricultural Research

EIAR and recently the RARIs have played a major role in developing improved crop varieties and ICM technologies with significant contribution to the growth in production and productivity of agricultural sector. However, there is no room for complacency as we are confronted with more difficult challenges than before such as climate change and its aftermath like emerging threats of new pests, increasing temperature and frequent droughts with serious consequences on the agricultural sector. The continued population growth and natural resources degradation of unprecedented magnitude calls for more action. Climate smart and market preferred varieties/hybrids with high productivity and specialty traits in food qualityand natural resources saving technologies are requiredmore than ever for a wide range of environmental conditions and farming systems in the country.

Germplasm conservation and utilization

The Abyssinian region is an important primary and secondary center of domestication for some 38 crop species (Worede, 1992). The Ethiopian Biodiversity Institute (EBI) not only a repository of the largest collection of plant genetic resources in the country, but a focal agency responsible facilitating its sustainable conservation, access and exchange for research purposes. EBI has a rich collection of thousands of accessions of severalagricultural and horticultural crops (52 species and 70316 accessions at the end of GTP I), which can be of great value forcrop improvement programs. The national germplasm collection needs to be evaluated systematically and made available to both public and private sector institutions with research capacity to ultimately bred superior varieties and hybrids for the benefit of smallholder farmers. The Ethiopian NARS and the EBI are expected to forge strong partnership and strengthen their capacity for exploiting this diversity in a much systematic manner to address the key agricultural development challenges of the country including emerging issues of climate change than veiled tussle between conservation and modernization.

However, Ethiopia as a signatory of CBD and IT-PGRFA is bound to the spirit of the international conventions in ensuring the sustainable conservation, utilization and exchange of these genetic resources. There is a need to develop national guidelines to facilitate the inflow and outflow of germplasm which is the basis of agricultural research and sustainable development in the country.

Application of biotechnology in agricultural research

There is a general decline or stagnation in rates of growth in crop productivity in recent years worldwide. Conventional crop improvement technology alone may not be sufficient to feed the ever increasing population without the use of modern tools such as biotechnology. An option is a balanced, safe and sustainable approach, using the best of conventional crop technology (well adapted germplasm) and the best of biotechnology (appropriate GM and/non-GM traits) to achieve **sustainable intensification** of crop productivity.The application of biotechnology to develop new improved varieties with special traits, particularly to provide effective and durable solutions against abiotic and biotic stresses deserves special attention. There is a need for effective implementation of EIAR biotechnology research strategy to make use of the benefits of new and modern breeding tools through sound investments in the R&D both by the public and private sector.

It will be appropriate to create awareness among farmers, civil society organization and the policy makers about the potential of plant biotechnology as well as its safe application. We must ensure that the regulatory process is also efficient and safe from environment and health.

Research in seed science and technology

The public sector institutions in the National Agricultural Research System, comprising federal and regional institutes, contributed significantly towards varietal development of agricultural and horticultural crops. There is limited research on technical aspects of seed science and technology for indigenous crops where there are knowledge gaps in seed production, seed storage, seed physiology, seed health and seed treatment as well as application of biochemical or molecular tools for quality assurance and enhancement. One of the important areas for research is a rigorous scientific approach and analysis of policy and regulatory framework and institutional innovations and its impact on seed sector development where NARS and universities can take the lead.

Expansion of small scale mechanization and conservation agriculture

Large-scale mechanization has been introduced with emergence of private estate farms and plantations and later expanded with public state farmsunder socialist government in different parts of the country. However, larges-scale mechanization failed to take root in the peasant sector probably due to high cost, land fragmentation and the challenging topography. EIAR's agricultural mechanization research is as old as crop improvement programs, but focused on improving traditional farm implements and tools than developing alternative low cost and appropriate technologies for small-scale farmers. There are several models of labor intensive hand or motor operated small-scale planters, cultivators, harvesters, threshers, etc available from foreign sources for local adaptation, manufacturing and use.

GTPII has a strategy to ensure sufficient supply and access to agricultural mechanization by encouraging domestic manufacturing through joint ventures, creating enabling environment for establishment of spare parts and maintenance service centers by private investors and formulating agricultural mechanization services delivery system. The government aimed at providing various incentives such as access to foreign currency and credits for machinery manufacturers, importers or service providers. Much is expected from NARS to develop science based standards for a national testing and certification system envisaged to be established for both imported and locally manufactured agricultural mechanization technologies.

Conservation agriculture has been widely adopted and its benefits have been manifold. Introduction of improved varieties and improved crop management as part of integrated soil, water and crop management packages should significantly increase resource use efficiency (water, nutrients), reduce costs of production and enable higher crop productivity. The introduction of conservation agriculture has relevance to Ethiopia.butit should be better coupled with mechanization as provision of appropriate machinery is prerequisites for its adoption at national level.

Expansion of irrigated agriculture

In Ethiopia, almost all crop production is traditionally concentrated in the highlands with few exceptions where the consequences of environmental degradation are huge leading to low productivity. Moreover, crop production is dependent on rainfed and subject to weather condition and exposed to the vagaries of plant diseases and pests like rust diseases of wheat in the highlands.Currently there is an estimated 3,798,782 ha of land suitable for irrigation in the seven river basins across the country including Afar, BeniShangul, Gambella, Oromia and Tigray regions of Ethiopia. This is an alternative for rainfed dependent agriculture and provides opportunities for expansion of irrigated agriculture in the lowlands which was predominantly inhabited by agro-pastoralists. Development of adapted germplasm for the lowlands with heat tolerance should be coupled with agronomic management technologies relevant to irrigated agriculture. Modern irrigation management technologies (irrigation scheduling, drainage, etc), water saving technologies (raised bed) need to be introduced, validated, promoted and disseminated.

Previous studies have demonstrated the potential of wheat production under irrigated conditions in the lowlands of Awash Valley of Afar region. Since 2006, there is growing interest for irrigated wheat production and in recent years, the WARC is introducing and testing germplasm from ICARDA and CIMMYT to identify high yielding and heat tolerant wheat, barley, chickpea and forage legume varieties for irrigated lowland areas. In recent years some new wheat varieties which are tolerant to heat, drought and salinity were released and recommended for irrigated lowland areas in Afar Regional State. Strong effort should be madeto accelerate seed multiplication and dissemination of these new varieties in target districts and other potential regions.

Research partnership with private sector

Agricultural research and crop improvement is confined to the public sector domain and academic institutions. The Ethiopian seed sector is attracting multinational seed companies due to the potential of the agricultural sector, favorable investment environment, provision of land and cheap labor force. Few private seed companies including multinationals introduce the germplasm for local testing, registration and commercialization where there is limited technology transfer.Experience elsewhere demonstrated that partnership with MNCs contributed significantly for the development of the seed sector. The partnership will provide access to germplasm, technology transfer and varietal choice for farmers. Ethiopian NARS and public or private seed companies should forge such partnership and benefit from transfer of new technology.

Research on value addition

Agricultural commercialization clusters and contract farming

Development of Seed Sub-sector

Two systemic bottlenecks in the seed sub-sector have been identified under GTPII where concrete steps need to be taken to: (a) Strengthen the enabling environment to attract investment and develop a vibrant and competitive seed sector; and (b) Strengthen federal/regional seed regulatory capacity, finalize structural reforms and legal frameworks to meet international standards. This objectives still shows the magnitude of the deficiency of the policy and regulatory framework of the national seed sector where detailed action plans are required for its improvement.

National seed policy and regulatory framework

Seed policy*:*The National Seed Policy and Strategy (1992) explicitly advocated the role of both the public and the private seed sector in Ethiopia. However, the country stands out for its ambivalent attitude towards economic liberalization and the private seed sector (Alemu, 2011). The national seed policy so far fails to bring about the desired level of pluralism and diversity attracting a critical mass of private sector investment in crop improvement and seed delivery. It would be interesting to undertake a case study to assess the impact of national seed policy on the development of the private sector in the country and what policy incentives should be put in place to ensure its progressive development.

Seed regulations: The revised seed proclamation provides strategic direction of the seed regulatory framework in the country. Moreover, the Bisoafetylaw is now approved whereas that of PBPRs is also under review. There are many gaps in terms of institutional capacity to undertake the huge task of variety registration, plant variety protection and seed certification to the level of regional or international norms where investment is required in infrastructure and human resources.

National coordination*:* The national seed sector is much complex and not only about polices and regulations on varieties and seeds and confined to the agricultural sector. It is also about private investments (domestic or foreign), access to finance (capital or operational) and seed trade (domestic, international) where jurisdictions are not only with MoANR but with different ministries. Implementation of the national seed policy and its various laws and regulations as well as institutional arrangements in agricultural research and seed delivery at federal and regional levels require strong and effective coordination, monitoring and evaluation.

Subsequent to national seed policy, the National Seed Industry Council was established in 1993 to provide oversight and guidance to the national seed system. It was disbanded with the dissolution of NSIA (later NAIA). We once again advocate reconstitutingthe National Seed Council which could provide policy advocacy and formulation as well as the coordination, monitoring and evaluation of the seed sector. The Council could be constituted similar to that of NARC from relevant ministries and stakeholders from federal and regional states and the public and private sectors.

Currently information on seed sector is scattered and reliable and consolidated data remain with institutions and not publicly available. Apart from policy advocacy and coordination, the NSC could also serve as a national reference point on all issues related to the seed sector information system.

Functional plant variety release and protection systems

Bishaw and Louwaars (2012) advocated for the establishment of an independent variety release and quality assurance systems. To date the Plant Variety Release, Protection and Quality Control is established as an independent directorate within MoANR to coordinate centralized variety registration and plant variety protection at federal level while seed certification is decentralized to regional offices under Bureaus of Agriculture of regional states. The policy and institutional framework exists both for variety release, plant variety protection and seed quality assurance, but theystill remain weak due to lack of capacity and competence as activities are scattered among different actors (Bishaw and Louwaars, 2012).

Mainstreaming variety release: Under the Ethiopian seed law, both DUS and VCU testing are required for release. PVP also impacts on variety release because granting a Plant Breeders Right requires an accurate morphological description of the variety, based on a DUS examination. It is important to move away from present ad hoc arrangements and establish a clearly defined operational mechanism to mainstream and implement these activities at national level taking into account different possible arrangements. It is either for PVRPQCD, to capacitate itself to conduct DUS and VCU tests on its own right or play a coordinating role through third party contract agreement with universities to undertake DUS testing and with NARS for VCU testing to ensure the independence of the system. The former may require substantial investments for physical, financial and human resources while the latter may make use of existing facilities and networks with some financial support. Given the proliferation of new varieties and the private sector interest for protection it is now time to introduce the DUS testing as part of the release program in the country.

Another important element in variety registration and release is the issue of vegetable crops where DUS testing is neither desired nor feasible. Experiences from elsewhere shows that imported vegetable varieties are tested for adaptation probably for a year or two to enter commercialization in the domestic market. This may also extended to registration of mother plants for fruit tree crops.

In whatever form it is important to establish aneffective, efficient and transparent variety release system that would promote not stifle to the growth of the seed industry.

Enforcement of PBRs: Breeding new plant varieties requires substantial long-term investment, be it by the public or the private sector. Any significant private investment in plant breeding particularly of non-hybrid crops depends on some form of legal protection to be innovative. The Ethiopian Plant Breeder's Right Proclamation (No 481/2006) accepted unequivocally the notion of intellectual property protection of plant varieties. In Ethiopian context, the purpose of PVP is manifold: (i) provide domestic plant breeders the legal rights to protect their varieties and ensure future investments in crop improvement; (ii) encourage foreign breeders and companies to introduce or develop new varieties for domestic seed market and commercialization; (iii) align and promote the development of the seed sector to international norms and standards; and (iv) fulfil the legal requirements for joining WTO and/or UPOV as deemed necessary.

The PVP law lay dormant for over a decade without implementation in either granting the protection or creating a mechanism for royalty collection, probably due to the indifference of the public nature of the national breeding program. The argument against extending PVP to public-bred varieties is neither valid nor accurate. Empirical evidence has shown that both public and private sector breeding benefit from PVP where it contributes to genetic improvement for example in wheat (Kolady and Lesser, 2008). Moreover, rapid yield improvements have been registered where private sector wheat breeding is a competitive business like the European Union (Curtis and Nilsson, 2012).

The PVP law does not guarantee return on investments unless backed by an effective royalty collection system. PVP can be enforced using a licensing mechanism and/or by designing an effective mechanism for royalty collection.It is time to take some initiatives and provide implementation guidelines to enforce PVP.

Managing variety list: It is stated elsewhere in this chapter that there is a very long list of improved varieties in the national crop variety register. Despite a long list of released crop varieties, just a few of them have entered large-scale commercial seed production and were made available to the farmers. The other tragedy, for some crops, most of the seed produced and distributed are old varieties with over 20 years. A review of existing list of released varieties does reveal that many old varieties are still in production with serious consequences. It is important to establish a review mechanism where 'obsolete' varieties with no demand are removed from the list and are no more recommended for seed production. This could coincide with annual review meeting for registration and release of varieties and managed by NVRC.

Institutionalization of early generation seed production

The present ad hoc arrangement and campaign type source seed production has lots to be desired. Four principal issues are important for streamlining early generation seed multiplication from the federal and regional national agricultural research systems: adequate variety maintenance, breeder seed demand, decentralized multiplication and quality assurance.

First, maintaining varietal identity and purity is a key in formal seed sector. NARS or breeding institutions are designated as responsible entities for maintenance of varieties they have released. However, the primary maintenance work, using ear to row techniques to maintain nucleus material, can absorb a considerable amount of time and land and require significant physical, financial and human resources. The establishment of a separate 'Seed Unit' with a defined budget and resources provides a way to manage this important work without jeopardising the main breeding program.

Second, availability of and access to breeder seed is critical in the seed supply chain where adequate planning is necessary involving all seed sector stakeholders. India has one of the extensively organized breeder seed indent and supply system where each state in consultation with ICAR Institutes (national varieties), SAUs (state varieties) and seedproducing agencies shall formulate seed plan (for Breeder,Foundation and Certified Seed) for the cropping seasons on thebasis of an assessment of existing and new varieties in terms ofactual or potential yield in each district/agro-climatic zone catering both for public and the private sector.In order to devise an efficient system, it would be beneficial to review these procedures and experiences.

Third, variety maintenance is handled by the NARS which releases the variety. In most cases lack of sufficient land and facilities does not permit the center to produce sufficient quantity of seed based on demand from other centers and seed producers. Decentralizing early generation seed production to regional centers where the variety is in demand may reduce the pressure and increase the availability of breeder seed.

Fourth, apart from breeder seed, all early generation seed (pre-basic and basic) is subject to certification where field inspection and seed testing are compulsory. The quality assurance either has to be conducted by the certification agencies or through accreditation based on internal quality control where expertise and facilities exist within NARS.

Whilst the breeders has vested interested in commercializing the varieties released by making available breeder in a matured and competitive seed market, the lack of interest from public breeding programs remains a dilemma of the seed sector.There is an intense ongoing debate of early generation seed production where two independent studies were commissioned by ATA and BMGFA. Whatever the outcome of the study, an action–oriented program should be developed and implemented and any full cost recovery from the program may not be feasible where some government support is desirable.

Diversification of the seed sector

The Ethiopian seed sector changed little over the last four and half decades in terms of diversity of seed suppliers and certified seed of crops and varieties available to farmers.

Participation of private seed sector

From the outset, the national seed policy encourages that the private sector to play greater role in variety development and seed delivery. Despite policy pronouncements and incentives the private sector remains weak in a primarily public sector dominated seed industry. Deregulation, liberalization and restructuring of a publicly dominated seed industries were meant to create a competitive and pluralistic seed sector. However, the diverging policy implementation between countries has resulted in varying degrees of market concentration and the roles of public and private sector. The Ethiopian seed sector is less diverse in many ways compared to Kenya even within East Africa.

Given government support for seed sector development and its critical role in agricultural development, we once again reiterate the need to create a funding mechanism to provide investment opportunities and incentives targeting the seed sector. Clear policy guidance is required on facilitating access to capital for investments including entry through joint ventures and direct foreign investments.

Moreover, efforts should be made to strengthen the yet infant Ethiopian Seed Growers and Processors Association to become better organized and truly represent the seed industry. It is expected to represent and protect the interest of its members particularly the emerging private sector both at national and international levels and become a strong partner in dialogue with a government at federal and regional state levels. The association should also be encouraged to develop its own code of conduct to overcome some fraudulent practices and linked to regional and international seed trade associations to promote the Ethiopian seed industry.

Promoting new technologies

Ethiopian farmers have demonstrated their strong demand for seed and their strong willingness to pay for hybrid technology. However, apart from the maize sector there is limited hybrid technology explored where such opportunities exist in crops like sorghum, millets, sunflower, cotton, etc and recently for rice and pigeon pea. The introduction of hybrids through public breeding programs and/or joint ventures and production of seed needs to be promoted aggressively to improve productivity of these important crops.

Despite a controversy surrounding the biotech crops, the last 19 years has shown a tremendous increase in terms of area covered and number of farmers adopted the technology across developed and developing countries. From a modest beginning in 1996, about *18 million farmers in 28 countries planted more than 181 million ha in 2014.* Both large and small scale farmers have benefited from adoption of biotech crops like cotton, maize, soya bean and rape seed, the major biotech crops. The approval of biosafety law is one step in the right direction and this should be pursued further to include as many crops as possible where the technology is available. Let the science lead the way not fear in shaping these decisions.

Root and tuber crops

In 2014, root and tuber crops cover about 216,971 ha and cultivated by 5.9 million small-scale farmers. Among this potato and sweet potato occupy, 67,362 ha and 59,398 ha, respectively and grown by 1.3 million and 1.7 million small scale farmers in the same order. Potato, become a food security crop because of its ability of high yield per unit of input compared to other crops and has a potential to grow on 10 million ha and (Hirpa et al 2010). Accordingly, the formal sector appears to play very insignificant role in potato seed supply where farmer groups and cooperatives play some important role. Options for true potato seed production should be sought.

Vegetables and fruit trees

Despite its great potential the horticultural sector has low priority in the country. Apart from limited research and private sector import and distribution of seed for some vegetable crops, neither research nor seed supply of many indigenous vegetables and fruit trees receive adequate attention. Ethiopia has great potential for expansion of fruit tree crops, local or introduced, for rehabilitation of degraded highlands. A systematic evaluation, release, multiplication and dissemination of fruit tree seedlings through the establishment of nurseries remain critical. Under GTPII it is envisaged to address the subsector through support to public and private sector.

Understanding the seed market

In Ethiopia, seed marketing is highly centralized and regulated by the government through Inputs Marketing Directorate (IMD) of the MoANR at the federal level and the Input Marketing Processes of regional BoAs (Alemu and Bishaw, 2016). The key market actors are the public seed enterprises as suppliers and the cooperative unions and their respective primary cooperatives as distributors.

Demand assessment: At present the potential seed demand based on cultivable land and the central seed production planning practiced by the state may not reflect a truly effective seed market in the country (Bishaw and Louwaars, 2012). The national seed supply should be driven by economics with some policy oversight and direction. There is a general lack of reliable seed market data across the country – be it in terms of potential market demand (crop area and its agro-ecological characteristics like drought incidence), actual market demand (varietal use and seed renewal) and supply (seed volumes produced/traded). The study on wheat seed commercial orientation of farmers indicates that on average the formal seed sector can target the wheat producers who are in the buying position and part of those who are in net selling and part of those who are in equally buying and selling position, targeting collectively 64% of wheat farmers in any given year (Alemu and Bishaw, 2015).

The seed demand collection and compilation process passes through different intermediary actors from farmers to district, zonal, regional and federal levels. First, there is a possibility to either over estimate or underestimate the demand questioning its reliability and transparency. Second there is no accountability attached to the volume of seed requested as neither farmers nor the institutions collating the demand information take any responsibility or enter any contractual agreement or make down payment for the seed demanded. In Syria, for example, submission of seed demand for winter (May of preceding year) and summer (August of preceding year) planting is fixed and farmers are required to make a down payment of 7-15%?for certified seed.

Seed marketing: Certifiedseed is supplied at the federal level by ESE and at the regional level by the respective regional seed enterprises. Regional BoAs normally inform the federal IMD, the variety and quantity of certified seed demanded taking into account the quantity supplied by their respective regional seed enterprises. The IMD, based on the recommendations of the National Seed Production and Distribution Committee, makes an equitable appropriation to the respective regions. Regional BoAs then make allocation to the different cooperative unions targeting different zones where the respective union caters. Each union and primary cooperative is assigned to a respective zone and *woreda* with a mandate area of service provision. Therefore, the unions work closely with zonal BoA and the primary cooperatives with *woreda*BoA and *kebele* administration. For instance, whereas formal seed tends to be certified – the actual aggregate national volumes of certified seed per year are not systematically reported in the public domain nor otherwise easily available.

Direct seed marketing: The regional BoAs in the Amhara region in 2011 and in the Oromia and SNNP regions in 2012, has piloted direct seed marketing in five districts with technical and some financial support of the Integrated Seed Sector Development (ISSD) program in Ethiopia. In 2013, the program was expanded by the Bureaus of Agriculture in 33 districts of Amhara, Oromia, and SSNPR Regional states. The major objective was to create accountability of the seed quality to the suppliers and for timely seed delivery to farmers. Under the direct seed marketing program, seed enterprises, both public and private, were authorized to sell seed, primarily hybrid maize seed, directly to farmers in the selected *woredas (Benson, 2014).*According to the findings, DSM allowed the private sector to be competitive and remain in business. However, future direction should make use of the lessons learned and expand the operation to more districts and crops. MacRobert (2009) suggested formation of partnerships or dealerships with agencies like agro-dealers, wholesalers, farmer associations, NGOs, crop commodity dealers, and agro-processors as key for success. It is therefore important for liberalized system that would encourage competitive pricing and development of an effective dealership network to reach more farmers.

Seed pricing: The core decision on certified seed prices is made by the board of directors of ESE, which is composed of the Director General of EIAR as chair, two ESE representatives, Director of Agricultural Extension, Director of the Agricultural Inputs Marketing, and Director of the Planning and M&E Directorates of MoA as the members. The set price is communicated to the Agricultural Inputs Marketing Directorate (AIMD) of MoA. The AIMD gives a direction on the price setting mechanism and communicates the amount appropriated and purchase price of seed to the regional Agricultural Inputs Marketing Process of the respective regions. The overall direction in price setting is to sell the certified seed at the same price throughout the country, while taking into account the differences due to overhead, transportation and handling costs.

The current price setting mechanism has both advantages and disadvantages (Alemu, 2011). The advantages are: (i) it limits the entrance of excess intermediaries in the market, which helps farmers to get seed at reasonably better prices, (ii) enables farmers with limited access to markets (those in distant areas with poor road) to purchase seed equitably, and (iii) promotes group marketing especially through membership in cooperatives. The disadvantages are: (i) it transfers the cost incurred due to the inefficiency of union and primary cooperatives to farmers, (ii) limits the competitions among the different seed producers, (iii) creates disincentive for seed producers to work and invest in their own distribution systems, and (iv) it is liable to corruption and promotes black market for seed. In recent years, however, direct marketing of seed is being piloted in some districts.

Strengthening institutions of the seed sector

Lack of institutional and individual capacity often undermines the long-term impact of otherwise technically sound programs. Human resources and technical capacities are fundamental to ensure the present and future development of the seed sectors. Strengthening the capacity of human resources and infrastructure for the seed sector should be one of the key policy directions. The emergence of the new PSEs and the private sector created stiff competition for the already limited experienced staff in the seed sector. A short and long-term strategy should be put in place to train a cadre of seed specialists who can lead and manage the seed sector with particular attention on seed business management.

From production of breeder seed to certified seed, adequate facilities would be required for field operations, seed processing and storage. NARS would require adequate facilities (access to land, irrigation, farm machinery, etc) to overcome the bottleneck in early generation seed (breeder and pre-basic seed) production, Although the formal seed sector has built up its seed processing capacity over the past two anda half decades, most of thefacilities are owned by the ESE and are not located strategically for serving smallfarmers throughout the country. Newly established PSEs and the private sector (except PHI-bred) do lack adequate facilities for seed operations and BoA for adequate enforcement of the seed law. Support should be provided to upgrade the processing and storage facilities.

Collaboration and linkage with regional/global seed bodies

Ethiopia has a great potential in seed production both for domestic and export markets owing to diversity of its climate and strategic geographic location. It is believed that with liberalization the domestic markets will be linked to the global seed industry to ensure that farmers have better choices and access to modem technology. Collaboration with and linkages to international and regional seed related organizations would help to gradually raise the standards and harmonize with international norms leading to eventual membership in these organizations as deemed necessary. This will improve the overall performance and profile of the seed sector and may attract the much need investments in the Ethiopian seed industry.

Conclusion

In Ethiopia, the evolution of organized seed sector is shaped by its socio-economic and political context. There is no 'one size fits all' recommendations, but there are ample experiences elsewhere to be shared and adapted to own unique situation. In countries with federal structure, for example in India, agricultural research is organized and coordinated at a national level (with state agricultural universities at state level), public seed production organized both at national and state levels and decentralized seed certification operating at state level. In Pakistan, there are both federal and provincial agricultural research establishments coordinated at a federal level, decentralized public seed production at a provincial level and centralized seed certification at a federal level with regional laboratories. In both countries, there a vibrant and dynamic private sector which plays an important role in agricultural research and/or seed delivery including a wide range of small to large domestic seed companies and multinationals owing to adequate policy and regulatory framework which advocates pluralism and diversity in the seed sector.

In Ethiopia, many organizations have supported the development of the seed sector over the past several years through multilateral agricultural and financial institutions, overseas development agencies and NGOs. The Agricultural Transformation Agency established by the government has recently developed the strategy,interventions and road map believed to provide the guidance in transforming the seed industry. Translating the strategy into actions for implementation through provision of adequate resources is critical whose success is dependent on adequate ownership, coordination, and accountability of partners at all levels.

The Ethiopian seed industry is at cross roads. The national seed policy and regulatory frameworks as well as institutional and organizational arrangements are in place. It is important that theseed operations are implemented in a coherent manner both at federal and regional state levels where strong coordination and guidance is crucial both in agricultural research and seed delivery. Reconstitution of an apex body such as a national seed council composed of relevant stakeholders would serve the purpose. Any reforms at national level should be harmonized withregional or international norms to enhance the competitiveness and facilitate linkages with the global seed industry.

The Ethiopian Government has identified improving the efficiency of the seed system as the most effective means of meeting the Sustainable Development Goals.In GTPII, it is also expected to strengthen the enabling policy environment to attract investment and develop a vibrant and competitive seed sector and reform or strengthen seed regulatory frameworks to meet international standards. Concrete steps are required if we need to support the entry of the private sector.

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Strategic Approach for Crop Postharvest Research in Ethiopia

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Introduction

Postharvest activities such as transport, storage, processing and marketing are crucial and dynamic components of the agricultural complex **(Goletti and Samman, 2002).** Crop yield/food losses due to postharvest pests may occur at any time during postharvest handling, from completion of harvest to consumption (Malcolm, 1977). Losses may be qualitative or quantitative, or a combination of both (Kader, 2005) (Figure 1). According to Food and Agriculture Organization of the UN, about 1.3 billion tons of food are globally wasted or lost per year (Gustavasson, *et al*. 2011). It has been presumed that food supplies would need to increase by 60% (taking 2005 food production as base line) in order to meet the food demand in 2050 (Alexandratos and Bruinsma, 2012)**.** Food availability and accessibility can be achieved by increasing production, improving distribution, and reducing the losses.

Reducing postharvest losses has been demonstrated to be an important part of sustainable agricultural development (Kader 2005). However, over the past decades, significant focus and resources have been allocated to increase agricultural yield and decreasing pre-harvest yield losses in order to produce more food (Malcolm, 1977). For example, 95% of the research investments during the past 30 years were reported to have focused on increasing yield and only 5% directed towards reducing postharvest losses (Kader and Roller 2004).

Food production is currently being challenged by limited land, water and climate change (Lundqvist *et al.*, 2008; WRI, 2013/14). To sustainably achieve the goals of food security, food availability needs to be also increased through postharvest loss reductions. Thus, reduction of postharvest food losses is a critical component to ensure food availability for human consumption and enhance future global food security.

Agriculture is the foundation of Ethiopia's economy. It is the main source of food calories, industrial raw materials both for export and in country use. Even though there has been piecemeal works on crop postharvest research, general research trend indicated that most of the efforts and resources have been invested on increasing yield and decreasing pre-harvest yield losses (pre-harvest plant protection research). In Ethiopia, as in the other developing countries, crop postharvest has never gained attention leading to various researches, capacity, legislative and other gaps.

Ethiopian population has been predicted to reach 174 million by 2050 and this will require a 70% increase in food production (World population prospect, 2009). However, Ethiopia is suffering from 40-50% postharvest losses valued at 12 million dollars annually which could feed one-third of Ethiopian's poor. Analysis of food aid, food import, and food security figures versus post-harvest losses suggested that addressing storage losses could have a significant impact on food security and farm-income without increasing pressure on the land (Abraham *et al*., 2008). Traditional storage practices in developing countries like Ethiopia cannot guarantee protection against major storage pests of staple food crops like maize. The lack of suitable storage structures for grain storage and absence of storage management technologies often force the smallholders to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce. Safe storage of maize at the farm level is crucial, as it directly impacts on poverty alleviation, food and income security and prosperity for the smallholder farmers. Without appropriate grain storage technologies, farmers are forced to sell maize when prices are low to avoid post-harvest losses from storage pests and pathogens, cannot use their harvest as collateral to access credit, and ultimately their food security is undermined. Therefore, food security and safe storage at the farmer level go hand-in-hand. Effective grain storage is an inflation-proof saving; grain can be cashed as needed or used directly as a medium of exchange (i.e. in payment for work such as field clearing and weeding). Food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2010). Post harvest losses lead to food insecurity. At the level of individual households in sub-Saharan Africa, reducing post harvest losses could increase food availability by both reducing physical losses and increasing income from the improved market opportunities that could be used to buy food (FAO and World Bank, 2010; Tefera, 2012). Several people in the developing countries, however, are food insecure.

Low agricultural yields in Ethiopia have been blamed for the country food problems, but can we continue to emphasize only on agricultural production when an average of 40-50 per cent of the grain harvested never reached the consumer? Postharvest losses occur at harvesting, threshing, winnowing, transporting, processing and storage. The biggest loss occurs during storage. Appropriate processing and packaging materials, proper storage facilities, appropriate management and transportation are required to minimize these losses. The primary aims of storing food commodities are to effect a uniform supply of food throughout the year, to make available reserves for contingencies and to speculate on higher prices whether it is for local or export markets. It is pointless to heavily invest in good agricultural practices, attain high yields, and lose 40-50% of it. Feeding the nation does not only require increased production but also a safeguard of all that is produced. Effective storage is more critical at this time of climate change, where the associated weather vagaries adversely affect production. Whatever little that we produce should be well stored for use at the desired time. It is, therefore, timely to consider how minimizing postharvest food losses, can help conserve resources and improve human well-being.

Given the current development strategy in the country, a lot is expected from the post-harvest sector in order to attain competitive produces at various market places (local and global), reduced losses in quality (nutritive value) and quantity, and value added produce.

This paper, provides summary of research status on post-harvest pests, indicates existing gaps, challenges and briefly indicates future research directions.

Focus Research areas

Research on crop postharvest pests in Ethiopia is incoherent. It is very recently that some attempts have been made on focused specific pests and considerable information has been generated by different institutions. Postharvest agricultural entomology research is relatively more focused on research areas with special emphasis to survey and surveillance, biology and ecology, yield loss estimation and management of insect pests (Girma *et al*., 2012, Addis, 2008; Girma *et al*., 2008a and b; Ahmed, 2007; Demissew, 2004; Demissew *et al*., 2004; Abraham, 2003; Firdissa *et al*., 2001; Mohammed, 1996; Fantahun, 1995 and Mekuria, 1995).

Mycotoxigenic postharvest fungi contaminating various agricultural food commodities have been considered major economic and health threats. In Ethiopia such toxic effects have been recognized when mycotoxins responsible for gangrenous ergotism broke out in 1978 (Kelbessa Urga *et al*., 2002). Since then, very few research works focusing on species distributions of mycotocigenic fungi across agroecology and agricultural produces, (Belay *et al,* 2012; Sisay, 2006; Mashilla, 2004; Amare, 2002;) have been conducted. Research work concerning management of mycotoxigenic fungi is almost untouched, except few attempts of biological control, disinfection treatments, packaging and modification of storage environment (Kefialew and Ayalew, 2008; Tefera *et al.,* 2007; Sisay, 2006). Bacterial postharvest diseases and others are almost unconsidered.

Past and present research achievements

Research on post-harvest pests is a relatively recent area of plant protection in Ethiopia. It is about one and a half decade since relatively concerted efforts on post-harvest pest research began. However, considerable information has been generated by research at different institutions since then. Most surveys on post-harvest pests focused on recording insect pests, and to a lesser extent, on fungi associated with stored grain. It is obvious that research on storage problems caused by rodents and birds has been almost non-existent so far in Ethiopia. Rodents were reported to be important based on sideline information from surveys of other storage pests in different parts of the country. In few other reports, birds and rats were considered to be important in storage. Nonetheless, there are some technologies that lend themselves to immediate use or after some modification and on-farm verification. In general, storage pests mainly associated with different cereal and legume grains were studied in different parts of Ethiopia. The major research focussed areas were: post-harvest fungi and other diseases, post-harvest entomological research, pest management methods viz., biological control, varietal resistance, chemical control, Integrated pest management (IPM).

Apart from entomological and pathological researches, postharvest agricultural mechanization research is another relatively better considered area of research, attempts have also been made in the area of storage facility design, development and technology adoption by Ethiopian Institute of Agricultural Research System. Cases in point are; works on metal silo, improved "*goterra*" and super bag. Likewise limited research achievements were made in the areas of food science in methods of preserving some horticultural crops, mainly onion and tomato. There is also some proven storage structure such as, DLS (diffused light system) in post-harvest management for potato.

Gaps and limitations

Until now, in developing countries like Ethiopia, postharvest yield/food losses were neglected as if they have no meaningful role in meeting the overall goals of food security, poverty alleviation and sustainable agriculture. As a result, research on postharvest activities have received no considerable attention and funding leading to various research, capacity, legislative and other gaps.

Research

- Inadequate and piecemeal postharvest research
- Inadequate postharvest handling and processing technology
- Insufficient postharvest loss information
- Poor postharvest technology dissemination/promotion

Capacity

- Limited human capacity
- Inadequate modern postharvest infrastructures /technologies
- Limited awareness on the importance of postharvest technologies
- Limited skill on usage of available postharvest technologies
- Limited designed curriculum for Postharvest professionals training
- Poorly equipped diagnostic laboratories and lack of modern techniques

Legislative

- Lack of specific standalone postharvest research policy and regulation.
- Lack of specific standalone postharvest research strategy
- Lack of institutional arrangements

Future direction/strategic focus

Solving the postharvest yield/food losses will require cooperation and effective communication among all stakeholders, research institutions and others. In most cases, to fill the existing gaps in the postharvest system of the country; coordination, structuring and restructuring of the system is needed.

Research focus areas

Postharvest entomology

- Distribution, occurrence, population dynamics and species composition of major postharvest insect pests.
- Postharvest Insect pest taxonomy and phylogeny.
- Postharvest losses caused by important insect pests
- Sources of resistance/tolerance against major insect pests
- Generation of Insect pest management options
- Bio-ecology of postharvest insect pests.
- Economic threshold levels of insect pests.
- IPM for major insect pests.

Postharvest pathology

- Prevalence, severity and epidemiology of major postharvest diseases.
- Assessment Postharvest losses caused by important pathogens
- Associations of fungi, mycotoxin development and factors enhancing its development
- Determination of mycotoxin level
- Generation of postharvest disease management options

Postharvest vertebrate pest

- Birds and rodents

Postharvest agricultural mechanization

- Equipment /structure/facility/material identification, development and evaluation
- Improvement of pre-harvest and postharvest tools and machinery (Soil digger, fertilizer applier, chemical sprayer, harvester, grader, sorter)
- Improving the processing (chopper, slicer, drier, miller, mixer, peeler) and packaging locally available materials and conduct participatory evaluation
- Multiplication/duplication of better agricultural mechanization technologies to minimize cost in terms of foreign currency

Postharvest physiology and preservation

- Crop products’ shelf life.
- Maturity index.
- Extrinsic (external environment) and intrinsic (chemical and Physiological changes) factors

Socio-economics and marketing.

- Gender responsive diagnostic survey.
- Gender responsive postharvest technologies.
- Adoption rate and impact of postharvest technologies.
- Postharvest value chain.
- Postharvest technology demonstration and popularization.

Food science and nutrition, product/food quality and safety

- Fresh cut horticulture and vegetable produce
- Harvested cereal, legumes, coffee, tea, spices and aromatic plants
- Crop products’ shelf life
- Maturity index
- Extrinsic (external environment) and intrinsic (biochemical and Physiological changes) factors

Product/food quality and safety

- Determination of mycotoxin level
- Crop products’ shelf life
- Maturity index
- Extrinsic (external environment) and intrinsic (biochemical and Physiological changes) factors determination

Cross cutting issues

Gender

- Gender responsive diagnostic survey (for priority crops).
- Gender responsive postharvest technologies
- Gender responsive postharvest value chain analysis and intervention

Climate

- Temperature, carbon dioxide and ozone exposure studies

Technology demonstration and dissemination

- Design channeling methods for the various research results and technologies from the research system to the users through extensive participatory demonstration and evaluation to verify improved postharvest technologies.
- Establishment of locally based postharvest technology research and development advisory group consisting of civil society, academic institutions, farmer organizations, trade associations, and ministries of agriculture and trade.

Information, communication technology (ICT)

- Data base establishment, documentation and Web-site development for promotion (Research technologies, market situation, postharvest data, nutrition/health)

Capacity

Human resources

- Dynamic human resource development plan revised and updated
- Train adequate researchers to address the research need of postharvest problems
- Provide training for agricultural experts, extension workers, warehouse manager, store keepers, developing agents and women and men farmers and other stake holders on postharvest technologies

Infrastructure and facilities

- Establish and expand Postharvest infrastructure
- Avail logistics, office, field and laboratory equipment that serve the NARS
- Establish model national postharvest laboratories

Finance

- Allocate specific budget targeting postharvest research and infrastructure development
- Solicit external funding.
- Allocate adequate budget for competitive research grant and incentive mechanism.

Legislative

- Design and formulate policy and regulation to promote postharvest research to institution level.

Conclusions

Though, major insect pests of some crops have been identified and losses caused by some of these pests determined and considerable information has been generated by research at different institutions, post harvest research in Ethiopia has not been given the attention it deserved. Hence, concerted efforts among all stakeholders should be made to address and work on the gaps and strategic issues that have been discussed in this paper. Following this, appropriate processing and packaging materials, proper storage facilities and transportation are required to minimize the losses caused by pests and other factors under different stages of harvesting, transporting and processing. Efficient production and utilization of food crops are needed to increase food self-sufficiency and export earnings. Modern food processing techniques and post-harvest technologies are the main tools to reduce food losses and maintain/raise the quality of products. Therefore, research and development works need to focus on the management of post-harvest pests, agricultural mechanization, post-harvest physiology, socio economics and marketing, food science and nutrition, product/food quality and safety, technology demonstration and dissemination, information and communication technology (ICT), capacity building and legislative issues.

Substantial amount of research works on post-harvest losses due to pests should come on board, by the same token research and development works need to be strengthened and focus on the management of post-harvest pests in the country.

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Plant Protection Research in Ethiopia: Major Achievements, Challenges and Future Directions

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Plant Protection Research in Ethiopia

Agriculture is the foundation of the country's economy and the most important activity in Ethiopia and it provides all the necessary dietary foods, raw materials for food industries and quality products for export markets. The country's agricultural potential for food production is known to be immense and in 2014 it contributed to about 42% of GDP, accounted for 85% of exports, and employed 85% of the labor force (CSA, 2015).The sector is dominated by smallholders who mainly produce for their subsistence and local markets. Although they contribute to about 95% of the total annual crop production, they pursue subsistent production system. The use of good agricultural practices and external inputs that boost production is minimal hence they experience significant yield losses. Crop losses due to pests are among the major causes of low crop productivity, food shortfall and food insecurity, low volume of export products and raw materials supplied for local industries. Crop losses of major crops due to pests in Ethiopia are mostly estimated between 20–40% (Abraham 2008 and 2009).

Despite the fact that, agriculture has been practiced for long in Ethiopia, its research part as a whole, and particularly plant protection research has begun quite recent in relative to other African countries. Publications: "Index of plant diseases in Ethiopia" by Stewart and Dagnachew in 1967 and "Insects of cultivated and wild plants, Harar province, Ethiopia" 1960-1964 by Bob Hill in 1966 are evidences, although they mainly focus on pest survey, identification and documentation. Some literatures cite research in plant protection began in the 1950s associated with the establishment of agricultural schools and colleges in Ethiopia (Eshetu *et al*., 2006). Intensified research work was started with the establishment of EIAR (the then IAR) in 1966 and strengthened by bringing the four disciplines (plant pathology, entomology, weed science and vertebrate pests) under the department of crop protection in 1976 (Abraham, 2008; Tsedeke, 1985).

In 1990, the department was dissolved and the experts working in the different disciplines were assigned to work in different crop commodities. Then after, it was raised to a program status during the reorganization of IAR in to EARO (Ethiopian Agricultural Research Organization) in 1997. Thus, National Entomology, Pathology, Weed science, and Biosystematics research projects were established at the national plant protection Research Center, Ambo. In 2007, BPR (Business Process Reengineering) became operational and, all the projects were merged into plant protection and put under the biotechnology and plant protection case team. Through business process improvement initiative, in 2014, EIAR upgraded plant protection research to the level of national case team, with four different projects included under it, namely: Entomology, Plant Pathology, Weed science, and Quarantine & Pesticide research.

To date, several major arthropods, pathogens, vertebrate pests and weed plants were identified as potential pest to Ethiopian agriculture and management options were developed by researchers from across the country (Abraham, 2009 and 2008; Tsedeke, 1985).

Major Research Achievements

Plant pathology Research

Identification, determination of economic importance as major, minor, epidemics or pandemics and management of the economically important crop pests have been documented on major crops earlier with the start of plant protection research (Abraham, 2008 & 2009; Tsedeke 1985; Dangachew, 1966; Awgichew, 1982). Estimated pre harvest losses due to major diseases varied to the total harvest failure depending on crop varieties resistance and other environmental backgrounds (Table 1 & 5). The yield loss estimates were from the experiments conducted at research centers with ideal conditions for the diseases development and thus represent potential losses, but the actual loss in farmer fields could different. The current plant disease record in Ethiopia shows over 470 but only about 20% of those are considered as major economic importance (Henry et al., 1995).

Table 1. Yield loss estimates on plot based in selected crops due to major diseases.

Crops	Diseases	Yield loss %	References
wheat	Strip rust	96-100	Eshetu (1986): Mengistu et al. (1991)
	Leaf rust	75	"
	Stem rust	60	"
	Septoria	25	Mengistu et al. (1991)
Barley	Scald	21-67	Eshetu (1986):IAR (1983)
	Net blotch	25-34	Eshetu (1986)
	Leaf rust	28-40	PPRC (1998):Getaneh (1998)
Tef	Rust	10-25	Eshetu (1986)
	smudge	40-50	Eshetu (1986)
Sorghum	Smut	1-25	IAR annual report 1995
Maize	Leaf blight	25-49	Assefa Teferi (1995)
Haricot bean	Anthracnose	19-63	Tesfaye et al (1997)
	Bean rust	30-85	Habtu et al (1997)
Field pea	Powdery mildew	25-48	IAR (1985; 1986; 1989)
	Fusarium root rot	70	-
Faba bean	Rust	27	IAR (1986)
	Chocolate spot	3-18	Birhanu et al (1992)
	Black root rot	14-75	-
	Wilt/root rot	30	-
Potato	Late blight	15-67	Bekele *et al* (1996)
Tomato	Late blight	38-65	IAR (1983); Tesfaye and Habtu (1986)
Onion	Purple Blotch	26	IAR (1986)
Citrus	Fruit and leaf spot	43-65	Eshetu (1997)
Pepper	Pepper viruses	15	Agranovsky (1993)
Coffee	CBD	24-30	Eshetu (1997)
Banana	Burrowing nematode	20-46	IAR (1983)
Kenaf	Root-knot nematodes	30	IAR (1986)
Enset	Bacterial wilt	100	-

Source: Eshetu *et al*. (2006) Facilitating the Implementation and Adoption of Integrated Pest Management (IPM) in Ethiopia

Ecological and biological understanding of pest worth helps in integrated crop pest management. Hence, Ecology and epidemiology, physiological race study, pest forecast and other basic studies have been done for major pest and crops (Table 2).

Table 2. Some Frontline Areas of emphases in plant disease studies on major crops and pests

Study area	Crop (s)	Reference
Ecology and epidemiology	Chick pea ,(Ascochyta blight, Bean Western yellow virus), lentil (lentil rust), Faba bean (*Ascochyta fabae*, Chocolate spot, rust, Black root rot), Chick pea (wilt/root rots) common bean (bacterial blight Anthracnose, rust), grass pea (powdery mildew), field pea (Ascochyta blight, powdery mildew)	Abraham, 2008; and 2009
Determination of physiological races	late blight and bacterial wilt of potato, rusts of wheat, scaled and net blotch of barley, coffee wilt, and cytogenetic race of root-knot nematodes	Abraham, 2008; Abraham, 2009
Disease forecasting models	potato late blight	Sparks et al., 2014

Agricultural Entomology Research

The African armyworm (*Spodoptera exempta*), the African migratory locust (*Locusta migratoria migratorioides*), and the desert locust (*Schistocerca gregaria)* were the major recorded migratory insects which can cause total crop failure during outbreak year but the majority of insect pests of economic importance in Ethiopia belong to non migratory insects (Eshetu *et al*., 2006) (Tables 3 and 4).

Losses attributable to arthropod pests, on cultivated crops in Ethiopia, ranges from 2 to 50% on experimental plots (Table 3). Moreover, the annual value of insecticide import and the application cost worth hundreds of millions birr. Other research result shows the average pre harvest losses on major cereal crops due to insect pests ranged between 31 and 65% on experimental fields (Henry *et al*., 1995). Mostly crop yield losses by major insect pests are dependent on the type of crop pest, environment and the crop variety (Tables 3 and 5).

Storage insect pests of major economic importance in Ethiopia include grain weevils (*Sitophilus* spp.), grain moths (mainly *Sitotroga cerealella*), and bean bruchids (*Acanthoscelides obtectus*, *Bruchus pisorum*, and *Zabrotes subfasciatus*) (Eshetu *et al.*, 2006).

Table 3. Pre harvest yield loss estimates due to insect pests in selected crops in Ethiopia

Crops	Loss % due to insect damage Pre-harvest loss %
Cereals	21-44
Legumes and Oilseeds	16-29
Vegetables	9 – 13
Root crops	17-39
Fruits (Citrus)	38-50
Cotton	2-9

Source: Entomology research strategy for the year 2015-2030

Table 4. Examples of major regular insect pests in Ethiopia

Scientific name	Common name	Crop(s) attacked
Busseola fusca, Chilo partellus, Sesamia calamistis	Stalk borers	Maize, sorghum
Helicoverpa armigera	African bollworm	Cotton, vegetables, pulses
Acyrthosiphon pisum	Pea aphid	Field pea, faba bean
Pachnoda interrupta	Sorghum chafer	Sorghum, maize
Diuraphis noxia	Russian wheat aphid	Wheat, barley
Several species	Grasshoppers	Tef
Decticoides brevipennis	Welo bush cricket	Tef
Ophiomyia phaseoli, O. spencerella	Bean stem maggot	Haricot bean
Phthorimaea operculella	Potato tuber worm	Tomatoes, potatoes
Thrips tabaci	Onion thrips	Onions, shallots
Brevicoryne brassicae	Cabbage aphid	Cabbage
Aonidiella aurantii	Red scale	Citrus
Ceratitis capitata	Med fly	Citrus
Cryptophlebia leucotreta	False codling moth	Citrus
Antestiopsis intricata	Antestia bug	Coffee
Leucoptera spp.	Leafminers	Coffee
Stephanodores (=*Hypothenemus hampei)*	Coffee berry borer	Coffee

Source: Eshetu *et al*. (2006) Facilitating the Implementation and Adoption of Integrated Pest Management in Ethiopia

Yield losses due to migratory pests can be catastrophic and losses due to vertebrate pests such as rodents and birds are estimated to reach between 10 and 25%. According to report from EARO (2000), during the period 1995 to 1999 an annual average of 74.5 million Quelea birds infested an average of 1, 500 ha of sorghum.

Table 5. Recorded pests of major crops

S/N	Crop	Insect pests	Diseases
1	Field pea (*Pisiumsativum*)	6	23
2	Faba bean (*Viciaefabae*)	8	26 + 1
3	Chick pea	9	16
4	Lentil	7	20
5	Haricot bean	15	10
6	Maize	30	49+1
7	Sorghum	93	28
8	Barley	21	13
9	Tef	19	5
10	Wheat	35	13
11	Potato	22	13
12	Enset	6	25
13	Sweet potato	44	7
14	Hot pepper	21	27
15	Cabbage	25	16
16	Onion	7	10
17	Tomato	24	11
18	Fruits	137	29
19	Noug	16	26
20	Sesame	17	-
21	Linseed	4	11
22	Coffee	47	13
23	Cotton	53	37
24	Aromatic and medicinal	46	84
25	stored grain	94	141 fungi

Source: Abraham 2008 & 2009 Increasing Crop Production through Improved Plant Protection

Basic studies on the most important insect pests of major crops were done and used in development of integrated management options.

The biology of Pea aphid (*Acyrthosiphon pisum*), Pea bruchid (*Bruchus pisorum),* stem borers Sorghum chaffer, the new barley shootfly, *D. flavibasis*, barley chafer grub, red tef worm, black beetle (*Heteronychus licas* Klug), Enset root mealy bug, sweet potato butterfly (*Acraea acerata*), diamondback moth (DBM), Potato tuber moth *(Phthorimaea operculella)* and *Tuta absoluta* were studied (Abraham 2008 &2009; Gashawbeza and Abiy, 2013; Tsedeke, 1985).

Population dynamics of**:** pea aphid pod borer Bean stem maggot (*Ophiomyia* spp.), stem borers potato tuber moth (*Phthorimaea operculella*), sweet potato butterfly (*Acraea acerata*), diamondback moth (DBM), Onion thrips (*Thrips tabaci*), Fruitworms, Noug fly were studied (Abraham, 2008 &2009; Emana, 2005).

Yield loss**:** caused by stem borers shoot fly, sorghum chaffer, termites, African bollworm, sorghum midge, bean stem maggot, Russian wheat aphid, epilachna beetles, red tef worm, Wollo bush cricket, black tef beetle, *Erlangerius niger*, sesame webworm, sweet potato butterfly (*Acraea acerata*), were studied. Moreover, the extent of damage on various varieties of citrus due to red ant, thrips, scale insects, fruit flies and false codling moth were recorded (Abraham 2008 & 2009). Major insect pests of major vegetable crops were identified, and postharvest grain storage systems and losses incurred both underground and above ground were studied (Abraham, 2008 & 2009; Tsedeke, 1985; Stewart and Dagnachew 1967).

Integrated Pest Management (IPM) options for: pea bruchid, faba bean insect pests, pod borer, bean stem maggot, Sorghum chaffer, sorghum stem borer, sorghum shoot fly, barley shootfly, Russian wheat aphid, chafer grubs, red tef worm, Wollo bush cricket, tef shot fly, black tef beetle and grass hoppers, major postharvest pests of cereals, and oil crop insect pests, onion thrips, tomato fruitworms, diamondback moth, termites on pepper, citrus thrips, citrus leaf miner, citrus fruit flies, sweet potato butterfly (*Acraea acerata*) were identified. Moreover, insecticides for the management of many other insect pests were screened (Gashawbeza A. and Abiy T., 2015; Mohamed *et al*., 2013; Abraham, 2008 & 2009; Tsedeke, 1985). IPM is an ecologically sound, environmentally friendly, and economically affordable pest management approach.

Weed Sciences Research

Until recent years, about 1093 different weed species belonging to 552 plant genera and 126 families, collected from different places of Ethiopia, are known to be highly problematic in affecting arable lands, range lands, forestry and aquatic environments. Impact of weeds on agriculture is sever as they cause huge reductions in crop yields, increase cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, act as alternate hosts for several insect pests and diseases. Crop losses approaching 100% in some instances are experienced in many crop production systems (Table 6). On average the loss due to weed accounts for about 20-49% of the total harvest yield (Henry *et al*., 1995).Weeds affect biodiversity and water bodies. They are poisonous to livestock and human health. Moreover, socially up to 40% of the farming labor engages in weeding (Weed science research strategic document for the year 2015-2030).

Table. 6. Potential yield loss due to uncontrolled weed growth in Ethiopia

Crop(s)	Yield losses (%)	Weed species
Wheat, Barley, Tef	12-36	Mixed flora of annual
Sorghum, maize	42 – 46	Mixed flora of annual
Sorghum	60 – 100	*Strigahermonthica*
Tomato	75 – 100	*Orobancheramose*
Noug, Linseed	87 – 100	*Cuscuta* spp.
Pulses	22 – 95	Mixed flora of annual
Oil seeds	43 – 57	Mixed flora of annual
Vegetables	66 – 93	Mixed flora of annual
Coffee	70 – 90	Perennial grasses & sedges

Source: Weed science research strategic document for the year 2015-2030

Plant families, Convolvulaceae, Orobanchaceae, Loranthaceae and Viscaceae represent the most important plant parasitic weeds among nine families known to occur in Ethiopia (Rezene and Parker, 1992) (Table 7). *Striga hermonthica* and *S. aciatica* are the most common species in Ethiopia but *S. harmonthica* is the wide spread followed by *S. aciatica* (Fasil and Parker, 1992; Parker, 1992). Among those, *S. hermonthica* is the most devastating, attacking important food crops such as sorghum, maize, and finger millet. More recently, it is becoming increasing important on tef, (*Eragrostis tef*), the main staple cereal food crop in the country (Fassil Reda, 2000).

Table 7. Parasitic weeds and their host crops in Ethiopia (Parker, 1992; Fasil and Parker, 1992)

Parasitic weed species	Host range
Striga hermonthica	sorghum, maize, dagusa and tef
Striga asiatica	sorghum, maize, millet (dagusa) and wheat
Striga gesnerioides	legumes
Striga forbesii	sugar cane and maize
Striga latercea	sugar cane
Alectra sessiliflora	wild compositae
Alectra parasitica	no host species recorded
Allectra vogelii	Groundnut, cowpea
Orobanche crenata	faba bean,
Orobanche ramosa	tomato, eggplant, tobacco potato, rapeseed, cabbage, linseed
O cernua = O. cumana	tomato, eggplant, tobacco
Orobanche minor	noug, sunflower, safflower, lettuce, groundnut, clovers faba bean, tobacco
Cuscuta campestris	noug, linseed
Cuscuta eplinum	Linseed
Cuscuta kilimanjari	forest species
Cuscuta pedicilleta,	wild vegetation
Cuscuta planiflora	wild vegetation
Cuscuta hyalina	wild vegetation

Source: Weed science research strategic document for the year 2015-2030

Pesticide research and registration

From the time pesticide research was started in Ethiopia, early 1970s, screening of insecticides, fungicides and herbicides, and some research works on screening of rodenticides have been done and recommendations on pesticides use have been delivered to end users. Since then a total of 372 chemical pesticides have been registered from 51 registrants until 2015 (149 insecticides, 106 herbicides, 95 fungicides, 5 rodenticides, 2 avicides, 1 nematicide, 10 miticide and 4 Adjutants, stickers and plant growth regulators, Defoliants) (MoA, 2015). In addition, a number of bio-control agents (predators and parasitoids, and bio-pesticides) are approved for release as natural enemies to control pests.

Challenges

Though, these remarkable works has been done, plant health issue has not been given the attention it deserves compared to variety of other crop technologies development both by the national and international agricultural research systems. It is sufficient to see the resources allocated for crop protection research in relation to crop improvement to substantiate this. The human resource too is incomparable to face the challenges of pests in crop production. Because of these and poor quarantine organization of the country, total crop failure in some crops after accidental or intentional introduction of pests is getting common. Cases in point are the maize lethal necrotic disease (MLND), the ginger wilt diseases caused by *Ralsonia solanacearum*, the tomato leaf miner, *Tuta absoluta*, the white mango scale, *Aulacaspis tubercularis* etc. One of the recent examples of a plant disease that could have severe impacts on global food production, livelihoods and changes in demographics in the 21st century is Ug99, a virulent strain of black stem rust (*Puccinia graminis tritici*) that has spread from East Africa into the Middle East and is threatening the wheat fields of South Asia and the high yielding wheat varieties developed. In 1958 the desert locust (*Schistocerca gregaria*) caused an estimated loss of 267, 000 tons of grain in Ethiopia and this was estimated to be enough to feed one million people for one year (Anon, 1993). Many other alien invasive disease pests, weeds, and insect pests were also recorded as recent introductions to Ethiopia. There are also enormous amounts of indirect cost that incurred on controlling plant pests. Ethiopia has been importing quiet a large amount of pesticides every year and obviously spent a large amount of its foreign currency. In addition, there are application costs and undetermined effect of the pesticides on the environment. Therefore, to address these troubles caused by biotic factors, crop production and research should reasonably involve plant protection research to reduce crop loss.

Which otherwise, literatures show how such introductions of new pests affect the human history. The Irish Potato famine is an excellent example of the effect of a plant disease on food security. The damage inflicted by the pathogen *Phytophtora infestans* on Irish potato in early 1840's resulted in the death of millions and a million more emigrated from Ireland shores. Coffee which is an important export commodity in east Africa is seriously threatened by the coffee wilt disease, caused by the fungus *Fusarium xylarioides.* The disease, has already severely affected producer livelihoods in Central and Eastern Africa, and continues to spread. The introduction of coffee rust (*Hemelia vastatrix*) in Srilanka in 1875 reduced coffee production from 400 million pounds in 1870 to 5 million pounds in 1889 and its introduction to India in 1876 affected the coffee industry severely forcing replacement of coffee plantation by tea.

Newly introduced crop biotic stresses and established pests

Plant pathogenic pests

Recent introductions include, the wheat stem rust strains (Ug99), Faba bean gall disease, avocado root rot and ginger bacterial wilt might occur as a result of pathogen pollution, introduction of pathogen outside their natural geographical or host-species range, climate change, temperature, precipitation, change in CO_2 concentration, changes in agricultural practice, intensification, diversification and globalization (Anderson *et al*., 2004). Here some essential information of newly introduced pests are discussed.

Faba bean gall

Origin and Symptoms: In Ethiopia it was first reported in 2012 from Degem, north Shoa of Oromiya regional state. The initial symptom was green and sunken on the upper side of the leaf and bulged to the back side of the leaf, and finally it develops light brownish color lesion, chlorotic galls are formed. The plant became stunted and with few pods, or even fail to give seed in sever conditions. The disease with similar symptom which was caused by the fungus *Olpidium viciae* was reported on Faba bean in China in 1984 and in 1912 from Japan (ICARDA, 1993). The disease is reviewed by different Ethiopian scholars and described its similarity with *Olpidium viciae*.

Hailu, *et al*. (2014), describes its distribution in central and northern part of Ethiopia in 2013/14 cropping season showed a mean of 48.5% prevalence, 15.4% incidence and 6.4% severity all over the surveyed area.

Damage and host range: In1936, S. Kusano confirmed that the small galls in Japan were caused by the same pathogen which had a wide host range, including faba bean and field pea. Xing (1984) found that by artificial inoculation of the pathogen can also infect rapeseed, cabbage, cucumber, spinach and buckwheat. In its area of origin, it causes a yield loss about 20% (ICARDA, 1993). Crop loss up to 100% was observed in Ethiopia during the survey in 2013/14 cropping season.

Citrus Canker:

Origin and symptoms: Citrus canker is a disease affecting Citrus species caused by the bacterium *Xanthomonas axonopodis* pv. *citri* a rod-shaped Gram-negative bacterium with polar flagella. The infection occurs on the leaves, stems, and fruits of citrus plant. Citrus canker is thought to have originated in the area of Southeast Asia-India. Plants infected with citrus canker have characteristic lesions on leaves, stems, and fruit with raised, brown, water-soaked margins, usually with a yellow halo or ring effect around the lesion. Older lesions have a corky appearance. Due to latency of the disease, infected plant may appear to be healthy.

Occurrence in Ethiopia: Its presence in Ethiopia was first recorded in 2004 (Eshetu *et al*. 2005). The pathogen is currently found in several areas of Ethiopia (Eshetu & Binyam, 2012). Wind, rain and farm materials such as contaminated cutting tools are major mode of short distance transmission of the pathogen *X. axanopodis* pv. Citri. Long-distance dissemination of the pathogen occurs primarily via the movement of infected planting and propagating materials.

Damage and host range: Trees infected with the disease may suffer from low vigor and a reduction in fruit quality and quantity. Citrus canker is a serious disease impacting on citrus production. **Numerous species of citrus and citrus relatives including orange, grapefruit, pummelo, mandarin, lemon, lime, tangerine, tangelo, sour orange, rough lemon, calamondin, trifoliate orange, and kumquat and** Rutaceae species, such as *Citrus glauca* (desert lime), *Acronychia acidula* (lemon aspen), *Micromelum minutum* (lime berry) and *Murraya paniculata* var. *ovatifoliolata* (native mock orange). Other plants such as wampee (*Clausena lansium*), white sapote (*Casimiroa edulis*) and elephant apple (*Feronia limonia*) are also known hosts.

Maize Lethal Necrotic Disease (MLND):

Origin and Symptoms: The disease is reported to be a result of combination between Maize chlorotic mottle virus (MCMV) with any cereal infecting potyviruses such as sugarcane mosaic virus (SCMV), Maize dwarf mosaic virus (MDMV) or Wheat streak mosaic virus (WSMV) although recent work of Adams *et al*. (2012) shows that MCMV is a threat on its own and may have a significant yield loss even in the absence of other viruses. The double infection of the two viruses gives rise to what is known as MLND, also referred to as Corn Lethal Necrosis (CLN).

Occurrence in Ethiopia: In Africa, maize lethal necrosis disease was first reported in Kenya in the year 2011 (Adams *et al*., 2012). Its presence in Ethiopia was detected in 2014.

Damage and host range: Total crop failure due to the disease was observed in east African countries including Ethiopia. Chlorotic mottle, usually starting from the base of the young leaves and extending upwards to the leaf tips, shortened internodes, premature aging of the plants, necrosis of leaf margins, that progress to the mid-rib resulting in dying up of whole leaf, necrosis of young leaves in the whorl before expansion leading to a 'dead heart' symptom, premature drying and poor grain fill of the husks. (Leaf let, Bako Maize Research Center).

Ginger Bacterial wilt

Symptoms and origin: Under favorable conditions, the plant wilts very rapidly and becomes yellow-brown in 3 to 4 days. The spread is commonly by soil, planting materials, insect vectors, equipments and irrigation water. The softening of the tissues is accompanied by the production of a strong odor.

Occurrence in Ethiopia: In most ginger producing countries like India, ginger is affected by different pathogens. Commonly Bacterial wilt (*Ralstonia solanacearum*), Pythium soft rot/Rhizome rot, Leaf spot (*Phyllostica zingiberi*), Nematodes etc. were known to cause disease on ginger crop but no pest incidence were recorded from Ethiopia. Ginger production in Ethiopia is in great threat by new disease incidence since 2014.
The pathogen was isolated and identified as bacterial wilt using biochemical analyses at Ambo Plant Protection Research Center. Unlike other bacterial diseases, rapid speared and complete devastation of the crop was reported on small scale farmers and commercial farms too.

Damage and Host range: In India, bacterial wilt is widespread on edible ginger and 100% yield losses have been reported (Dohroo, 1991). Bacterial wilt has been reported from other members of the Zingiberaceae family, including Alpinia (*Alpinia* spp, turmeric (*Curcuma longa*).

Avocado Phytophthora root rot (*Phytophthora cinnamomi*)

Origin and symptom: Foliar symptoms of avocado root rot include small, pale green or yellowish leaves. Leaves often wilt and have brown, necrotic tips. There may be little leaf litter under infected trees. Small branches die back in the tree top, exposing other branches and fruit to sunburn because of the lack of shading foliage. Fruit production declines, but diseased trees frequently set a heavy crop of small fruit.

Damage and host range: Phytophthora root rot is the most serious and important disease of avocado worldwide. Small, fibrous feeder roots are scarce where present, small roots are black, brittle, and dead from infection. Foliage is wilted even when soil under diseased trees is wet. Affected trees will decline and often die either rapidly or slowly. Avocado tree shoots die back from the tips, and eventually the tree is reduced to a bare framework of dying branches. Small feeder roots on diseased avocado trees may be absent in the advanced stages of decline. When present, they are usually black, brittle and decayed, in contrast to healthy creamy-white feeder roots. The causal agent, *P. cinnamomi,* has over 1,000 hosts, including many species of annual flower crops, berries, deciduous fruit trees, ornamentals, and vegetables. Trees of any size and age may be affected. They spread easily and rapidly in water moving over or through the soil. Entire areas can readily become infested.

Wheat rust (*Puccinia graminis*)

Wheat is the second most important crop in Ethiopia after maize. Though the wheat yield in Ethiopia have been increasing since 2002, wheat rust the pathogen without border is threatening wheat farmers by outbreaks of new races of yellow and stem rust almost on yearly basis. It takes persistent and continually evolving international efforts to protect staple crops on a global scale. Wheat breeders at international stem rust screening nurseries in Ethiopia and Kenya evaluate candidate of wheat varieties against evolving pathotypes and participatory variety selection to keep one step ahead of wheat pathogens, breeders and fellow farmers who develop, evaluate and recommend the release of new varieties resistant to wheat diseases.

Arthropod pests

The Greater grain borer (*Prostephanus truncates*)

Description and origin: It is indigenous for Central America, tropical South America, and the extreme south of the USA as a major. Adults are small (4mm) beetles have a uniform dark brown to black colour and larvae are approximately 3-4 mm long, white to yellowish in colour with stubby thoracic legs. They have distinctive pits on the elytra with its ends appear serrated and small teeth on the front of the thorax. Body shape, teeth on the thorax, and the deflexed head are major characteristic features of differentiating them. *P. truncates* has a characteristic feature of flattened end of wing cover and two curved ridges at slopping region of the wing (Bayeh, 2012).

Damage and host range: It is primary pest of whole grains of corn and dry cassava root. The adults bore in the kernel causing small irregular holes and then lay eggs inside the grain. Damage is rarely noticed until exit holes appear and adults are seen roaming the grain mass. In addition to maize and dried cassava, adults have been reported on, cacao beans, coffee beans, haricot beans, cowpea and groundnuts. Yam, sorghum and wheat are also reported as secondary host (Bayeh, 2012).

Occurrence in Ethiopia: Its presence was confirmed in 2009 through trap catches deployed at Moyale, Ethio-Kenyan border. However, according to Abraham *et al*. (2012) the pest was not reported to be found in any of the grain samples obtained from different stores and market places in suspected areas in the districts of Moyale, Bule Hora and Arsi Negele suggesting that detecting the presence of the pest at low population is difficult (www. infonet-biovision.org).

Woolly apple aphid, (*Eriosoma lanigerum* Hausmann).

Description and origin: The aphid is native to North America and identified in the United States in 1842 and it is a key pest of apple. It distribute in almost all apple growing areas of the world (Nicholas *et al*., 2005). The adult is reddish brown to purple and the characteristic feature is usually obscured beneath a white, cotton-like substance secreted from the aphid's abdomen as a form of protection.

Occurrence in Ethiopia: The woolly apple aphid was reported in Ethiopia nearly three decades ago on several introduced apple cultivars at Holetta research center and latter at Tseday farm, the first apple orchard in the country (Bayeh, 2012b). The aphid inhabits both the aboveground and underground parts of an apple tree. It induces hypertrophic galls on the roots and branches of apple trees which affect the normal growth of the plants (Nicholas *et al*., 2005). The Woolly aphid is a common pest of apple trees, living in colonies on stems and branches.

Damage and host range: Galls, or swollen enlargements formed on the plant and the corky galls that often form may severely defect young trees and some time the galls may split and wounding which can allow entry of apple canker. Roots of infested trees have large, abnormal swellings and can result in reduced tree growth by killing the roots or even death of young trees. The sticky masses of 'wool' produced by the woolly aphid may contaminate foliage and developing fruits. It reproduces on apple year round but other alternate hosts include hawthorn, mountain ash and cotoneaster.

White mango scale *(Aulacaspis tubercularis*)

Description and Origin: White mango scale *(Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae)): has firstly reported in India on mangoes (Ben Dov *et al*. 2006). Scale cover of adult female is approximately circular, white and transparent, with dark, oval exuviae (Cunningham, 1989). Scale cover of male smaller, rectangular, white with three raised longitudinal ridges; exuviae terminal. Uncovered body of gravid adult female is 1.5-2.0 mm long, brownish. Adult male winged. Mode of spread is mainly by the transportation of infested plant materials and it is now widespread in many mangos growing countries.

Occurrence in Ethiopia: It was reported in east Wellega zone, in Indian agro-industry farm in 2010 and later its presence in the Central Rift Valley was confirmed after infestation of mango leaf at Melkassa Agricultural Research Center in 2014 (Gashawbeza *et al*., 2015; Mohammed *et al*., 2012a; Temesgen, 2011). After the incidence, it was identified as *Aulacaspis tubercularies* Newstead (white mango scale) at Ambo Plant protection research center and it was further confirmed by Gillian Watson senior insect bio system analyst, USA in 2011 as similar organism. Gashawbeza *et al*. (2015) provides information on the distribution of the pest in the central rift valley and current efforts to manage the pest. The area coverage of the insect occurrence is expanding very fast and moved to wide mango growing regions such as Assosa and Mendi (Mohammed *et al*., 2011).

Damage and host range: The insect infested mango at all stages, injures by feeding on the plant leaves, branches and fruits, causing defoliation, retard growth, drying up of young twigs, poor blossoming and so affecting the commercial value of fruits and their export potential. The white mango scale insect is the major insect pest of mango. It has been recorded mainly from plants belonging to four families: Palmae, Lauraceae, Rutaceae and Anacardiaceae (Borchsenius, 1966). Severe infestation can result in leaf drop and even die back of stems, especially in young trees (De Villiers and Vilijoen, 1988).

Tomato leaf miner (*Tuta absoluta*)

Description and Origin: Tomato leafminer, *T. absoluta* (Meyrick), is a lepidopteran moth belonging to the Gelechiidae family and is considered as one of the most devastating tomato pests. The pest is native to South America and in East Africa, the first record is from Sudan in 2010 (Mohamed *et al*., 2012b). Adults are silvery gray with black spots on the forewings and a wingspan reaching 10mm. Their activity is concentrated in the early morning and during the rest of the day they remain hidden in the leaves.

Occurrence in Ethiopia: Its occurrence was confirmed following heavy infestation of tomato, *Solanum lycopersicum* L., in the Central Rift Valley region of Ethiopia in 2013 (Gashawbeza and Abiy, 2013). Wind-assisted natural spread of the adult and transportation of tomato fruit from place to place assumed to the major means of its long-distance dissemination (Desneux*et al*., 2010). The damage cause incomparable demand and supply of the product that result in the transportation of the product from long distance which facilitate the spread of the pest.

Damage and host range: The larvae of *T. absoluta* damage tomato plants from seedlings to mature plants by producing large galleries in leaves and consuming apical buds and fruits with possible yield loss of 100%. It is a highly destructive insect pest of tomato in several countries of Latin America, Europe, Africa and Asia (Desneux *et al*., 2010). Its main host is tomato, but also been reported on aubergine (eggplant), potato and common bean, *Solanum nigrum*, *Datura stramonium* and *Nicotiana glauca* as alternate host.

Citrus woolly whitefly (Aleurothrixus floccosus):

Description and Origin: The woolly whitefly, *Aleurothrixus floccusus* (Maskell), the insect is native to Tropical and Subtropical America. Adults resemble tiny moths with two pairs of wings. The wings are mealy-white (except for the citrus blackfly) and cover the body in a sloping roof-like manner. They are usually flat, oval, transparent, 1 to 3 mm long and lack legs or antennae. Nymphs are active only during the first instar (crawlers), becoming sessile for the rest of the nymphal instars.

Occurrence in Ethiopia: Its occurrence in Ethiopia was detected from leaf samples collected from orange trees planted in homesteads around Wonji and Nazareth towns in 2001. Its occurrence in Ethiopia however was made public during the 11th annual conference of the Crop Protection Society of Ethiopia (Getu et al. 2003).

Host range and damage: It was recorded in Ethiopia on all citrus fruits, guava and coffee. Whitefly nymphs injure crops by attaching themselves to the underside of leaves where they feed on plant juices, thus removing nutrients from the plant. The pest sucks phloem sap, decreased photosynthesis, causing leaves to wilt and drop when populations are large. Honeydew droplets collect dust and support the growth of sooty mold. Heavy infestations where copious amounts of honey dew are produced can result in the blackening of entire trees and it causes tremendous yield loss.

Noxious invasive weed pests

Over thirty-five invasive alien plants were recorded as great concern to Ethiopia and creating chaos. Among them, *Prosopis juliflora*, *Parthenium hysterophorus* and water hyacinth (*Eichhorina crassipes*) are ranked top as they are threatening biodiversity by displacing native species causing reduction of native flora and fauna (Rezene, 2008; Taye *et al*., 2009). Some of the species were well known and long-established invaders, such as the widespread prickly-stemmed shrub *Lantana camara.* Biological invasion has impacts on the economy of a country and its biodiversity. Losses caused by weeds in selected crops have been reported to be as high as 100%. The overall average loss on crop yield estimated to reach between 52- 76% (Holetta research center, 1988).

Prosopis juliflora: It is a perennial thorny shrub or small tree in the Leguminose family. It is native to Mexico, South America and Caribbean. Among forty-four species of the genus, only one species was believed to introduce to Ethiopia in early 1970's during the Middle Awash Irrigation Project intentionally for agro-forestry purpose (Kassahun, 1999). It spreads rapidly and taken over pasture rangelands, invading river valleys & watercourses, and lowering the water-table and displacing native trees and grasses. *P. juliflora* is aggressively invading pastoral areas, destroying natural pasture, displacing native trees, plains and colonised diverse habitats.

It also cover areas which previously used for growing the traditional grain staples and other crops grown on large-scale farms in the area, irrigation catchments are now also under threat. Now it is a big concern and threat to ecosystems and livelihoods in arid and semi-arid regions of the country.

Parthenium: *Parthenium hysterophorus* L., belongs to the diverse and cosmopolitan family Astraceae (Parsons and Cutherbertson, 1992). Its introduction was in early 1980's with different speculations and probably it was introduced unintentionally with food aid. Now it is widely spread in most parts of Ethiopia. In parts of eastern Ethiopia, Parthenium weed severely affect crop yields, mainly of sorghum and finger millet, and it is locally called, translated, means 'No Crop'. In some un-weeded fields, sorghum yields have drop by as much as 90%. Now it is growing out of control everywhere with great threats to local biodiversity, agricultural productivity, socio-economic and human health impacts.

In India, where it is known as "Congress Weed", its infestations have been responsible for declines of as much as 40% in crop yields, and for reductions of as much as 90% in the livestock carrying capacities of grasslands.

Water Hyacinth (*Eichhornia crassipes*): It is perennial aquatic monocotyledon plant of the Pontederaceae. In Ethiopia it was reported in 1956 in Lake Koka and the Awash River (Stroud, 1994). Water Hyacinth is a challenge, in both protected and settled areas, to the continent's lakes, rivers, wetlands and floodplains. It also threatening all terrestrial ecosystems and biodiversity, from farmlands and grazing pastures to riparian habitats in settled areas. The weed impedes irrigation, navigation, electricity generation, fishing and any activities practiced in the water bodies.

Lantana weed: *Lantana camara* is originally from South America and its introduction to Ethiopia is deliberately as an ornamental and quickly spread all over the country by birds and animals that eat its fruits but cannot digest the woody seeds (Rezene *et al.* 2012). Similar to other invasive plants it affects grazing land and disturbs the ecology. It releases inhibiting chemicals in the soil to prevent other plants from germination (https://en.wikipedia.org/wiki/Lantana_camara). *L. camara* is good example on the impact of introduction and invasion on biodiversity of the country (Rezene *et al.,* 2012).

Quarantine Research

To avoid introduction or spread of exotic pests, the Ethiopian government has issued a plant quarantine regulation of 1971 Decree number 56 which empowers the Ministry of Agriculture (MoA) to prevent the entry of exotic plant pests into the country. This Decree was updated as plant quarantine regulation number 4 of 1992. Similarly, a Special Decree Proclamation No. 674/2010 was issued for the registration and control of pesticides in 1990. Ethiopia is signatory member and ratified the IPPC convention of 1951 on 20th June 1977 and the current revised version in 2005 to promote international cooperation in controlling pests to prevent their international spread (Abraham, 2008).The approach to managing the risk of incursions of exotic pests and diseases is multi-layered; involving complementary measures applied along the bio-security continuum at pre-border, border and Post border points.

Accordingly, plant quarantine unit was opened in the plant pathology section of Holetta Agricultural Research Center (HARC) in 1978. Besides, plant quarantine services are provided by stations located at Bole International airport (Addis Ababa), Adama, Moyale, Dire Dawa and Metema. In addition to these stations liaison offices to the regional agricultural Bureau are found in Bahar Dar, Mekele, Mehoni and Kombolcha (Teklu, 2014).

From the year 1979-2015, Ethiopia imported over 877,128 accessions of germplasms of different plant species for different purposes. Serious pests include *Colletotrichum graminicola* on maize, *Ascochyta rabei* on chickpea from India, *Bruchus dentipes* on faba bean from Syria, *B. Rufimanus* s on faba bean from USA, scale insect on cowpea from West Africa, *Cuscuta* spp. on linseed, and many weed species from genus *Amaranthus*, *Polygonum*, *Rumex*, and members of the family Poacae from Europe and America were intercepted. At different stations, 3 weed species, 17 plant diseases and 10 insect alien pests were intercepted in the last years (Abraham, 2008; Abraham, 2009).

However, in the past three decades alone more than 20 dangerous pests are believed to be accidentally introduced into the country among which groundnut rust; coffee berry disease, Cyprus aphid, pea bruchid, water hyacinth, *Parthenium*, and *Prosopis* have received highest attention by the public and the government due to the tremendous damage they caused to the Ethiopian agriculture and environment.

Future directions

- Establish, strengthen and expand the national pest diagnostic and management laboratories and greenhouses /insect rearing house
- Establish national biosystematics, national reference collection center and providing pest identification service
- Develop infrastructure and human capacity
- Offering trainings on pest management at all levels of stakeholders and Conducting awareness creation/enhancement tools
- Establishing awareness raising platforms and pest checklist database
- Conducting regular pest survey, monitoring, pest forecasting, early warning system and reporting
- Providing technical backstopping and advisory service to growers on pest and pest management
- Use ICT and develop database software for pest management and pest information exchange network
- Creating awareness on pesticides use and Enforce the available pesticide registration and control legal provisions.
- Determine the major economic pests and affected crops on regular basis
- Develop or search and adopt pest and crop management practices for identified crop pests
- Produce guidelines, manuals for use on important pests
- Narrowing the gap of breeding for pest resistance / tolerance materials.

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Dairy Cattle Research and Development Demands for Ethiopia

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Introduction

Cursory reviews show that in the first half of the 20th century, dairy in Ethiopia was mostly traditional (Ahmed et al., 2004). Though there are slight inconsistencies in reports, the emergence of modern commercial dairying in Ethiopia dated back to the end of the Second World War (1940s) during which Ethiopia was able to obtain dairy cattle through the United Nations Relief and Rehabilitation Administration (UNRRA). With the introduction of these cattle into the country, commercial milk production started on large farms in Addis Ababa and Asmara (Ketema 2000). In the 1960s, evidences (Ahmed et al., 2004) indicate that the government intervened to promote the introduction of high-yielding dairy cattle in the highlands around urban areas with simultaneous establishment of milk processing and marketing facilities to augment intensive dairy production systems in the country. To this effect, UNICEF established a public sector pilot milk processing and marketing plant at Shola in 1960 with the objective of facilitating growth of the dairy sector. Following the emergence of modern dairying in Ethiopia, the government established the Addis Ababa Dairy Industry (AADI) in 1966 to organize and control the collection, processing and distribution of locally produced milk (Ahmed et al. 2004). The milk processing and marketing facilities was establish in a short period and started collecting milk both from smallholder farmers who produce mkil using indigenous cattle and from large dairy farms by establishing satellite milk collection centers.

Other grand effort made during the mid of 1960 include the establishment of Chilalo Agricultural Development Unit (CADU) with the financial aid obtained from Swedish International Development Agency (SIDA). The project aimed at multiplying and distributing crossbred dairy heifers, extension services, credits, input supplies, veterinary supplies, artificial insemination services and introduction of improved forages and improvement pasture lands. Similarly, the Wolaita Agricultural Development Unit (WADU) was established during the same time with the objective of improving local cattle breeds through establishment of bull station. In summary, development of AADI, CADU and WADU are some of the three nationally launched and grand dairy development programs initiated and implemented in the late 1950s and early1960s.

However, the concept of dairy cattle research for development (R4D) in the National Agricultural Research System (NARS) was started with the establishment of Higher Learning Institutions such as the former, Jimma, Ambo and Alemaya College of Agricultures in 1939, 1949 and 1955, respectively.

The former Institution of Agricultural Research (IAR) was established in 1966, in the midst of booming modern dairy production and changing political landscape in Ethiopia. Dairy is one of the research disciplines established along with the establishment of the IAR in 1966. Unlike the commercial dairy system of the country, which was influenced by political changes and subsequent economic and policy reforms, the dairy cattle research of the National Agricultural Research System of Ethiopia passed through three distinct but interactive phases guided by scientific principles and established procedures.

Past dairy cattle research experiences in the EIAR

Phase I. Dairy cattle research and development from 1966-1972

Unlike the first half of 20 century, the second half of the 20th century (1950-1974) marked the emergence of modern commercial dairying in Ethiopia. In 1966, following the establishment of EIAR, an epic journey was started to venture on dairy cattle research in the institute. The first and foremost step taken to enhance milk production of the traditional dairy system was characterizing and evaluating milk production and reproductive performances of selected indigenous cattle breeds on experimental stations established under EIAR. The selected indigenous cattle breeds that were characterized for their performances include Begait, Borana and Horro. Studies on primary traits of interest (milk production) was conducted between 1966 and 1972 and level of milk produced by the three breeds for complete lactation length is indicated in Table 1. Though the study was not comprehensive, indicative results revealed that the level of milk produced per lactation of these selected cattle breeds was relatively low and not sufficient enough to satisfy growing demands for milk and products in the country. Some of the drawback of this experiment was that all commonly known cattle breeds were not considered for evaluation. Secondly all the breeds were not evaluated *in situ* under their own production environments. Such factors probably introduced systematic errors on the level of milk production and reproductive performances of the breeds evaluated.

Table *1*. Milk production and reproduction Performances of selected indigenous cattle breeds.

Breed	Average milk yield (lit)	Lactation length (days)
Borana	563	120
Horro	494	132
Begait	675	194

Source: Beyene Kebede (1992)

Phase II: Dairy cattle research and development from 1972-1992

After thorough analysis of performance of indigenous cattle for their milk production and reproduction performances and expert consultation on the way forward, it was unanimously agreed that crossbreeding between local cattle breeds and dairy types of European origins was one of the viable and alternative genetic improvement strategy to improve milk production in Ethiopia. Thus, the first nationwide and systematic national dairy cattle crossbreeding experiment was designed in 1972 by a German FAO consultant, G. Weiner. Accordingly, the crossbreeding experiments were started in 1972 at four research stations that represent different agro-ecological zones and dairy production systems in Ethiopia (Fig. 1). Selected dairy cattle breeds of European origins and traits of interest for which they are selected are depicted in Table 2.

Table *2*. Exotic dairy breeds selected for crossbreeding purposes

Breed	Reasons why the breeds were selected
Frisian	Higher milk production
Jersey	Higher milk fat yield and adaptation to stressful climates
Simmental	Milk, meat and draft power (multiple purposes)

The four agricultural research stations selected for testing crossbreeding experiment were:

- Holetta: Represented cool central highland agro-ecology
- Bako: Represented mid altitude and humid agro-ecology
- Werer: Represented dry and lowland arid climate agro-ecology
- Adami Tulu: Represented semi-arid mid altitude agro-ecology

Figure 1. Dairy cattle experiment stations in the former IAR

Due to longer generation interval, longer gestation period and inherent genetic characteristics, dairy cattle research needs long-term breeding plan and endurances. Thus, the first preliminary results of the long-term dairy cattle crossbreeding experiments in Ethiopia was reported in 1987 (Sendros et al., 1987), 20 years after the start of the experiment. The results indicated that first generation (F_1) crossbred dairy cows in general produce three to five times more milk than indigenous cows (Table 3). Moreover, it was also concluded that Jersey crosses produce higher milk yield per metabolic body weight than Friesian and Simmental crosses reflecting higher efficiency of Jersey crosses for milk production under low-input low-output dairy production systems. Likewise, crossbred calves were found to have higher birth weight and growth rate to reach at puberty earlier as compared to local calves.

Table *3* . Initial results of milk production performances ofrossbred dairy cows in Ethiopia.

Genotype	Lactation milk yield (Lit)	Lactation length (dairy)	Daily milk yield (lit)
Friesian x local (F_1 generation)	2355	348	7.1
Jersey x local (F_1 generation)	2092	343	6.2
Simmental x local (F_1 generation)	1845	327	5.3

However, comprehensive research report of the systematically designed dairy cattle crossbreeding experiments was reported in 1992 by Beyene (1992). The long-term dairy cattle crossbreeding experiments in various agro-ecologies concluded that 50% Friesian crossbred dairy cattle and crosses near to 50% are appropriate dairy genotypes under smallholder dairy production conditions in Ethiopia. Hence, results of the experiments and the associated management information generated on 50% and various dairy genotypes targeted to various dairy production systems have been adopted by various partners that substantially enhanced adoption of crossbred dairy cows in Ethiopia.

One of the major drawback of dairy cattle research in Ethiopia was that the dairy cattle crossbreeding strategy designed in 1972 tailored merely towards performance evaluation of various crossbred dairy genotypes produced in different agro-ecologies. However, the program didn't design subsequent crossbreeding programs on how to maintain the blood level of crossbred dairy cows to 50%. Moreover, there hasn't been any policy support that guide production of proper dairy genotypes for specific dairy production systems in Ethiopia.

Phase III: Dairy cattle research and development from 1992 to date

Following the 1991 political changes and subsequent decentralization program in the country, it was decided that Bako and Adami Tulu Agricultural Research Centers was decided to be administered by Oromia Agricultural Research Institute (OARI). All dairy cattle crossbreeding experiments at Werer Agricultural Research Center were abandoned in the early 1990s due to outbreak of skin diseases. Holetta Agricultural research Center has remained as the only Federal Agricultural Research Center responsible for guiding the national dairy cattle research in Ethiopia.

Following termination of a comprehensive dairy cattle breeding strategy in 1992, two interconnected approaches of dairy cattle research and development have been conceived. Firstly, it was agreed to verify the performance of improved dairy cows and associated dairy production packages at on-farm through verification trial following participatory approach. The second approach was the extension on the conclusive results obtained from the first national dairy cattle cross breeding program. The aim of this approach was to develop 50% synthetic dairy breed around the milk sheds of Addis Ababa with nucleus herd planned to be established at Holetta Agricultural Research Center. A community-based open nucleus breeding scheme was suggested and the program was designed to span over a period of 10 years (1995-2005). However, this strategy was unsuccessful and finally failed due to absence of on-farm dairy cattle performance recording schemes. Moreover, there are glaring facts that the center missed a guiding technical direction to continue as per the breeding plan after the initiator of the program left the country. However, the participatory on-farm verification of improved dairy cattle and their associated packages have registered remarkable achievements in pilot project areas in West, Southwest and North Shoa.

Yet, there is no any nationally agreed and comprehensive dairy cattle research and development program in Ethiopia. However, attempts are being made at HARC to develop 75% synthetic/composite dairy breed. Performance of the newly established 75% crossbred dairy herd using locally produced and imported World Wide Semen are indicated in Table 4.

Table *4*. Milk production performances high grade dairy cows using locally produced and imported semen

Genotype	Lactation milk yield	Lactation length
High-grade (75 % Frisian x 25% Boran) crosses using locally produced semen at National Artificial Insemination Center (NAIC)	2566	340
High-grade (75 % Friesian x 25% Boran) crosses using imported WWS semen	3274	291

Major achievements of the dairy cattle research in EIAR

Improved dairy cattle technologies and innovations

The Ethiopian Institute of Agricultural Research is one of the leading science and technology innovation institutes in Ethiopia. As an institute of center of excellence in science and technology, one of the key mandates of dairy cattle research in the EIAR is to generate, adopt and verify pro-poor new agricultural technologies and innovations targeted at solving the major dairy production bottlenecks in three prevailing dairy production systems (mixed crop-livestock system, urban and peri-urban and large-scale commercial systems) of the country. Major dairy technologies and innovation generated by the dairy cattle research of the EIAR is indicated in Table 5. Moreover, the dairy cattle research continues to generate new technologies and innovations that fit to the dynamics of livestock production scenarios as driven by social and economic developments, climate and other drivers of changes that has significant implications to dairy development of Ethiopia.

Table 5. Types of dairy cattle technologies generated by the dairy cattle research in Ethiopia

NO.	Type of technology and innovation	Discipline	No.	Breakthroughs/Achievements
1	50% Friesian:50% local crossbred dairy cattle	Animal Genetics and Breeding	1	• Under sub-optimal management conditions, 50% Friesian crossbred dairy cows produce more than 2000 liters of milk per lactation. • Full package (feeding, housing, disease control and husbandry) recommended. • Appropriateness of 50% Friesian crossbred dairy cows for low-input low-out smallholder dairy production system recommended • 25-50% fall in milk production and poor reproduction performances in inter-se mated F_2 crosses of all kinds proved.
2	75% Friesian:25% local crossbred dairy cattle	Animal Genetics and Breeding	1	• Under sub-optimal management conditions, 75% Friesian crossbred dairy cows produce on average 2500 liters of milk per lactation. • Their appropriateness for market oriented medium-input medium-output dairy production systems proved. • Dramatic fall in milk production and poor reproduction performances of this genotype under low-input low-output subsistence systems noticed.
3	50% Jersy:50% local and 75% Jersey:25% local crossbred dairy cattle	Animal Genetics and Breeding	2	• Under sub-optimal management conditions, 50-75%Jersey crossbred dairy cows produce on average 1800 and 2200 liters, respectively per lactation. • Full package (feeding, housing, disease control and husbandry) recommended. • Appropriateness of 50% -75% Jersey crossbred dairy cows for low-input low-out smallholder dairy production system recommended.
4	Urea Molasses Block (UMB)	Animal Nutrition	1	• Compact feed reconstituted from locally available feed resources and industrial by-products that provide all the nutrient required for dairy and other animals in a single pack. • Played significant role particularly in drought-prone ecosystems that continuously affected by drought.
5	Effectiveness of effective microbes (EM) and urea for the treatments for non-convention feed resources to enhance their digestibility and nutritive value as well as effectiveness of EM as malodor control under Ethiopian condition discovered	Animal Nutrition	1	• Effective microorganisms that used to solubilize conventional feed resources for increased digestibility and nutritive value proved. • Levels of urea and ensiling duration of urea as means to treat crop residues to determined. • The effectiveness of EM a means to control barn malodor proved.
6	Development of Total Mixed Ration from locally available feed resources as new feeding system for dairy animals	Animal Nutrition	1	• A new and innovative approach that mix all feed ingredients in one unit from locally available feed resources as new dairy ration developed.
7	Determination of weaning age of crossbred dairy calves under artificial rearing	Husbandry and Management	1	• Crossbred dairy calves of all genotypes can be weaned at 98 days of age through bucket feeding without significantly affecting their growth rate and overall performance of early growth traits discovered
9	Effective rearing practices and of management of post-weaned crossbred dairy heifers	Husbandry and Management	1	• Proportion economically feasible and biologically sound concentrate to hay ratio that accelerate early growth rate in pre-pubertal crossbred heifers determined.
10	Post-harvest dairy technologies	Dairy technology	1	• Processing of various dairy products into various type value added dairy products demonstrated. • Major contaminants of dairy products and hygienic practices to be followed at different milk value chain to keep the milk safe and clean recommended. • Efficiency of traditional and different improved churner in milk fat recovery (butter) determined.
11	Luteolytic doses of estrus inducing hormones (Prostaglandins $F_{2\alpha}$ and estrumate…) as estrus synchronizer and body condition, parity, ovary status…of the animals to be determined (under experimentation)	Reproduction	1	• Hormone factor: Level of luteolytic doses of different estrus inducing hormones for different dairy genotypes will be determined. • Animal factor: Body condition, parity and ovary status of animals to be synchronized will be determined.

Availing scientific information

The second mandate of the dairy cattle research for development (R4D) of the EIAR is to generate different types of information and make them available to individual farmers, private dairy producers and other stakeholders in the form of publication (leaflets, production manuals, posters, proceedings, journals, etc) and other means of communications. The number of different sources of information generated on dairy cattle R4D in the EIAR is depicted in Table 6. Though the data is not completely exhaustive, a total of 264 information were made available on dairy cattle R4D in Ethiopia.

Table 6. Information (publications) by discipline, type and period of publication

Category.	Indicator	No. of publication
Research discipline	Animal Genetics and Breeding	27
	Husbandry and Management (Animal Nutrition)	109
	Dairy processing (post-harvest)	12
	Animal Reproduction and physiology	11
	Multi-disciplinary research reports	11
	Equine research	5
	Others	90
	Total	**265**
Publication Type	Journal Articles	65
	Proceedings (conference papers)	94
	Newsletters and Bulletins	10
	Research Progress Reports	34
	Other research publications (MSc thesis, PhD Dissertations, chapters in a book…etc)	62
	Total	**265**
Publication periods	1966-1980	45
	1981-1990	29
	1991-2000	49
	2001-2010	61
	2011-2015	48

Participatory on-farm verification of crossbred dairy packages

In earlier days, smallholder farmers were skeptical towards the use of crossbred dairy cows for milk production and had no interest to have them. With the advent of milk marketing system, demand was created on keeping crossbred dairy cows by smallholders' farmers through carrying out series of demonstration and verification activities in different parts of the country. Accordingly, on-farm participatory verification of improved dairy cattle production packages has started since 2000. One of the centers that heavily engaged in the pre-extension dairy technology demonstration and transfer program was Holetta Agricultural Research Center. So far, more than 315 crossbred dairy cows were demonstrated to 10 districts (Table 7). Consequently, participating farmers have proved to significantly benefit from the dairy technology transfer program. Moreover, the spillover effects of the dairy technology transfer program to neighboring farmers were enormous to induce horizontal transfer of knowledge and skill on improved dairy production.

Table 7. Weredas participated in dairy technology transfer and number of farmers participated in the program

Weredas*	Number of participating farmers
Welmera and Ejere	142
Dandi	49
Jeldu	38
Ambo and Guder	25
Weliso	12
TikurEnchini	33
KersaMalima	10
GhoaTshion	6
Total	315

*Only data obtained from Holetta Agricultural Research Center included. Other on-farm verification and pre-demonstration activities done by other federal and regional agricultural research centers as well as universities not included.

Driving forces that shape the future of dairy cattle research and developments in Ethiopia

Climate change

The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. Different climate change projections indicated that Sub-Saharan Africa (SSA) will experience a strong warming trend over the 21st century (roughly +2.0 to 4.5^{0}C) by 2100, which is expected to be stronger than the global average (Thornton et al., 2006). The Fifth Assessment report of IPCC reported that Africa's climate is already changing and the impacts are already being felt. Evidences suggested that a 2.5^{0}C increase in global temperature may see major diversity losses: 41-50% loss of endemic plants and anything between 13 to 80% of various fauna in different regions of Africa. A 4.5^{0}C increase in surface temperature, reported to cause major faunal extinction globally, and few ecosystems would be able to adapt, which is difficult to imagine.

Ethiopia is one of the most vulnerable countries to the effects of climate change. Under the Ethiopian context, estimates indicated that temperature could rise between 2.7-3.4^{0}C by 2080. This potentially affects ecosystem balances and induces a shift in the livestock production system (Fig. 2). Therefore, a climate-smart dairy cattle research directions and development approaches are key to adapt to these changes. This involves designing of breeding strategies to select within and between adapted indigenous cattle genetic resources for pastoral and agro-pastoral systems and genetic improvement programs through crossbreeding accompanied with feed developments and health care services in the mixed crop-livestock system.

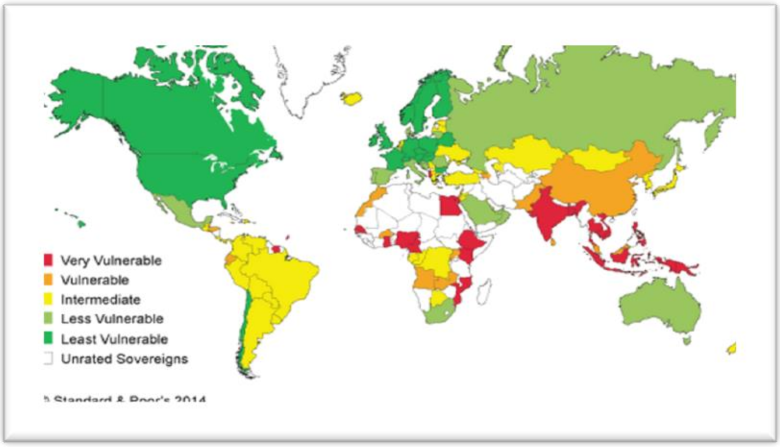

Figure 2. Relative degree of vulnerability to climate change

Human population growth vs increasing demand for animal source foods

Ethiopia is one of the second populous nations in Africa and is characterized by rapidly exploding human population. FAOSTAT (2015) estimated that currently, the population of Ethiopia is estimated at about 99.3 million, grow at 2.5% per annum and about 20 million (20%) are concentrated in towns and cities. Yet, about 79.67 million (80.16%) of the population reside in rural areas and make their living from agricultural activities in one way or another. Interestingly, however, the human population is growing at a decreasing rate. It is not unsurprising to observe that about one-fifth of the population are living in towns and cities currently booming in Ethiopia (Fig. 3).

High human population growth, booming urbanization and income growth in some segments of Ethiopian population inevitably lead to shifting consumer preferences to diversify their diets, among which demand for dairy products is already high. Therefore, the future dairy cattle research and development of the country need to reposition and prepare itself to technically support emerging market-oriented and commercial dairy producers in various dairy production in Ethiopia. Moreover a value chain approach of dairy cattle research and development are key to supply quality and safe dairy products to consumers.

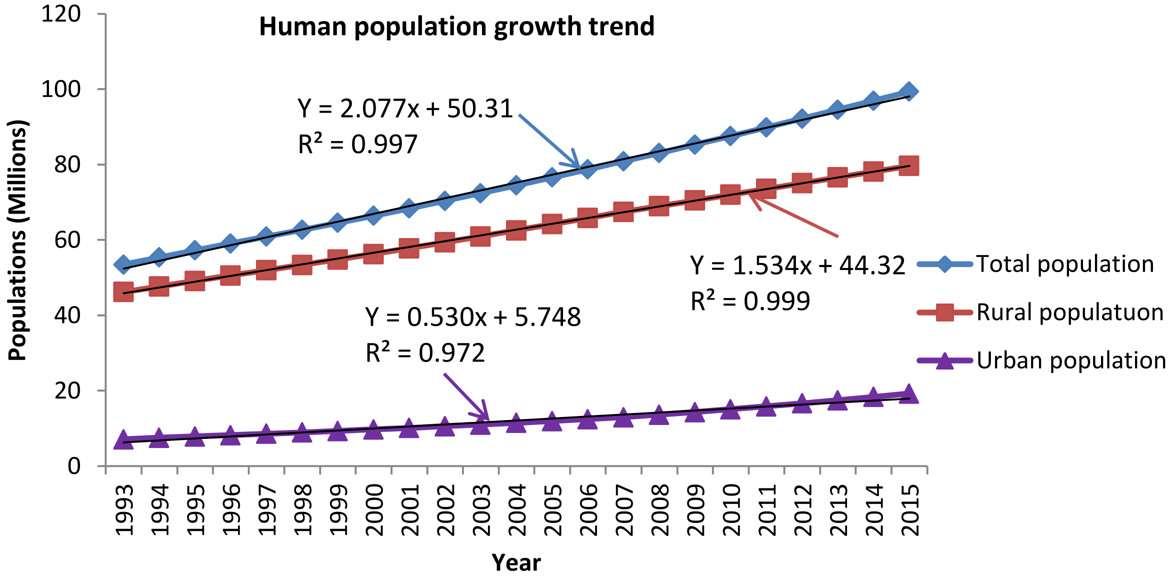

Figure *3*. Trends in human population growth (Source: FAOSTATE, 2015)

Milk production trend

Milk production linearly increased in the last decade (Fig. 4). This mainly attributed to booming private and market-oriented dairy system stimulated by interactive elements such as dairy investment reforms, lucrative milk price, and expansion of milk processing industries, rapid urbanization, and increase in income. Excluding camel and sheep milk, total domestic annual milk production exceeds 4.5 billion liters. According to the reports of the Central Statistical Authority (2012), the total annual domestic milk production from all livestock species reached close to 5 billion liters. A value chain research approach is highly demanding to add value to milk in order to satisfy consumer preferences and produce safe and quality dairy products.

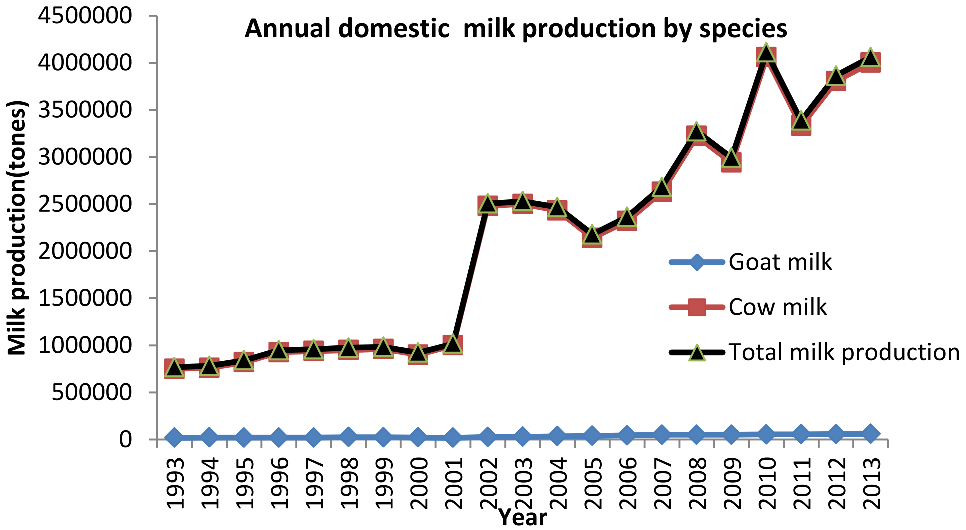

Figure *4*. Trends in domestic milk production (Source: FAOSTATE, 2015)

Imported milk in various forms and import value

Due to unmet demands of milk and milk products, the country is spending tremendous amount of hard currency per annum to import milk in different forms (Fig. 5). FAOSTAT (2015) estimated that, milk import linearly increased from 2002 through 2010 during which the country spent about 1.6 billion USD to import milk. Import trend showed a decreasing trend for consecutive three years from 2011 probably attributed to booming domestic milk production and dairy products processing plants.

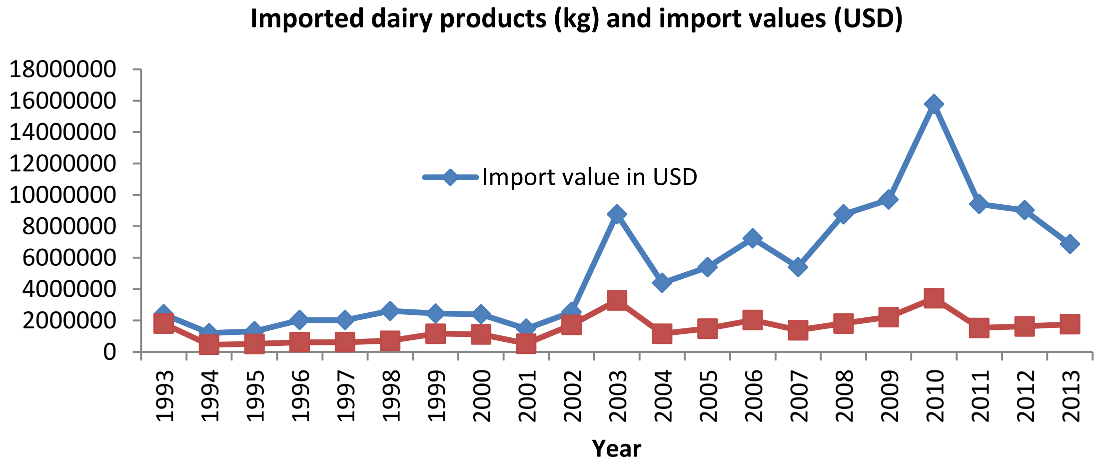

Figure *5*. Trends in of imported milk in different forms and import value in USD
(Source: FAOSTATE, 2015)

Milk consumption trend

For so long, it has been frequently reported that per capita milk consumption oscillate between 16 and 19 liters. However, latest report by FAOSTATE (2015) on domestic milk production and milk import in different forms or showed that per capita milk consumption of Ethiopia is more than 40 liters per annum (Fig. 6).

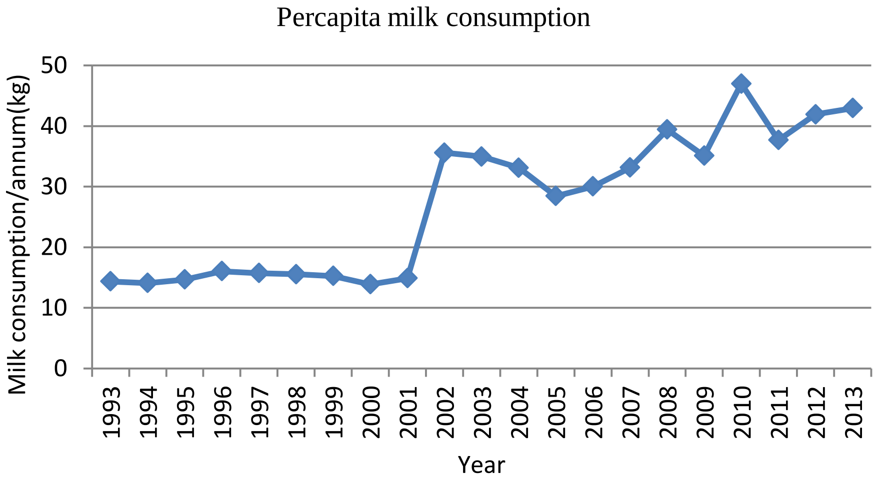

Figure *6*. Trends in per capita milk consumption in Ethiopia over years
(Source: FAOSTAT, 2015)

Investment opportunities and collaborative dairy projects

Ethiopia has prepared dairy sector development plan known as the Livestock Development Master Plan and other conducive dairy development policies that aim at transforming the dairy sector by involving both the smallholder and commercial dairy producers. As a consequence, Ethiopia has widely opened the opportunity for global partnership in dairy and is currently becoming one of the dairy investment and donor destinations in East Africa. For instances, Dairy Business Information Service and Support *DairyBISS* (Wageningen-UR, Livestock Research, The Netherlands), a multimillion dollar African Dairy Genetic Gain (ADGG) and Public-Private Partnership for Artificial Insemination Delivery (PAID) both funded by Bill and Melinda Gates Foundation are some of the upcoming diary projects to venture in our country. Moreover, there is promising domestic initiatives from *MEDROC* Company to establish complex and modern dairy farm along with simultaneous establishments of cultivated forage using irrigation technologies. This initiative further contributes to dairy developments in Ethiopia.

Alignment of national dairy cattle research strategy in relation to agro-climate

The Federal Democratic Republic of Ethiopia set forth major national development plans and strategies that propel Ethiopia to the position of middle income countries by 2025. The national development plan includes Growth and Transformation Plan I (GTP I) (2010-2015), GPT II (2016-2020), Livestock Master Plan (LMP) (2016-2020) and Climate Resilient Green Economy (CRGE). Thus, national dairy cattle research and development activities of the country need to be responsive and gear up itself towards realizing the Grand National development goals in one way or another. To this effect, the national dairy research system positioned itself and strategically set up its research activities in ranges of agro-ecologies by involving federal and regional research centers as well as Higher Learning Institutions (HLI) to focus on regional priority areas and livestock genetic resources in each agro-ecology endowed with (Table 8).

Table 8. Institutions involved in dairy cattle research, strategic research priority areas and genotypes/breed involved

No.	Research Center	Agro-climate	Priority Dairy Research Area	Breed of interest
1	Holetta Agricultural Research Center	Mixed crop- livestock system	Crossbreeding and selection	Frisian and Jersey and commercial dairy system
2	Debre Zeit Agricultural Research Center	Mid altitude mixed crop-livestock system	Crossbreeding and selection	Gyr breed
3	Werer Agricultural Research Center	Arid and pastoral system	Selection among indigenous cattle breed	Afar cattle
4	Asossa Agricultural Research Center	Agro-pastoral system	Selection for disease resistance (Trypanosomosis)	Gumuz cattle
5	Humera Agricultural Research Center	Agro-pastoral system	Selection for milk production	Begait cattle
6	Andassa Livestock Research Center	Mixed crop- livestock system	Selection on for milk and meat production	Fogera cattle
7	Yabello Agricultural Research Center	Pastoral and agro-pastoral	Selection on for meat and milk production	Borana cattle
8	Tepi Agricultural Research Center and MizanTepi University	Humid tropical climate (crop-livestock)	Selection for disease resistance (Trypanosomosis)	Sheko cattle
9	Pawe Agricultural Research Center	Pastoral and Agro-pastoral system	Selection for disease resistance (Trypanosomosis) and milk production	Begaria/Felleta cattle
10	Haramaya University	Chat-based crop-livestock system	Commercial dairy system	Commercial dairy breeds
11	Mehony Agricultural Research Center	Crop-livestock and agro-pastoral system	Milk, animal feeds and nutrition	Raya cattle
13	Gambella Agricultural Research Center	Pastoral system	Selection for disease resistance (Trypanosomosis) and milk production	Nuer/Abigar cattle

Limitations to dairy developments in Ethiopia

Feed and diseases

It is becoming apparent that the landscape is changing in favor of dairy development and dairy value chain driven by population growth, urbanization, income growth and conducive agro-climatic conditions. However, dairy development suffers from inadequate feed supply both in terms of quantity and quality, excessive tax imposed on processed feed and inadequate feed processing plants. Prevalence of both infectious and non-infectious diseases, mastitis and other systematic and feed related disease are among major limitations that warrant intensive research.

Other constraints

Unlike crop, dairy development in Ethiopia suffers from absence of centers that interested in multiplication of proven dairy and related technologies and innovations. Moreover, there is no any dairy herd performance recording and tracing systems and platforms except a pilot project recently demonstrated by MTT project financed by Finland Government and implemented by National Artificial Insemination Center (NAIC) of the Ministry of Agriculture. Above all, the country doesn't have livestock breeding policy and strategy in general and that of dairy in particular. Therefore, dairy cattle R4D in the need to provide policy recommendations and briefings to policy makers and development planners to help them make informed development decision for dairy developments in the future.

Conclusion

Dairy cattle research started at the end of first half of 20th century during which Ethiopia was able to obtain dairy cattle through the United Nations Relief and Rehabilitation Administration (UNRRA). Establishment of former Ambo, Jimma and Alemaya Colleges of Agriculture are also considered as some of the milestones for the emergence of dairy cattle research in the National Agricultural Research Systems. However, systematic and well-designed dairy cattle research was started in 1966 along with the establishment of the former Institute of Agricultural Research (IAR).

Since its establishment, the dairy cattle research has generated handful of dairy breeding and management technologies and innovations targeted different dairy production systems in Ethiopia. Data generated in the long-term dairy cattle crossbreeding experiments have been translated into valuable information such as leaflets, brochures, manuals, poster, proceeding papers and journals that have meaningful implication for dairy development. Moreover, plenty of dairy and related technologies and associated packages have been generated and popularized to target beneficiaries in the form of verification trials and pre-extension demonstrations. However, absence of multiplication centers for proven dairy technologies coupled with some biological factors such as longer generation interval and longer gestation length and non-biological factors high cost of individual animal, high initial investment cost and late return to investment, dairying is one of the underdeveloped sub-sectors in Ethiopian agriculture.

Currently, however, the dairy sub-sector of Ethiopia is rapidly growing in response to rapidly increasing human population, urbanization, increase in income and changing consumer preferences to value added milk and milk products. Such opportunities open up new avenues for dairy development in the future. Moreover, for the dairy cattle genetic improvement to be effective, farming system-based research approach is warranted for Ethiopia.

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Beef Cattle Research Achievements, Challenges and Future Directions

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Introduction

Cattle production is the major component of livestock production in Ethiopia owing to 56.7 million head (CSA, 2014) and the diverse genetic resources (Albero, *et al*., 1981). Cattle have diverse functions and services for farmers in the highland mixed crop-livestock systems as well as in the lowland pastoral production systems. At smallholder and pastoral level, cattle are the major sources of food security and serving a diverse function including cash income, saving and socio-cultural functions. Cattle are also the major sources of drought power and fertilizer for crop production for smallholder farmers in mixed crop-livestock production system. The potential of cattle production in foreign currency earning is substantial in Ethiopia, which are often with limited export items (Cheeke, 1993; DeHaan, 2002). Beef was the most important type of meat consumed, accounting for more than 60 percent of all meat consumed.

Beef cattle research have been practiced for decade in Ethiopia to improve the productivity of indigenous herd, increase their contribution to the livelihood of farmers and pastoralist, and to the national economy. Research in Beef cattle In Ethiopia, as separate entity was initiated in 1989 and in 1997 it was independently operating as national program under IAR. After the re-form, since 2011 it has been operating as Beef Cattle Research Commodity under Ruminant Case team. Several research projects have been undertaken by national, regional research and international agricultural research institutions, and higher learning institutions.

Achievements, challenges, impacts on beef industry and existing gaps need to be periodically evaluated to direct the research to achieve desired goals. For this, systematic evaluation and documentation of past research work in beef cattle is required. Therefore the objectives of this paper are to provide information on beef cattle research and activities, including the major achievements for last 50 years, research gaps and future direction of beef cattle research.

Beef cattle research in Ethiopia

Beef cattle research dates back to early 1960s. Several research projects have been initiated to address different aspects of beef industry. The major focus area includes, description of production system, identification of major beef cattle constraints, characterization of cattle genetic resources, genetic improvement, development of feeding package to attain export market weight, introduction and evaluation of forage species, identification of major diseases and parasites and development of health interventions and marketing system

Beef cattle research in Ethiopia has gone through various stage of transformation. These transformations involve change in research strategy, approach and organizational structure. Beef cattle research in the early years was largely station based technology generation for problems identified through diagnostic survey and researcher's observations. More emphasis was given to identification of farming problem through farming system research approach. Recently beef cattle research involves on-farm research through participation of farmers in planning and implementation of research project including scaling-up of technologies.

In Ethiopia, the research entities engaged in beef cattle research includes Ethiopian Institute of Agricultural Research (EIAR), Regional research institutes/centers, Agricultural Universities, International research centers and NGOs. In the following section beef cattle research and their major outputs are presented.

Cattle resources in Ethiopia

The cattle population in Ethiopia is estimated to be 56.7 million (CSA, 2014). About 70% of total cattle population is found in mixed crop-livestock system, 28% in pastoral-agro-pastoral production system, 1.19% in urban and peri-urban small holder production system and the rest 0.14% in medium commercial production system (Table 1).

Table 1. Cattle livestock population in Ethiopia by region and by production system

Region	Rural mixed cop-livestock	Pastoral and Agro-pastoral	Small commercial	Medium commerci al	Cattle total	Percentage
Oomiya	10,637,708	11,936,193	326,570	25,265	22,925,736	40.43
Amhara	14,513,855		174,218	22,838	14,710,911	25.94
SNNPP	9,396,331	1,673,434	130,695	15,176	11,215,636	19.78
Tigray	4,519,707		41,925	16,549	4,578,181	8.07
Afar		1,580,313			1,580,313	2.79
Benshangul Gumuz	659,587				659,587	1.16
Somali	0	645,166			645,166	1.14
Harar	61,709			692	62,401	0.11
Gambella	278,584				278,584	0.49
Deredewa	0	49,880			49,880	0.09
Total	40,067,481	15,884,986	673,408	80,520	56,706,395	100
Percentage	70.65%	28.01%	1.19%	0.14%		

Source: CSA (2014)

Achievements in Beef cattle breeding and genetics

Phenotypic and genetic characterization

Few research projects have addressed the origin and classification of Ethiopia cattle. The exact origin of African cattle remains uncertain but it now becomes widely accepted that Africa has been a center of domestication. In the past, it was assumed that cattle were domesticated elsewhere and later introduced into Africa. In around 1500BC, long horned zebu cattle were introduced into Africa. Those were mated with hump less longhorn cattle in Ethiopia and Somalia, resulting in Sanga cattle. Sangas then spread from Ethiopia into central and southern Africa. In around 670AD, Short-Horned Zebu cattle were introduced via Ethiopia and Somalia, largely replacing Sanga cattle from East Africa. Those Sanga was interbred with already existing Sanga, creating the Zenga type (sanga-zebu interbreeds). The zebu cattle spread further westwards and southwards and become the dominant cattle in this area.

Cattle types in Ethiopia (Table 2) have a regional distribution and have evolved under the impact factors including climate, altitude, available feed supply, endemic diseases, preferred function and management circumstances (Albero and Solomon, 1982). There are a total of 23 recognized indigenous cattle breed types (zebu types) identified (Workineh *et al*., 2003), that fall into 5 distinct breed groups. Only 6 of the 23 breed types have a fair description of their physical appearance, indications of their levels of production, reproduction and genetic attributes.

A more recent phenotypic classification of Ethiopian cattle database classify Ethiopian cattle to 7 distinct breed categories (DARGIS, 2006, 2007) containing about 27 types\breed of cattle. These are Small East African Zebu (Adwa, Ambo, Bale, Goffa, Guraghe, Hammer, Harer, Jam-Jam, Jijiga, Mursi, Ogaden zebu, Smada), Sanga (Aliab Dinka, Anuak, danakil, Raya-Azebo), Zenga (Arado, Fogera, Horro), Large East African Zebu (Arsi, Begait, Ethiopian Borana, Murle), Hampless Long horn (Kuri), West African Zebu (Red Fulan) and Humpless Shorthorn (Sheko).

Projects on molecular characterization in cattle have been initiated in ILRI in collaboration with EIAR and Haramaya University but it is limited to study diversity of Ethiopian cattle. Appropriate research facilities with specialized molecular laboratory, researchers and technicians trained in molecular genetics are lacking. Moreover, among the large variety of indigenous cattle breeds that Ethiopia has, only 8 of the 27 breed types have a fair description of their physical appearance, indications of their levels of production, reproduction and genetic attributes. The main cattle breeds/populations identified and characterized so far (if not comprehensive and complete), include the Boran, Fogera, Horo, Sheko, Abigar (Nuer), Gurage, Ambo, and the Afar breeds (Zewdu et al., 2013; and Fedlu et al., 2007).

Research in cattle breed characterization in previous projects are not complete, genetic characterization was done for few breeds. Further research is required to fill the gaps in breed characterization in the previous projects. Population considered distinct through district level survey/observations and those that need further characterization (genetic) includes Begait, Raya Azebo, Afar, Ogaden and all cattle types under Small East African Zebu group. Moreover, further research is required to fill the gaps in phenotypic and genetic parameters estimates for growth, reproductive and health performance traits. Research has not yet focused on direct application of molecular genetics to the design of breeding program. Breed characterization using microsatellite may not help much in identifying Quantitative Trait Loci (QTLs) that help for designing improvement program using Marker Assisted Selection (MAS) tool for low heritability traits.

Table 2. Ethiopian Cattle diversity, special attribute and risk associated to biodiversity

Group/Category	Cattle type	Geographical distribution	Reference
Large East Africa Zebu	Arsi	Oromiya (Arsi, Bale, E. Shoa)	Albero et al., 1982; Hailu Dadi, 2011;
	Boran	Borana, lowlands of Bale, part of Somali	Albero et al., 1982
	Barca	N.W. Tigray	Albero et al., 1982
Hampless Shorthorn	Sheko	Bench Wereda of SNNP	Takele Taye, 2005; Albero et al., 1982
Small east Africa Zebu	12 zebu cattle types	All over the country	Albero et al., 1982 Hailu Dadi, 2003
Senga	Anuak,	Gambella region	Albero et al., 1982
	Afar/Danakil/Keryu	N.E lowlands Afar, Rift valley	Albero et al., 1982 Shiferaw et al., 2006
	Raya-Azebo	South Tigray, North wello	Albero et al., 1982
Zenga	Arado	N. Highlands Tigray	Albero et al., 1982
	Fogera	Around lake Tana & Gondar	Albero et al., 1982
	Horro	E.Wollega, W. Shoa, Keffa, Illubabor	Hailu Dadi, 2003

Phenotypic and genetic parameters for some Ethiopian cattle breeds

Estimation of genetic parameters (heritability, phenotypic and genetic variance) are good indicators of genetic characteristics of the population and are the base for development of breeding program for genetic improvement of the population. From on station performance evaluation projects, phenotypic and genetic characterization for growth traits was done for Boran, Horro and Fogera cattle breeds at Abernosa ranch, Bako research Center and Andasa research center, respectively (Mekonnin H/Mariam 1992; Habtamu 2010). Estimates of the phenotypic and genetic parameters are presented in Table 3.

Table 3. Phenotypic and genetic parameters for some Ethiopian cattle breeds

	Phenotypic Variance			**Genetic variance**			**Heritability**		
Trait	Horro[1]	Fogera	Boran[2]	Horro[1]	Fogera	Boran[2]	Horro[1]	Fogera	Boran[2]
Birth weight	14.7	5.58	4.32	9.9	1.165	1.036	0.68	0.21	0.24
Weaning Weight	80.4	1672	492	42.2	303.192	142.65	0.53	0.18	0.29
Yearling weight	556		495.12	427		170.19	0.77		0.33

Note: [1]Habtamu Abera, 2010; [2]Mekonnin H/Mariam 1992;

On station performance evaluation

Indigenous cattle breed evaluation: Maintenance of cattle herd at research station and ranch dates back to introduction from Italy by CADO (MOA, 2000). In 1967, CADU conducted performance evaluation of Arsi, Horro, Barka cattle breed at Asella station. Following this, performance evaluations were conducted by the then Alemaya University on Barka and Boran cattle at Debre Zeit research station and by the Institute of Agricultural Research (IAR) on Boran, Horro, Barka, Fogera cattle breed at Holetta, Werer, Adami Tulu and Bako research Centers. The purpose of these experiments was to evaluate growth and milk production performance the local breeds under different environment. Research outputs from these on-station performance evaluation showed that there was a large variation in body weight at different age between indigenous cattle breeds (Table 4).

Table 4. Growth performance of some Ethiopian cattle breeds

Breed type	Birth weight in kg	Weaning weight In kg	Yearling weight in kg	Adult weight in kg	Reference
Begait	22.6	96.67	120.23	360	Beyene (1992), Hailu (2003)
Boran	23.3-26.6	99.92-157	128.47	268	Beyene (1992), Hailu (2003),Amsalu (2004) Goshu et al, 2003
Fogera	21.5	88.64	125.2	-	Addisu Bitew, 1999; Goshu et al., 1983
Horro	17.5-19.9	80.00	106.9	250	Beyene (1992); Demeke et al. 2003 and 2004; Habtamu, 2008;1010; Zewdu,2004

Crossbreeding indigenous Boran cattle breed with exotic beef cattle breeds: Beef cattle breed improvement projects was initiated at the then Alemaya College of Agriculture in 1961 by crossbreeding Boran cows with Hereford, Angus, Charolais, Brahman and Santa Gertrudis bulls (Wagner *et al.*,1969). The major outputs from this project indicated that crossbred calves were higher in weight by 19.6% and 23.6% at birth and at weaning time (240 days) than Borana caves, respectively. In the feedlot, Borana cattle grew at the rate of 1.74 lb per day as compared to 2.40 lb per day for crossbred cattle, representing a superiority of 37.9% above the Borana cattle ($P<0.01$).

Characterization of livestock production system

Numerous studies have described livestock production systems in Ethiopia since mid 80s when a farming system approach were Adapted by the then IAR (now EIAR). Few of the most important assessments are presented in Table 5.

Table. 5. Livestock production system characterization activities

Production system	Agro-ecology	Reference
Survey on traditional livestock production systems in Manasibu District of W. Wollega, Ethiopia.	Welegga, 2003	Alganesh et al., 2003
Smallholder livestock production systems and constraints in the highlands of North and West zones.	Highland of N.W.zone	Tesfaye et al., 2001
Laval Traditional Horro Cattle production in Boji District, West Wellega	West Wellaga	Lavel et al., 2002
Beef and Feed Value Chain Study in Adama District.	Adama district	Addisu et al. 2012
Food production trends and the contribution of livestock to food security in Ethiopia: Forthcoming challenges and technical support imperatives	Ethiopia	Deriba et al., 1999

Livestock marketing

Characterization of cattle marketing structure has been a major component of livestock marketing research (Ayele et al., 2003; Belachew and Jemberu, 2003; Zewdu et al., 1988; Netherlands-African Business Council or NABC, 2010). According to the findings, livestock markets in Ethiopia are reported to function at three levels, namely; primary, secondary and terminal markets. In the primary markets, no facilities are available for weighing, watering and feeding of animals and less than 500 heads are sold weekly, whereby producers sell their animals to traders, other farmers as replacement stock and sometimes to consumers and local butchers. Whereas in secondary markets, middlemen, traders and butchers dominate with a turnover of 500–1000 animals per week consisting of finished, breeding and draught stocks and located mainly in regional capitals . In terminal markets, which are mainly located in the large urban centers, medium to large-scale traders dominate these markets and more than 1000 animals are marketed in a week. Challenges and Opportunity of livestock marketing in Ethiopia are also reported (Belachew and Jemberu, 2003; Alemayehu 2001).

Livestock marketing system in the country faces several constraints including lack of market information system, several service fees and charges that enhance black markets, and cross border trade (Ayele et al., 2003). Recently, increasingly strict health and quality control regulations in the importing countries restricted considerably exports. A major problem for exporters from Ethiopia, as elsewhere in the region, is that they have little knowledge about the market structure, rules and regulations, as well as consumer tastes and preferences in importing countries. Apart from diseases, the apparent poor state of health of the animals caused by long rough journeys also reduce their marketability. Second, alternative suppliers, who are better prepared and able to meet the market demand and conditions enter the market gradually replacing Ethiopia as a supplier.

Achievements in Beef nutrition

Research on beef cattle feed and feeding system has been carried out at different centers and universities. EIAR and the International Livestock Research Institute (ILRI) has recently developed a simple tool known as TechFit for prioritization of feed technology options to enable better targeted interventions to address livestock feed problems in specific locations. Six potential feed technologies were identified in Horro district of Oromia Region, West Ethiopia, after filtering and prioritizing among thirty eight feed technologies with TechFit tool to address the quantity, quality and seasonality issues of livestock feed supply. Similar works were also conducted by Holetta research center at western Shewa. The International Livestock Research Institute (ILRI), rumen ecology/ microbiology research was initiated and some isolate of rumen microbes from different sources collected, and stored using in-vetro techniques at ILRI laboratory. Research on strategic dry feed supplementation on reproductive performance of cattle (Mekonnen, 1987; Azage 1989, Azage, 1999).

Research on establishing simple techniques for improving feeding value of crop residues such as Urea treatment is important for improving the nutritive value of cereal straws and stovers was undertaken. Research on generation of technology on feeding options for male animal to attain 300 kg export market were undertaken by EIAR, for different age group of Boran, Fogera, Horro and high land zebu and Afar breeds at Adami tulu, Andasa, bako, Areka and Werer research centers respectively (Table 6).

Table 6. Summery of result on feeding options for male animals to attain export market weight:

Feeding package	Breed	Duration	Dressing %	Average daily weight gain g/day	Reference
Growth performance of one year old Fogera cattle (Grazing with molasses, wheat bran, linseed cake and salt 2%,)	Fogera at andasa	150 days		728	Adebabay et al.2013
Growth performance of zebu cattle under different feeding (Rhodes grass cut carry with Taro-Godare/hamicho-Enset root or chopped sugar cane	Zebu at Areca	14 weeks	58-60%	750	Zekariyas et al. 2014
Evaluation of different options on yearling Boran bulls to attain export market weight at Adami Tulu Agricultural Research Center.	Boran	224 days	62%	780	Mieso et al., 2013
Effect different of feeding options on growth response and carcass characteristics of two years aged Borna bulls for export market weight gain at Adami Tulu Agricultural Research Center.	Boran	154	61%	753	Girma et al., 2015

Animal health research

In Ethiopia, research in the area of animal health involves development of diagnostics and vaccines against economically important diseases including zoonotic diseases. The National Veterinary Institute and the National Animal Health Research Center of MOA at Sebeta are undertaking these activities, as they have been involved in these areas of research and development and production of vaccines. The National Veterinary Institute (NVI) has over the years developed capacity and capability to produce vaccines against bacterial, viral, and paratactic diseases mainly in large ruminant including small ruminants and chicken. Moreover the recently re-opened PANVAC within the NVI is utilizing animal health biotechnology for development of diagnostics and improved vaccines. Using recombinant DNA methods a number of products have been developed that have direct application in animal health. Improved and cheaper vaccines against a number of diseases have been produced, e.g. vaccines against foot-and-mouth disease, enteric diseases and ecto-parasites (Yilma, 1989; 1990). The presence of livestock diseases apart from affecting the efficiency of production hampers export market development as a result of frequent bans by importing countries (Belachew and Jemberu, 2003). Diseases such as CCPP, Antrax, blackleg, haemorrhagic septicaemia, trypanosomiasis, bovine tuberclosis, streptothricosis and brucellosis are also common in the country. External parasites such as lice, keds and ticks are also abundant and are major causes of rejection and down grading of hides and skins in international trade. There are also diseases specific to intensified type of production systems such as lameness, infertility, tuberculosis and reproductive wastage (Alemayehy *et al.*, 1999; WHO, 1993). The direct mortality of ruminant livestock is generally estimated to in the order of 8-10% of the national cattle herd per annum. Altogether, the direct annual economic losses from animal disease alone may be estimated to range between 1.5 and 2.5 bill. When compared with the estimated value of livestock production in Ethiopia, the losses represent 30-50% of total production value (Wondwosen et al., 2002, FAO, 1993).

Research gaps

Technology gaps: Beef cattle breeding and reproduction: Further research is required to fill the gaps in phenotypic and genetic parameters estimates for growth, reproductive and health performance traits. Research has not yet focused on direct application of molecular genetics to the design of breeding program, characterization of forage species. Breed characterization and identifying Quantitative Trait Loci (QTLs) that help for designing improvement program using Marker Assisted Selection (MAS) tool for low heritability traits. Moreover, genetic parameters estimate for economic important traits need to be addressed for important breeds.

Nutrition: there is a need to generate technologies that improve the nutritional composition of animal feed (conventional feed, grazing/range land, crop residue etc.), and to develop improved forage verities mainly for drought prone areas. It is also important to assess the nutritional composition of existing feed resources and development of associated quality parameters.

Health: research is limited to address the prevalent animal diseases such as FMD (Foot and Mouth Disease) that are restricting trade, meat quality and food safety given the need to meet standard set by importing countries. Recently, increasingly strict health and quality control regulations in the importing countries restricted exports to these countries, which requires technological solutions to alleviate the problems. There is also a gap in developing mechanisms that improve the apparent poor state of health of the animals caused by long rough journeys, which reduces their marketability.

Research capacity: Strong national and regional research capacity and well-trained manpower/scientists in animal breeding nutrition and health are required. Among technical constraints limiting productivity of the livestock sector are low genetic potential, poor reproduction, high morbidity and mortality due to various diseases and poor livestock nutrition and management. These constraints can be addressed if there is adequate research capacity both in term of human and physical facilities.

Challenges

- The traditional livestock husbandry such as communal ownership of resources, communal herd management, and uncontrolled livestock herding and breeding is one of the major challenges to improving breeds, forage development and health interventions;
- Lack of infrastructure and skilled manpower to apply advanced science and technologies in beef cattle research;
- Lack of application of modern technologies that improve beef potential indigenous cattle breed;
- Limited capacity to generate technology that can increase product quality and safety to meet the rising demand of beef at local and export market;
- Limited availability of knowledge/ information and technologies that transform producers to market-oriented and empower all actors along the value chain
- Increasingly strict health and quality control regulations in the importing countries restricting exports to these countries and limited domestic capacity to fulfill these requirements in sustainable manner;
- Climate change/recurrent draughts
- The overall challenge related with the establishment of strong national and regional research capacity and well-trained, development-oriented scientists in appropriate disciplines.

Opportunities

The country owns large and diverse indigenous livestock resources, which are genetically diverse and this genetic potential is not yet adequately exploited. Some of the breeds have special merits that meet the requirements of certain niche markets and fetch premium prices. For instance, lowland breeds are in high demand in the Near and Middle East countries. There is also a large domestic market expected to grow with increasing population size, urbanization, and per capita income. The diverse and favourable production systems and production environment provides opportunities for development of alternative feed resource base and profitable and sustainable beef production systems to increase productivity.

The recently established sugar estates in different areas in the country create opportunity for wider availability of byproducts from sugar factories as feed resources. The rangeland resources in pastoral areas provide huge potential to produce quality anumal feed of supported with technologies such as suitable forage varieties, fodder conservation, padlocking and advanced irrigation. The abundant water resources such as rivers, lakes and underground water provide also opportunity to expand access to irrigation. A number of others opportunities are currently available that encourages investing in livestock marketing such as shifting of diet from grain to high quality livestock and livestock products: Buoyed by high GDP growth, globalization, higher incomes and increased urbanization particularly in the developing world. Diets are rapidly diversifying away from traditional staple commodities and towards high-value products, including meat. In this regard, Delgado *et al., (*1999) projected rapid demand growth for livestock products that will predominately come from the developing world. The projections suggest that meeting increased demand in developing countries by 2020 will necessitate per capita meat production rising by 38% (Delgado *et al*., 1999).

Future Beef Cattle Research Directions

The development, dissemination and adoption of relevant improved technologies and adaptation of worldwide available technologies to the needs and capabilities of farmers and pastoralists, complemented with the development of relevant policy and support programs, are necessary conditions for improving and sustaining beef cattle productivity.

Animal breeding: The current direction of the Ethiopian government is to boost beef production and export earnings by improvement of indigenous breeds to attain a desired marketable weight at earlier age through, selection of indigenous cattle for superior growth performance, cross breeding with appropriate beef breed, improving feed quality and quantity, improving animal health, establishing different cooperatives specialized for rearing, growing and finishing of beef cattle for local and export markets. Technologies in area of internal and external parasite infections, gastrointestinal parasites and tick infestation are required. Moreover, research on establishment of disease free zone in selected areas need to be considered. The application of modern technologies in beef cattle research and development are crucial, specifically identification of genetic markers such as microsatellites, SNPs in identifying Quantitative Trait Loci (QTLs) are required for designing improvement programs using Marker-Assisted Selection (MAS) tools. For application of reproductive biotechnology such as In-vitro embryo production, multiple ovulation and embryo transfer in breeding program require protocol optimization.

Beef marketing: Research on problems associated with the supply of beef cattle to export market need to focus on: how to meet quality standard to meet market demand, whare the causes of inconsistent supply and demand, what are mechanisms to improve the efficiency of supply chain, how to increase off take rate, and what methods to follow in designing approaches and mechanisms for efficient delivery of improved genetics.

Animal Feed: The rangeland resources at pastoral areas are invaded by unwanted invader weeds and bush encroachments, which need technological intervention to and over sowing with suitable forage verities, fodder conservation, padlocking and advanced irrigation.

Research capacity: Development of research infrastructure such as laboratory for breed characterization, animal nutrition and animal health laboratory at major beef cattle research centers are required. Development of manpower (Beef cattle researchers) in area of Animal breeding and genetics, animal reproduction, Animal feed and feeding system and Animal health at different level need to be addressed.

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Small Ruminant Research in Ethiopia: Reflections and Thoughts on the Way Forward

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Introduction

Small ruminant production in Ethiopia

Ethiopia has an estimated population of 27.3 million sheep and 28.2 million goats (CSA, 2014), which are distributed in all agro-ecological zones of the country. More goats (45 to 73%) and less sheep (25-52%) are found in pastoral areas (Halderman, 2004) than in areas of sedentary farming. The small ruminant production practices in Ethiopia are largely subsistence type (Girma *et al.*, 2007) but have significant importance in the livelihood of smallholder farmers and pastoralists (Fufa *et al.,* 2007; Girma *et al*., 2007). This emanates from the requirement for small investment, shorter production cycles, relative ease of marketability, and greater environmental adaptability of small ruminants.

Apart from their role at household and communal level, small ruminants have national importance as they provide for about 46% of the national meat consumption, 58% of the value of hide and skin production (Kassahun *et al.*, 1991) and significant amount of export earnings. Unlike improved breeds elsewhere, most of the indigenous breeds are not selected for their production performance. Gross off-take rates were estimated to range from 10 to 35% for sheep and 11 to 38% for goats while commercial off-take rates were in the range of 6 to 22% for sheep and 7 to 18% in goats (MoA, 1985; Belete 2009; Belachew and Jemberu, 2003; Mohammad *et al*., 2007; Asfaw and Jabbar, 2008). This would mean, under the higher scenario of the current level of productivity, about 6.0 million sheep and 5 million goats are available for market every year.

Given the non-seasonal reproduction of Ethiopian sheep and goats, there appears a huge gap between potential and current level of gross and commercial off take rates. Despite potential for faster growth with improved management (e.g. creep feeding) market weights are usually achieved at late ages and live and carcass weights are also low. Concerted effort in the area of research and development is required to narrow these existing gaps. In this paper, past research and developments endeavors are presented along with the way forward for significant improvement in production and productivity small ruminants.

Production constraints

A number of complex technical, institutional and socio-economic constraints are known to limit improvements in small ruminant productivity and production. The principal constraints are: diseases and parasites, poor nutrition (quality and quantity), unimproved genetic potential of local breeds, poor marketing infrastructure and access to markets, minimal institutional and support services, and poor access to and sub-optimal utilization of knowledge, information and technologies (Markos 2000; Tsedeke 2007; Gizaw et al., 2013). The influence of these constraints is manifested through reduced reproductive efficiency, high mortality, slower growth rate of survivors, low off take rate and return.

Historical development of small ruminant research

Research on sheep in Ethiopia dates back to the 1960s (Gizaw *et al.,* 2013) while research on goats started during the mid-1970s as part of the small ruminant research program (Aschalew et al., 2000). Some introduction of exotic germplasm (Merino sheep) has taken place as early as 1944 (DBSBMC, 2007 as cited by Getachew et al., 2016) though information on subsequent development is lacking. Several research and development projects have been initiated that pertain to different aspects of the small ruminant production. The focus areas include description of farming systems, identification of small ruminant production constraints, characterization of genetic resources, genetic improvement mainly through crossbreeding and to a limited extent through selective breeding, introduction and evaluation of forage species, development of feeding packages, identification of major diseases and parasites, development of health interventions, and marketing studies (Gizaw *et al*., 2013; Solomon *et al.,* 2014).

The establishment of Debre Berhan Sheep Breeding and Multiplication Center in 1967 on 650 ha of grazing land can be considered, because of the number of researchable issues included in the objectives, as the first significant activity towards sheep research. The objectives for the establishment of the center were studying the performance of indigenous sheep breeds, multiplying the most productive types of the indigenous animals, testing the adaptability of various exotic mutton and wool breeds to local conditions, crossing the exotic breeds with the indigenous ones and assess the degree of upgrading and the corresponding gain obtained, and providing selected improved breeding stock to local farmers for upgrading their own local breeds (Hizkias, 1991). Subsequently, similar center with the same objectives has also been established at Amed Guya and the two centers focused on distribution of crossbred rams to farmers. Exotic breeds involved from the outset include Merino, Rambouillet, Romney and Hampshire with introduction of Awassi at later stage (Getachew *et al.*, 2016). Cross breeding of Corriedale, Romney, Hampshire and bleu de Main sheep breeds with a number of indigenous breeds has also taken place in Arsi highlands since 1971 (Teferawork, 1989). In addition to these, introduction of Dorper sheep to Jijga ranch in the 1980s by the Ministry of Agriculture is worth mentioning. Later more introduction of Dorper sheep has taken place by a program known as Ethiopian sheep and goat productivity improvement and subsequently by regional Agricultural bureaus and research institutes.

Large number of fragmented efforts to characterize sheep population in various parts of Ethiopia has been taking place in the past. Gizaw *et al.* (2008) have undertaken a relatively comprehensive phenotypic and molecular characterization and categorized the fourteen traditional sheep breeds of the country into six breed groups and nine breeds. The same work has also addressed conservation priorities and breeding strategies for the indigenous sheep population. Since 1977 on-station characterization of sheep breeds namely Horro, Adal (Afar), and Blackhead Somali (BHS) have been carried by the then Institute of Agricultural Research (IAR). A research flock of BHS has been kept by Alemaya College of Agriculture (now Haramaya University) starting from the early eighties. Later similar breed evaluation and improvement programs were carried on Menz sheep at Sheno and on Menz and Horro sheep at Debre Birhan research centers by IAR and ILRI (formerly ILCA), respectively (Markos et al., 2004). Though the objectives included, apart from evaluation of breed performance, application of selection for economically important traits, lack of sustainability of efforts and well-focused breeding program and absence of well qualified personnel hindered realizing sizeable improvements (e.g. Solomon and Gemeda, 2001). Additionally, the flock size kept at the different stations was small leading to small selection differential. Recently sizeable improvements have been registered from selective breeding of Menz sheep (Gizaw *et al.* 2013) and community based breeding of Bonga sheep. Limited crossbreeding between indigenous breeds has taken place in Amhara region (Getachew et al., 2016).

In the mid-1970s goat crossbreeding studies involving Afar and highland goats and their crosses with Saanen was implemented at Melka Werer in Eastern lowlands and Holleta in the Central highlands. Since 1988, a collaborative dairy goat development project has been implemented by Farm Africa, Ministry of Agriculture, Alemaya University of Agriculture, Awassa College of Agriculture, and several other non-governmental organizations (Peacock et al., 1991). Anglo-Nubian goat breed has been introduced for crossing with Somali goats. Togenburg goat breed has also been introduced at some later stage (Mahlet, 2008). Other exotic breeds of goats introduced into the country include Brown Alpine and Nera Verzasca but information on developments after introduction and on the extent of use of these breeds is lacking. There is no reliable information to what extent these exotic genotypes have been diffused into the indigenous populations, but it is probably of very little significance.

Limited introduction of Begait goats to Southern Ethiopia has also been undertaken by Agri-service Ethiopia in collaboration with Hawassa University (Workneh, 2009) but the activity was not sustained for long. Between 2006 and 2011, the ESGPIP, which was implemented in collaboration with several institutions (higher learning, research and agricultural development) has undertaken introduction of Boer goat as improver breed. Research on on-staion characterization of Arsi-Bale and Boran (long-eared Somali) goats at Adami Tulu Research Center is the longest project on indigenous goats in Ethiopia, running for more than 15 years since 1992. Fourteen goat types have been identified as a result of comprehensive phenotypic characterization of Ethiopian and Eritrean goats (FARM Africa 1996). Later Tesfaye (2004) has undertaken a molecular characterization of eleven populations of Ethiopian goats which resulted in identification of eight genetic entities.

In terms of dynamics in the past four decades, small ruminant research has evolved in terms of coverage (breeds and area) and from disciplinary (production, feeds, health) to multidisciplinary/commodity-based, from experiments/trials to project-based research formulation, from Researcher-driven to Farming systems to participatory (PRA, FRG) and health unit from mainly service provider to full-fledged program.

Research outputs and achievements

Small ruminant research and development has been going on formally for decades in Ethiopia targeting: (i) the characterization of the genetic resources of the country, (ii) the prevalent and various constraints, (iii) the improvement of the productivity of the local flocks, (iv) improvement of off-take rates, and (v) increased contribution to the livelihoods of farmers and pastoralists, and the national economy.

Large number of studies have characterized the sheep and goat production systems in the various parts of the country (e.g. Tolera 1998; Endeshaw 2007; Gurmesa *et al*. 2011; Assen and Aklilu, 2012; Dhaba *et al.* 2012). These studies have described the production system, identified constraints and suggested areas of intervention.

On station studies on characterization of performance of some indigenous sheep and goats have shown that the sizes required by the market may not be achieved until about one year of age (Table 1) unless higher supplemental feeding is practiced (e.g. Galal *et al.,* 1981). Carcass yields were shown to be low (Table 2). Goats appear to have higher dressing percentage than sheep. Information with regard to types of cuts from some sheep and goat breeds has been generated (Sendros et al., 1998; Ameha, 2006) and can be made use of to develop market based on joints and parts, rather than the whole live animal or carcass. Milk production performance of goats along with its quality has also been a subject of research particularly in areas where goat milk is consumed (Getnet *et al*, 2000; Fekadu and Eyasu, 2000; Mestawet *et al.*, 2012). Estimated average daily milk production as high as 1.5 kg has been obtained in some goat breeds (e.g. Getnet *et al*., 2000).

On station and on farm genetic improvement of Menz sheep has resulted in sizeable gain in terms of weaning and yearling weight (Gizaw *et al.* 2007). Community based breeding program on Bonga sheep has also resulted in sizeable improvement of weight at birth and at later ages.

Table 1. Growth performance of some indigenous sheep and goats

Species	Breed/Population	Age	Sex	Body weight (Kg)
Sheep	Horro	12 month	Both	24.0
	Black head Somali	12 month	Both	23.8
	Afar	12 month	Both	24.5
	Menz	12 month	Both	17.4
Goats	Short eared Somali	2PPI	Male	19.77
	Afar	>16 months	Male	24.7
	Arsi-Bale	18 month	Unidentified	19.56

Note: PPI=Pairs of permanent incisors

Table 2. Age, body weight, carcass weight and dressing percentage of some Ethiopian sheep and goats

Species	Breed/Population*	Sex	Age	Body weight	Carcass weight	Dressing percent
Sheep	Horro	Male	Unspecified	19.7	7.5	37.9
	BHS	Male	> 1 year	40.5	18.7	46.1
Goats	Afar	Male	Yearling	24.7	9.8	39.5
	Afar	Male	Unspecified	18.94	8.4	44.6
	Afar	Castrated	Yearling	24.9	10.4	41.6
	CHG	Male	Unspecified	19.44	8.3	42.5
	LES	Male	Unspecified	21.16	9.2	43.7
	Arsi-Bale	Male	Unspecified	21.0	9.5	45.4
	Woyto Guji	Male	Unspecified	19.4	8.8	45.2
	Afar	Male	Yearling	24.7	9.8	39.5
	Afar	Castrated	Yearling	24.9	10.4	41.6

Note: *BHS=Black head Somali sheep CHG=Central Highland goats LES=Long Eared Somali goats

Apart from breed evaluation, crossbreeding has been applied on a number of sheep and goat breeds in the country. The intent of the crossbreeding was combining the adaptability of the indigenous breeds to the environment with high performance of the various exotic breeds. Some preliminary results of on-farm evaluation have shown performances in terms of daily gain and weaning weight of crossbred (37.5%) lambs were not superior to local animals (Hassen *et al*., 2002). There was superiority in birth weight, but this was not maintained at weaning implying the inability of the local dam to support higher growth rate in the lamb. On station studies have shown superiority of crosses (in terms of weight and wool yield) over local animals (Table 3) both under feed supplementation and no supplementation. The superiority was very high under supplementation (Sisay *et al*., 1991) implying exotic animals require superior management. Similar result was obtained for carcass traits (Sendros *et al*., 1998; Tsegaye et al., 2013). Other studies (Brännäng *et al*. 1987; Sisay *et al*., 1988, 1989) have also shown superior performance of crossbreds. The relative performance of the crossbreds with respect to reproductive traits was not consistent (Sisay *et al*., 1988; Brännäng *et al*., 1987; Getachew *et al*., 2013). A comprehensive review of results of crossbreeding in sheep has been undertaken by Getachew *et al*. (2016). Apart from growth and wool production, and reproductive performance the effect of crossbreeding on milk production (particularly in goats) and skin quality has received attention (e.g. Tadelle, 2008, Taye *et al*., 2009; Seid, 2011). Improvement in the level of milk production as a result of crossbreeding has been observed under on station condition (e.g. Kassahun *et al*., 1989).

Table 3. Mean body weights, daily gains and greasy fleece weights for supplemented and unsupplemented progenies of Menz and crosses with Awassi and Corriedale breeds

Variable	Supplementation status	Menz	Awassi crossbred	Corriedale crossbred
Initial body weight	Unsupplemented	13.3	14.8	13.4
	Supplemented	12.6	14.6	13.0
Average daily gain (g)	Unsupplemented	21	33	37
	Supplemented	68	118	113
Final body weight	Unsupplemented	17.5	21.3	20.5
	Supplemented	25.8	37.5	34.9
Final weights of crossbreds related to purebreds	Unsupplemented	-	122	117
	Supplemented	-	145	135
Greasy fleece weight (kg)	Unsupplemented	0.65	0.85	1.07
	Supplemented	0.75	1.21	1.36
Crossbred performance in relation to pure local genotype (%)	Unsupplemented	100	131	165
	Supplemented	100	165	181

Source: Sisay *et al.*, 1991

Research to address nutritional and health related constraints have also been done at various research centers within the country (e.g. Kassahun, 2000; Simret, 2005; Takele *et al*., 2006; Tibbo, 2006; Ameha et al., 2007; Samson, 2010; Kassa and Mekasha, 2014). In addition to that the economics of various strategic feeding options to finish sheep or goats have been evaluated by a number of researchers (e.g. Solomon et al., 1991; Gizaw et al., 1991; Shapiro et al., 1994; Ulfina *et al*., 2003). In most cases such practices were found to be profitable though periodic input-output price dynamics need to be taken care of.

With respect to health, research has contributed to identification and mapping of geographical and agro-ecological prevalence of economically important diseases, vaccine development, and design of health interventions (e.g. strategic deworming regimens, vaccination for viral diseases; mode of delivery of Animal health services) (Aklilu, 2008; Amare, 2004; Gizaw *et al.*, 2013) .

In addition to research addressing the production aspect, marketing of small ruminants has received research attention. These studies have described the market, identified constraints and identified recommendations (e.g. Andargachew and Brokkeen, 1992; Mahmud, 2000; Endeshaw, 2007; Tsedeke, 2007; Gizaw *et al.*, 2010).

Gap analysis

Strategy formulation and implementation

There has been a lot of effort to formulate strategies to guide the small ruminant research and development in Ethiopia (e.g. MoA, 1996; EIAR, 2001; EIAR, 2011; Hailu eta al, 2011, Gizaw and Abegaz, 2011). These strategy documents could be vital to direct and regulate genetic resource utilization and conservation, developing research and development projects that are relevant to the country's development needs, and institutionalization of the research system to effectively and efficiently deliver research outputs. However, most of these strategy document seem to be left at draft stages as grey literature and are not accessible or circulated widely to users. As a result, there has been a tendency to develop strategy documents anew every half decade or so. There is little or no reference to previous documents while developing new ones. And yet, there is very little difference between strategy documents although a progression in the research strategy is observed (Table 4). A major gap in strategy-led research programs is the lack of adherence to strategies when projects and programs are developed. Although strategies commonly claim agro-ecological and system-specific implementation strategies, this is for the most part not the case. Strategies focus more on technological interventions or design of research agenda and little or no consideration on institutional aspects of research organization.

Table 4. Research strategies, organization and agenda based on strategy documents and research programs

Period	Contents/focus of strategy
Pre-IAR	- Crossbreeding; evaluation with feeding; forage development
IAR (1990)	- Center dev't; AEZ and system consideration; - Breed identification; on-station/on-farm comparative evaluation; Crossbreeding, nucleus Selection;
	- Management practice; feed evaluation, feeding practices; nutrition; epidemiological survey; control strategies; prod. system, marketing ;
EARO (2000)	- Center development; AEZ and system consideration - Characterization of breeds, systems; crossing, selection
	- On-farm assessment of technologies; Pre-extension technology demonstration; effective technology transfer;
EIAR (2015)	- Coordination NARS; Targeted breed characterization; Village- and nucleus-programs; breeding and reproduction biotechnology;
	- Value chain approach; sustainable prod system; marketing strategies and policy analysis

The institution of small ruminant research

The small ruminant research system has evolved institutionally over the past 50 years. Research used to be organized as independent centers (e.g. CADU, ARDU, Ranches, and Universities), then transformed into institutionally coordinated system with the establishment of IAR, to National Research system (EARO, EIAR) and then to regionalization of the research system (the national EIAE with its centers and RARIs with their respective centers).

Research is costly. Every effort needs to be made to avoid/minimize duplication of efforts and overlapping of mandate areas. Observations show that there are some duplication in the small ruminant resrach system. Goat research is undertaken under Afar Pastoral and Agro-pastoral Research Institute and EIAR with their centers in the region. Abergelle goat breed is being studied by both ARARI and TARI. Begait goats are under study with established on-station flocks at Humera research center and Humera Ranch. It is important that resources be coordinated and mandates be delegated among institutions. Incoordination would result in aggravating the already limited skilled manpower. Lack of coordination could hamper effectiveness of promising research programs. A case in point here are the promising community-based small ruminant genetic improvement activities which are currently dispersed across the country under various institutes without technical coordination. The Dorper/Boer breeding program was meant to be nationally coordinated (Gizaw and Abegaz, 2011) since the breeds are under development by several institutes and regions. Yet the Dorper/Boer strategy never implemented as planned. It is possible that the Dorper/Boer program could be a missed opportunity for a breakthrough in small ruminant genetic improvement in Ethiopia. Lack of coordination between research and development could hamper technology transfer and efficiency of both systems. Lack of coordination between breeding research centers (better technical skill but limited resources like large flocks) and breeding ranches (less technical skill but large resources like large flocks) is a big disadvantage for the country.

Research agenda/project

The research projects are expected to address the development goals. The country's livestock management approach has recently shifted to tethering/cut-and-carry system. It is important to consider the research projects addressing this approach. Its feasibility, applicability to the various systems of production including within the highland mixed crop-livestock system, generation/adoption of suitable technologies for system intensification which the tethering system requires need to be addressed. For this, a new approach to classification of the small ruminant systems could be helpful (Gizaw et al., 2016).

Currently, the research projects by the research system (including MSc research projects) largely focus on characterization of breeds and production systems. Molecular characterization work has been hijacked by evolutionary genetics or focus more on conservation genetics, rather than applying genetic characterization to the development of breeding programs. Molecular genetic research activities that are directly relevant to livestock genetic improvement are highly limited. Small ruminant breeding research projects do not seem to have the end in sight; some are experiment-like activities with nucleus flocks established in research centers with very little connection to the ultimate objective of improving the village flocks. Those that are well linked with village flocks such as community-based breeding projects have stagnated within a couple of villages. Breeding objectives of research projects focus mainly on improving growth, but the current climatic scenario calls for efficiency (feed conversion efficiency) and resilience of livestock breeds.

Feeding trials seem standalone activities. Most are not usually leading to feeding packages, which could be adopted by the extension system. This is despite the 'project' research approach with relevant activities leading to a full technology package. The project approach needs to be strengthened in implementation. Research departments/processes are organized with production, input (feed, health), marketing sections. Yet, there is limited projects that follow the value chain development approach, integrating the various components. Given technology adoption is could be enhanced by the pull factor, market research seems yet inadequate in terms of market requirements in quantity and quality and niche market outlets. The contribution of small ruminants to the smallholders and particularly to pastoralists and the national economy does not seem well quantified in terms of tangible and intangible benefits. However, there have been quite a number of research endeavors and information and technologies have been generated. Yet, this wealth of information is yet to be collated in accessible form for strategy/policy formulation (e.g. information on production systems) and users.

The way forward

- *More collaboration and coordination of the NASRS*: The National Small Ruminant Research System is coordinated by EIAR. However, the current level of coordination and the functionality of the coordination could need an assessment to indicate the loose links and revise. From the discussions in this paper, it seems there is a need for more coordination and collaboration. A sticky point here is the mechanism for a binding collaboration/coordination under autonomous administration of institutes. The new Agricultural Council could shade light on this.
- *Mechanism for cost-effective research*: It is evident that there are 'overlapping' centers (even within a single administrative area) operating in similar agro-ecological zones, production systems, and in close geographic proximity. On the other hand, most of the strategy documents point to agro-ecology-production system specific research programs. Secondly, there is limitation in resources. Thus a cost-effective approach to this end needs to be sought out.
- *Consolidation of research organization:* Research centers are mandated with a number of livestock species/commodities and research areas (breeding, management, socio-economics …). This is usually with a few or commonly a single researcher commonly with MSc or BSc degree and few years of experience in each commodity/discipline. This may not be effective. Organization of research with few selected centers with a critical mass of man power and resources for each commodity supported by satellite center (sub-centers) for regional or agro-ecological or production system representation. This approach could go further to establishing institutins for important commodities (e.g. Institute of Sheep Research, with satellite centers).
- *Coordination of breeding programs/activities*: Coordination of research projects may not necessarily involve administration coordination. It could well be technical coordination. Technical coordination is rather more important genetic improvement programs as it is resource-intensive and long-term. On the other hand, there is a high skill gap in genetic improvement. Examples that need immediate action could be breeding programs under the research system and livestock ranches; Community-based small ruminant breeding programs or fragmented breeding activities run by the International Research Centers, the national research system including; and the Dorper/Boer breeding program.
- *Long-term commitment to genetic improvement:* Small ruminant genetic improvement in Ethiopia could be described as a tragedy for the most part. One reason could be lack of long-term commitment from stakeholders. There is a need for breeding programs for selected breeds with log-term commitment. The national effort could be supported by directing and persuading big donor funding to mega projects/programs (this would involve breeding programs, efficient health service delivery, feed project).
- *Man power resource:* Stable and attractive condition to create researchers who 'eat, work and sleep research'. A talent pool (including from outside Ethiopia) for commodities to lead technically.
- *Research Agenda*:
  - A major shift from surveys and characterizations to technology generation and transfer;
  - Value chain approach (Efficient input/service delivery mechanisms, Market outlets, information and Linkage modalities);
  - Intervention packages to reduce mortality;
  - Feeding packages for specific agro-ecologies and production systems;
  - Breeding objectives and husbandry packages to address resilience to climatic changes and sustainable intensification;
  - Research agenda be defined by agro-ecology and systems.

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Overview of Poultry Research in Ethiopia

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Introduction

Poultry research in Ethiopia started in the early 1950's with the establishment of the Jimma Agricultural and Technical School (JATS), Alemaya College of Agriculture (ACA), the USOM/Ethiopia (US Operations Mission to Ethiopia) agricultural projects, and the first four agricultural experiment stations (Jimma, Alemaya, Debre Zeit and Shashemene). However, it has experienced a lag phase between the mid-1960's and the mid 1990's. Poultry remained outside the research agenda of the national institution mandated for agricultural research, the Institute of Agricultural Research (IAR), during this period. Poultry research was undertaken only by institutions of higher learning and to some extent by the regional agricultural development projects such as the Chilalo Agricultural Development Unit (CADU) and the Wolayta Agricultural Development Unit (WADU), and the activities were uncoordinated and limited in scope. Poultry research was recognized as a national program at the inception of the Ethiopian Agricultural Research Organization (EARO) in 1997. Since then research in poultry is being carried out nationally in an organized way being coordinated by the Ethiopian Institute of Agricultural Research (EIAR) with the major goals of availing packages of technologies suitable for increasing the productivity of chickens mainly under smallholder village settings. Currently, research in poultry is being carried out under two research themes; the layer and dual purpose chicken research and the broiler chicken research.

The current status of poultry research

Institutions involved: Currently, both federal and regional research institutes as well as higher learning institutions are engaged in various poultry research activities. Since the inclusion of poultry in the research agenda of the EARO in 1997, the research has been nationally coordinated by the Debre Zeit Agricultural Research Center. Higher learning institutions, particularly Haramaya University, Jimma University, Hawassa University, Ambo University, Mekele University and Addis Ababa University were among the institutions actively engaged in poultry research and development. The Research in higher learning institutes was mostly carried out by involving graduate students. Most of the research activities dealt with feeds and nutrition, health, genetic improvement and management practices. In almost all the institutions the research activities were financed by the government. Unlike many other livestock species and crops, there was very little support from external funding sources and donors, and limited collaborations with international research institutions.

For instance chicken was and still is rarely in the research agenda of the CGIAR centers, until the very limited efforts initiated recently through the ILRI. Among the regional agricultural research institutes (RARIs), the Amhara research institute is the most actively involved institute with enough physical and human resources in chicken research while most of the remaining ones have very limited research facilities and are mainly engaged in on-farm testing of technology packages developed elsewhere.

Research facilities and human resources: Since the last decade, the human capacity and physical facilities of poultry research at the Debre Zeit Agricultural Research Center (DZARC) has improved significantly. As a result, the center demonstrated considerable successes by identifying and characterizing local feed ingredients suitable for poultry feeding, developing various feed formulae and improved management and health care practices, introducing, maintaining and evaluating different breeds of grandparent and parent stocks and distributing suitable stock to farmers in different regions of the country. At present although RARIs and institutions of higher learning are building up their capacities in poultry research and development, the DZARC has become the best placed institution to realize the GTP goals related to poultry development.

Constraints of the Ethiopian poultry sector

Disease: Estimates show that about 60% of chicks die before 8 weeks of age. Incidence of mortality continues at significant rates even during adult stages. A significant proportion of loss in adult birds is associated with diseases although losses due to predators also contributed substantially. The major challenges related to disease at producer household level include inadequate knowledge and awareness of farmers on better health care practices and inadequate veterinary services.

Improved genetics: Poor productivity of local breeds and lack of access to productive and adaptable chicken breeds is the other most critical challenge to increasing the economic contribution of the sub sector. Most of the chicken kept by smallholder farmers are unimproved indigenous flocks, with slow growth rates and very poor egg productivity. Attempts to increase productivity of the sub sector are mainly focused on introduction of high yielding exotic chickens to replace indigenous stocks which has generally resulted in failure due to the failure of imported breeds to adapt to local conditions. On the other hand, efforts to develop productive breeds adaptive to local circumstances are still insufficient.

Feeds and nutrition: The backyard chicken production, the main practice in Ethiopia, is mainly dependent on scavenging feed resource base (SFRB) that are occasionally supplemented with household feed scrapes. Availability and quality of the scavenging feed resources is highly seasonal and the carrying capacity of the SFRB can only support a very limited number of chickens. Similarly, feed accounting for about 70% of the production cost of commercial chicken meat and egg production, is generally short in supply and poor in quality. Apart from that the cost of imported items such as premixes and locally produced major feed raw materials such as maize and soya bean is extremely high due to the inadequate supply of these grains.

Training and extension support: Lack of awareness and knowledge of smallholder producers on modern chicken production practices is another important challenge to the backyard chicken production.

Institutional constraints: The development of the chicken sector should be viewed in the context of addressing the entire value chain. Engaging and mobilizing the multiple array of actors, both public and private, involved in the value chain is critical to address the many issues involved in developing the sector such as marketing, delivery of inputs, provision of services and credit facilities, and building capacities of research and relevant development institutions, etc.

Past research accomplishments

Characterization of production systems

Substantial mass of production system studies were carried out in the past focusing on the characterization of chicken production systems in different agro-ecological regions under rural, per-urban and urban settings and the analysis of the chicken value chain and marketing systems in different regions of the country. Poultry production systems representing different agro-ecological zones of Ethiopia have so far been studied extensively. These include baseline studies and production system characterizations in Oromia, Amhara, SNNP and Tigray regions. The findings of most studies revealed the dominant poultry production system characterized by small flock sizes (5-6 chickens per family), seasonally varying availability and quality of feed resources, and serious disease problems (Halima, 2007; Negussie, 2010). The studies generated important information that helped design right technologies for improving productivity of backyard chickens. The findings also provided the basis for on-farm testing, packaging of right technologies, and pre-extension demonstration of improved poultry technology packages in different parts of the country. The Rohde Island Red (RIR), Fayoumi and Koekoek were among the chicken breeds widely tested under the village production system. Packages based on 15 female and 2 male Fayoumi chicken for egg production and 50 one-day-old chicks (DOCs) of Koekoek dual purpose chickens were widely demonstrated for improving both egg and meat production under village condition.

Breeding and genetics

The research on genetic improvement mainly focused on introduction and evaluation of exotic breeds of layers, broilers and dual purpose chickens and under research stations and on-farm conditions. At the first stage of introduction four breeds of exotic chickens (Rhode Island Red, Australorp, New Hampshire and White Leghorns) were imported from Kenya, Denmark and the United States by Jimma Agricultural and Technical School and Alemaya College of Agriculture in 1953 and 1956, respectively (FAO, 2008). Later on the DZARC has also been involved in evaluating the performance of these breeds including more introductions such as the Brown Leghorn, Light Sussex and Barred Rock. Egg production, hatchability and mortality rates of the breeds were evaluated over several years. The White Leghorn was rated the best in terms of egg production, adaptability, disease tolerance and feed efficiency (DZARC, 1984). In 1996 the Ministry of Agriculture introduced the Fayoumi chicken from Egypt. The Fayoumi chickens were directly distributed to rural households throughout the country to improve the scavenging production system (NPRCT, unpublished document).

In the later years supply of pure breeds from foreign sources kept on declining due to various reasons while the demand for improved chickens remained so huge. Thus, local interest shifted towards use of commercial breeds. Following this the DZARC initiated introduction and evaluation of commercial lines of chickens. Starting 2008 the research center introduced three layers strains (Lohmann silver from Germany, dominant CZ from Czech and Bovan brown from the Netherlands), two broilers lines (Hubbard classic and Hubbard JV from France) and one dual purpose breed (Koekoek from Lesotho), testing their performance both under research station and village production environments.

The Lohmann Silver did not adapt the village production system while Koekoek performed well in several villages (Wondmeneh et al., 2011). In 2010 a layer grandparent (GP) breed was imported and tested at the Debre Zeit poultry research farm for the first time. Two commercial broiler parent stocks from Hubbard breeders (Hubbard classic and Hubbard JV) were tested. The parents and commercial broilers of classic line outperformed their JV counterparts. The GP was generally found to be adaptive and suitable under on station conditions at Debre Zeit. In addition to ensuring sustained supply of improved genetics to producers the establishment of the grandparent stock enabled the national poultry research program develop the skill required to manage larger breeder flocks and demonstrated the capacity of the research farm as a future source of parent stock.

In 2015, more exotic breeds known for their wider adaptation and high performance were tested. Three dual (Red barred, Lohhmann Dual and Novo color) and three layers (Lohmann brown, dominant Sussex and Novo brown) breeds are being kept at Debre Zeit research center. These six breeds are now under evaluation until mid of 2017 under research station and on farm conditions. The on farm test on those different lines will be performed in different agro-ecologies and management conditions. Cross breeding will also be conducted among the strains in a bid to identify the best cross for future use in Ethiopia.

Studies on local genetics involved genetic and phenotypic characterization of local ecotypes for further use and conservation and selective breeding for increasing egg production and growth. Indigenous chickens have been reported to have an inherent scavenging and foraging, and nesting behavior, and well adapted to harsh environmental conditions (Halima 2007). Under village conditions, birds are continuously exposed to pathogens and thus survival or longevity under these conditions is an indication of their ability to withstand bacterial or viral infections. Such resistance to various disease causing agents is a result of years of natural selection under scavenging conditions. Studies conducted by Tadelle (2003), Halima (2007), Nigussie (2011) and Emebet (2015) showed that despite their low overall productivity, indigenous chicken populations have wide ranges of morphological and phenotypic variation within and among the them. Further, phenotypic and genetic characterizations of different ecotypes from different ecological zones of Ethiopia have been conducted (Tadelle, 2003, Halima, 2007, Negussie, 2011, Emebet, 2015). The goal of these studies was to show the genetic diversity and variability among and within indigenous chicken populations that can be exploited through breeding programs. Recently, a Genome wide association study was conducted in two ecotypes (Horro and Jarso) to identify SNPs associated with resistance to Gumborro and Salmonella (Psifidi et al, 2014). Among the ecotypes, the Horro ecotype has been under selective breeding program for 8 generations now. This nucleus breeding program has been established at DZARC in 2008 and improved egg production by 123% and body weight by 95% at the 6th generation (Wondmeneh, 2015). This selective breeding program, the first of its kind in the country, has so far been successful and demonstrated the existing huge opportunities for developing improved local breeds for egg and meat production for village smallholder systems.

The attempts made for improving egg and meat production under village production environments also included cross breeding of exotic breeds with local chickens. Studies on research stations have shown that egg production could be increased to more than twice the level of the indigenous birds in the F1 crosses. A preliminary analysis of data collected at DZARC on cross breeding of local birds with the White Leghorn showed that the annual egg production of the 50 and 65.5 percent Leghorn crosses was 146 and 193 eggs, respectively (Alemu and Tadelle, 1997). Performance evaluation of a cross between local naked neck and white leghorn chickens under heat stress condition revealed a better performance in cross-bred chickens compared to the local naked neck (Abera et al., 2005). A four-way cross breeding using two local lines (Naked Neck and white feathered chicken) as sire and Fayoumi and RIR as dam this chickens was also carried out under on station and on farm conditions at Hawassa (Fasil et al., 2012), though the results are not yet conclusive. A study by Million et al. (2005), showed that egg production performance of the crossbred of indigenous chickens and white leghorn exotic chicken was largely determined by additive genetic effects and the contribution of the heterosis effects was small. In the study conducted in 2011 at DZARC, a cross between improved Horro and RIR was evaluated. Selected Horro hens of 6th generation were crossed with RIR cocks using AI (Artificial insemination). The result of this cross breeding experiment showed a significant increase in the growth and egg production performance of the crossbred as compared to the improved and unimproved locals.

Synthetic breed development

A four-way cross breeding program was used to develop synthetic lines (Fasil et al., 2012). However, the research did not go through and did not yield a promising synthetic breed. A synthetic breed development program was also initiated at Debre Zeit research center in 2009. The program involved use of Lohmann silver, Rhode Island white and Koekoek lines to develop dual purpose chicken for semi-intensive production system. Currently, a fifth generation chicken are being tested, which is expected to be released soon as the first synthetic line developed locally.

Feeds and Feeding

The scavenging feed resource base (SFRB) in the central highlands was assessed (Tadelle, 1996). Until now, exhaustive studies have not been carried out to quantifying the SFRB in the village production systems. Additionally, the extent to which the SFRB supply the necessary nutrients for production has not been studied yet. Alternatively, several formulations meant for small-scale and commercial production systems, were developed and tested on farm. Grass pea and bitter sorghum were evaluated as sources of protein and energy sources in commercial broiler diets (Alemu et al., 2005). Different methods of improving the nutritional value of these feed ingredients were also tested. Alternative feed ingredients such as moringa leaf meal and cassava root chips were evaluated in the diets of layers (Etalem et al., 2013). Works to improve egg yolk coloration to meet local consumer preferences by including an industry by-product (pepper spent) and alfalfa were conducted and appropriate levels of inclusion determined.

Health

Some of the major research undertakings related to poultry health include evaluation of vaccines against Newcastle, Marek's and Gumboro diseases, development of strategies for application under commercial layer and broiler production systems and bio-security gap analyses for the poultry value chains. Some of the studies led to the development of vaccines such as Marek's disease and fowl typhoid. Although several research outputs were made available through the years; use by farmers was limited. The main reasons for the poor utilization of vaccines particularly under village production systems were presentation of the vaccines in large doses and the lack of cold chain facilities for transporting the vaccines. Research has indicated that prevention and control of Newcastle disease in village systems can improve the production system and increase flock size at the household significantly. The other focus of research in poultry health includes testing different herbs and ethno-veterinary practices and developing scientific recommendations and standard manuals for users.

Husbandry and Management

Several studies have been carried out by different institutions for improving poultry management practices. Significant successes were achieved in terms of developing technologies for raising day-old chicks in areas with no access to electricity and designing and testing improved chicken houses for smallholder producers. The Bangladesh integrated poultry development model was tested under smallholder rural and urban producers conditions using different packages. The model emphasizing on mapping and addressing the constraints in the poultry value chain by involving and benefiting all the chain actors has provided useful lessons for enhancing rural poultry development in Ethiopia. A complete technology package based on a 100 day-old chicks of hybrid layers was also tested in per-urban smallholder producers with successful outcomes. This scheme was found to be significantly efficient, resulting in less than 10% chick mortality and providing high profit margins to the participant households (Negussie, et al., 2006). The studies indicated that the village poultry system requires tailor-made technological packages in order to transform it into a semi-intensive and intensive commercial systems.

Future directions of poultry development

The government of Ethiopia envisions to meet the chicken meat and egg demand for its growing population and produce surplus for export and make substantial contributions to reducing poverty and malnutrition among rural and urban poor. This is planned to be achieved by transforming the traditional backyard family system (TFP) to improved family poultry (IFP) and increasing the scale of the operation of the specialized layer and broiler production (SP).

National poultry development targets (LMP, GTP II, CRGE strategy)

The Ethiopian government, recognizing the ever increasing gap between supply and the ever increasing demand for poultry products, has put a huge target in its Livestock Master Plan (LMP) (Shapiro et al., 2015) for the second Growth and Transformation Plan (GTP) to boost the supply of poultry products over the coming five years period (2015-2020).The overall target is to raise chicken meat production to 164 thousand tons and eggs to 3.9 billion by the year 2020 through Improved Family Poultry (IFP) and expanded specialized Poultry (SP). The country's Climate Resilient Green Economy (CRGE) strategy envisages a major shift towards increasing the share of chicken meat consumption to total meat consumption from the current 5% to 30% by 2030 by substituting red meat that comes from larger high emitting ruminants. The second Agricultural Growth Program (AGP II) has also placed a lot of emphasis on the development of the small scale poultry production. All this clearly shows the huge supply leap expected and the need for substantial research support required if these goals are to be met.

Proposed areas for future research

Feeds and nutrition: Reduction of feed cost by developing best-cost ration using alternative feed ingredients should be an area of high priority. Technologies that help to improve feed quality, feed efficiency and nutrient utilization should be generated with an application of biotechnology tools such enzymes, feed additives (probiotics and prebiotics), and single cell proteins (algae, bacteria, and yeasts). Problems of mycotoxins in poultry feed ingredients and rations have so far been overlooked. Therefore, assessment of the extent of mycotoxins along the value chain is important. The nutritional quality of feed rations should be optimized by designing different options for supplementing methionine or cysteine, selenium, vitamin C and others. The scavenging feed resource base should be quantified; and nutritional profiling of exiting feed ingredients including non-conventional feed resources in different production systems should be given due attention. Seasonal assessment of feed resources coupled with laboratory analyses, feeding trials and registry are important to developing supplementary rations based on locally available ingredients.

Breeding and genetics: In the past 50 years, the poultry research failed to develop locally registered breed. Currently, the national poultry research at Debre Zeit is the only center carrying out breeding programs to develop improved indigenous breeds and synthetic lines. The breeding program should strive hard to realize genetic improvements in egg production, growth, residual feed intake, immune competence and adaptation. Substantial improvement in immune competence can be achieved by incorporating GWAS results (Salmonella and IBDV) into the existing breeding programs. Molecular genetic tools, such as microsatellites revealing differences among populations and GWAS showing associations between SNPs and desired traits, should support the conventional breeding program. Comparative studies of different strategies of selection for feed efficiency, reproductive performance should also be given due attention. BLUP, multiple culling levels and index should be considered as selection procedure in the existing breeding programs.

Lines appropriate for village poultry setup should be developed and tested in simulated or similar village setups. Promising strains of layers and broilers based on existing information of performance and future needs (experimental and commercial) should be identified, imported and evaluated along with their crosses. These lines should also be used to develop synthetic lines by combining two or more lines with desired traits. Genotype and environment interactions studies should be considered as a cost effective approach to mitigate the stress. Breeds for tropical adaptability and immune competence should be developed by introducing genes like naked neck (Na) and dwarf (dw) into improved lines for high rate of lay in hot and humid stress areas. Developing production packages and designing sustainable dissemination mechanisms should also be given due attention.Research efforts supporting saving poultry bio-diversity should be directed towards conservation and utilization of local breeds of poultry. This is especially important in the context of adaptability of breeds to the production environment. Poultry breeders have brought about tremendous improvement in economically important traits of egg and meat type chicken. Substantial further improvement seems difficult due to decrease in genetic variability reaching a plateau. Future breeding in commercial poultry would have to depend largely on searching high tech procedures much of which will be beyond the reach of our current programs. The focus of national commercial poultry breeding research needs to, thus, focus on the utilization aspects of the modern day commercial poultry breeders with heavy reliance on international collaboration and networking for expertise and resources.

Health: Appropriate disease surveillance program needs be developed by studying the evolution of pathogenic infectious agents resulting in infectivity, virulence, transmission etc. This should be supported by developing a strategy that help to follow-up dynamics of endemic, emerging, re-emerging diseases and further developing an outbreak management mechanisms. Evaluation of advanced diagnostic techniques for quick and accurate diagnosis employing real time PCR, sequencing etc. along with conventional techniques like ELISA should help the development of appropriate poultry diseases diagnosis and field-applicable diagnostic tools. Easily applicable vaccines (such as cocktail) and vaccine administration mechanisms should be developed. A national vaccination schedule using locally identified/endemic strains of avian pathogens should be considered. Designing the prevention and control tools/guidelines for economically important and zoonotic diseases is very important.

Husbandry and management: Poultry waste management/alternative uses of poultry litter should be considered in such a way that manure management systems which do not contaminate crops, soil, or water with plant nutrients, heavy metals, or pathogenic organisms and which optimize recycling of nutrients are developed. Housing designs which promote health, minimize stress, and maximize production for various breeds in various regions should be developed and evaluated along with appropriate poultry equipment, storage and transportation facilities. Additionally, appropriate user friendly IT support services should be developed.

Extension and economics: Improving occasional eating habits and market fluctuations in demand and supply must be studied in order to identify market drivers, consumer preference using appropriate tools along the value chain. Packages of proven and appropriate poultry technologies should reach poultry users through demonstration and up scaling. The actual contribution of poultry for the national economy, household income and proportion of income from livestock should be studied. Adoption and impacts of poultry technologies should be considered as well. Research to identify alternative poultry technology packages should be strengthened.

Product processing and marketing: Appropriate poultry products and processes for increasing the consumer base with a large variety of products need to be developed to take account of changing consumer demands and preferences. Low cost poultry meat based products that could potentially substitute and compete with meat products from other species should be developed. Research interventions attempting to label the household poultry eggs and meat as organic products for possible niche local and export markets should be supported. Links and intermediaries involved and scope for market segmentation and product differentiation should be studied. Poultry products should be assessed for toxic residues like bacterial and fungal toxins, insecticides, antibiotics, hormones etc. to make them safe for human consumption and public health.

Policy and strategy issues: Research findings need to generate evidence based recommendations supporting implementation of the existing policy and strategy for market oriented backyard chicken and chicken commercialization cluster development. Partnership of commercial poultry farms and processors with smallholder producers, particularly in areas chosen as chicken commercialization clusters should be considered. Identification and designing of appropriate intervention strategies for overcoming systemic bottlenecks to improving productivity and market success in the backyard chicken value chain should be given due attention.

Challenges, issues and what we should do differently

In view of increased demand of smallholder farmers for new technologies, huge demands set in the different plans and strategies, huge demand for poultry products, lucrative export potential and a need for research to win the confidence of the poultry industry, there is a need to change the existing conventional approaches to poultry research in the future. The research set up needs to be supported and capacitated if it has to operate and deliver the desired outputs adequately. Policy should support the development of an autonomous national poultry research and development institute commensurate with the tremendous tasks ahead and the mounting expectations. The unique nature of poultry research (e.g. strict biosecurity needs) requires upgrading existing facilities and development of advanced infrastructure and research facilities. The capacity of the poultry research farm at the Debre Zeit Agricultural Research Center capacity has currently reached a stage where it cannot be expanded anymore. The location of the research facilities are not in a situation one can regulate bio-security up to the required level. There is, therefore, a need to establish up to date and separate facilities for each of the research undertakings on indigenous poultry, testing of introduced breeds and commercial hybrids. Establishment of input quality and safely regulatory mechanism specifically for poultry will avoid the importation of poor quality products and breeds. It is imperative to put in place a breeding policy to avoid indiscriminate cross breeding. There is an urgent need for designing long term, aggressive and enduring programs for selectively improving indigenous breeds that require long term commitment both by institutions and researchers.

Research institutions should create strong linkages amongst themselves and with farmers as well as with the industry to explore ways to implement research and provide a forum for industry to suggest research topics. Research institutions should provide regular update to poultry industry on research trends and other pertinent items. Effective international networking should be aggressively pursued to make the research internationally competitive and benefit from unique international expertise and resources. It is essential that focus and concerted effort be put on prioritized agenda given the limitations of funds, personnel and facilities vis a vis the huge expectations. There is a need to frequently revise priorities through continued dialogues among stakeholders, academia, and government. The huge task ahead requires the research system to recruit, retain and motivate experienced and qualified researchers to deliver the desired outputs. Upgrading the capacity of scientists and technicians through exchange visits, focused training in pertinent institutions internationally and nationally is very important to enable them effectively respond to the huge challenges of research. The task also requires huge financial resource mobilization. A system needs to be put in place to develop and secure external grants and strengthen industry-research collaboration to work on industry's real problems and get financial support. Capacity of research centers needs to be strengthened in order to ensure sustainable supply of new appropriate technologies. Capacity of regional research centers to effectively and aggressively engage in poultry research needs to be strengthened to live up to the challenges.It is important to increase multiplication of suitable technologies generated through engaging public and private sector actors and cultivating partnerships so that the technologies are put to the service of the sector as quickly as possible.

Conclusion

This review gives a brief account on the path the poultry research took over the past 18 years. The research efforts made has contribited substantially to the growth of the poultry sub-sector particularly by delivering various breeds of chickens and associated packages. The technology demonstration activities resulted in a huge demand from the consumer's side. Given the expected increased demand, existing production and marketing challenges, the future poultry R&D requires considerable investment and "doing things differently" including strengthening public-private partnership.

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Fishery and Aquaculture Research In Ethiopia: Challenges and Future Directions

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Background

The start of research on the aquatic resources in Ethiopia dates back to the early 1940s and was based on short-term expeditions by European travelers and short- term residents. Ethiopian scientists became increasingly involved after the 1970s and the studies were focused on the description of the water bodies and limnological features (Amha and Wood, 1982;Tudorancea et al., 1999), the biology of few fish species (Getachew, 1987; Wudneh, 1998; Zenebe, 1999), fish diversity and ecology (Shibru, 1973; Shibru and Fisha 1981; Abebe and Stiassny, 1998; Golubtsov and Mina, 2003) and estimation of fish production potentials (Mebrat, 1993; Breuil, 1995; FAO, 2003).

Ethiopia being a land locked country, its capture fishery is entirely based on inland water bodies including lakes, reservoirs and rivers. Capture fishery is the main source of protein supply and means of income particularly for those who are residing in the vicinity of major water bodies like rivers in the Gambella region, Rift Valley lakes and Lake Tana. Except for inaccessible water bodies, subsistence fishing is basically carried out in any water body but commercial fisheries are mainly concentrated in the central and southern Rift Valley lakes, the Northern lakes (Tana, Lugo and Ardibo) and some reservoirs. However, most of the riverine fishery is being exploited for subsistence with the exception of the commercial fishery rivers Baro and Omo.

The production potential for the major water bodies had conservatively been estimated to 40,000 to 51,500 tons/year (Breuil, 1995; FAO, 2003). However, recent study that considered 106 water bodies estimated to a higher potential yield of 94,500 tons/year (73,100 tons/year for lakes, reservoirs and small water bodies and 21,400 tons/year for the riverine systems) (Gashaw and Wolff, 2014). This value is higher by about 83% than previous estimates due to the larger number of water bodies considered in the study including the newly constructed reservoirs for irrigation development and hydropower generation. For the first time, fisheries and aquaculture research was recognized as one of the research commodities in the Ethiopian agricultural research system in 1997 under Ethiopian Institute of Agricultural Research through the Proc. No. 79/1997. With this, Sebeta Fish Culture Station was renamed as National Fishery and aquatic Life Research Center (NFALRC) and mandated to conduct, coordinate and support fishery and aquaculture research nationwide. In addition to its research activities, NFALRC continued culturing commercially important fish species namely tilapia, common carp and catfish to stock and restock water bodies in the country. In the past seventeen years, the center has undertaken enormous improvement in terms of research coverage, scientific information generation and adaptation and up scaling fishery and aquaculture technologies, development on human resources and research capacity and strengthened local and international collaboration. Currently, NFALRC is conducting and coordinating several research projects under aquaculture and capture fishery commodities funded by government and donors.

The high plateau above 2500 m could be appropriate for all year round farming of cold water fish species. The surrounding mid altitude present temperature favorable for breeding large number of fish species, from cold to warm water species in a very good condition. The lowlands offer ideal temperature conditions for warm water species including Tilapia, but are unfortunately water-deficient zones, with a long dry season susceptible to drought. In lowlands, soils are generally sandy with less water holding capacity for pond construction. However, water storage micro-dams and reservoirs could be employed for fish breeding and production in these areas. Despite favorable physical and environmental conditions in the country, aquaculture is still unknown to Ethiopian farmers.

In addition to the indigenous aquaculture fish species known for having good breeding and growing potential such as Tilapia and Catfish, exotic fish species were also introduced to develop aquaculture and for other related uses such as game fishing and control of weeds and disease vectors. For example, Carp species have been introduced into lakes and reservoirs for stock improvement and trouts were introduced in 1973-1974 into the rivers Wieb, Dinka, Chacha, and Beressa. However, the potential of many indigenous fish species for aquaculture production and their use as other source of income generation such as tourism and ornamental purpose need further studies.

On the other hand, fish is the only aquatic resource recognized and exploited from aquatic resources in Ethiopia. Other exploitable resources like freshwater crustaceans (e.g. crabs, shrimps, edible snails) are poorly known. A microalga of great economic potential with high nutritional benefits to humans known as *Spirulina*, which is renamed as *Arthrospira*, is another un-exploited aquatic resource in the country. The presence of these aquatic resources is shown in previous studies conducted in major river systems (Harrison and Hynes, 1989; Cumberlidge, 2009) and in Rift Valley lakes Aranguade, Chitu and Kilotes (Kebede and Ahlgren, 1996). However, none of these resources is exploited for human consumption, mainly due to lack of awareness, scientific information and production technologies.

In this paper, challenges, opportunities and the future directions of the fisheries and aquaculture research and development in Ethiopia are reviewed and analyzed based on information gathered from literature and personal experiences of the authors. While preparing this review article, a number of secondary information were collected from literature published in international and local journals either by local or foreign scholars. Moreover, MSc and PhD thesis available at the Department of Biology, Addis Ababa University and from foreign Universities were also used as source of information. In particular, information on the diversity of fish fauna was largely obtained from scientific publications, scientific proceedings compiled by the Joint Ethio-Russian Biological Expedition (JERBE) group. The annual fish production of the fishery from different lakes, reservoirs and rivers were obtained from reports delivered by the Ministry of Agriculture.

Aquatic resource base

Ethiopia is endowed with 12 drainage basins (8 river basin, 1 lake basin and 3 dry basins) with a mean annual flow (runoff) estimated at 122 billion cubic meter and a total length estimated at 8065 km (Table 1). The country has also many lakes and reservoirs, small water bodies and large floodplain areas distributed throughout the country and covering a total surface area of about 13,637 km^2 (Gashaw and Wolff, 2014). The reservoirs under-construction such as Gilgel-gibe III and GERD, which are not included, will undoubtedly increase the total inland water by over fifty percent at the end of GTP II plan period (2015 – 2020). Small water bodies include lakes and manmade reservoirs or micro-dams, ponds and irrigation canals with an area of less than 10 km^2 as described by Marshall and Maes (1994).

Over 200 fish species representing 12 orders, 29 families and 70 genera have been known to harbor rivers, lakes and reservoirs, of which some 40 fish species are endemic and 10 species are exotic fish introduced into the country (Shibru & Fisseha, 1980; Golubstov & Mina, 2003; Redeat, 2012). Among the drainage systems, the White Nile system (Baro-Akobo basins) accommodates the most diverse fish fauna (nearly 113 species) (Golubstov & Darkov, 2008). Some introduced fish species such as Carp are well adapted and established breeding and production base in some lakes and reservoirs such Ziway, Koka, Finca and Hashengie and trout fish in Bale highland rivers. However, introduced *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Gambusia holbrooki* and Esox species did not establish breeding population and were not re-sampled from Ethiopian water bodies. Out of these, fishers always look for the commercially important ones. Although reports indicated more than 20 commercially important fish species in the Gambella region, the most important species that constitute large proportion of commercial catches include Tilapia, African catfish, Nile perch, *Bagrus docmak*, Barbus species and common carp. The spatial distribution of these commercially important fish species differs within the country due to their availability in the nearest water bodies and transportation facilities.

Table 1: Fish production potential estimates from water bodies of Ethiopia (Modified from Gashaw and Wolff, 2014)

Major water bodies	Area (km^2)	Length (km)	Potential yield (ton/year)
Major lakes	7740		38727
Major reservoirs (area >10 km^2)	1447		8059
Major rivers		6665	15974
Miscellaneous small rivers		1400	5426
Small water bodies(area <10 km^2)	4450		26314
Total	**13637**	**8065**	**94500**

Capture fishery in Ethiopia

The capture fishery in Ethiopia is mainly artisanal, which are conducted by wood and reed boats. There are also few motorized commercial based fishery using out board engine in Lakes Chamo, Tana and Hawassa, Ziway and Langeno supported by the LFDP. The gears used are mainly gill nets of different stretched mesh size (60 mm-200 mm stretched mesh). Beach seine, hook and line and caste nets are also used in some lakes and rivers. Destructive gears such as monofilament gill nets, beach seine and Gancho nets were reported from lakes Tana, Ziway and Chamo. Especially the Gancho net in Lake Chamo has been reported for the collapse of the Nile perch fishery in Lake Chamo, which indiscriminately removed the juvenile fish from the lake. This has collapsed the Nile perch stock of the lake in less than two years time in the late 1990s (LFDP, 1997).

Over 67,000 people are reported to be directly engaged on the capture fish for their livelihood. In addition some 337,000 people are known to benefit indirectly from this sector (Hussien *et al*., 2010). Especially the business men, who are actively involved in the processing, transport and marketing of the fish across the vale chain, are directly benefited from the sector (Gahaw Tesfaye & Wolff, 2014). For example, the 38000 tons of fish harvested from the capture fishery in 2014 generated over four billion Birr (Fig. 1). If the capture fishery is managed properly in a sustainable way; the production and income of the community can be double in the next decade. In addition to local market, it is possible to produce quality fish like Nile perch for export market as it was reported in the 1990s where some 600 tons of fish were exported.

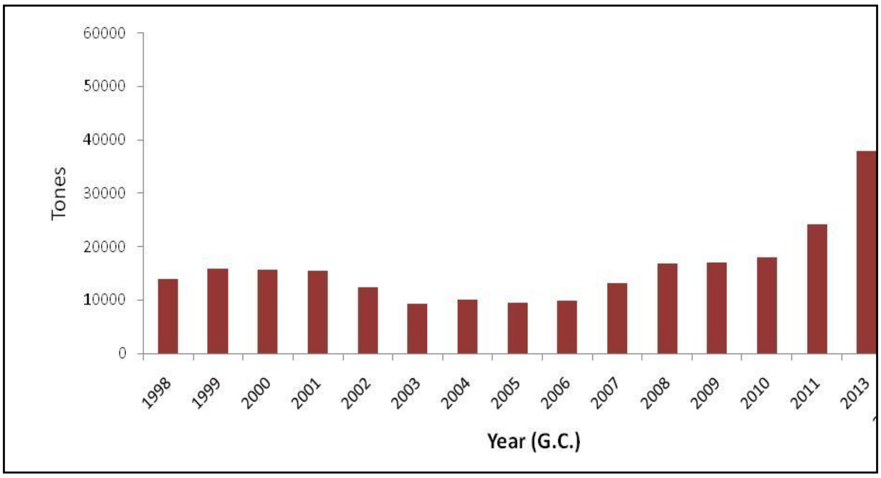

Fig. 1. Trend showing fish production level from major water bodies in Ethiopia

In general, the capture fishery plays an important role for local food security, food availability and improves access to nutritious and healthy food for rural poor. It also plays an important role in poverty alleviation as it provides employment opportunities to millions of people, both in the sector itself as well as across the value chain.

Challenges of the capture Fishery

In spite of the benefits and services given to the people, the capture fishery faces a number of challenges, which should be addressed by the research and development partners of the sector. Major challenges of the sector are defined below.

Over fishing: Earlier reports indicated that most Rift Valley lakes have shown signs of overfishing and hence depletion of major stocks (Reyntejens and Tesfaye Wudneh, 1998). In particular the O. niloticus stock of Lake Ziway and the Nile perch of Lake Chamo have been depleted due to the use of illegal gear mainly seine nets and Gancho nets, respectively which removed the juvenile and adult fish indiscriminately.

The decline in the fish stocks reported in some of the lakes have been attributed to: use of excessive fishing effort well beyond the stock potential; use of destructive fishing gears and methods; use of small sized mesh which capture immature fish; weak management and extension systems etc. This problem was further exacerbated by the large number of illegal fishermen operating in many lakes who are not abided by the rules and regulations in place in the country. Although, legal proclamations and directives are issued by the Federal and Regional states, none are practically implemented or exercised on the ground.

Unprotected and free access to the fishery resources: The capture fisheries are considered as common resources to be accessed freely. This attitude of the community makes it difficult to protect the resource from over-exploitation. As a result, fishing is frequently undertaken when alternative employment opportunities are unavailable. Many fish stock are not “owned” by either a fishermen or fishermen cooperatives. The communal ownership of fisheries resources therefore makes it difficult to protect and use the resource in a sustainable way. It is clear that communal ownership usually associated with no defined responsibility to protect the resource. Therefore, different forms of property rights enforcements and bylaws have to be exercised to limit access to common fishery resources and define rights and responsibilities of beneficiaries.

Catchment degradation of water bodies: Intensive agricultural activities and the subsequent deforestation leads to catchment degradation and soil erosion, which results in increased siltation into lakes. Such anthropogenic impacts do not only affect the breeding ground of aquatic organisms but cause gill clogging of small fishes. Increasing human populations and the subsequent demand for food lead to farming marginal land and lakes shores which enhances soil erosion. Accordingly, the following are the main threats to fish breeding and spawning activity in the aquatic ecosystem:

- Deforestation of the catchment and the subsequent soil erosion that results in increased surface runoff and siltation, woody debris and sawdust into the shoreline, which is the main spawning habitat for many fish species.
- Inland navigation: construction of canals and unregulated dredging for effluent discharge in the lake basins can change stream flows (inflows), which can either fill in or remove important habitats.
- Mechanical macrophyte harvesting, along the littoral spawning ground for many fish species and feeding site for juveniles.
- Shoreline modification, fragmentation and destruction, which is the main breeding site for fish due to the intense investment activities along the shore of lakes.
- Water abstraction (using water pumps) from the lake shore during breeding season, which possibly remove the eggs of the fish and/or fry arbitrarily.

Aquatic pollution: Urbanization and the subsequent human settlement in the lake basins are amongst the main sources of pollution and changes in water quality (Zinabu Gebremariam, 2002). The pollutants either from point or non point sources could lead to changes in physical, chemical and biological processes of the lakes which in turn distress fisheries and the functioning of the whole aquatic ecosystem (Zinabu Gebremariam *et al.,* 2002). The growing population and industrialization of major cities cause serious consequences on the lake limnology. Since fish production and sustainability depend on the health of the fish habitat, there is a need to consider management of pollution and eutrophication along with the fisheries management. Moreover, leaching of heavy metals from some of the effluents into the lake systems and their bio- magnification renders the fishery resources more vulnerable and the fish unsuitable for human consumption in the future. A related pollution source is the growth of urban centers and industries around the lake. While this is inevitable, the discharge of untreated or semi-treated industrial and municipal wastes should be prohibited legally.

Poor data recording and monitoring system: Continuous or periodic monitoring of the fishery is a mandatory for the purpose of effective management and sustainable utilization of fishery. Both physical and socioeconomic data are required for proper management and optimum use of fishery resources. However, for most lakes exploratory fishery monitoring is not generally carried out, or if carried out, the data are not available to users of such information. The situation with socio-economic factors is even worse. Impacts of the lakes on the livelihoods of the beneficiaries, like farmers, fishermen and domestic water consumers have not been evaluated at all for most lakes. Therefore, insufficient scientific knowledge and lack of awareness are major obstacles for improving policies and management. Inadequate statistics on catch effort data hamper fisheries activity and lake management. un finished sentence are still lacking for most water bodies nearly all lakes lack updated and adequate exploitation models and information on stock dynamics to make informed decisions. The few MSY data analysed based on fishing effort are either old or absent for most lakes (Tudorancea et al. 1988). Absence of reliable MSY for most lakes makes the estimation of the stock to be based on empirical models, which are crude and rough estimates for decision makers.

Unhygienic post harvest processing of fish: Fish contamination, spoilage and unhygienic handling and processing at landing sites were identified as major problems affecting fish trade in nearly all lakes and rivers in Ethiopia. Earlier studies on fish post harvest processing conducted in Rift valley lakes revealed a loss of 30-40% of the total harvest (Yared Tigabu, 2010, 2013). Improving quality and sanitation issues during fish handling and processing is critical for improving marketing opportunities across the country as quality standards are becoming an important requirement for trading fish across borders. Regionally harmonized quality standards should increase competitive access for traders and help to ensure improved quality of fish for consumers. Capacity building for all those involved in the value-chain is an important prerequisite to consider. Fishermen, fish processors and traders in the country often rely on simple equipment and work in remote areas where basic services and facilities are absent. The processors also lack knowledge, skills, and hence fish is often handled and processed in unhygienic conditions causing spoilage, contamination and loss of income as fish are sold for a low price. It is worth remembering that all stakeholders involved in fishery activities have a responsibility to make sure that fish is handled in the best possible way and in the best conditions possible, so that the consumer receives good quality and safe fish food.

Introduction of exotic fish: Historic records indicate that over 10 exotic fish species have been introduced into the country since the 1930s (Shibru Tedlla & Fisha Hailemeskel, 1981). Among these some species of carp, trout and tilapia have established their population until today whereas *Esox lucias* and *Gambusia hollbrooki* and *Ctenopharyngodon idella* failed to survive and establish themselves. Since then there have been frequent introduction of fish into natural and artificial water bodies with the intention of enhancing fish production in the country. It is true that some introduction of fish into lakes Haiq and Hashengie cold be taken as successful in providing fish to the local community. However, placement of the indigenous fish such as *O. niloticus* with common carp and crussian carp in Lake Ziway may cause problems which could lead to genetic erosion of the local fish gene pool. Therefore, any transfer of fish from one water body to the other should be done with precaution and permit obtained from the authorized bodies.

Limited research on capture fishery: The history of research on natural water bodies dates back to the 1930s associated with the Italian invasion. However, the involvement of Ethiopian scholars on lake fishery and limnology started relatively late in the 1980s. Most of these studies focused on the limnology (Amha Belay & Wood, 1978; Tudorancea et al., 1984; Wood & Talling, 1988), biology of tilapia and catfish (Getachew Tefera, 1987, Zenebe Tadesse, 1988, 1997, 1999; Demeke Admassu 1989, 1994; Eliad Dadebo, 2000) and the taxonomy and systematic of Ethiopian fish fauna carried out mainly by the Joint Ethio Rusian Biological Expedition (JERBE) group since 1987 (Golubstov & Mina, 2003). The scientific information so far generated by different scholars is vital for proper management of the lake fishery and in understanding of the trophic stats of the lakes. However, such studies are limited in terms of coverage, seasonality and discipline. The fish biology for example focused on mainly two commercial fish species the Nile tilapia and catfish. In most cases the biology focused on the feeding and reproductive, age and growth aspect which is associated with the interest of the researchers and their training background. Therefore, the research in the future should include other fish species which are less addressed so far. Moreover, the research so far relied mainly on lake fishery and seems to ignore the diversified fauna of the riverine fish fauna. Thus, the biological research should give attention to the highly diversified fish fauna. In addition, the MSY of Ethiopian fishery should be studied based on catch effort data and other biological parameters of the fish, which give more accurate estimate than the crude empirical ones we have at present.

Poor coordination between stakeholders: There are different institutions, which are conducting research on fisheries, aquaculture and limnology in the country. HLI, EIAR and RARIs are believed to be the major stakeholders generating fishery technologies and scientific information in various disciplines of the fishery. Other CGIAR organization and the FAO are also involved in the research and development aspect of the fishery. However, the coordination and cooperation in research between these actors should be strengthened more that what is observed now. The cooperation so far seems loose and is based on informal communications between individual colleagues but not based on formal institutional linkages. There are no regular communications of research out puts of the different institutions. For example, MSc and PhD thesis are not formally circulated to different research institutes and similarly research out puts of the research system are not communicated to the HLIs regularly. Thus, strong linkage and communications based of stakeholders, and formation of common form between them could synergize the research and minimize duplication of efforts.

Impact of climate change on the fishery: Climate change has become a major threat of all countries globally. The rise in carbon dioxide emission and the subsequent rise of temperature caused several damages including excessive rain fall and flooding in some areas and complete drying of rivers and lake in Africa and elsewhere. This will damage crop harvest and lead to shortage of food in some countries. This problem is more pronounced in poor sub Saharan Africa including Ethiopia. The aquatic water bodies mainly rivers and lakes are most affected by the climate change. Rise in temperature increases the rate of evaporation ad reduced the inflow rate into lakes which in turn lowers the level of lakes and reservoirs. The littoral regions which are the breeding and feeding ground of juvenile fish will be affected easily. This decreases the newly fish recruitment of the stock and reduces the annual fish yield. In our field visit held recently to Koka reservoir, we noted drastic decline of the reservoir which has not been observed over the last decade. This fluctuation of the lake water level is believed to be due to El Nino induced by the climate change.

Opportunities of the capture fishery

The capture fishery in Ethiopia is based exclusively on inland waters from lakes, reservoirs and rivers. This resource can be further expanded and more can be obtained by managing the fishery based on research out puts. Enhancement the capture fishery productions will be achieved by exploring all possible opportunities in the sector. Major opportunities identified include the following:

Construction of new dams and reservoirs: Ethiopia has launched a number of projects aiming at increasing the national economy and improving the livelihood of its people. As explicitly indicated in the GTP plan of the countries large sized reservoirs and dams will be constructed primarily aiming at generating green hydropower electricity. Others are dammed to store water for the purpose of irrigation based agriculture. These water bodies can be used to integrate capture based fishery and enhance the fishery production nationwide. Among the projects in progress include the Grand Ethiopian Renaissance dam (GERD) and the Gilgel Gibe III which is in its final phase ready for operation. There are some reservoirs such as Tendaho and Koga which are built for irrigation purpose. Along with the newly established sugar can factories more reservoirs will be ready in the coming years. Therefore, these newly added water reservoirs can be integrated with fishery and enhance the production in a sustainable way.

Introduction of new fishery curricula/programs in HLI and research systems: Fishery and limnology courses were introduced to the curricula of Higher Learning Institutes when the Department of Biology opened a gradate masters program in the early 1980s. At that time fishery and limnology were given as compulsory courses under Zoological Sciences stream. The number graduate students enrolled into the program were less than 10, of which one or two students were conducting their thesis on fisheries and limnology. Today fisheries and aquatic science stream is opened at MSc level under the Department of Zoological sciences. A Joint PhD program was also launched in the late 1990s and currently there are many PhD students enrolled under the in house program. In addition to the Addis Ababa University other universities like Hawassa University, Bahir Dar University, and Ambo University are training fishery experts at MSc level specializing in fisheries, aquaculture and limnology which is contributing in solving trained human resources in the sector.

Availability of surface water at different agro ecologies: Ethiopia is commonly referred as the 'water tower' of Easter Africa. This has been attributed to the presence of large rivers and lakes which are mainly the source of large and long trans boundary rivers such as Rivers Blue Nile (Abay), Wabishebele and Genale-Dawa rivers. In addition, to the huge surface water of major lakes (7400 km^2), reservoirs (1290 km^2) and rivers of over 7000 Kms long, the country is also endowed with huge underground water (FAO, 2003) which can be used to enhance the fish production using modern aquaculture technologies. The newly built hydroelectric dams and reservoirs can boost the fishery production. Moreover, the country is also endowed with different agro-ecologies ranging from below sea level. The low lands below 1500 meters a.s.l. are beloved to be suitable for farming warm water fish such as tilapia catfish and carp. The high mountains with close to temperate climate are also suitable to raise cold water fish like trout.

Growing demand for fish: The per capita consumption of fish is generally very low 300 gram/year/person in Ethiopia as compared to the average African consumption rate (8 kg/year/person). However, the consumption rate in towns close to the Rift valley lakes and rivers in Gambella appears to be close the African average. Moreover, there is an increasing demand for food fish in some Rift Valley regions. The high demand for food fish in Addis Ababa and major cities like Hawassa, Adama, Bahir Dar and Meqelle has been attributed to growing human population, intensive economic activities and rise in family incomes. Moreover awareness of the urban community on the health benefits of fish could be the driving force for increased fish consumption in the cities. It is now well established that fish are known to be rich in omega 3 long chain polyunsaturated fatty acids such as eicosapentaenoic acid (20:5w3, EPA) and docosahexaenoic acid (DHA, 22:6w3) which prevent cardiovascular diseases and lower the accumulation of cholesterol in the blood vessels (Zenebe Tadesse, 1998a, 1998b, Zenebe Tadesse, 2010).

Diversified fish fauna and other biota: Over 200 different fish species have been described and documented from major river systems and lakes of which some 40 fish species are endemic and 10 fish species are reportedly exotic fish imported from abroad (Shibru Tedlla, 1973; Shibru Tedla & Fisha Haile Meskel, 1981, Golubstov & Mina, 2003; Redeat Habte Selassie, 2012). These fish inhabit rivers, lakes and small water bodies situated in different agro-ecologies ranging from the extremely desert type like climate in Lake Afambo (-150 m below sea level) to the Bale highland rivers such as River Woyib where the temperate trout fish are using the water for breeding and growing. Therefore, the presence of such diversified climate will enable to enhance the fishery in different agro-ecologies. This will also diversify the fish market nitch and demand of the various communities in the country. It is also possible to raise the shellfish in the highland cold waters and make available crayfish for foreigners residing in the capital Addis Ababa and other major cities.

Establishment of the new Ministry of Livestock & Fisheries: The fishery resource of the country has been governed by Department of Fisheries under the Ministry of Agriculture until the 1990s. Following the establishment of the Federal Government, the Bureau of Agriculture of Regional states took the responsibility to administer the fishery. For over four decades there have been several restructurings of the Ministry, but none has considered the fishery sub sector as important commodity. However, very recently, the government of Ethiopia has split the Ministry and established a new Ministry of Livestock and Fisheries in September, 2015. This has been officially ratified by the Federal Parliament of the country. This will be the right time for the renaissance of the fishery sector nationwide. Our neighbors such as Kenya and Uganda improved their fishery sector by taking similar measures and restructurings. Both governments supported the fishery by introducing special stimulus package which directs the small scale fishers and the private community. This package should include establishment of infrastructure like training and research institute (e.g. upgrading National Fishery and Aquatic Life Research Center as a training and research institute).

Enforcement of proclamations and policies: The fishery sector in the country has been administered in the absence of legislature, which directs the exploitation, and use of the fishery resource. Considering the problem, the Federal parliament has endorsed a new proclamation entitle 'Fisheries development and utilization proclamation'(proc. No.315/2003). The approval of this legal document is one step forwarded for the proper and sustainable management of the capture fishery and aquaculture nationwide. Following this federal proclamation, the Amhara Federal state and the Southern Nations Nationalities and People's Regional states approved their own regional proclamations (Fish Resources Management Development and Control Proclamation -Proc. No.78/2004) to sustain their fishery. Moreover, fishery directives have also been developed and approved by respective regional institutes and councils for legal implementation of the proclamation at regional level. However, there have been acute limitations in the actual implementation of these legislations on the ground. Therefore, different stakeholders should collaborate to protect the fishery resource of the country.

Table 2: Some stocked water bodies by NFALRC (Pre and during EIAR system)

Region	Water body	Stocked fish species
Tigray	Hashengie, Midmar, Maingus, many small dams	*Oreochromis niloticus* and common carp
Oromia	Fincha , Melka Wakena, Koka, Amerti, Tolay, Birati, Sorga, Denbi,Gefersa, Giligel Gibe I, Legedadi, Muger, Debrezeyt crater lakes, Dendi, Wonchi, Ponds (Wonji, West and South west showa)	*O.niloticus, Tilapia zilli* and common carp
Amhara	Haik, Ardibo, Zengana, Mullo, Bahire georgies, Maibahir, Tachibahir, Laibahir, Ango-mesk, Washa, Geray, Terba, Washa, Ponds (north showa zone)	*O.niloticus* and common carp
SNNP	Small Abaya, Cile chefe, Dembi, Chencha kure, Damte, Areket	*O.niloticus* and common carp
Gambella	Bishanwaqa	*O.niloticus*
Afar	Tendaho	*O.niloticus*
Somali	Ela bayehi	*O.niloticus*

Future Research directions

The challenges and limitations described above require the intervention of several institutions involved in fishery research and development. In particular Federal and Regional Research Institutes as well as Higher Learning Institutes should collaborate and work together to address the major research challenges of the fishery sector. The following intervention measures are suggested to address the problems.

Focus on research that ensure sustainable production of the capture fishery: The maximum stainable yield (MSY) of major lakes, reservoirs has been based on empirical models which are remotely linked with the fishery. Hence, the research has to focus estimation of MSY based on catch data and other biological parameters including maturity size, fecundity rate etc. This gives more accurate estimate for fishery managers to use appropriate fishing gear and catch quota, fish post-harvest can also be another area of research to reduce the loss.

Establish central fishery data base system: A fishery central data system has to be established centrally which serves as a source of fishery data nationwide. Through this body new research findings and technologies could be disseminated to the end users

Diversify the scope and coverage of aquatic resource research: The research undertaken so far focused on limited fish species and disciplines. The research has to diversify and include shellfish, microalgae etc which are potentially useful for export market. Applications of modern biotechnology tools and equipment have adapted in the research system especially to be focusing on producing fast growing tilapia, catfish and other more culture fish. New culture fish have to be recruited both from indigenous and exotic high value fish targeting the export market.

Focused research on climate variability and aquatic degradation: Research focusing on the impact of climate change on the diversity and production of the fishery has to be conducted nationwide. Mitigation measures that curtail its impact have to be recommended for sustainable use of the fishery and aquatic resources. This requires development of grand project involving various actors and institutions.

Focus on legal issues and policy matters: Research should identify and undertake researchable issues, which can serve as inputs for the actual implementations of legislations. The need for more legislation should be addressed by the research and follow the impact on the ground.

Aquaculture in Ethiopia

Culturing of fish species in natural and manmade water bodies dates back in the early 1940's during the time of Italian invasion. Introduction of exotic fish species like *Esox lucius* and *Gambusia holbrooki* into Lake Tana as a biological control of aquatic vector was performed by the Italians in 1938. Introduction of trout species from Kenya into Bale highland rivers in 1950's and *Cypernid* species (Common carp, Grass carp and Gold fish) from Japan into the then Sebeta Fish Culture Station at present National Fishery and other Aquatic Life Research Center (NFALRC) late in 1970's were some of the attempts made to introduce aquaculture practices to Ethiopia.

Sebeta Fish Culture Station was established in 1997 with the objective of culturing both indigenous and exotic fish species. Since then, quite a number of water bodies were stocked with fingerlings of Nile tilapia (*Oreochromis niloticus*), common carp (*Cyperinis carpio*), *Tilapia Zillii.* Grass carp (*Ctenopharyngodon idella*) were also cultured to stock water bodies with aquatic weeds (e.g. Fincha reservoir) to use as a biological control. In addition to stocking the above fish species into different water bodies, NFLARC performs breeding and dissemination of ornamental fish, gold fish (*Carassius auratus*), to users. Since the establishment of the culture station over 3 million fish fingerlings were stocked into different water bodies to establish fish stocks and/or enhance declining fish stocks in lakes (Table 2).

NFALRC has conducted several research trials focusing on different culture systems (e.g. mono and mixed sex, polyculture, cage culture, Integrated aquaculture agriculture), fish feeds, characterization of Nile tilapia from geographically isolated water bodies, growth & survival of culture fish species, semi artificial and artificial fish breeding techniques etc and published its results in different local and international journals (Adamneh Dagne *et al.*, 2013; Kassahun Asaminew et al., 2012; Zenebe Tadese et al., 2012; Adamneh Dagne, 2012; Yared Tigabu *et al.* 2011; Kassaye Balkaw and Gjeon,, 2012). Regional fishery research centers such as Bahir Dar fishery and other Aquatic Life Research Center and Ziway Fishery Resources Research Center are also doing both on station and on farm aquaculture research activities mainly on fish feeds and culture systems. Higher learning institutions, universities like Addis Ababa, Ambo, Hawassa and Jimma are also engaged in conducting aquactulure research (Eshetu Yimer *et al.,* 2014; Kassaye Balkaw and Gjeon, 2012; Ashagrie Gibtan *et al.,* 2008).

Currently, aquaculture is one of the priority thematic research areas for both federal and regional fisheries and aquaculture research centers. In addition to establishing culture based capture fishery in reservoirs and dams, the research centers are trying to develop small scale backyard aquaculture. However, lack of input suppliers (fish feeds, seeds) and high initial investment requiring nature of aquaculture are the major bottle necks for its development.

Challenges of aquaculture research and development

Studies indicated that aquaculture is one of the fastest growing food producing sectors in the world today (Aguilar-Manjarrez & Nath, 1998; FAO, 2011). Global aquaculture production grew 10 to 11 percent per annum over the past decade and is projected to continue growing in the coming years (FAO, 2010). In spite of the fact that fish are an important source of food for many African countries to provide their animal protein, fish production is mainly from capture fishery where the global contribution of aquaculture from Africa remains < 2% (FAO, 2008). A report by FAO (2012) also revealed that aquaculture is the most feasible option that can sustain adequate fish supply in Sub-Saharan Africa. Due to declining capture fishery coupled with growing population and increasing demand for fish, many African countries are now looking towards aquaculture to supply an increasing demand for fish. Over the past decades, several fish stocks have been showing a declining trend worldwide including Ethiopia due to overfishing (Reyntjens and Tesfaye Wudneh, 1998; Froese, 2004; Winker *et al.,* 2011; Hicks and McClanahan, 2012). Despite the country's potential (suitable agro-ecological conditions, water resources, land and labor) aquaculture development in Ethiopia has a number of challenges. Limited fish culture technologies (improved fish seed and quality fish feed, improved management practice), limited human resource (experienced and skilled aquaculture professionals) , lack of fish seed multiplication hatchery, poor fishery extension service and less attention to the aquaculture sub-sector are the major bottle necks for the development of aquaculture in Ethiopia.

Opportunities for aquaculture development

The importance and potentials of aquaculture in terms of poverty alleviation, food and nutrition security, job opportunity and source of income, reducing fishing pressure on capture fishery, applicability at various agro-ecology (where there are land and water resources) and possibility to integrate with other agricultural commodities and hence maximizing resource utilization are generally known and are widely applied be several countries. Ethiopia has conducive environment for aquaculture development. It has diverse agro-ecological zones with wide temperature ranges ranging from as low as 180 m below mean sea level in the Danakil area to mountain slopes of over 4000 m above mean sea level in the highlands. Temperature is very important for fish farming. With such altitude range variation in temperature is imminent and aquaculturists will have different options to culture both cold and warm water culture species. Well established Trout species in Bale highland rivers and well adapted Cypernid (common carp) fish in many water bodies are few examples from the exotic fish species. On the other hand presence of over 200 fish species (both indigenous and exotic) in different water bodies is also additional advantage for the development of aquaculture. It is not only culture fish species but also crustaceans and algal species with high productivity like *Spirulina* which are available in Ethiopian water bodies which further gives options for the aquaculturists.

Availability of surface and ground water sources (several lakes ranging from a few square meters to 3150 km^2) is one of the potential for Ethiopian aquaculture development. A recent study by Gashaw Tesfaye and Wolf (2014) estimated that 13600 km^2 area of water bodies (lakes, reservoirs and dams) in Ethiopia. An increasing numbers of manmade water bodies of few square meters such as small micro dams and reservoirs in most regions as well as big dams and reservoirs like Fincha, Koka, Koga, Gilgel Gibe 1& 3 and the upcoming Grand Ethiopian Renaissance Dam with an area of 1860 km^2 (which will have twice the volume of Lake Tana) can serve as a dual purpose water bodies for hydropower generation as well as fish production. The fishery production can be either culture base capture fishery and or by deploying different aquaculture technologies in the reservoirs (example cage culture).

Agriculture is one of the major economy drivers in Ethiopian which is an advantage for the development of aquaculture. Several crop commodities such as cereals, oilseeds, pulses, fruits and vegetables (agricultural products and agro-industrial byproducts) can serve as fish feed ingredients. Increasing human population (for labor and market demand) is also an opportunity to develop aquaculture in Ethiopia. Possibility of using agricultural products for fish feed preparation and or partly with agro-industrial byproducts will also reduce total aquaculture production costs. According to Gabriel et al. (2007) locally produced and reasonably priced feedstuffs of sufficient nutritional quality are a key element in the development of aquaculture in developing countries. Flourishing agro processing industries such as brewery factories, oil refineries and mills for various products have enormous byproducts that can be used in formulating appropriate fish feeds.

Future prospects

Several countries have made enormous success in advancing the aquaculture sector. Egypt for example has produced over a million tons of fish from aquaculture in 2012 (FAO, 2014). Uganda, Kenya and Tanzania also devised different mechanisms to develop aquaculture in their countries. Aquaculture stimulus package in Kenya in 2009; Africa fish, Aqua-Spark Fish for good investment facility and the Farm Africa concepts of aqua shops in Kenya were some of the approaches in those countries.

Therefore, to develop aquaculture in Ethiopia there has to be strong and effective cooperation system among different partners such as higher learning institutions, research institutes, the private sector and the government. Unless there are skilled and experienced human resources, timely technology adoption and generation, delivery of aquaculture inputs particularly quality fish feeds and seeds and good policies and strategies with effective implementation, aquaculture development will be rather theoretical than actual practices. From the research institutes point of view the research should focus on the following major areas:

- Generating fish seed and feed for small, medium scale and commercial aquaculture
- Diversify culture fin and shell fish, crustaceans and micro algae
- Adapting and demonstrating fish culture technologies
- Develop aquaculture stimulus package
- Human and institutional capacity building (state of the art training and research center establishment)

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Apiculture Research Achievements, Challenges and Future Prospects in Ethiopia

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Introduction

Owing to its varied ecological and climatic conditions, Ethiopia is home to some of the most diverse flora and fauna in Africa, making it highly suitable for sustaining a large number of honeybee colonies. Ethiopia is endowed with immense apicultural resources and long-standing beekeeping practices, having about 10 million honeybee colony populations and 7000 species of flowering plants. It is the leading honey and bees wax producing country in Africa and one of the ten and fourth largest honey and bees wax producing countries in the world, respectively. Beekeeping is one of the major incomes generating agricultural activity for the poorest and other beekeepers dwelling in areas where other livestock cannot exist and other income generating activity options are very limited. Beekeeping is less vulnerable to the fragile environmental conditions and thus considered as key agricultural activity to alleviate or minimize food insecurity and poverty. It also serves as means of income diversification for beekeepers in potential areas where other agriculture could be practiced.

Beekeeping supports the national economy through foreign exchange earnings. Beeswax and honey are one of the important agricultural export products. Beekeeping significantly contributes to enhancing food security, poverty reduction, food production and natural resource conservation through pollination services from honeybees.

Though the contribution of apiculture to the landless and beekeepers in particular and the national economy in general is significant, compared to the potential of the country, its contribution is far below anticipated. Beekeeping is at its infant stage. This is attributed to the fact that beekeeping is predominantly practiced in traditional way resulting in low production and productivity of honeybee colonies. Lack of technical knowledge and skills, appropriate technologies are worth mentioning among others. Improving the apiculture sector demands the modernization or transformation of the production systems through apiculture generation of problem oriented technologies and providing of technical assistances.

Cognizant to this situation, the former office of Livestock & Meat Board established the then Beekeeping demonstration station at Holeta in 1965 with the objective of demonstrating improved beekeeping practices in the country. In 1985, the station was upgraded to Beekeeping Research and Training Center. However, its objectives were reformulated in such a way that more of its activities to be focused on Extension & Training services and to lesser extent on adaptive beekeeping research activities. After regionalization process, the center was transferred from MOA to Oromia Agricultural Development Bureau (ODAB) Livestock and Fishery Resource Development Department in 1992. For three years (until 1995), the center had conducted its activities in line with the objectives formulated when it was under MOA. In January 1996, the center was again reorganized under Oromia Agricultural Development Bureau (ODAB), Agricultural Research Co-ordination Service. After this reformation the center's objectives were clearly formulated to focus on in full time apicultural research activities. Currently, HBRC is operating under Oromia Agricultural Research Institute (OARI) and engaging in full-time Apiculture researches. HBRC was the only apiculture research center in the country until recently, but since 2008, seven federal agricultural research centers and seventeen regional centers started to engage with apiculture research activities. Since then more than 150 information and technologies were generated and promoted. Holeta Bee Research Center (HBRC) is the pioneer institution in the research and development of apiculture sector in Ethiopia and now it is National Apiculture Research Program Coordinator. Therefore, it is possible to say that the generation of technologies and promotion in the area of apiculture is directly linked with the born of HBRC.

The purpose of this paper is to give an overview of the major achievements in the areas of apiculture resources improvement and utilization research in Ethiopia, to summarize the major challenges in improving and to highlight the future research and development needs in apiculture research.

Major Apiculture Research Achievements

Important research information and technologies in the areas of honeybee biology, management, health, products, forages and equipments have been generated principally by HBRC. The respective major achievements are indicated below.

Major research achievements in the area of Bee biology

Morphometric analysis of Ethiopian honeybees were conducted and multivariate analysis established five statistically separable morphoclusters occupying ecologically different areas: *Apis mellifera jemenitica* in the northwest and eastern arid and semi-arid lowlands; *A. m. scutellata* in the west, south and southwest humid midlands; *A. m. bandasii*, in the central moist highlands; *A.m.monticola* from the northern mountainous highlands; and *A.m.woyi-gambell*" in south western semi-arid to sub-humid lowland parts of the country (Amssalu et al., 2004). Relatively high reproductive swarming tendencies were noted for *Apis mellifera scutellata* and *A. m. jemenitica* and low for *A. m. bandasii*, *A. m. monticola* and *A. m. woyi-gambella*. Swarming periods correlated with variations in rainfall, physiography and temperature (Nuru et al, 2002).

The general trends of morphological and behavioral characters of these bees show that, bigger, darker and gentle honeybee populations with less inclination to swarm and migrate occur towards the higher altitudes and small, lighter and more defensive bees with a high tendency to swarm and migrate occur at lower altitudes. In general, as the ecologies of the country, the honeybees are also very heterogenic and indicate the high genetic potentials for selection and breeding towards the improvement of the productivities of these bees.

Table 1. Frequency and percentage of colonies that swarmed and of hives occupied by swarms

Morphoclusters	Total No. of colonies	No. of swarmed colonies	% of swarmed colonies	Total No. of bait hives	No. of hives occupied	% of hives occupied
A. m. jemenitica	665	352	52.9%	742	485	65.4%
A. m. scutellata	1167	742	63.6%	1371	920	67.1%
A. m. bandasii	846	311	36.8%	625	257	41.1%
A. m. monticola	212	34	16.0%	60	5	8.3%
A. m. woyi-gambella	45	4	8.9%	13	1	7.7%

The effects of hive volume and management on reproductive swarming intensity and Honey yield of colony has been determined and it was found that small-volume hives and poor beekeeping management encourage swarming and result in low honeybee production. The study recommended that on time supering and seasonal management reduces reproductive swarming there by increases honey and other honeybee products production (Dereje Weltedji --)

Tendency to migrate and migration phenology also varied within and between honeybee groups. *Apis mellifera jemenitica* and *A. m. scutellata* have a high propensity to migrate while *A. m. bandasii* of the central highlands has a relatively lesser tendency to migrate. The whole areas of *A. m. monticola*, north and northeast *A. m. jemenitica* and northern *A. m. bandasii* are migration free zones. *A. m. woyi-gambella* is intermediate in migration behaviour. Migration in Ethiopia generally occurs during dry season (December – February) in dry and lowlands and during wet or rainy season (June – August) in the highlands and wet regions of the country. Decline of forage and attacks of enemies are thought to be the main causative factors for migration (Amssalu B. and Nuru A. 2012a).

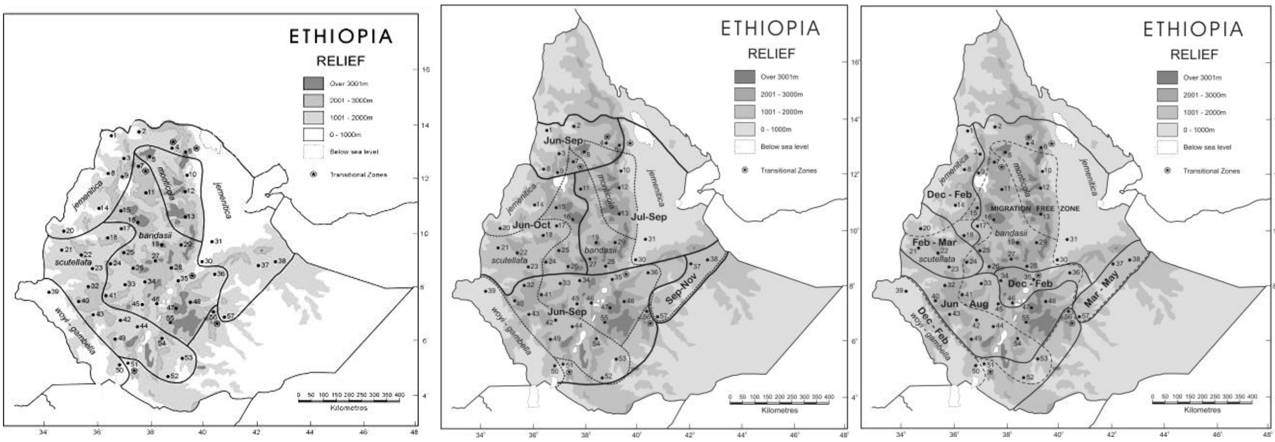

Fig.1 (a) Honeybee races distribution (b) Major reproductive swarming periods (c) Migration phenology

Table 2. Migration rates of honeybee groups of Ethiopia

Honeybee groups	No. of colonies	No. of colonies migrated	Migration %.	Statistical Test F (4, 224)
A. m. jemenitica	725	319	44.0	18.30***
A. m. scutellata	1266	545	43.0	
A. m. bandasii	977	179	18.3	
A. m. monticola	212	0	0.0	
A. m. woyi-gambella	48	19	39.6	
Total	3228	1062	33	

Note: *** statistically significant at P<0

At present, in most parts of the country, acquiring honeybee colonies is major problem to start bee keeping and to expand the existing stocks. To fill this gap, efficient ways of queen rearing method that can suit to the behavior of local bees and feasible to local condition was identified. In this regards, splitting and Miller methods of honeybee multiplication are found to be more suitable techniques to the local bees. Specially splitting technique is more suitable to be adopted by local beekeepers as the technique requires less inputs and easy to carry out at farmers level. Using this multiplication technique, farmers are able to produce 5-10 honeybee colonies from a colony per year. This method produces more queens during October to November than May-June active season (Nuru A and Dereje W., 1999)

The effects of embossed wax foundation sheets made by a European casting mould on the activities of central highland honeybees has been determined and found that embossed wax foundation sheets made by European casting mould forced the local honeybees to construct larger worker cells than their normal sizes and thus slows the buildup of the colonies (Amssalu B and Kebede D., 2004). Plain foundation sheet (Kebede D. and Amssalu B., 2001), and Centrifugeable honey without foundation sheets (Kibebew W and Dereje W, 2006b.) were developed to replace embossed foundation sheet made by casting mould and to sonve the problems of building up on time.

Major research achievements in the area of honeybee management

The efficiency of different hives assessment revealed that zander hive is easy manageable for farmers while Langstroth hive, though has some inconvenience to be handled at farmer level, is convenient for research works such as queen rearing activities. No significant honey yield differences have been observed between both hive types (Tolera *et al*, 2012).

Approporate time of superring was studied. As soon as flowering commences, the egg laying efficiency of queen increases resulting in high congestion. Therefore on time increase in the hive volume is paramount important to get control unwanted reproductive swarming and obtain better honey yield. If superring is too late, the colony may swarm and if too early, bees face difficulty to build new combs and manage the unnecessary space provided. In this regard, the appropriate time for superring was identified for the honeybee colonies of central high land (*Apis mellifera bandasii*). It was found that presence of 4-5 sealed brood combs and freshly secreted white beeswax on top of frames in base hive are the best indicator of suppering times (Kibebew W and Dereje W., 2006).

The effect of using starter strips on the production of centrifugeable honey combs was assessed and found that starter strips can be used in improved hive in place of embossed foundation sheet, made using casting mould (Kibebew W. and Dereje W., 2006)

Major research achievements in the area of Bee health

Twenty different pests and predators, including wax moths, small hive beetles (SHB), ants, spiders and death head hawk moth (DHHM) were identified and control measures against economically important pests such are ants and wax moths were developed (Amssalu B. and Desalegn B, 1999; Desalegn B and Amssalu B,2000). The economical effects of wax moth on bees and their bee products of South west, west and east Shewa zones of Oromia regional state were determined and the pests causes losses of 85.8 - 223.5 tons of crude honey and 2.5 -2.9 ton of pure beeswax per annum, the highest honey and bees wax loss being in west and south west Shewa zones, respectively (Amssalu B.and Desalegn B. 2012). The study was conducted to identify effective wax moth preventive and/ or control management practice(s) to minimize the damage inflected by this pest. Accordingly, significantly low wax moth infestation level and high honey yield were recorded when management packages like feeding, reducing super and unoccupied frames were applied on time. Wax moth infestation level was reduced by 82.3% using this package (Alemayehu G. et al 2012).

The study conducted on the economic importance of ants in West shewa zone also indicated that ants cause the loss of 0.8 millions of Birr every year. Three types of ant protection technologies were developed. These technologies were rapidly defused among the farmer beekeepers and it was able to save the loss of economy due to ants attack using these technologies (Amssalu B and Desalegn B., 2012).The prevalent assessment of Small hive Beetles revealed that infection level of SHB is highest in Jimma zone (60.05%,) compared to Esat Wollega (22.49%),West Showa (22.55%), Horo Guduru Wollega (5.28%) and Illuabbabora (14.47%,) zones (Amssalu B., and Desalegn B., 2012).

Four honeybee diseases (Nosema, Amoeba, Chalk brood and Varroa) have been identified and their economic importance and distribution were determined (Gezahegn T and Amssalu B, 1991; Desalegn B and Amssalu B., 2000, Desalegn B., 2006). Nosema disease is distributed in beekeeping potential regions, Oromia, Amhara and South Nation, Nationality and People (SNNP) and Beneshangul Gumuz (Fig 2). The degree of infestation and distribution of Nosema disease is higher in Amhara regional state compared to others (Amssalu B and Desalegn B, 2005). The study on economical effects of Nosema revealed that the disease has no effects on brood rearing, pollen and nectar collection of *Apis mellefera bandasii (*Amssalu B., 2012b)

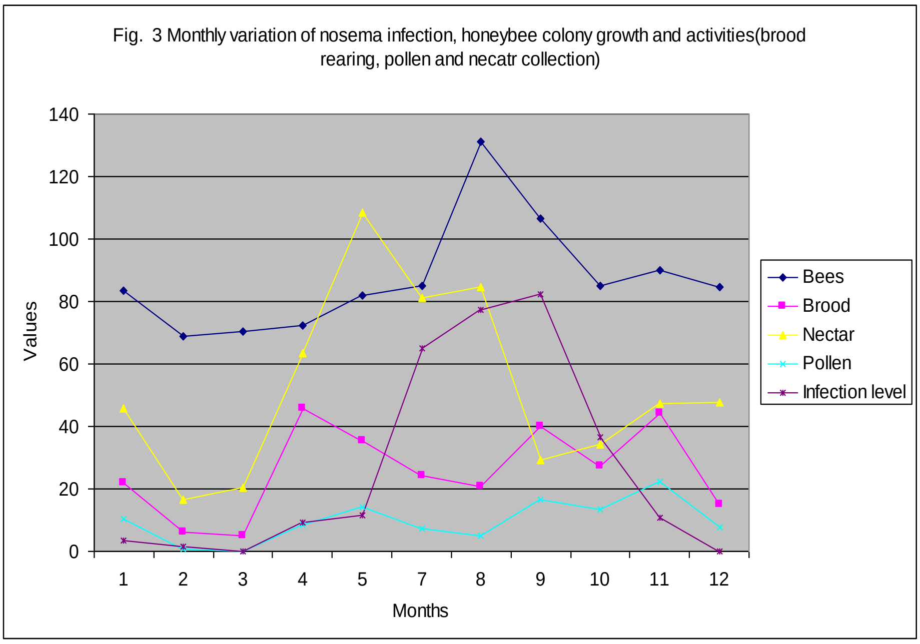

Fig.2 Monthly variation of Nosema infection rate, honeybee colony growth and activities(brood rearing, pollen and nectar collection)

Aster et al. (2009) studied the ecological distribution of Chalk brood disease, which revealed that moist dega, moist weina dega and wet weina dega ecological zones were found to be the best suitable ecological zones for chalk brood disease prevalence (Fig 3).

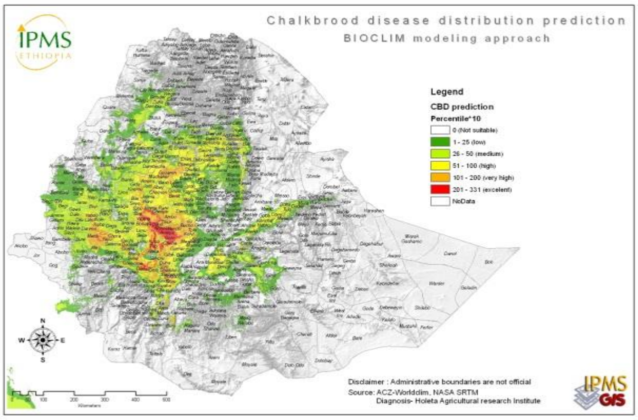

Fig. 3 Ecological distribution of chalk brood disease

With regards to Varroa mite, Amssalu et al., (2012) identified its occurrance in Oromia, Tigray, SNNP and Amhara regional states and the distribution and infestation rates are significantly vary among regions, with the highest being in Tigray regional state.

Toxicity of commonly used pesticides (Thionex 35 EC, Fyfanon 50%, Ethiozinon 60% EC, Endosulfa (Ethiosulfan) 35%, Decis® 2.5% EC, Dicopur 720SL, Agro-Thoate 40% EC, and Agro-2, 4-D Amin 720 A.E) on honeybees at laboratory and field were determined. The study indicates that all pesticides except Agro-2, 4-D Amin 720A, are significantly toxic to Ethiopian honeybees when ingested with food. Fyfanon 50%, Ethiozinon 60% EC and Decis(R) 2.5% EC are also exhibited significant toxic effect to honeybees through vapor. Ethiodemetren 2.5% EC, Ethiolathione 50% EC and Agro-thoate 40%EC (control) are found long acting toxic chemicals compared to others. Application of these toxic chemicals when honeybees are less active is recommended to minimize honeybees poisoning (Amssalu et al, 2012).

Major research achievements in the areas of Bee forage

Two books on Ethiopian honeybee flora, each containing the descriptions and pictures of more than 500 bee forge species were published (Fitchl R. and Admasu A, 1994; Admasu et al, 2014) and are serving as scientific references. More than one thousands of honey plant species were identified, their habitat distributions, apicultural and other values were documented. Besides, a book entitled Atlas of honey plant pollen grain, that contains pictures and description of each pollen grain morphological structure has been published (Nuru A. 2007).

A total of 62 melliferous plant species were identified **in** arid and Semiarid agro-ecologica zones of south east of Oromia. *Acacia senegal, Acacia tortolis, Peterolobium stellatum, Hypoestes forskali* and *Ziziphus spina-christi* are the most frequent species in the area (Debisa L. and Admasu Adi, 2012). On other hand, based on potential evaluation of honeybee forage, *Guizotia scabra, Guizotia abyssinica, Brassica carinata* and *Caylusea abyssinica* were found be major honey bee forage around Holeta areas (Amssalu B., 1997). *Guzoita spps*., *Brassica napus*, *Bidens species* & *plantago lanceolatum* are the major pollen sources of spring (September-November), while *Vernonia spps, Plantago lanceolatum & Heliminthothea echioides* are the chief pollen source of the period December-February and *Plantago lanceolatum, Pinus spps* and *Eucalyptus species* are the leading pollen source in both autumn (March-May) and winter (June-August) (Amssalu B., 1999). In addition to the documentation of of important honeybee plants, seeds and seedlings of the dominant honeybee plants are distributed to the end users every year by HBRC.

The contribution of honeybee on pollination of some crops and horticulture were assessed and found that honeybees increase the yield of *Guizotia abyssinica* (Noug), *Allium cepa* (red onion) *and Vicia faba* (bean) *by* 43%, 84% and 28%, respectively. Furthermore, honeybee pollinated *Citrus sinensis* (orange) showed early ripening of fruits compared to none pollinated ones (Admasu A. et al, 2006; Admasu A. and Nuru A., 1999).

Major Research achievements in the area of Bee products

The quality of Ethiopian honey and beeswax was analyzed and confirmed that both products fit the standards of world market. Quality control and grading systems of honey and beeswax have been developed and endorsed by Ethiopian Standard Authority (Nuru A., 1996; Nuru A., 2007). Moreover, ten mono floral honey each with distinct color, flavor and taste have been identified. The results initiated more than ten honey and bees wax processors and exporters to flourish and formed Ethiopian Honey and Beeswax Processors and Exporters Association (EHBPEA). At present, Ethiopia is one of the four African countries that is eligible to export honey to EU countries. Techniques to differentiate floral honey from adulterated honey were developed and consumers are able to detect and purchase pure and safe honey using the the developed techniques.

Locally processed and packed table honeys mostly suffer from granulation and problems associated with granulation like coarse crystallization, different layers formation, fermentation, and gas bubble production. Crystallized honey ferments more readily than liquid honey. Moreover, most local people also associate coarse honey crystals with adulteration of honey with table sugar. Most consumers prefer honey in a clear liquid form (Crane, 1990). A study conducted by HBRC to retard the granulation/ crystallization of table honey and make it stay longer in liquid form indicated that storing temperature is an important factor among others. Well drained and strained honey kept in refrigerator (4^oC) and cold room for 10- 40 days and 20- 40 days, respectively showed a tendency to granulate very slowly, varying from 109 days to more than two and half years.

The visual attractiveness of honey to consumers can be improved by facilitating rapid fine crystallization process and a term creamed (or spun) is applied to honey processed in such away (Dyce, 1975). Finely granulated honey is preferable by many consumers for its manageability in table since it is easy to spread on bread (Crane, 1990). Therefore, in conditions where granulation is unavoidable it is better to process the honey in to creamed form. A study conducted by HBRC to prepare finely and uniformly granulated table honey of three widely produced honey types (*Schiffleria abyssinica*, *Guizotia scabra* and *Croton macrostacheys*) indicated that all the honey samples treated with

5%, 10%, 15% starter nuclei by weight and kept in the temperatures between 14°C and 16°C showed rapid crystallization. However, there were variations in degree of uniformity and texture of the crystals based on the amount of starter nuclei added. For honeys of *S. abyssinica* and *C. macrostacheys*, very fine and uniform crystallization was observed for samples mixed with $\geq$10% starter nuclei at 14°C and 16°C. However, very fine and uniform crystallization of honey of *G. scabra* was observed for samples mixed with $\geq$5% starter crystal nuclei and placed in the above temperatures.

Beeswax is one of highly valuable bee products having high demand in the world market. Thus, processing and maintaining quality of beeswax helps to increase and diversify the income of beekeepers. The percentage of pure honey and crude beeswax obtained from crude honey varied from 34.4 % to 95.0% with mean of 73.15% and 5% to 65.62% with mean of 27.5%, respectively. On other hand, 45.8 % to 92.2% with mean of 73.61% of pure beeswax can be obtained crude beeswax. (Nuru A., 2007). The study also revealed that about 35% net profit could be obtained from sell of pure honey and pure beeswax through processing crude honey into pure honey and pure beeswax.

The efficiency of traditional beeswax rendering method is very low with an average yield of 3.42kg of pure beeswax per 10 kg of crude beeswax compare to mechanical rendering method which yields an average yield of 6.47kg per 10 kg of crude beeswax. This indicated that the traditional rendering method is only 50% efficient compared to Mechanical jack presser developed by HBRC (Nuru A., 2007).

In recent time, bee products like bee-collected pollen become very important to increase and diversify the incomes of beekeepers. In Ethiopia, in spite of extensive beekeeping practices high value bee products like bee collected pollen are not yet exploited. The type of pollen trap on the market is that of European type having 5 mm opening size. To increase the harvesting of pollen from local bees, improving of the efficiency of pollen trap is very important. The study conducted to design appropriate pollen trap indicated that pollen trap with 4.5mm size is best suitable for honeybees of the highlands of Ethiopia (*A.m. bandansii).* Using such type of pollen trap it is possible to increase the pollen yield of colonies without affecting the honey yield during peak flowering periods. In the same way techniques to harvest propolis from traditional and movable box hives were developed.

Major achievements in the area of Bee keeping equipments

Movable frame hives were introduced to the country and demonstrated to a number of farmers. By 2016, more than 1.2 million box hives were on use in the country. The national honey yield increased from 7k.g (average obtained from traditional) to 25k.g./hive/year. Though movable frame hive improves the quality and yield of honey, the technology requires other expensive accessories such as casting mould, which cannot be affordable to poor farmers. Plain foundation sheet and centrifugeable honey without foundation sheets were developed to replace embossed foundation sheet made by casting mould (Kebede D and Amssalu B 2001; Kibebew W. and Dereje W., 2006)

Moreover, transitional (chefeka hive) and movable frame hives, which are cheaper than movable box hive were effectively produced from cheep locally available materials (Bamboo and twigs). These technologies were demonstrated to users and 7,484 farmers, beekeeping technicians and experts were trained on how to construct transitional hives (chefeka). Beyond using chefeka hives for honey and bees wax production, in Dandi woreda of West Shewa zone generated 10,000Birr/farmer from the sale of transitional hives. Currently, women and disabled people are also engaged on making and selling of chefeka hives. Smoker, veil and gloves, which are used to be imported from abroad, were made from locally available materials by Holeta Bee Research Center and farmers, private beekeepers, investors, and bee technicians and experts were trained on the technologies. As the result of this intervention, many private investors are engaged on mass production and marketing of these materials and hence saving foreign currency. In addition, pollen traps that fits to Ethiopian conditions for harvesting pollen grains. Mechanical jack presser that have two fold efficiency than manual ones to render crud bees wax have also been developed.

Challenges and Opportunities

Despite the favourable agro-ecology for honey production, a high number of honeybee colonies and great diversity of honeybees and honeybee flora, honey production and productivity in the country is low. The critical factors for this low honey productivity are: the limited uptake to new technologies in beekeeping, lack of adequate and appropriate bee management, processing and handling of bee products, lack of efficient and effective marketing network for bee products, poor quality and quantity of honey, beeswax and other bee products, and lack of adequate knowledge about production potential of honeybee races of the country. Farther more, honeybees are threatened by chemical poisoning (especially pesticides), land clearing for agricultural and industrial development and bush fires, which kill the honeybees, bee forage and destroy the natural habitat of the honeybee. Apiculture research program is suffering from critical shortage of trained manpower, finance, in adequate infrastructure and poor extension services.

Future prospective

To enhance the production and productivity of apiculture sub-sector, technology and information generation needs focus on major thematic areas related with beekeeping and genetic improvement, bee forage and pollination ecology, bee health, bee products quality improvement and value addition, api-mehanization and extension and socio-economics. To speed up the generation of high quality apiculture technologies and information, it is vital to use high tech research facilities, skilled manpower, establish enabling research environments, and well organized research structure in multidisciplinary approach.

Though the national apiculture research has been conducted at seven federal and five regional agricultural research centers, the work is at its infant stage. This is attributed to the limited capacity in human resource, research facilities and inadequate budget. Accordingly, it is possible under the current situation to categorize these research centers into the center of excellence, high and moderate potential research centers based on their respective geographical location and the current resource capacities. Capacity building of these centers with skilled manpower and other enabling research environments will therefore be the priority intervention of the country is to benefit from apiculture. This is expected to enhance research efforts in generating and multiplying appropriate technologies, knowledge, and information through a well-coordinated, demand-driven and resource-efficient research system. This in turn ensures production and productivity increment, processing, value addition, address the challenges of climate variability, and better exploit the on-going natural resource rehabilitation**.** Specific, it will be important to give due attention to the following issues in the future apiculture research and development:

- Strengthening linkage among stakeholders including national and international institutions and diversify the scope and coverage of apiculture research
- Application of advanced science and technologies in area of improving feed quality
- Adaptation of worldwide available technologies to the needs and capabilities of farmers
- Addressing issues related to honeybee products quality and food safety
- Improving the genetic apicultural resources through selection
- Formulate quality bee feeds ration and
- Address global and local apiculture challenges
- Establish apiculture health problem monitoring and management tools
- Diversify the utilization of honeybee products
- Develop appropriate and affordable bee equipment and materials
- Integrate beekeeping with natural resource conservation and crop production
- Develop bee floral data base, generate and adopt bee forage technologies

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Animal Feeds Research in Ethiopia: Achievements, Challenges and Future Directions

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Introduction

Ethiopia is recognized to have a huge livestock resource in Africa. Livestock keeping is a key livelihood activity for the agricultural, agro-pastoral and pastoral societies, which account for over 80% of the Ethiopian population. Despite the large livestock resource base and importance of the sector to millions of smallholder farmers, pastoral communities and the national economy at large, livestock production and productivity has remained to be the least in sub-Saharan Africa, and the available potential has not been adequately exploited. Constraints to the livestock productivity are generally associated with backward agricultural practice together with man-made and natural environmental degradation. Among the various constraints limiting livestock productivity, the first and foremost one is poor quality and quantity animal feed. Corroborating to this background, critical feed scarcity for more than 9 months a year and average annual feed deficit of 35% of the requirement (maintenance plus production) has been noted in the study on the status of feed resources in the central highlands of Ethiopia (Tadesse *et al.,* 2007).

Along the path of market led economy and commercialization, the Ethiopian feed industry need to be strengthened substantially to avail quality feed to support transformation of animal agriculture in Ethiopia. Smallholder farmers, pastoralists/agro-pastoralists, cooperatives, organized youth and commercial farmers are the expected actors towards production and utilization of quality feed to realize the necessary intensification of animal agriculture in Ethiopia. Such a process basically demands science based development which inter-alia requires pertinent technology and information on feed industry. The major objective of this review is thus to provide 1) an overview of major achievements in the areas of feed resources improvement and utilization research in Ethiopia 2) summarize the major challenges in improving feed supply and utilization and 3) to highlight the future research and development needs in the areas of livestock feed resources and nutrition in Ethiopia.

Major Achievements

Status of major feed resources and management: A series of studies on the status of Ethiopian feed resources, feeding management and feed resource characterization have been carried out by EIAR formerly IAR and EARO. From farming systems perspectives, the series of studies on feed resource status (Seyoum and Zinash, 1991, Tadesse *et al.,* 2007) identified major feed resources, their contribution, farmers practice on feeding management, challenges and opportunities towards production and utilization of quality feed in enhancing animal productivity. Feed resource characterization of EIAR has laid foundation for national feed data base on chemical composition and nutritional attributes of major feed resources. Information on Ethiopian feed composition was first generated in 1989 (Seyoum and Zinash, 1989) and later updated (Seyoum *et al.,* 2007) to include information on digestibility and energy values. Key characteristics and peculiarities of Ethiopian feed resources have been documented and facilitated development of nutritional interventions at smallholder and commercial levels. Additionally information on appropriate model of choice to describe digestion kinetics and rumen/post- rumen degradability characteristics of different protein supplements such as selected herbaceous legumes, browse species and major oilseed cakes has been generated to complement the basic chemical composition and nutritional attributes (Seyoum, 1995). Efforts towards modernizing feed resources characterization have led to the use of near infrared spectroscopy (NIRS) technique (Dereje *et al.,* 2010a and 2010b). To date, NIRS based prediction equation for chemical composition and nutritional attributes of natural pasture and crop residues have been successfully developed and application for other feed resources is under way. The feed resource characterization effort, besides generating basic information for various actors engaged in feed industry (researchers and academicians, farmers, development workers, feed manufacturers, planners and policy makers) has inter alia provided an opportunity for enhancing national capacity for students enrolled in animal nutrition and development actors engaged in feed production.

Natural pasture: The total grazing and browsing land was estimated to be 61-65 million hectares constituting 53% of the total area of the country (Alemayehu, 1998). The area coverage, productivity and quality of natural pasture is dictated by various biophysical and management factors among which agro-ecology accounts for the major variation. In the low lands, with a wide range of grasses, legumes, and other herbs, the natural pasture accounts for 90 % of the feed supply while in the mixed crop-livestock system of the highland agro-ecology, its contribution has declined from 80-90 % in the early 1960's to 30-40% during the last decade of 2000's. Currently, with the rapid increase of human population and increasing demand for food, grazing lands are steadily shrinking being converted to arable lands, and are restricted to areas that have little value or farming potential such as hill tops, swampy areas, roadsides and other marginal lands. This is particularly evident in the mixed highland and mid altitude farming systems.

Recent information on the area and productivity of natural pasture is scarce because of the expensive (in terms of time and money) nature of data collection. Productivity estimates also vary, probably due to variation in time and ecological change, rainfall, soil type and cropping intensity. Annual pasture yield assessments on the highlands and mid altitude areas have shown 1-2 tons and 4-6 tons DM/ha on well drained and water logged soils respectively (Lulseged and Alemu, 1985; Lulseged, 1987). In the drier lowlands, the yield is much lower, about one ton DM/ha. MoA (1984) estimate was 1.5 and 0.56 tons DM/ha for the highland and lowland, respectively. On un-supplemented natural pasture, weight loses of 20% have been recorded (IAR, 1976). According to on-station research findings (Zinash *et al.*, 1995) the natural pasture in the highlands is just adequate for live weight maintenance and weight gain during wet seasons and would not support maintenance for the rest of the year. Under maximum herbage intake, protein supply was adequate for maintenance only for three months of the year. Grazing trial conducted at Holeta indicated that optimal carrying capacity of natural pasture is 1.5 LSU per ha per year and well managed natural pasture could support up to 2.5-3 LSU/ha during the main growing season (Lulseged and Alemu, 1985).

Fertilization, legume over sowing and bush control were some of the major interventions studied to improve productivity and quality of natural pasture. According to studies on highland pastures around Holetta, higher herbage yield was recorded with an increase in the levels of N and P fertilizers (Table 1). Phosphorus is also useful to improve crude protein content of the total herbage by enhancing the growth of native legumes through its positive effect on nodulation and root development. Suitable time of fertilizer application is suggested to be at the beginning of the rainy period. Split application has been found to result in better yield and quality than single application. Cattle manure applied at the rate of 10 t/ha on natural pastures has also been found to improve yield and quality of native pastures.

Table 1. Average herbage dry matter (t/ha) yield of natural pasture as affected by different levels of N anf P_2O_5 fertilizer at Holetta

P_2O_5 level (kg/ha)	N level (kg/ha)				**Mean**
	0	40	80	120	
0	2.46	-	-	-	**2.46**
80	3.68	5.76	7.92	9.43	**6.70**
160	4.73	5.57	8.37	11.33	**7.50**
Mean	**3.62**	**5.67**	**8.15**	**10.38**	**5.55**

(*Source: Gezahegn et al., 2015*)

Over-sowing the natural pasture at Holeta with selected forage cultivars was attempted but, establishment was reported to have been poor for most of the species. The only species suitable for over-sowing the highland pastures was found to be vetch (*Vicia dasycarpa*) (Lulseged G/Hiwot, unpublished). Coating vetch with cattle manure during over-sowing was also found to improve both the establishment of vetch in the pasture and pasture herbage productivity as observed in a study conducted at Holetta (Table 2).

Table 2. Herbage DM (t/ha) yield of natural pasture over-sown with two vetch species at varying seeding rates with or without manure coating at Holetta

Over-sown vetch species	Vetch seeding rate (kg/ha)				Mean
	0	25	50	75	
Vicia dasycarpa (coated)	7.36	5.66	6.43	5.52	6.24
Vicia dasycarpa (uncoated)	6.57	5.61	5.14	5.20	5.63
Vicia villosa (coated)	7.86	7.72	6.66	10.48	8.18
Vicia villosa (uncoated)	6.87	6.20	6.18	6.83	6.55
Mean DM yield (t/ha)					
With coated vetch	7.61	6.69	6.55	8.00	7.21
With uncoated vetch	6.77	5.91	5.66	6.02	6.09
% increment in DM yield due to manure coating	***12.41***	***13.30***	***15.64***	***33***	***18.46***

Improved forage and pasture crops: Improved forage and pasture research as a national program was formally started with the establishment of Institute of Agricultural Research (IAR) in the mid 1960s (Alemayehu and Getnet, 2012; Getnet, 2012). The research was initiated via the introduction of a wide range of tropical and temperate pasture and fodder species by the then IAR from different parts of the world including South America, North America, Australia and some parts of Africa with the support of the Food and Agriculture Organization (FAO) of the United Nations (Lulseged and Alemu, 1985). The aim was to broaden the forage genetic base for evaluation and selection of suitable species/cultivars for the highly diverse agro-ecological conditions of the country. The former ILCA (the current ILRI) has also played a significant role in introducing various fodder species besides its involvement in the collection and evaluation of indigenous species.

Agronomic evaluations focused on various desirable characteristics including adaptation to the prevailing climatic and soil conditions, ease of establishment, persistence, herbage productivity, seed yield, resistance to pests and diseases, forage quality, multi-purpose uses and suitability for integration into the farming system. Significant successes have been registered in identifying various adaptable and high yielding fodder species belonging to grasses, herbaceous legumes and browse trees that have been recommended for use in the various agro-ecological zones of the country. Official variety release procedures and guidelines for improved forage varieties have been established and implemented since 2009 Ethiopia. Despite the absence of formal variety release mechanism in the past, about 9 forage species/varieties which were informally promoted and fairly accepted by the different users (ex-state farms, private farms and smallholder farmers) were registered in the crop variety register book of MoA. So far, about 33 improved forage varieties have been registered and released for different agro-ecologies of the country. List and herbage productivity of the released varieties have been compiled by Fekede *et al.*, 2015 and presented in Table 3.

Table 3. List and herbage productivity of officially registered/released forage species and varieties in Ethiopia

SN	Species	Variety	Common name	Altitude (masl)	DMY (t/ha)	Year registered	Breeder Institute
	Grasses						
1	*Avena sativa*	CI-8237	Oats	1500-3000	10-13	1976	HARC
2	*Avena sativa*	CI-8251	Oats	2000-3000	8-12	2013	HARC
3	*Avena sativa*	Bonsa	Oats	2300-3000	9.7-10.8	2011	SARC
4	*Avena sativa*	Bona-bas	Oats	2300-3000	9.8-10.3	2011	SARC
5	*Avena sativa*	SRCPX80Ab2806	Oats	1500-3000	12.0 -15.0	2015	HARC
6	*Avena sativa*	SRCPX80Ab2291	Oats	1500-3000	11.5-16.0	2015	HARC
7	*Penisetum purpureum*	ILCA-14984	Elephant grass	Up to 2004	10-15	1984	HARC
8	*Phalaris aquatic*	Sirossa	Phalaris	2400-3000	6-8	1982	HARC
9	*Chloris gayana*	Massaba	Rhodes grass	1000-2400	7-12	1984	HARC
10	*Panicum coloratum*	blue grass	Colo Guinea	1000-2400	6-10	1984	HARC
11	*Andropogon gayanus*	Dirki Ayifera	Andropogon	Up to 2000	8-10	2009	PARC
12	*Panicum maximum*	Local panicum	Guinea grass	Up to 2000	9-14	2014	PARC
13	*Penisetum polystachion*	Nech Sar	Netch sar	900-1500	7-12	2014	PARC
14	*Penisetum sphacelatum*	Shebela Sar	Bebeqa Sar	Up to 2000	13.2	2014	DZARC
15	*Cynodon aethiopicus*	DZF-265	Qola Serdo	Up to 2000	12.2	2015	DZARC
16	*Brachiaria mutica*	DZF-483	Para grass	Up to 2000	13.3	2015	DZARC
	Herbaceous Legumes						
17	*Vicia dasycarpa*	Lana	Vetch	1500-3000	5- 7	1976	HARC
18	*Vicia sativa*	ICA-61509	Vetch	2200-2004	5-6	2012	HARC
19	*Vicia sativa*	Gebisa	Vetch	2300-3000	4.3-5.1	2011	SARC
20	*Vicia villosa*	Lalisa	Vetch	2300-3000	6.6-8.4	2011	SARC
21	*Vicia narbonensis*	Abdeta	Narbon vetch	2300-3000	3.1-3.4	2011	SARC
22	*Trifolium quartinianum*	(Native)	Clover	1500-3000	3-6	1976	HARC
23	*Lablab purpureus*	-	Lablab	1000-2004	3-5	1984	HARC
24	*Vigna unguiculata*	Sewinet	Cowpea			2009	PARC
25	*Vigna unguiculata*	Temesgen	Cowpea			2014	Humera
26	*Medicago sativa*	DZF-552	Alfalfa			2014	DZARC
27	*Lupinusangustifolius*	Sanbor	Sweet blue Lupin			2014	Andassa
28	*Lupinusangustifolius*	Vitabor	Sweet blue Lupin			2014	Andassa
	Browse Trees and Shrubs						
29	*Chamaecytisus palmensis*	-	Tagasaste	2000-3000	6-10	1992	HARC
30	*Sesbania macrantha*	DZF-092	Sesbania	400-2000	8-10	2012	DZARC
31	*Cajanus cajan*	Dursa	Pigeon pea			2009	MARC
32	*Cajanus cajan*	Kibret	Pigeon pea			2014	Humera
33	*Cajanus cajan*	Tsigab	Pigeon pea			2014	Humera

Research results have indicated that improved fodder species generally have higher herbage yield potential than natural pasture. Yield potential of improved grasses usually varies from 8.0 to 15.0 t DM/ha/yr with a mean of about 13.0 ton/ha. Yield of herbaceous legumes also varies from 6.0 to 10.0 t DM/ha with a mean of 8.0 t DM/ha. Productivity of tree legumes ranges from 9.0 to 13.0 t DM/ha with a mean of about 10.5 t DM/ha. These yield potentials have been recorded under rain-fed conditions in which mainly a single cut is possible per year. If forage production could be supported by supplementary irrigation, multiple cuts could be possible and the potential herbage yields could be far higher than the figures indicated above, especially in the case of perennial forage species.

In general, average productivities of improved fodder crops in Ethiopia has been found to be about 13, 8 and 10.5 t/ha DM yield for grasses, herbaceous legumes and browse trees, respectively, while the average herbage DM yield obtained from seasonally rested pasture and continuously grazed pasture was 4 and 1 t/ha, respectively (Figure 1). Accordingly, the overall average productivity of the improved fodder crops per unit area has been found to exceed the productivities of seasonally rested and continuously grazed natural pastures by about 3 fold and 10 fold, respectively (Fekede *et al.*, 2015).

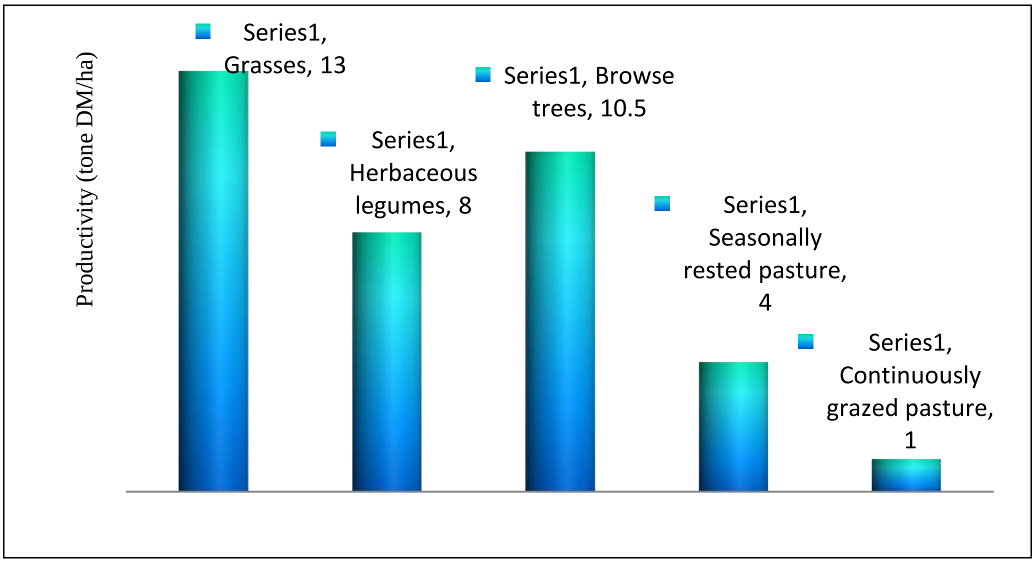

Figure 1. Average productivities of improved fodder crops in comparison to natural pasture in Ethiopia

In addition to their productivity, most of the improved forage crops are also nutritionally superior to that of natural pasture and crop residues. They also have a long growing season and help to extend the green feed period so as to provide useful nutrients mainly in rural areas where availability and accessibility of agro-industrial by products is limited. Moreover, improved fodder crops especially the legumes can complement crop production through maintaining soil fertility via fixation and accumulation of nitrogen and also help to prevent soil erosion and replenish degraded land when integrated into natural resource management schemes.

In terms of choices of alternative forage species/germplasm, suggested species or varieties are too few with respect to herbaceous legumes and fodder trees in the highlands. While in the arid and semi-arid low lands, the recommendations are very much limited to few species mainly due to environmental determinants, lack of irrigation facilities and inadequate attention given to this ecosystem in the national research agenda. There are different environmental determinants which limit overall performance of forage crops in the highland agro- ecological zone. These include, low soil temperature and low radiation intensity leading to slow establishment and growth of mainly perennial grasses; seasonal frost (October-January) affecting most of the tropical forage species; drainage problems especially on *Vertisols*; sever competition from weeds and low soil fertility. In the highland agro-ecology, planting of pasture seeds (mainly perennials) is recommended using the light rains during March to May in order to take advantage of the favorable environmental conditions for better establishment. In situations where the light rains are short and inadequate, planting is done early during the onset of the main rain in June. In the arid and semi-arid lowlands, erratic rainfall, periodic drought and short plant growing periods are the major environmental determinants limiting growth and establishment of forage crops. On the other hand, the mid-altitude highland areas are comparatively favorable for most tropical forage crops.

In addition to agronomic packages, studies on forage seed production has been carried out for selected species. Available information in this regard includes seed productivity, suitable production sites/agro-ecologies, fertilizer application, harvesting management, seed threshing, cleaning and processing and germination.

Series of studies on animal evaluation of improved forage crops has been carried out as part of feed evaluation project. Among the various forage crops, the study on fodder beet marked the first initiative in which milk yield of 11 lt per cow per day was recorded using crossbred dairy cows (Seyoum *et al.,* 1991). Additionally, a study was conducted to identify appropriate level of supplementation of Napier grass based basal diet with various level vetch (*Vicia dasycarpa*) hay (Aemiro *et al.,* 2009) to dairy cows. The preferred level of vetch supplementation was noted to be up to 20% of their daily dry matter intake and with this level of supplementation daily milk yield of 8.81 lt has been recorded per cow per day.

As part of on-farm studies, series of demonstration and pre-scaling up of forage technologies have also been carried out by EIAR and various other institutions during the last two decades and substantial results have been recorded. The most notable technologies include forage management/production and forage seed production. Most of the demonstration and pre-scaling up of feed technologies and practices were supported by training and field days.

Crop residues: Estimates of crop residues are based on harvest indices under research condition assuming certain field losses (Nordbloom, 1988). Using conversion factors developed from production indices, the national total crop residue production for the year 2014/15 was estimated to be 51.3 million tons out of which cereal straws account for 47.1 million tons, pulses straws 2.75 million tons, and oilseed straws 1.43 million tons (CSA, 2015).

Crop residues are generally characterized by low crude protein content but high cell wall and cell wall constituents (Seyoum, 2007). Their crude protein content is lower than the threshold required for maintaining the N balance of an animal in the positive side. The fiber content is also higher than the value suggested to limit intake of animals. Digestibility of crop residues is also low and varies with the crop type from which the residue is produced. Tef straw has better digestibility compared with wheat (45%), and oats (48%) straws. Pulses have medium to high digestibility ranging from 34-56%. Energy value of cereal straws ranges between 7.14 Mj/kg (wheat) to 8.35 Mj/kg (tef) while pulse straws have fairly higher energy value in the range of 7.4 (beans) to 9.4 MJ/kg (lentil) (Seyoum and Zinash, 1989). In general, nutritional quality of crop residues is influenced by several factors like morphological fractions of the residue and varietal difference of the crop (Seyoum *et al.,* 1996). A recent study by Fekede *et al.,* 2015 also showed that nutritional quality of crop residues is also highly affected by storage method and storage duration as investigated in tef and wheat straws. According to the study, CP content and IVOMD showed decreasing trend while the NDF content showed increasing trend with prolonged storage duration in both the crop residues (Table 4). It was also noted storage in open air resulted in higher nutrient losses in both the crop residues than storage under shelter shade.

Table 4. Nutritional qualities of teff and wheat straws stored under shelter shade and in open air for different durations

Crop residue	Storage duration	Storage under shelter shade (g/kg DM)			Storage under open air (g/kg DM)		
		CP	IVOMD	NDF	CP	IVOMD	NDF
Teff straw	0	47.1[a]*	522.3[a]*	720.6[d]*	50.3[a]*	514.8[a]*	723.5[d]*
	1	43.9[b]*	492.3[b]*	739.4[c]*	37.9[b]*	476.6[b]*	764.3[c]*
	2	37.6[c]*	429.4[c]*	765.3[b]*	33.2[c]*	385.4[c]*	795.4[b]*
	3	32.9[d]*	335.6[d]*	781.8[a]*	29.7[d]*	303.3[d]*	822.2[a]*
	Mean±SE	***40.4± 3.2***	***444.9±41.3***	***751.8±13.6***	***37.8±4.5***	***420.0±47.4***	***776.4±21.2***
Wheat straw	0	40.9[a]*	470.6[a]*	730.8[d]*	41.6[a]*	466.3[a]*	734.9[d]*
	1	36.5[b]*	451.0[b]*	754.9[c]*	32.2[b]*	419.8[b]*	772.1[c]*
	2	32.7[c]*	411.4[c]*	776.1[b]*	26.3[c]*	355.4[c]*	797.3[b]*
	3	31.8[d]*	313.7[d]*	795.9[a]*	22.1[d]*	267.9[d]*	829.5[a]*
	Mean±SE	***35.5±2.1***	***411.7±34.9***	***764.4±14.0***	***30.6±4.2***	***377.4±43.0***	***783.5±20.0***

Table 5. Productive and high quality fodder species selected for diverse agro-ecologies in Ethiopia

Common name	Botanical name	Altitude Ranges of adaptation (masl)
Tree Lucerne	*Chaemacytisus palmensis*	1800-3500
Sesbania	*Sesbania sesban*	1000-2400
Leucaena	*Leucaena pallida* *Leucaena leucocephala* *Leucaena diversifolia*	500-2000
Calliandra	*Calliandra calothyrsus*	500-2000
Desmanthus	*Desmanthus virgatus*	500-2000

[a-d] Parameter values with different superscripts for each crop residues within a storage method in a column differ significantly (p<0.05)
* Values for the same parameter differ significantly between the two storage methods within a row (p<0.05)
Storage durations: - 0=at threshing (immediately before storage); 1=two months; 2=four months; 3=six months
(***Source: Fekede et al., 2015***)

Because of low N, high cell wall and low digestion, animals fed on a sole tef or barley straw diet cannot maintain their N balance. Especially growing animals may lose weight due to their high N requirement. Consequently, losses of up to 75 g/day were reported for young calves fed on a sole diet of tef straw. The energy supply of a sole cereal crop residue diet is marginal to maintenance requirement of the animals. For instance, the nutrient supply from an average quality wheat straw is only 90 and 45% of maintenance requirement in terms of protein and energy needs, respectively. Animal production on such a diet, therefore, requires supplementation with energy sources especially fermentable carbohydrate. The provision of readily fermentable carbohydrate improves utilization of ammonia for microbial growth.

As discussed above, the limiting nutrients have to be augmented by feeds that are known to contain these nutrients not only in ample amounts but also have to be readily digestible in the ruminants' digestive tract. A review of research outputs on supplementation (Seyoum, 2007) indicated that supplemented crop residue diets can support a mean live weight gain of about 555g/day for local cattle while growth performance for crossbred cattle on similar diets varied from 820 to 940g/day with a mean of 907g/day. Tremendous changes in live weight gain per day have been reported elsewhere in the research system as a result of supplementation with several feed stuffs. Supplementation of tef straw based diet resulted in a live weight gain of 629g/day for indigenous animals and this performance was about 78, 56 and 32% higher than similar animals fed on a basal diet of wheat straw, oats hay and native hay. In a series of trials where maize residue was used as a basal diet at the level of 35-50% of the daily intake and supplemented with concentrate, growth performances of about 750g/day and 913g/day were realized for native steers and crossbred bulls, respectively (Alemu *et al.*, 1978, O'Donovan and Alemu, 1978).

Strategic supplementation of crop residues and poor quality native hay substantially increases the palatability and digestibility of the total diet thereby improving body growth and productivity of animals. High quality fodder legumes both from herbaceous and browse trees have been selected to meet the need for quality supplementary fodder well adapted to the various climate and soil types of the various regions. Notable species are listed in Table 5 below.

Digestibility and intake of straw can also be increased by chemical treatment, and if accompanied by supplementation, better animal responses can be attained. Among various chemicals globally used to treat crop residues, application of fertilizer-grade urea has been explored locally. Results suggested that depending on the type of crop residue, crude protein content can be improved by about 5.5% and digestibility by 8.4% through urea treatment (Seyoum, 2007)

Agro-industrial by-products: Among various agro-industrial by- products, nutritional quality and supplementary values of oilseed cakes have been evaluated using bioassays and animal response trials. Results of series of experiments suggested that there is substantial difference in rumen degradability parameters and post rumen digestion kinetics of oilseed cakes (Seyoum, 1995). Oilseed cakes such as peanut cake and noug cake can be used as sources of rapidly degradable N source while cottonseed cake and flax cake can be used as sources of escape N. Among agro-industrial by- products, use of molasses as multi-nutrient block (MNB) has been studied extensively both under on-station and on-farm conditions. The on-station studies identified appropriate feed ingredients and levels to be used with molasses. Subsequently, series of animal response trials using growing animals or lactating crossbred cows have been carried out which was followed by an on-farm evaluation of the interventions in three distinct production systems *viz.* peri-urban dairy, mixed crop-livestock, and pastoral or agro-pastoral. In peri-urban dairy production, use of multi-nutrient block was noted to be a good option for saving feed cost while in mixed crop-livestock production system and pastoral set up, use of multi-nutrient block has substantially increased milk production of dairy cows (Mesfin, 2012; Seyoum *et al.*, 2008). Additionally potential use of MNB in fattening diet was also validated on-farm as a preferred supplement in central highlands of Ethiopia (Mesfin, 2012).

Other supplements: Among other supplements, use of effective microbes (EM) in improving utilization of ruminant livestock feed resources has been tested recently and found worthy. Technologies pertaining to this option include application in lactating crossbred cows (Getu *et al.,* 2012) and crossbred dairy calves (Aemiro *et al.,* 2012). Based on these information manual for enhanced utilization of effective microbes in ruminant diet has been developed and published (Getu *et al.,* 2015).

Major Challenges in Feed Resource Management and Utilization

Inadequate feed supply and quality: Because of increase in human population and livestock population, grazing areas per unit of animal are remarkably declining putting substantial pressure on quantity and quality of feed resources. Increase in urbanization and economic growth are also putting substantial pressure on demand of livestock and food of animal origin. Added to this scenario is the fact that feed cost accounts for about 70% of the cost in animal production and is a key or central commodity that all forms of livestock production compete for. Thus, towards ensuring adequate supply and quality of feed resources, technological interventions need to be developed aggressively and transferred to user community than ever before.

Inefficient utilization of available feed resources: Besides the move towards commercialization and market led economy, livestock and feed production is still subsistence oriented. Livestock producers are still keeping large herd but low in productivity. Cattle are primarily kept for draft power and a good portion of feed resources is directed towards feeding unproductive animals for very long time. Additionally low feed processing technologies and capacities to conserve or transport extra feed production is very much limited towards ensuring feed security.

Crop-biased extension system: Livestock production in general and forage development in particular has not been adequately addressed in the national agricultural extension system. Promotion of improved forage technologies has been made sporadically via different externally funded livestock development projects, which usually have a fixed and often limited duration and scope, and may not be suffice for the smallholder farmers to buy in the interventions and take it up in a sustainable manner. Moreover, most of the projects had no proper phase out strategies, which ensure sustainability through incorporation of the1 development initiatives into the government development programs. As a result, most of the project initiatives in promoting forage technologies have been subjected to total collapse after phasing out of the projects. Although the extension system is structurally accommodating livestock production, the actual service is skewed to crop production in terms of input supply and technical support, while the livestock aspect has been remained subordinate. This is further exacerbated by a blanket extension approach followed throughout irrespective of potential suitability of different areas for different enterprises (e.g. we do not have different extension approaches for Selale area which is highly suitable for dairy production vs other areas which have comparative advantage for grain production). The lack of adequate extension and demonstration services has resulted in limited awareness of farmers on the role of improved feed technologies.

Very weak market orientation and low adoption of technologies: Despite various research and development programs in feed resources, the system is largely low input – low output systems oriented leading to low adoption of improved feed technologies. Poor supply, access and unaffordable price of inputs like concentrate feeds, forage seeds, and other technologies are still critical problems towards market orientation and enhancing adoption of feed technologies. Additionally shortage of land for production of improved forages, poor product marketing systems/linkages and lack of incentives generally account for low adoption of technologies.

Lack of focus in research program orientation: Despite remarkable efforts in nutritional studies during the last 5 decades, there are thematic areas, which are totally untouched to remove nutritional barriers in enhancing livestock productivity. Livestock water supply and quality (accessibility and quality i.e., clean from microbial and other impurities) has never received the attention they deserve. Aspects of macro and micro mineral nutrition (deficiencies and toxicity) and feed additives specifically for poultry have not been captured adequately in nutritional research. Nutritional technologies and practices for ensuring climate resilient ruminant livestock production have not been given adequate attention.

Frequent drought, natural resource degradation and climate change/variability: Frequent drought, natural resource degradation and climate change/variability are becoming serious challenges in Ethiopian agriculture including livestock production. Lack of strong adaptation and mitigation technologies and practices to curb this situation is now at an alarming stage towards ensuring feed security. Feed conservation practices are currently very weak to escape such calamities and implementation of options in ensuring green economy have not yet started. National capacities in availing climate smart technologies towards realization of green economy and transformation of Ethiopian feed industry are not yet created.

Future Research and Development Needs

Strengthening demonstration and scaling up of available technologies and best practices: Attempts in demonstration and scaling up of feed technologies require new dimension and practices. Among various measures to be taken in this regard is strengthening stakeholder partnership in promoting improved feeding practices. Additionally technology multiplication like forage seeds and delivery systems need serious attention.

Intensification of livestock production: Intensification of livestock production is a key driver towards application of improved feed technologies. The move towards creating market oriented systems and the search for options of appropriate packages for intensification such as productive animals, better feeding systems, health services and strong market linkages are key issues. With respect to feed resources, improved management and utilization of available feed resources, adopting irrigated forage production and farm mechanization to reduce dependence of farming on animal power to ensure feed utilization for more productive animals deserve attention in intensification of livestock production.

Development & promotion of cost effective feeding packages for different classes of livestock: Proper exploitation of all available feed resources including non-conventional feed resources and focusing on limiting nutrients such as energy, protein and mineral nutrition should be given proper attention. Additionally limiting resources such as water should be a focal point in feed resources research.

Climate change/variability: Expectedly climate change /variability will continue to happen with severe impacts on feed and livestock production. Thus, there is a need to understand the change and develop sustainable interventions. Main streaming climate change/variability in the research system in line with the countries strategy, developing appropriate technologies to adapt and mitigate the impact of climate change and strengthening efficient information and early warning systems for feed and livestock production are the likely measures to be taken. Cognizant of the climate change and the need for smart technology, it is essential to create national capacity in identifying preferred techniques in monitoring gas emission at field level and developing options based on use of supplements, pasture management, forages, indigenous browses and genetics of ruminant livestock.

Socioeconomic and policy issues: There is a need to explore major socioeconomic and policy issues in formulating appropriate policy measures regarding input supply systems, service provision, marketing, commercialization, feed production, free grazing systems, and incentive systems to attract investment on livestock. Moreover, feed quality and safety issues deserve research and development attention to ensure transformation of feed and livestock industry.

Conclusions and the way forward

Feed scarcity in terms of both quantity and quality has remained to be the main limiting factor hampering productivity of the Ethiopian livestock sector. Provision of adequate feed supply is essential to ensure economically viable and environmental friendly livestock production. This requires complementing the traditionally available low quality feed resources with other alternative feed resources and improved utilization. Various technologies in feed resources have been generated during the last five decades of research. However, the generated technologies largely remained untapped. Possible reasons for low adoption of improved feed technologies include lack of adequate demonstrations on comparative advantages of the technologies, lack of specialization in livestock production and the underdeveloped market-oriented livestock enterprises, lack of inputs such as forage seeds, the overall low attention given to feed development by the extension service, and the consequent low public awareness. Historically, most development efforts in Ethiopia in terms of feed resources have been associated with different short-term projects of external sources and lacked strategic and sustainable development approaches. Therefore, while addressing the aforementioned key issues highlighted in the above section, strong coordination and institutional linkages should be established among the different actors (research, higher education, extension, seed enterprises and concerned private sectors) for advancement and utilization of technologies and practices in feed resources.

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Animal Health Research: The Ethiopian Experience and Future Prospects

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Introduction

Ethiopia's current plan to join middle class economy by 2025 is expected to create an unprecedented increase in demand for animal protein nationally, which will further exacerbate the existing shortage. Given the livestock population, the existing and forecasted increase in demand for livestock products, the situation can be considered as an opportunity to enhance the country's economy. This is because, Ethiopia is endowed with 56.7 million cattle, 29.3 million sheep, 29.11 million Goats, 2.03 million horses, 7.43 million donkeys, 0.4 million mules, 1.16 million camels, 56.87 million poultry and different types of fish resources (CSA, 2015). Thus, considering the number and diversity of livestock resources it has and a rapidly growing economy, the Ethiopian livestock industry is expected to serve as a new source of income for the national economy. Currently, the country is unable to satisfy the nutritional requirements' of its people. This is mainly due to the traditional livestock production system characterized by wide spread animal disease. Animal diseases directly affect livestock production with consequences for food security and food safety, trade, rural development, and the environment, while also affecting the livelihood of farmers (EC, 2012).

To control many of the endemic animal diseases of the country and prevent the occurrence of pandemic diseases, many efforts have been done by different institutions for decades. Other than EIAR, Universities and the National Veterinary Institute have been engaged in animal health research. However, the coverage of animal health research was limited to surveillance based epidemiological researches and even most of these researches have been redundant and without focus. This is because, animal health research was completely missed out from the national agricultural research system until the establishment of Institute of Animal Health Research (IAHR) in 1992 (Tsedeke *et al.*, 2004). In 1997, a National Animal Health Research Centre (NAHRC) was established in Sebeta under the Ethiopian Agricultural Research Organization (EARO), taking the responsibility of conducting and coordinating animal health research programs nationwide. But in 2007, NAHRC was handed over to the Ministry of Agriculture for veterinary diagnostic and investigation services. Subsequently, the animal health research has been neglected again from the national agricultural research agenda. Thus, in the last decades, the livestock resources development effort of the country didn't get the right support from the research side in developing and delivering technologies, methods and other decision support tools for disease control and prevention. This resulted in incompetent and weak veterinary services and regulations that don't comply the animal health and food safety standards needed to export live animal and animal products in to lucrative global markets.

The Ethiopian Institute of Agricultural Research (EIAR) has recently realized the significance of animal health research in achieving the projected livestock development goals of the country. In the meantime, EIAR is celebrating its 50 years of anniversary. On this occasion, detailing the achievements made so far in the area of animal health research and the lessons learnt in the past decades, will have a significant importance in designing future research plans and directions. Thus, the focus of this review is to summarize and assess previous efforts made in animal health research of the country and examining the challenges and future prospects. This is because; future research builds on past achievements and responds to emerging needs.

Disease Surveillance and epidemiology

Timely animal disease surveillance and monitoring helps making decisions that could finally be used to control and prevent those disease. Decision making on animal disease surveillance is a multi-stakeholder, and multi-criteria process that includes a variety of decision alternatives (Guo *et al.*, 2015). Disease surveillance and monitoring programs should also be supported by a responsive, dynamic and competent animal health research. Research should focus on development of rapid pathogen detection tools, risk analysis, epidemiological modelling and potential biosecurity risks and measures that should be taken to curb the emerging and re-emerging animal diseases.

Animal diseases that need a routine surveillance and risk analysis can be transboundary diseases, zoonotic diseases, production disease and other disease that may have a negative impact on the safety and quality of foods of animal origin. These disease have a special peculiarities which can help in disease prioritization. These special features of each of the diseases are discussed below.

Transboundary animal diseases (TADs): Transboundary animal diseases (TADs) constitute a global threat that afflict livestock and they do not recognize national borders (Ahmed *et al.*, 2006). In spite of their impacts on the production and productivity of animals, these disease hamper local and international trade. *(Roess et al*., 2015). Because of these reasons, Ethiopia is unable to export livestock and livestock products to the lucrative European market. Furthermore, trade with Middle East countries is frequently hampered and embargo is sometimes imposed due to such diseases (AGP-LMD, 2013b).

The type and extent of TADs endemic in Ethiopia have already been known since 1957 (Peck, 1961). Since then, there have been a pan African rinderpest control campaign and as a result of intensive disease investigation and strategic vaccination, the country has become a rinderpest free(Roeder, 2011). whereas, there are many other endemic transboundary animal diseases which are highly prevalent in Ethiopia.

Foot and mouth disease (FMD), brucellosis, Newcastle disease, *bovine tuberculosis, peste des petis ruminants* (PPR), *contagious bovine pleuropneumonia* (CCBP), *contagious caprine pleuropneumonia* (CCPP), African horse sickness are among the most predominant ones. Quantitative data on the real economic burden of these and other TADs prevalent in Ethiopia is missing. But some reports has already indicated the economic impact of few of these diseases. Of which, in feedlot bulls, Alemayehu *et al.* (2014) reported FMD prevalence rate 14.5% and an annual loss of 3.3 million USD due to bulls' rejection from international market. The economic losses of FMD outbreak due to milk loss, draft power loss and mortality were found to be USD 76 per affected herd and USD 9.8 per head of cattle in the affected herds in crop-livestock mixed system; and USD 174 per affected herd and USD 5.3 per head of cattle in the affected herds in the pastoral system (Jemberu *et al*., 2014). Jibat *et al*. (2016) also reported a herd level rabies prevalence rate of 11-21% with an annual cost of 228-477USD. A sero prevalence rate of lumpy skin disease (6% to 64%) (Gari *et al*., 2012; Abera *et al.,* 2015), Newcastle disease (5.9%-27.4%) *(Chaka et al., 2012; Chaka et al*., 2013) and infectious bursal disease (76.64% -91.9%) (Degefu *et al.,* 2010; Zeryehun and Fekadu, 2012) was reported. This indicates that the prevalent TADs, both in ruminant animals and poultry, remained to be a serious economic burden for the overall development of the country.

The existing animal health intervention options have not been able to control or eradicate those TADs. Low vaccination coverage of the existing vaccines, absence of vaccine, low efficacy and efficiency of vaccines are among the major reasons responsible for diseases control failures in Ethiopia. Gelaye *et al*. (2015) reported that low performance of the local vaccine and insufficient vaccination coverage are the main problems in *goat poxvirus* (GTPV) and lumpy skin disease control in Ethiopia. The development of new, more efficient vaccine strains, a GTPV strain for small ruminants and a LSDV for cattle, is needed to better control of *Capri pox virus* in Ethiopia (Gelaye *et al.*, 2015). Due to antigenic variability of the virus, the existing FMD vaccines are unable to protect against some serotypes of FMD virus found in Ethiopia (Negussie *et al.*, 2013). For many other diseases like infectious bursal disease, which are endemic and highly prevalent in Ethiopia, their high prevalence and wide distribution doesn't justify the effectiveness of the previous and current disease control strategies of the country. To mitigate the burden of these disease, animal health research should focus on genotyping the specific strains of these pathogens, risk analysis, development of early detection, emergency preparedness and biosecurity plans.

Zoonosis and food safety: Though, the economic burden of zoonotic and foodborne diseases in Ethiopia haven't been studied yet, their high prevalence rate and wide spread distribution is a clear indicator of their economic and public health significance in the livestock development of the country. The different fragmented research reports indicate that, the safety of foods of animal origin is mostly compromised and carries risks to consumers. Zoonotic and foodborne disease which are prevalent in Ethiopia continue to negatively affect the livestock sub sector and also the health of the public.

In Ethiopia, due to some cultural and traditional practices, livestock and humans share same housing and people have a tradition of consuming raw milk and meat. Due to this, Ethiopia ranks highest in Africa in the health burden of zoonotic diseases (Grace *et al.,* 2012). On the other hand, suboptimal use of antimicrobials coupled with unhygienic animal husbandry practices is an important risk factor for emerging zoonotic disease and resistant pathogens (Roess *et al.*, 2015). There are many zoonotic diseases which are prevalent in Ethiopia. Some of the most common zoonosis and foodborne disease are described below.

Bovine tuberculosis (BTB) is endemic in Ethiopia, with low prevalence in the traditional small scale farming system, varying from 0.2% to 18% at animal level (Gumi *et al.*, 2011; Gumi *et al*., 2012; Mamo *et al*., 2013) in pastoral setting; and high prevalence in in intensive dairy farms, 50% at herd-level and 30% at animal level (Firdessa *et al.*, 2012). BTB has also been reported in camels (Gumi *et al*., 2012; Beyi *et al*., 2014) , and sheep and goats (Gumi *et al*., 2012; Kassa *et al.*, 2012). The trend of BTB prevalence appears to increase with intensification of husbandry and proportion of high-yielding exotic lines in farms (Firdessa *et al.,* 2012). BTB has been isolated in apparently healthy cattle slaughtered in abattoirs resulting in condemnation of some organs and carcasses (Shitaye *et al.*, 2006; Shitaye *et al.*, 2007; Mengistu *et al*., 2014). Reports (Tigre *et al.*, 2011; Mengistu *et al.*, 2014) indicate that BTB can be easily transmitted between animal and human populations. Usually, BTB has both public health and economic impacts.

Brucellosis, an endemic disease in Ethiopia, is a global zoonosis that presents severe public health challenge and major economic burden. Herd- and animal-level prevalence of bovine brucellosis (5.9 % and 2.4 % respectively (Berhe *et al.*, 2007; Asgedom *et al.*, 2016); and animal level prevalence in small ruminants ranging from 1.9% to 22.8% (Sintayehu *et al.*, 2015; Tschopp *et al.*, 2015) has been reported in Ethiopia. In camels, animal-level prevalence rate of Brucella ranging from 1.6% to 5.4% (Mohammed *et al*., 2011; Bekele *et al*., 2013) was reported. Brucellosis is usually linked to abortion both in cattle and small ruminants (Megersa *et al.*, 2011).

Toxoplasmosis is another worldwide zoonosis which is highly prevalent in Ethiopia both in animals and humans (Gebremedhin and Tadesse, 2015). Animal-level prevalence in pigs 32.1% (Gebremedhin *et al.*, 2015), in camels 49.62 % (Gebremedhin *et al*., 2014), in small ruminants 31.8 % (Gebremedhin *et al*., 2013) and in cattle 6.6 % (Bekele and Kasali, 1989) have been reported in Ethiopia. Toxoplasmosis usually is associated with abortion both in ruminants (Gebremedhin *et al.*, 2013) and humans (Gebremedhin and Tadesse, 2015)

Bovine cysticercosis (*Taenia saginata*) is one of the zoonotic diseases that threaten food safety and food security, particularly in Ethiopia. Economic losses due to bovine cysticercosis are associated with total condemnation and downgrading of carcasses (Dorny *et al*., 2009). Bovine cysticercosis is prevalent in cattle population of various regions of Ethiopia in a range of 2.2 % to 26.25% (Kumar and Tadesse, 2011). The other parasite related to meat is, *Cystic Echinococcosis* (CE) caused by *Echinococcus granulosus*, is a neglected helminth zoonosis affecting humans and various animal species. 35.15% of cattle, 11.78% of sheep, 4.9% of goats, 16.79% of camels and 0/150 (0%) pigs slaughtered in 21 different abattoirs located in various parts of the country were found harboring hydatid cysts(Abebe and Yilma, 2011). The total estimated economic loss from hydatid cysts infested organ condemnation, carcass weight and milk yield decrease amounts to 1,691,266,200 BIRR (101,203,734 USD) (Fromsa and Jobre, 2012).

The overall prevalence of *Salmonella* in raw meat samples (beef, goat meat, mutton, pork, and camel) collected from abattoirs and markets was 5.6% and 11.7% respectively; and 10.8% of milk samples from farms were positive(Tadesse and Gebremedhin, 2015). Similarly, the pooled prevalence estimates of *Salmonella* in humans were 8.7% in diarrheic children, 5.7% in diarrheic adults, and 1.1% in carriers. *Salmonella* was also isolated from 3.1% of food handlers in Gonder (Garedew-Kifelew *et al.*, 2014). Salmonella serovars isolated from food of bovine origin showed high resistance to cephalothin, Chloramphenicol, tetracycline, gentamicin, streptomycin and sulphisoxazole (Sibhat *et al.*, 2011; Abebe *et al.*, 2014). Salmonella isolated from milk and milk products also showed high resistance to Tetracycline and ampicillin (Liyuwork *et al.*, 2013) and to Sulphamethoxazole, Erythromycin, Spectinomycin, Streptomycin (Abraham *et al.*, 2013).

Listeria monocytogenes (*L. monocytogenes*) were detected in 5.6%.milk and milk products (Seyoum *et al.*, 2015) and 6.25% of meat and meat products and a higher resistance rate was recorded for penicillin, nalidixic acid, tetracycline and chloramphenicol, (Garedew *et al.*, 2015). *L. monocytogenes* was detected and isolated mainly from raw milk (13%) and liquid whole egg (4.3%) followed by raw beef (2.6%) and cottage cheese (1%) *(Gebretsadik et al.*, 2011). Globally, listeriosis has in general a low incidence but a high case fatality rate in humans.

Campylobacter jejuni and *Campylobacter coli* cause acute diarrheal diseases in humans worldwide, they mostly manifest themselves in an apparently healthy carrier state in other mammalian species and its presence in chickens is a significant risk for zoonotic infection. In Jimma area, thermotolerant Campylobacter species have been detected in chickens (68.1%), pigs (50.0%), sheep (38.0%) and cattle (12.7 %). Among the isolates, 70.3% were identified to be *C. jejuni* , 26.6%) were *C. coli* and 3.1 % were *C. lari* (Kassa *et al.,* 2006). All of the strains were found resistant to cephalothin (Kassa *et al.*, 2007).

Escherichia coli O157:H7 (*E. coli* O157:H7) is now recognized as a major cause of diarrhea, hemorrhagic colitis and hemolytic-uremic syndrome worldwide. Consumption of raw or undercooked meat of bovine origin has been the most common means of transmitting this organism. *E. coli* O157:H7 were isolated from 4.2% of meat samples *(*Adem *et al.*, 2008). *E. coli* O157:H7 was isolated from goats in the Somali region of Ethiopia and found resistant to erythromycin, ampicillin, and nitrofurantoin (Dulo *et al.*, 2015). The isolation of multidrug-resistant *E. coli* O157 from goats from a remote pastoralist system highlights the need for national action on regulating and monitoring antimicrobial use in both human and animal populations (Dulo *et al.*, 2015).

Previous and current zoonosis and food safety researches have been focused, most of the time, on detection of pathogens. Whereas, research on zoonosis and safety of foods of animal origin should also focus on earlier risk analysis at different food production chains and communicating the research findings to the public for awareness. The isolation and detection of antibiotic resistant microbes both in meat and milk products imply that the risks associated to consumption of these foods is of beyond our imagination and poses a significant public health risk. Thus, strategies and policies that enable prudent use of drugs both in humans and animals has to be designed and implemented in Ethiopia.

Production diseases: African animal trypanosomiasis (AAT), helminth parasites, ecto-parasites, mastitis, and some bacterial and viral disease are common in animals. These diseases impacts the production and productivity of animals due to their high morbidity and mortality. Some of these disease could be mitigated by changing the livestock production systems and their environments. But in this paper, only few of the most important production diseases have been selected for discussion. This doesn't mean that disease which aren't discussed here don't have a negative impact in animal production of the country.

In Ethiopia, while tsetse- borne trypanosomosis is excluding some 180,000 to 200,000 km^2 of agriculturally suitable land in the west and south west of the country, 14 million heads of cattle, an equivalent number of small ruminants, nearly 7 million equines and 1.8 million camels are at risk of contracting trypanosomosis at any one time (MoARD, 2004). In cattle alone, AAT is estimated to cost the sub-Saharan African economy billions of U.S. dollars annually (d'Ieteren *et al.,* 1999). Trypanocidal drugs are expensive and may be rendered ineffective by drug resistance, vector control can be environmentally damaging and difficult to maintain, and there is no vaccine for AAT. In consequence, despite a century of research, AAT still ranks among the country's more serious livestock diseases.

The burden of livestock parasites on communities living in developing countries ultimately contributes to chronic malnutrition, greater human disease burdens, and decreased productivity of both humans and livestock (Rist *et al.*, 2015). In the Ethiopian cattle, sheep and goat populations, the overall prevalence of ecto parasite is generally high which may result in enormous economic losses through decreased production and productivity, damages to the skin and hides, and deaths of the animal (Hagos *et al.,* 2013; Kemal and Terefe, 2013; Amare *et al.,* 2014). Even in backyard chickens, diverse fauna of ectoparasite with a significant prevalence rate have been reported (Zeryehun and Yohannes, 2015). Internal parasites like *Fasciola, Eimeria, cryptosporidium*, (Ayana *et al*., 2009; Luu *et al.*, 2013; Gebru *et al.*, 2014); cestodes, trematodes and nematodes (Ameni *et al.,* 2001; Regassa *et al.,* 2009; Asmare *et al.,* 2016) are predominant and responsible for the production loss and death of animals.

With the emergence of intensive urban and peri urban dairy production systems, the incidence of dairy cattle mastitis has been increasing. In some areas a bovine mastitis prevalence rate of up to 80% have been reported (Tamirat and Getu, 2014). Wudu *et al*. (2008) and Awoke (2015) also reported higher rate of Young Stock mortality and morbidity caused by different livestock diseases.

In general, almost all of the current animal health research efforts has been focused on describing the type, and distribution patterns of these and other pathogens. Whereas, the research should have been focused towards solving the existing disease burdens in livestock and planning mitigation options for the other emerging diseases which may appear unexpectedly. To prevent production disease except AAT, research should focus on farm biosecurity, development of effective veterinary service delivery systems and improvement of general animal husbandry practices. In general, a dynamic animal health research that best fits to the evolving production system is required to mitigate the existing and other emerging animal production related diseases. For AAT, research should focus primarily on controlling the insect vector without compromising the environment and for mechanically transmitted trypanosomiasis, an effective parasite control program has to be designed.

Development of animal health technologies

Animal health technologies like diseases surveillance and risk analysis systems, diagnostic and detection systems, vaccines, drugs, animal and product tracking systems play a crucial role for the control and prevention of diseases and also assuring the safety of foods of animal origin. These technologies, in spite of their global use, the extent of their utilization in Ethiopia is meager and the previous and existing research focus on the development and/ or adoption of such technologies have also been slow. In Ethiopia, the efforts made so far for development or utilization such technologies is presented below.

Animal trypanosomiasis and Tse tse control technologies: In Ethiopia, to control and gradually eradicate AAT, different efforts have been made in the past couple of decades. Some reports (Girmay *et al.*, 2016) indicate that, in some areas, Community-based tsetse fly control significantly reduces fly density and trypanosomosis prevalence. In some areas, medicinal plants used for the prevention of animal trypanosomiasis have also been identified (Shilema *et al.*, 2013). Some local cattle breeds (Sheko) relatively tolerant to trypanosomiasis infection have been identified (Lemecha *et al.*, 2006; Stein *et al.*, 2011). Other than these findings, information on technologies generated or adopted in Ethiopia for controlling AAT are limited. This suggests that, though AAT is highly prevalent in most part of the country, the research focus has been only on epidemiological studies rather than developing technologies that could control the Tse-tse vector or the Trypanosoma parasite.

Veterinary vaccine development: Vaccination remains the most viable alternative for controlling livestock diseases. Vaccination strategies have been responsible for the control and eradication of some of the deadliest diseases in human and livestock populations. In Ethiopia, veterinary vaccine research has begun 3 decades ago (Thiaucourt, 1988). Vaccine development efforts for FMD (Ayelet *et al.*, 2013), rabies(Ayele *et al.*, 2001; Hurisa *et al.*, 2013) and PPR (Silva *et al.,* 2014) have been reported. But data on veterinary vaccine development against other many endemic diseases is still lacking in the country. Many of the diseases responsible for animal mortality and morbidity don't have a vaccine in Ethiopia. Thus, vaccines for 7 bacterial diseases and 9 viral disease are the only veterinary vaccines available at the national veterinary institute (NVI), which is the only vaccine manufacturer and supplier of the country (MoA, 2011). This all indicates that the success of veterinary vaccine development and adoption haven't been encouraging and more remains to be done.

Diagnostics: Most of the existing methods for the diagnosis of livestock disease have a number of limitations, such as the inability to distinguish mixed-species infections, time consuming, expensive, a heavy reliance on technical experience and also sub-sampling errors. These limitations might be solved through the development of improved diagnostic assays. In Ethiopia, a documented evidence of previous research attempts on the development of improved diagnostic assays for animal diseases is lacking. The existing evidence indicate that research on diagnostic assays are focused on the comparison of already developed diagnostic technologies or methodologies elsewhere (Ameni *et al.*, 2010; Aylate *et al.,* 2013; Biadglegne *et al.,* 2014). Thus, research on development of improved disease diagnostic/detection tools has to be given priority in the national animal health research agenda.

Improved drugs: Drugs are routinely used as a prophylaxis and treatment against many disease conditions of animals and humans. In this process, some diseases may develop resistance mechanisms to the existing drugs which will gradually lead to drug failure. Failures during antimicrobial therapy may also occur when the pathogenic microorganism is unknown and combination of two or more drugs administered empirically. To mitigate this, globally, there are ongoing efforts on the discovery and synthesis of new drugs with broader antimicrobial spectrum, stronger action and more satisfactory safety profile (Vitomir *et al.*, 2011).

In Ethiopia, evidence on drug use both in animals and humans is scarce but some of the fragmented reports (Beyene *et al.,* 2015) have already indicated the absence of rational use of drugs both in human and animals. Among the animal-patients admitted to veterinary clinics found in Bishoftu town , only 57 % of the prescriptions were written adequately, 43 % incorrectly prescribed and from the adequately specified prescriptions, 96.6% of the cases were tentatively diagnosed without any laboratory confirmation (Beyene *et al.*, 2015). From this, it's easy to infer what happens in other areas of the country where access to veterinary services and related infrastructures are limited.

Although large-scale studies on drug resistance in Ethiopia have not yet been conducted, in animals, drug resistance has been reported in trypanosomiasis (Chaka and Abebe, 2003; Miruk *et al.*, 2008), Salmonellosis (Abraham *et al*., 2013; Liyuwork *et al.*, 2013), *Escherichia coli* (Dulo *et al*., 2015), *Campylobacter* (Kassa *et al.*, 2007), *Listeria monocytogenes* (Garedew *et al.,* 2015), *Staphylococcus aureus* (Daka *et al*., 2012), helminth parasites of small ruminants (Kumsa and Abebe, 2009) and cattle ticks (Regassa and de Castro, 1993). Oxytetracycline, penicillin and streptomycin combination, sulfa drugs, and albendazole, ivermectin, isometamidium chloride, diminazene diaceturate are the most commonly used veterinary drugs in the country (Miruk *et al*., 2008; Beyene *et al.,* 2015). In humans, the available reports indicate that antibiotic resistance rate is increasing among pathogens such as Escherichia coli, Shigella spp., Salmonella spp. and Staphylococcus aureus to commonly prescribed antibiotics, including ampicillin, amoxicillin, penicillin, tetracycline and trimethoprim/sulfamethoxazole (Moges *et al.*, 2014). This is a clear indicator of the seriousness and complexity of the drug resistance state of the country.

To address the emerging drug resistance problems, judicious use of drugs both in animals and humans is strongly recommended and again research on the development of an alternative drugs and designing a system that can enable minimum use of drugs especially in food producing animals should be given priority. To this end, programs on development of alternative veterinary drugs or treatment options haven't been designed so far. On the other hand, some reports (Yineger *et al.,* 2007; Berhane *et al.,* 2014; Yigezu *et al.,* 2014) have already indicated the presence of different plant species traditionally used for treatment of animal disease in different communities of the country. But these valuable ethno veterinary practices haven't been yet evaluated, validated and used scientifically.

Animal health research in wild and companion animals

There are many pathogens that can live in harmony and could easily be transferred among different animal species. Thus, many of the disease that affect livestock and even humans can also infect pet animals and wild animals. Pet and wild animals could in turn serve as a reservoir of disease. Pet-associated infections can significantly affect the health of humans (Morrison, 2001). As humans have an intimate relationship with pets, the risk and exposure level of contagious pathogens of pets to humans is higher than ever.

For many reasons, the health of wildlife is of a major concern throughout the world. Apart from important influences on the health of many wildlife species, infectious diseases of wildlife have significant impacts on public health and health of livestock. Foxes and other wild canids are responsible for maintaining zoonotic agents, e.g. *Echinococcus multilocularis,* as well as pet-relevant pathogens, e.g. *Hepatozoon canis*. Together with the canids, and less commonly felids, rodents play a major role as intermediate and paratenic hosts. They carry viruses such as tick-borne encephalitis virus (TBEV), bacteria including *Borrelia* spp., protozoa such as *Toxoplasma gondii*, and helminths such as *Toxocara canis*(Yabsley and Shock, 2013; Duscher *et al.,* 2015). In dogs, a higher prevalence of helminth parasites such as *Neospora caninum, Ancylostoma spp, Dipylidium caninum, Toxocara canis, Strongyloides stercolaris, Echinococcus granulosus, Trichuris uulpis, Taenia* spp and *Toxoascaris leonine w*ere identified in Ethiopia *(*Zewdu *et al.*, 2011; Asmare *et al.*, 2014; Merga and Sibhat, 2015). Many of these parasites have more than one host and could infect other animals and humans causing a serious economic and public health impact. In Ethiopia flea infected by Rickettsia and Bartonella, emerging zoonotic diseases worldwide, have also been isolated from dogs and cats (Kumsa *et al*., 2014). In cats, high prevalence (24%-75%) of *T. gondi* was reported from Addis Ababa, Ethiopia (Dubey *et al*., 2013; Tiao *et al.*, 2013). Furthermore, the role that wild and feral animal populations might play in the incursion and spread of important transboundary animal diseases, such as foot and mouth disease is higher than expected.

Flagship rare endemic species such as the mountain nyala (*Tragelaphus buxtoni*) and the Ethiopian wolf (*Canis simensis*), a critically endangered canid, may be at risk for BTB (Tschopp *et al.,* 2010). Moreover, with evidence of rabies, canine distemper virus, canine adenovirus and canine parvovirus infections in sympatric domestic dogs and Ethiopian wolves, canid diseases clearly pose a significant threat to the future persistence of the Ethiopian wolf population (Laurenson *et al.,* 1998). Consequently, other reports on the Ethiopian wolf showed severe decline in number between 1989 and 1992 due to rabies epizootics(Stephens *et al.,* 2001). On wild animals, research on prevalence and conservation impacts of diseases should be a priority. Thus, broader and longer-term studies should be conducted to further describe and comprehend disease dynamics among livestock and wild animal populations.

As a mitigation option, sustainable control of zoonotic and transboundary animal pathogens in wildlife, all measures that aim to prevent infection in humans and livestock species or that encourage us to avoid infectious contacts with wildlife should be recommended (Artois *et al.*, 2011). Furthermore, effective veterinary research and disease surveillance is essential for formulating control strategies and this depends critically on the development and application of methods of disease diagnosis which are both accurate and rapid.

Challenges and Future prospects

Key research challenges include controlling transboundary animal disease, food-borne and zoonotic pathogens and drug residues and evidence-based companion animal medicine and its translational applications to human health. Meeting these challenges will require cross disciplinary collaborations and significant national research investment (Christopher, 2015). To address these challenges, an institutional or corporate research and product development should focus in improving or developing animal health products- improved vaccines and drugs, diagnostic kits, laboratory equipment, risk analysis systems, cutting-edge epidemiology tools, and more (Burgos and Otte, 2009).

The use of vaccines and diagnostic tests are a key disease control component as they have the potential to support control and eradication and to be highly cost-effective. At present, there are no antiviral medicines for use against the major viral diseases of animals. Consequently, vaccines and diagnostic tools are often the only solution available for control. Although subunit vaccines offer many theoretical advantages, our lack of understanding of immune mechanisms to primary and secondary infection and the capacity of many protozoa to evade host immunity remain obstacles to developing effective vaccines (Jenkins, 2001). Furthermore, recent disease outbreaks have highlighted the necessity for not only producing new vaccines but also for improving existing vaccines and providing marker vaccines. And again, as an effective vaccine for most of the parasitic diseases of animals is lacking, new and improved vaccines are required for a range of major animal diseases including parasitic diseases.

The other emerging challenge is, some bacterial and parasitic pathogens have already been proven resistant to the existing antimicrobial and anthelmintic drugs (Holden *et al.*, 2009; Singh *et al.*, 2010; McNair, 2015). Thus, to mitigate animals from mortality and morbidity and human food safety risks caused by many parasitic and bacterial infections, new animal treatment options has to be developed. In addition, improved diagnostic tests must be developed to enable the early diagnosis and detection of outbreaks along with tests to demonstrate the effectiveness of control programs.

The development of new pharmacological or biocidal solutions to the containment and control of disease outbreaks also needs to be considered. There is an urgent need to boost research with effective funding so that new or improved veterinary medicines — vaccines, pharmaceuticals and diagnostic tests can be delivered. The need to develop innovative and better tools to control disease is now more critical than ever. Thus, due emphasis should be given on development of animal health technologies that could help detect pathogens early, prevent diseases before their onset, treat effectively when animals are affected and predict animal health risks.

Thus, to realize the development of livestock industry by exploiting its huge natural resources, Ethiopia has to focus in unlocking the bottle neck of livestock production and international trade mainly imposed by animal diseases. Future animal health research in Ethiopia should focus on development of technologies that could help control animal diseases and mitigate associated public health risks. As animal health research is complex in its nature, researches should not only focus on livestock disease and but also has to address the interconnected nature of some diseases occurring both in domestic and wild animal species as well as in humans.

Conclusions

Given the fact that animal diseases impose a high impact on society in terms of lost production due to endemic diseases, international trade ban on livestock products, extremely high costs due to epidemic diseases and an ongoing public health threat due to zoonosis, investment in animal health research is needed than ever. Animal health research is critical for the development of evidence-based policies and the introduction of legislative measures to govern disease surveillance, prevention, control and eradication strategies. These policies must be based on the best scientific evidence. To realize the livestock development goals of the country, the national agricultural research system, particularly EIAR has to give due emphasis on development of animal health research technologies and scientific evidences that could best fit to the existing and emerging future needs.

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Role of Research in the Transformation of Pastoral and Agro-Pastoral Systems in Ethiopia

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Introduction

Global overview of the pastoral and agro-pastoral production system

Various definitions have been given to pastoralism based on disciplinary focus: socio-cultural, ecological or economic perspectives. Swift (1988) and Niamir-Fuller (1999) defined pastoralism and agro-pastoralism economically, while Baxter (1990) defined it culturally and some others (Blench, 2001; Davis and Nori, 2008) ecologically (the use of natural resource, grazing & wateringsystems). Pastoralism is an extensive livestock production system with herd mobility and flexible arrangements regulating access to resources. It covers about 25% of the earth's land area, and has persisted for centuries (FAO, 2001; WISP, 2009). It is composed of three broad subsystems, including economic resource (livestock production), ecology (water and pasture), and social and institutional sub-systems (institutions and governance systems with norms and rules). Thus, pastoralism is a way of life involving ecological, political, economic, technological, cultural and social dimensions. It supports some 200 million pastoral households globally with herds of nearly a billion head of animals (camel, cattle, and smaller livestock) and generates valuable products (protein of milk & meat, fibres) from marginal lands.

The Ethiopian context

The pastoral production system in Ethiopia is wide spread and the major pastoral areas are the Somali, Afar and the lowlands (Borena) of Oromia regions, where the majority of the pastoralists are referred as Somalis, Afar and Borana (comprising 90% of the pastoral population). The remaining (10%), 26 groups are scattered in micro-territories, mainly along the southern, Gambella and Benishanguel regions. They rely on a grazing area of about 545,100 km^2, almost equal to 89% of the total land mass of the pastoral areas (Beruk, 2008). The system is highly diversified and has three complexes. The browsing complex covers 50% of the total rangeland area of the country and is located in Somali and Afar regions, where the dominant animals are goats and camels. Parts of Afar, Oromia, Somali and South Nations Nationalities and People (SNNP) States, grouped as grazing complex and cover 35% of the total rangeland area of the country arebased on raising cattle and sheep. The flood land pastoral complex located in western Gambela region, where cattle herds used to graze on the area after the seasonal floods of Baro River, covers 15% (PADS, 2005). In spite of the importance of the system in the economic, social and political arenas of Ethiopia, it has not been in the main agenda of agricultural research system up until the late 1990s and early 2000s where more involvement of research and development institutions established for pastoral and agro-pastoral systems in different parts of the country. Thus, the purpose of this review is to document the role played by research in the transformation of pastoral and agro-pastoral systems in Ethiopia during the past 50 years.

Pastoral and agro-pastoral production (PAP) systems in Ethiopia

Area coverage, human and livestock population

Most pastoral areas are found around the periphery of the country, almost surrounding the central highland mass and most of which are located in the east, northeast, southeast, and southern parts of the country. Reports indicated the area covered by pastoral and agro-pastoral areas to be 61- 67% of the total land area (PADS, 2005). Pastoral and agro-pastoral communities are about 12 million people belonging to 29 ethnic groups in 7 regions of the country (Beruk, 2008), and possess about 27% of cattle, 67% of goats, 26% of sheep and almost 100% of camels of the country (WISP, 2009). Exact figures differ with time and locations (Table 1).

Table 1. Data sheet of Ethiopian's pastoral regions

Region	Total surface of the region	Pastoral Areas only	Pastoral Districts	Population of 122 pastoral Districts	Livestock of 122 Pastoral Districts	Livestock density
	Km^2		Number	People	TLU	TLU/Km^2
Afar	90400	90,400	29	1,301,000	621,300	7
Benshanguel&Gumuz	48,290	8,410	3	40,640	10,100	1
Dire Dawa	1,200	1,200	1	108,570	39,200	32
Gambela	25,000	17,330	5	133,000	288,900	17
Oromiya	325,00	152,040	34	4,007,950	4,996,300	33
SNNP	112,340	30,370	6	219,670	693,900	23
Somali	325,070	325,070	44	4,002,170	2,533,300	8
Total	956,030	624,880	122	9,813,600	9,183,500	16

Source: PADS (2005)

Physical characteristics of pastoral areas

Climate: Most of the pastoral and agro-pastoral areas are characterized by arid (64%), semi-arid (21%) and dry sub-humid (15%) environments (EPA, 1998; Alemayehu, 2006), with high spatial and temporal variability of rainfall distribution and pattern (Adugna and Aster, 2007), hot temperature (annual mean temperatures ranging from 20 to 25°C) and high evapo-transpiration. The most important uni-modal rainfall system is to the extreme north and northeast of the country (Afar) where the precipitation ranges between 200 and 600 mm. The other unimodal system, referred to as the 'Sudan type' has an annual delivery of 800 to 1,200 mm, which occurs in the western lowlands along the Sudan border (Gambella and Benishangul). The bimodal system occurs in the Ogaden, Borena and extreme south-West (SNNP), where the annual rainfall ranges between 250 and 750 mm (Kidane, 2006).

Soil, landscape, topography: Soils are diverse and types are widely scattered; usually shallow, although deep alluvial soils may still occur in river valleys. The shallow soils are drought sensitive due to limited water holding capacity. The soils in the valley bottoms and flat plains are dominantly vertisols, while in the undulating to gently rolling plateau Luvisols, Nitosols and Acrisols are common types (Kidane, 2006). Landscape and topographyvaries from place to place due to variations in vegetation and soil type (Oba and Kotile, 2001); may also include climatic, topographic and edaphic factors in the broader sense (Coppock, 1994). It is mostly flat and below 1500 masl (Alemayehu, 2006).

Vegetation, wildlife and water resources

The natural vegetation of the dry land areas varies from dry woodland and grassland savannas totrue desert plant communities. It includes forest thicket, mixed forest grassland formations(woodland, wooded savannah, tree and shrub savannah and steppes), grass and steppe althoughseverely degraded (Alemayehu, 2004). The lowlands are not only home for these communities but also for wide variety of flora and fauna. The country as a whole has 277 species of mammals (out of which 31 are endemic) and 861 species of birds (out of which 23 are endemic). Out of the 23 endemic bird species in the country, 19 species are in the lowland (Beruk, 2008). Almost all national parks are situated in the lowlands with the exception of Bale and Simen mountains. These national parks, sanctuaries and reserves make the rangelands of Ethiopia, a considerable base of an expanded Eco-tourism.Six major rivers- Awash, WabeShebele, Genale-Dawa, Omo, Baro and Blue-Nile- furrow the rangelands, spreading in 30,000 km^2 of fertile floodplains in pastoral lowland areas.

Importance, challenges and opportunities of the production system

Importance of PAP system: The pastoral and agro-pastoral (PAP) system in Ethiopia is predominated by extensive pastoralism and to a lesser extent by agro-pastoralism. Pastoralism is the source of employment for 12% of the population and it is potential resource for capital investment and savings. A study by IGAD (2011) estimated the total economic value of livestock in the production system to be 113 billion birr with unofficial cross-border trade of 138 billion birr in 2008/09 and about 90% of the export of live animals comes from PAP areas (Aklilu*et al.*, 2013). In PAP system, livestock are the primary source of food (milk, meat and blood) and cash income for the households. Their agro-ecologies provide opportunities for promoting livestock development activities in the form of ranching, feedlot finishing, slaughtering and processing.Theyare also centers of genetic diversity of faunas and floras(Beruk, 2008).These areas are source of minerals, gums and resins to fetch good foreign currency exchange for the national economy, and are also of prime interest for archeological and socio-anthropological studies (Abule and Alemayehu, 2015).

Challenges (major problems) in PAP system

Drought, climate change and variability: Periodic drought is a common phenomenon globally and a characteristic of the arid pastoral production system. Currently, drought has been more pronounced and its frequency has become short recurring every 2 to 3 years in Ethiopia (Beruk, 2008). Ithas brought about significant effects resulting in the decline of rangeland resources, productivity and survival of livestock (Abule *et al*., 2011)that eventually caused changes in the size and composition of livestock herdsin affected areas (Desta, 2002). In severe cases, it resulted in widespread disruptions of food supply and emigration owing to loss of livestock and other factors (Beruk, 2008; Abule *et al*., 2011;Flintan*et al*., 2013).Kassaye (2010) reviewed the major flood incidences that occurred during the 1960s, 1970s and 1980s in Somali,Afar and SNNPregions,and also in 2006, 2007 and 2008 in similar regions, which affected livelihood of thousands of households and their resource basis. Currently, the global climate change is raising new challenges for livestock herders in pastoral and agro-pastoral areas although its effect is expected to be more visible in the futures (Wu and Topp, 2008).

Bush encroachment and other invasive plants: Bush encroachment is the process of open grassland savannas being transformed into thick bushes (Barnes, 1979) and is one of the major problems (Coppock, 1994; EARO, 2001, 2005) in pastoral areas. The lack of prescribed burning, accompanied by severe overgrazing, and the expansion of farming in the dry-land were among the main problems associated with bush encroachment in Borana rangelands.There are no accurate data as to the area covered and amount of encroacher plants in the Afar region, however, rapid expansion of*Prosopilisjuliflora (an estimated areas of 20,000 hectares), Acacia seyal, Acacia melifera*as well as *Acacia senegal* are major concerns (Beruk, 2008). Currently, the rapid expansion of *Parthenuimhysterophorus*commonly known as “congress weed” is another threat encroaching in both the rangelands and crop farming areas.

Contraction of the pastoral territories: Beruk (2008) reviewed the losses of pastoral land to other non-pastoral land uses in the PAP areas of Ethiopia. Over a 60-year period, the pastoral areas lost about 2.6 million ha of their prime grazing territories to other non-pastoral uses includingrain fed agriculture, irrigated agriculture, national parks and etc in Afar, Somali, Borana, South Omo, Gambellaregions. These changes may have displaced 2.6 million breeding cattle (equivalent to about 1.8 million TLU),posing significant impact on the lives and livelihoods of pastoral households and their environm

Human and livestock population increase: As compared to neighboring east African countries, human population in Ethiopia has increased substantially since the 1960’s. Increased demand for livestock products is evident in developing countries owing to rapid population growth, urbanization, income growth and the increased production is also associated with increase in animal numbers which is also true for Ethiopia (Thornton, 2010). Exacerbated by land use changes (increasing size of crop land and declining grassland size and productivity), population growth has been another challenge in the development of pastoral areas.

Conflicts, weakening traditional pastoral system and others: Conflicts of different kind (inter and intra clan) and weakening of the traditional pastoral system is very evident in Ethiopia (Abule and Alemayehu, 2015). The other major problems associated in this regard include the lack of adequate knowledge of the PAP production system, shortage of appropriate research technologies and extension services, shortage of qualified manpower and facilities. Although there are some improvement recently, inadequacy of basic social services, infrastructure and communication facilities,poor veterinary and market services in terms of area coverage, manpower and facilities as well as lack of appropriate land use plan are also bottlenecks to the system.

Opportunities

Though the PAP system inculcates numerous problems, there are still opportunities and potentials that can be utilized to improve production/productivity of the system and livelihood of the communities. The government is taking measures that indicate the concern towards the welfare of the pastoralists, by establishing standing committee representing the pastoralists in the federal parliament (house of people), issuing proclamations regarding pastoral welfare (Beruk and Tafesse, 2000), establishing the pastoral commission in different regions, the opening of many colleges and universities and the establishment of research divisions in the national research system. The presence of many non-government organizations in PAP areas and the establishment of the Ethiopian Pastoralists Forum is also an added opportunity.

Major pastoral development efforts in Ethiopia: past and present

The Borana Rangeland Pilot Project: The project was initiated in 1965 with the aim of improving rangeland use efficiency through pond construction and controlled grazing. The project area covered about 2 400 km^2 of the rangelands near Yabello (Borana). This project attracted settlement around the new water points (overgrazing).

Drought in northern Kenya also led to the migration of Kenyan Borana pastoralists into the project area and the collapse of the rotational grazing program. Furthermore, there was little local support for the project (Solomon, 2002).

Second Livestock Development Project (SLDP): The World Bank funded the SLDP as of 1973, which was executed in Jijiga areas. It was initiated to develop an integrated market and stock route system in order to improve livestock off-take rate. The SLDP created some infrastructure that contributed to the opening up of pastoral areas and facilitated the expansion of livestock marketing. This project did not take into account the traditional stock routes, which would have been successful otherwise (Solomon *et al*, 1991; World Bank, 2001).

Third Livestock Development Project (TLDP): TLDP was established in 1975 with blended fundingfrom World Bank, International Foundation for Agricultural Development (IFAD) and African Development Bank (ADB). It was the first large-scale development project and sponsored studies (research) in the Borana, Afar and Somalia rangelands, implemented by the International Livestock Center for Africa (ILCA) (World Bank, 2001). The project was meant to rehabilitate and develop the three areas through its sub-units namely, North East Rangeland Development Unit (NERDU), Jijiga Rangeland Development Unit (JIRDU) and Southern Rangelands Development Unit (SORDU). The project had the most pronounced impact on pastoral area development and continued to provide services with funding from the Ethiopian Government until 1996 (World Bank, 2001).

Fourth Livestock development project (FLDP): In 1989, the FLDP funded by IDA, provided support to SORDU project where the objectives were to improve feed and food security of the pastoralists and their livestock, and to increase income and livestock off take. The project resulted in the creation of service cooperatives, the transfer of fattening ranches to these cooperatives, the construction of roads and maintenance of wells, the training of pastoralists in primary animal health care and the development of a range monitoring system. Persistent security problems, however, limited the attainment of the targeted objectives. The FLDP, though promising, collapsed as a result of the Ethiopian political turmoil in 1990 (Alemayehu, 1998). In general, according to PADS (2005), previous development efforts were not participatory, had no monitoring and evaluation components and had little regard to the cultural and economic differences between the regions.

Pastoral Community Development Project (PCDP): The PCDP project has been planned for 15 years divided into 3 phases of five years each; and the first phase was begun in 2003. It is funded by the World Bank, IFAD and the Ethiopian government. The aim of the project is to establish effective models of public service delivery, investment, and disaster management that address pastoral communities' priority needs, improve their livelihoods, alleviate poverty and reduce their vulnerability. It has a people-centered, holistic approach and gender participation. It has contributed to the improvement of the social and economic welfare the pastoral and agro-pastoral communities (PCDP, 2007).

Research in pastoral and agro-pastoral systems of Ethiopia

Brief historical background to research in PAP system: The first coordinated rangeland research program particularly in pastoral areas of Ethiopia was initiated in 1976-77 by ILCA and TLDP, which continued until 1985 (Getachew *et al*., 2004). These areas attained further attention by the government in the early and mid-1990s through the establishment of pastoral development departments and units at federal level which led to the emergence of pastoral development bureaus at region level. More involvement of national research and academic institutions appeared to the verge of the millennia where Institute of Pastoral Studies was launched at the then Alemaya University, Dryland Research Program started at Ethiopian Agricultural Research Organization, and Pastoral Research Institutions emerged in pastoral areas of Oromiya, Afar, Somali and Gambela regions (Solomon, 2006).

Research actors in PAP production system: Currently, major research actors in pastoral and agro pastoral system of the country include national agricultural research institutions (comprising the Ethiopian Institute of Agricultural Research and Regional Agricultural Research Institutions), national higher learning institutions and international research/development institutions and organizations (Fasil, 2010;Afework, 2015), despite limitations in their capacities and integration for meeting the desired goal to these areas, communities and their environments so far. Within the national agricultural research institutions, about 16 research centers (3 of the EIAR and 13 of the RARIs) are located in pastoral regions and most of them engaged in multiple field of research programs including crop, livestock, natural resources (soil, water, rangelands), agricultural economics and extension as well as agricultural mechanization in few cases (EIAR, 2015). The number of higher learning institutions working on pastoral issues has increased gradually over the last decade. Haramaya University was the first of all to have separate department of PAP studies (HU, 2013). Despite limited research experiences, the new Universities have been playing roles in the development of pastoral areas through education, training, community services and research. Moreover, local and international non-governmental organizations have also showed increased commitment in addressing such areas through research or development at better scale in recent times than earlier (http://www.slideshare.net/ILRI/ilri-sdc-visitjul2015).

Major studies conducted in PAP systems

There are many studies undertaken in line with livestock production, rangeland management, institutions and local practices in PAP systems as well as many other issues in Borana, lowlands of Bale, Kereyu-Fantale, western Hararghe, Afar region, the Somali rangeland; the lowland areas of Southern Nation, Nationality and People's Region, Gambella and lowlands of Tigray. Nevertheless, the authors reviewed documents to which they had access to and were not fully exhaustive in specific issues.

Livestock production and management studies: Livestock, being the major resource of the PAP system, has been primary focus of agricultural research by research actors of the system, regardless of the purpose, range and depth of the studies which greatly vary across regions or areas within regions. In general terms, most of these studies attempted to grasp baseline information on existing livestock production systems, husbandry practices, species identification and characterization, market conditions and marketing practices, types of livestock diseases and parasites, commonly found in specific areas (localities, woredas or zones) of a certain region (Gebru*et al*., 2004). Though fragmented, several studies have also looked into improvement options (breed, feeds and nutrition, health) for particular livestock species and/or type of breed for specific purpose (meat or milk production, or reproduction); most of which have ended up with bulk of information but also with limited outputs that hardly benefited the larger pastoral or agro-pastoral community. Reviews of some livestock studies in PAP areas and their findings are discussed here under.

Herd composition, herd size and livestock holding: Most studies in herd structure (livestock species, herd size and holdings) concluded that the compositions of livestock species vary among pastoral areas (Adugna and Aster, 2007; Yohannes*et al*., 2007; Yayneshet and Kelemework, 2004) even though most PAP communities keep multiple species and multipurpose stock including camels, cattle, goats and sheep. The male to female ratio is systematically managed in such areas, where female dominating herds are quite common in all (Coppock, 1994). This is due to predominance of livestock management strategy towards risk minimization (PPACC, 2010), which again may depend on the nature of local environment and its resources (Natnael*et al*., 2014; PPACC, 2010). In addition, regional herd size and livestock holding per household was reported different for different livestock species among major pastoral areas (Table 2). Larger herd size was reported for Boranna area as compared to Afar and Somali (Yayneshet and Kelemework, 2004).

Table 2. Livestock holding among southern (Borana), Somali and Afar pastoralists

Livestock species	Livestock holding (Mean±SD)		
	Southern*	Somali**	Afar***
Camels	9.8±9.6	17.4±4.3	6.0±1.0
Cattle	21.1±15.5	5.7±3.3	17.4±1.8
Goats	13.8±12.9	4.7±3	15.6±1.1
Sheep	9.5±9.7	1.9±0.2	12.0±1.3
Donkeys	1.2±0.8	0.4±0.4	0.74±0.1
Mules/Horse	0.09±0.3	0.02±0.01	0.02±0.02
Chickens	4.4±4.5	0.03±0	?

Source: *Adugna and Aster, (2007); **Yohannes*et al*, (2007) ***Philmon*et al*., (2016)

Feed resources and feeding management: The main feed resources of pastoral areas are natural pastures including herbaceous vegetation composed mainly of grasses and forbs and browses such as shrubs, tree leaves and pods (Adugna and Aster, 2007; Alemayehu, 2005). Seasonal variation in availability and quality of feed was observed based on variability of rainfall distribution across regions or localities (Adugna and Aster, 2007). In the view of feed resources management, livestock production in pastoral areas can be regarded as opportunistic management of the rangelands with mobile herds, with central strategy of herd size maximization due to uncertainty of forage and water availability (PPACC, 2010).

Breeding, reproduction and nutrition: Certain efforts were made in the past in improving breeds of pastoral livestock through cross breeding, particularly of cattle, because productivity in terms of milk production, growth rate and reproductive performance is generally low (Adugna and Aster, 2007). Nevertheless, crossbreeding did not lead to improvement of lowland cattle breeds under semi intensive management conditions (Dadi, 2003). It was not recommended for lowland grazing PAP systems due to shortage of feed and high temperatures in the lowland grazing areas (LMP, 2014). Studies on feeds and nutrition were also undertaken for different livestock species of PAP areas, though the outputs have not been utilized by pastoralists and feedlot operators.

Pastoral livestock marketing studies: Pastoral livestock has been not only means of livelihoods for pastoral communities of the respective regions, but also source of food and income to the rest of communities in the country, due to increasing trend of livestock trade off in and outside of these regions. This has brought inculcation of livestock market studies in the system, though it is not the sole reason per se. These studies generated information on livestock market and marketing practices, and have been taken up by development actors for intervention measures. Some are reviewed and discussed below. In economic terms, livestock are key economic assets of PAP communities than other resources (Kejela *et al*., 2005; PPACC, 2010), alternating between income generation and food diversification for livelihood improvement. For instance, pastoralists sell livestock and animal products (e.g., milk) usually to pay for basic needs such as medical care, veterinary services, food staples, household items and etc (PPACC, 2010; Kedija*et al*., 2008; Belachew and Jemberu, 2003). Findings of earlier studies also indicated challenges or gaps in pastoral livestock and products marketing. Most prevalent ones in this regard include poor market infrastructure, absence of market oriented livestock production system (Belachew and Jemberu, 2003, Ayele *et al*., 2003; PPACC, 2010), low level of quarantine procedures, repeated bans, and stiff competitions with outsiders (Belachew andJemberu, 2003). Aggravated by drought cycles and traditional production practices, the absence of a pastoral-friendly market system and structures was also mentioned among major challenges in this regard (Ayele *et al*., 2003;PPACC, 2010; Getachew *et al*., 2014).

Common livestock health problems: Due to poor management and environmental conditions as well as lack of proper disease control and prevention strategies, pastoral livestock suffer from different diseases and parasites frequently and widely. Diseases such as foot and mouth disease (FMD), anthrax, black leg, contagious bovine pleuropneumonia (CBPP), contagious caprinepleuropneumonia (CCPP) and trypanosomiasis are reported to be occasional health problems in pastoral areas, though prevalence difference from one another (Bekele *et al*., 2003; Adugna and Aster, 2007). Besides, external parasites, particularly ticks and mange mites were reported to be significant health problems in PAP areas (Adugna and Aster, 2007). Lack of awareness in zoonotic diseases and limitations in controlling them were also indicated in some areas, where possible risks of human health are anticipated at higher level (Angesom, 2015).

Rangeland ecology and management studies

Studies on rangeland and livestock management practices, rangeland condition and trend, rangeland degradation and suitability: Based on the number of documented research reports (published or unpublished) for this review work, rangeland ecology and management practices were the most extensively studied issues in pastoral areas as compared to other ones.Different studies in rangeland and range-livestock management practices were undertaken in Borana (Oba, 1998; Ayana, 1999; Solomon, 2003; Gemedo, 2006; Ayana, 2007; Getachew, 2007; Getachew*et al*. 2007; Abule, 2009; Fekadu, 2011; Mizan, 2011; CCAFS, 2013; Berhanu, 2014; YPDCRC, 2016); the lowlands of Bale (Teshome, 2006; Takele, 2008);some areas of Kereyu-Fantale (Schloeder and Jacobs, 1993; Abule, 2003; Getachew*et al*. 2004); western Hararghe (Mohammed, 2014), Afar region (Kidane, 2006; Zelalem, 2007; Yosef, 2008; Lemlem, 2009; Mohammed, 2009; Asheber, 2009; Diress, 1999, 2010); the Somali rangelands (Amaha, 2006; Belaynesh, 2007; Lishan, 2007; Shashe, 2007; Selam, 2008; Fikrete, 2008; Helen, 2009; Muhudin, 2009); the lowland areas of Southern Nation, Nationality and People's Region (Admassu, 2006; Muluneh, 2008; Gebre, 2011; Worku, 2011; Abule, 2012)as well as some areas ofGambella (Fasil, 2010) andBenishanguel (e.g., Fasil, 2010). Although there are variations among regions in terms of area coverage and extent of the studies, socio-economic and field level survey methodologies were commonly used for studying indigenous knowledge in range-livestock management practices; indigenous and scientific knowledge for ecological studies; assessment of woody and herbaceous plant species (in terms of quality/type and quantity/production and productivity); carrying capacity, livestock species as well as associated production practices and the like studies in the rangelands.Somestudies also included sub-habitat characterization; plant species palatability and desirability groupings; model based analysis of climate-livestock-rangeland interactions; analysis of land use/land cover change and ecosystem dynamics using GIS and remote sensing tools. Most of thestudies addressedidentification of livestock, feed and water resources and system of utilization. Some of the major findings of these studies are described below.

i. Declining rangeland condition and decreased grass cover and loss of biodiversity
ii. Importance of enclosures (e.g., herbaceous biomass production in enclosure= 1405 kg/ha and communal = 407 kg/ha) varying depending on the condition of the land
iii. Increasing bush encroachment (40 to 63% in Borana rangeland) (Gemedo, 2006; Ayana, 2007; Abule, 2009) in areas like Aydora open savanna and Hurso close savanna *Acacia nubica*and *A. mellifera*were aggressive encroaching species (Amaha, 2006)
iv. Variable woody vegetation cover (While there is an increase in the density of woody vegetation at Yabello the reverse is true for Gode) (Getchew*et al*., 2010; Muhdin, 2009)
v. Drought, aridity and rangeland degradation have increased over time due to environmental degradation and mismanagement of rangeland resources

vi. Expansion of invasive plants like *Partheniumhysterophorus, and ProsopisJuliflora*
vii. Livestock still is the backbone of the economy across the different pastoral regions
viii. Need for livelihood diversifications and rangeland rehabilitation is important

Studies on rangeland rehabilitation, improvement and technology promotion: Limited studieswere undertaken in the area ofrangeland rehabilitation and improvement optionslike re-seedingin few degraded rangelands, i.e., Borana (Yabello RC, 2015), Afar (Kidane, 2006) and Fantale(Abule *et al*., 2012) areas. Integrated use of biological and physical techniques (such as the use of local grass species and moisture conservation structures) were also examined anddemonstrated in some areas wheremulching was another option in restoring degraded rangelands(Kidane, 2006; Abule *et al*., 2012). In addition, collecting/ conserving, preserving and multiplying genetic materials of plant species has been recent effortsbeing undertaken byfederal and regional research institutions including the Ethiopian Biodiversity Institute (personal communication).

Soil seed bank studies: Soil seed bank plays a significant role in rangeland ecosystems where grasses account for a large part of the vegetation and their role is categorized into three major advantages. Firstly, it is the potential pool of propagates for regeneration of grasses after disturbance (Laura and Brenda, 2000). Second, the seed bank may reduce the probability of the population extinction of plants (Venable and Brown, 1988). Thirdly, it is also likely to be the major source of establishing above ground plant communities following environmental changes such as rainfall (Du Preez and Snyman, 1993). Based on these facts, limited soil seed bank studies have been undertaken in Somali (Amaha, 2006), Borana (Samuel, 2009), at Allideghe(Kidanie, 2010) and Fantale area (Abule *et al*., 2012). At Fantale, the results indicated that with regard to the species composition of the soil seed bank, most of them were less desirable species and the two vegetation layers were less similar. Similarly, Amaha*et al*. (2008) indicated that there is no adequate evidence to prove that severe degraded rangelands in eastern Ethiopia maintain adequate soil seed banks that would improve the condition of it through restoration. On the other hand, the study at Yabello revealed that within all study sub-habitats of each acacia, there were more grass species than the non-grasses, except under the canopy of *A. mellifera*and the open area of *A. brevispica*.

Studies on soil physical and chemical properties: Soil physical and chemical properties were also studied in Borana (Getachew*et al*., 2007; Samuel, 2009), in Afar (Kidane GM, 2006; Kidanie D, 2010), in Somali (Belaynesh, 2006; Selam, 2008; Muhdin, 2009) and around Kereyu area (Abule *et al*., 2007). The organic matter content of all land use/ cover types were very lower except for Dida Tuyura Ranch (5.42%) in Yabello and Arero districts of the Borana zone. The soil nutrient composition of the Erer district of the Shinile zone is low for plant growth and indicates a decline in the condition of the rangeland (Selam, 2008). Highest organic matter values were also observed in the enclosure grazing type 2.82% while the least figures observed in the riverside grazing land soils 0.95% in Gode district (Muhdin, 2009). A study by Kidane*et al*. (2006) at Alideghe revealed that there are soil differences in the grazing gradient caused by impact of grazing, particularly in the severely degraded area. A study by Abule *et al*. (2007) in the middle Awash revealed the nutrient status of soil under the canopies of trees to be higher than the open grassland, especially with regard to soil pH, total N and organic carbon.

Studies on ecosystem services/carbon sequestration and financing: In addition to provisioning, supporting and cultural services, rangelands provide regulating services such as climate regulation through carbon sink and source functions (MEA, 2005). Ecosystem services are mostly not remunerated (ADB, 2014) and much less attention has also been paid to the potential of incentive schemes in grasslands in developing countries like Ethiopia although Fund for REDD-plus embarked for forest protection (Dubale, 2010; Getachew, 2013). Grassland soils are very significant stores of carbon with global carbon stocks estimated at about 343 Gt C and tropical savannas have greater potential to store carbon below ground than any other ecosystems (FAO, 2010). Ethiopia has high potential for carbon sequestration potential and financing, however, very limited research activities were undertaken in relation to rangelands (Getachew, 2013). Woody species species-specific allometric models were developed to predict aboveground biomass (AGB) in Boran (Hasan *et al.*, 2013) and a study by Bikila*et al*. (2016) revealed enclosures (300.38 $tCha^{-1}$) to have higher carbon sequestration potential than communal rangelands (141.5 $tCha^{-1}$) and fire prescribed rangelands (184.93 $tCha^{-1}$) (Bikila*et al*., 2016). In general in developing countries like Ethiopia, the relationship between management practices and environmental services is often not well understood or easily quantified, and many schemes are based on assumptions about the flow of ecosystem services rather than payments for actual services delivered (ADB, 2014). Thus, improving the knowledge base for payment for ecosystem services (PES), developing mechanisms for PES, addressing issues of land tenure, linking public investments in livestock and rangeland management with environmental outcomes and involving communities are essential.

Studies on crop production: Generally, PAP regions have been considered less favorable for crop production due to lack of sufficient moisture with the exception of some irrigated areas. However, in areas where moisture is sufficient (either from rainfall or irrigation water), the national agricultural system has tried to generate or adapt few technologies to these areas either for large scale commercials or smallholder producers, most of which flourished in recent years. Summaries of these crop technologies are shown below (Table 3).

Table 3. Crop technologies adapted to pastoral areas

Cereal crops	Grain legumes	Oil crops	Forage crops	Horticulture	Others
Sorghum, Maize, Teff, Millet, Wheat, Rice	Common bean, Cow pea, Mung bean, Pigeon pea	Sesame, Groundnut	Grasses, legumes, browses	Fruits, vegetables	Cotton, cassava, potato, sweet potato
Sorghum: 26 for dry lowland, 3 for the wet lowland and 11 for the intermediate altitude areas of the P & AP areas; Maize 40% of the maize is produced in the drought stressed areas; Rice upland rice varieties mature in 90 days; Cash crops (cotton, sesame etc) have been managed by smallholder pastoralists; Forage crops: many of them have been adaptable to different pastoral regions					

Sources: EIAR (2015)

Changes observed in the production system

This section addresses the overall changes observed in the pastoral and agro-pastoral areas of Ethiopia over the last past decades in terms of economic, social and institutional perspectives with a focus on the role played by research in the system.

Shifts in pastoral livestock production and strategies: In pastoral areas, the subsistent livestock production has been under debate since 1960s, in Ethiopia and other countries with similar production system. On one hand, pastoralism was considered inherently irrational, largely or solely responsible for poverty and degradation of the land (Hardin, 1968). On the other hand, comparative studies of ranch and pastoral herd output demonstrated pastoral livestock production either equals or exceeds the productivity per unit of land area of commercial ranching in comparable ecological environment. For instance, according to Cossins (1985), Upton (1989), Cossins and Upton (1988), the pastoral Borana system has higher returns of both energy and protein per hectare compared to industrialized ranching systems in Australia,which realizes only 16% of the energy and 30% of the protein per hectare, compared to the Borana system (Table 4).

Table 4. Comparative productivity of commercial ranching and open-range pastoral production under comparable ecological conditions (ranching = 100%)

Country	Pastoral vs ranch productivity	Units of measure
Botswana	188% (relative to Botswana)	Kg protein production/ha per year
Ethiopia (Borana)	157% (relative to Kenya)	MJ/ha per year of gross energy edible by humans
Kenya (Maasai)	185% (relative to East Africa)	Kg protein production/ha per year
Mali	80–1066% (relative to United States)	Kg protein production/ha per year
	100–800% (relative to Australia)	Kg protein production/ha per year
Uganda	667% (relative to Uganda)	Uganda shillings/ha per year
Zimbabwe	150% (relative to Zimbabwe)	Zimbabwe dollars/ha per year

Source: Behnke and Abel (1996) and Ocaido *et al*., (2009)

Though there are differences among the regions of Ethiopia, research has revealed increased market orientation of pastoral livestock production (e.g., Akililu *et al*., 2013). Some studies revealed that private investments in feedlots, ranches, abattoirs and live animal trade signify confidence on the sector nationally (Aklilu, 2008; Getachew*et al*., 2014), substantiated by strategic geographic location and high demand for lowland livestock breed by neighboring countries (Belachew and Jemberu, 2003) (Table 5). These studies also suggested several options to create more conducive market conditions in the system. These include interventions in policy directions and enforcement, development of infrastructure, market promotion, advocacy and awareness campaigns, facilitating involvement and concerted efforts of all actors, regional collaboration, combat smuggled livestock and products; establishing disease free zones, control of major trans-boundary animal diseases (Aklilu, 2008; Wondwosen, 2003; Sintayehu, 2003; Belachew and Jemberu, 2003).The falling per capita herd wealth has also created different wealth classes (PADS, 2005; Morton and Kerven, 2013) in pastoral areas where the majority being in poor category (70%) in terms of livestock wealth. Exacerbated by declining livestock productivity, such circumstances have evolved the need for income/livelihood diversification (e.g. Saving and credit in Borana, forage seed sale in Afar). Implementation of collective action and human capacity building in helping pastoral women in Borana area can be mentioned here in the view of pastoral transformation (Coppock *et al*., 2013).

Table 5. Livestock exports from Ethiopia

Years	Live animals	Value (US $ '000)	Meat (t)	Value (US $ '000)
2005 – 06	163,000	27,252	7,717	15,598
2006 - 07	234,000	36,507	7,917	18,448
2007 – 08	298,000	40,865	5,875	15,471
2008 – 09	150,000	77,350	64,000	24,480
2009 – 10	334,000	91,000	10,000	34,000
2010 – 11	472,000	148,000	16,877	63,200
2011 – 12	800,000	207,100	17,800	78,000
2012 – 13	680,000	150,000	16,500	68,000

Source: National Bank of Ethiopia

Engagements in crop production: Cropping in many dry land areas is risky with crop failures in as many as 2 to 3 years out of 5.Surprisingly, it remains to be a popular diversification strategy, especially among poor herders in Ethiopia where conditions are enabling.For instance, a study in Rayitu district (Ethiopia) revealed 94% of the respondents were totally pastoralists 30 years ago. Currently, only 36% are purely livestock herders, with 63% combining livestock and crop production (Abate *et al*., 2010). However, it is difficult for smallholder producers to get an adequate return on investment to consistently lift them above the poverty level (Harris and Orr, 2012). Furthermore, as more dry areas are cropped, it typically exploits key resource patches that are vital to pastoral production, which can hinder mobility and increase conflicts between herders, farmers and wildlife (Haan*et al*., 2014). Similarly, it is not clear that the economic benefits of large scale cultivation outweigh the costs imposed on livestock production through the loss of grazing land and access to water points.A study conducted in Afar region(Behnke and Kerven, 2013) revealed that pastoralism is consistently more profitable than either cotton or sugarcane farming while avoiding many of the environmental costs associated with large-scale irrigation projects (Figure 1).Nonetheless, expansion of cropproduction in pastoral areas is still at increase.

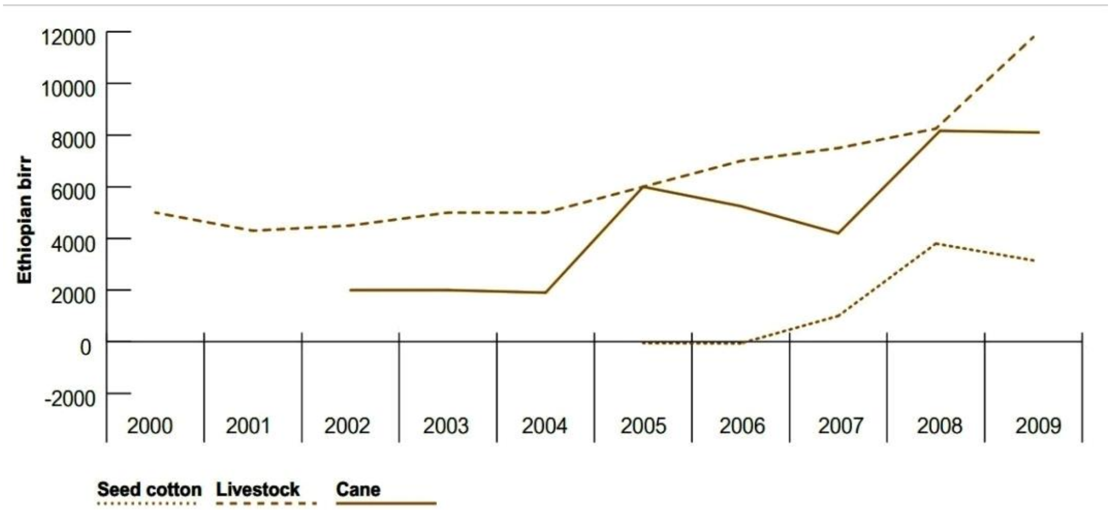

Figure 1. Economic return of pastoral livestock, large scale cotton and sugarcane production (Source: Behnke and Kerven, 2013)

Wildlife and tourism: In the 1960s and 1970', the national parks in Ethiopia were regarded as alien territory by the pastoralists (e.g., Beruk and Tafesse, 2000). Nowadays, there are different initiatives to solve the problems of benefit sharing and challenge of co-existence (Getachew *et al*., 2007). Yet, habitat loss and poaching are critical problems in some parks (e.g. Awash National park). Compared to the previous concept of strict conservation, the economic perspective for wildlife is encouraging and pastoralism is a more favorable land-use system for wildlife although pastoral and rangelands are heterogeneous. Given proper policies and facilitating conditions, it is possible for livestock and wildlife to co-exist.

Emerging social issues and shifting local institutions

Among the social issuesinthe PAP system, traditional/local institutions, mobility, grazing/water management system and land tenure are the most important indicators in the transformation of pastoral and agro-pastoral societies. Hardin (1968) reported decisions by pastoralists are motivated by tradition, rather than scientific knowledge. Studies thereafter have revealed the existence of complex social mechanisms and ecological management strategies which regulate the use and distribution of resources as discussed below.

Traditional/local institutions: Flexible property boundaries, reciprocal use of pastures, and underlying social networks allowed pastoral herders to use pastures efficiently (Coppock, 1994). These traditional institutions/formal and informal regulations have evolved over centuries and were well suited to the biophysical characteristics of the pastoral areas. Changes are observed although the extent and types of changes vary among regions, and even with different communities in a given locality. In most cases, customary political and management systems are becoming weaker with increasing lack of clarity in the mandates of formal and traditional systems leading to overlap and competing conflict-resolution outcomes (e.g., Oba, 1998; Ayana, 2007). The strong social cohesion and hierarchical structure within certain communities is eroding and the archaic lineage model is impaired. Despite such limitations, there are improvements in involvement of the local communities in local government processes, ensuring adequate social services, improvement in education, health, improved communication facilities and change in gender roles as compared to cases in the past.

Mobility, grazing systems and land tenure: Based on the findings of several studies, scholars agreed that a decline in mobility (e.g., Abule *et al*., 2007; Ayana, 2007; Amaha, 2006) has prevailed in recent periods, posing detrimental effect on the system by disrupting long existing traditional strategy in the management and utilization of scarce resources. Pastoralists have developed elaborated (like wet and dry seasons grazing, use of fire etc) mechanisms of negotiating exclusion areas and ways of enforcement. However, with declining management practices, vegetation & soil conditions of grazing areas, changes has been observed from communal to individual landholdings (privatizing and intensifying them), unstable relationship between animal numbers and feed availability especially in drought-prone areas (ILRI, 2002) leading to the need for further studies and/or intervention options for improving grazing systems or land tenure systems in pastoral areas.

Conclusion and recommendations

As seen from the literature review, the PAP is changing due to internal and external factors. There are many research problems ecologically, socially and economically yet to be addressed in light of changing climatic conditions. The rangelands and the resources contained in them are degrading mainly because of anthropogenic factors. As the problems of PAP cannot be answered by research alone, increasing inclusion of PAP communities in national development issues, strengthening local institutions of PAPs, further improvements in communication and infrastructures, level of education of the communities', capacity development and knowledge management are very essential. The research system has to be strengthened in terms of manpower, facilities and research approaches encompassing strong ecological, social and economic dimensions.

Future research areas

Some of the research areas that need focus include are: (1) reviewing and synthesizing past research and development interventions, (2) strengthen scaling up (suitable livestock, wildlife and rangeland technologies); (3) Developing simple methods of rehabilitating degraded rangelands, bush control, and invasive plants, (4) Livestock feed supply and demand imbalances, (5) strengthening research in ecosystem goods and services, carbon sequestration potential, developing appropriate mechanism of payment for ecosystem services, (6) livestock marketing system analyses, (7) determining the ecological and socio-economic impacts of conflicts, drought and climate change, (8) study on how to balance the multiple uses of goods and services in rangelands, (9) Socio-economic and ecological analyses of the different interventions to be undertaken in PAP areas

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Soil Fertility Management in Ethiopia: Research Findings, Challenges, Opportunities and Prospects

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Introduction

Agriculture is the core driver for Ethiopia's growth and long-term food security. Besides food security it also plays a key role in provision of industrial raw materials, about half of the country's Gross Domestic Product (GDP), up to 90 percent of foreign export earnings and about 80% of the labor force (*IFPRI*, 2009; World Bank, 2006). The Ethiopian government adopted a strategy known as Agricultural Development Led Industrialization, which is largely based on expanding agricultural production (Worku, 2000). Currently, high rates of economic growth have been linked to increases in area cultivated and agricultural productivity (Byerlee et al. 2007; Diao *et al.* 2007). It focuses on productivity improvement of smallholder agriculture through the use of fertilizers, improved seeds and setting up credit schemes (EEA, 2002; Asefa and Zegey, 2003; Weeks and Geda, 2004). Ethiopia's Growth and Transformation Plan (GTP) recognizes the importance of fertilizer for maintaining soil fertility and maximizing agricultural growth in the country.

However, soil degradation and nutrient depletion have gradually increased and have become serious threats to agricultural productivity in Africa (Vanlauwe et al., 2002). Land degradation in Ethiopia stems largely from improper land use and poor land management practices, population pressure, overgrazing, deforestation and removal and use of crop residues and dung for fuel in rural areas (FAO, 2012). These are further exacerbated by factors such as inadequate input supply, insecure land tenure, weak linkage between agricultural research and extension services and poor marketing systems. Since most of the soils do not provide the requisite nutrients necessary for the growth and health of plants, they have to be fed with fertilizers to overcome the deficiency. Soil fertility management is one of the major components to ensure food security and economic growth in a sustainable way. Technologies that can restore the fertility status of our soils improve nutrient availability and supply to plants and, hence, ensure optimum crop productions. Fertilizers constitute an integral part of improved crop production technology and their proper management to crops is important for maximum yield and minimum contamination to the environment (Corbeels *et al.*, 1999). Different soil fertility management practices have been anticipated for crop production by different organizations in the country. Various fertilizer sources have been used, among which inorganic and organic sources are the common once. Besides applying limited amounts of organic fertilizers the common chemical fertilizers used were DAP and Urea. Over the two decades following the introduction of fertilizer to smallholder farming in the country under the Freedom from Hunger program in the late 1960s, national annual fertilizer use grew from 3,500 tons to about 140 thousand tons by the early 1990s. Thereafter, fertilizer use substantially increased to about 200 thousand tons by 1994, to 400 thousand tons in 2005, and to 550 thousand tons in 2010. Given the emphasis of increasing crop production through higher fertilizer use, import of chemical fertilizer increased from 246,722 MT in 1995 to more than 890 thousand MT in 2012 (IFPRI. 2013).

This paper reviews research findings of various national and international institutions on inorganic, biological and integrated soil fertility management over the last 50 years. The review also includes the current research priorities, scenarios, challenges, opportunities, and future research directions of soil fertility management in Ethiopia.

Historical Perspectives of Fertilizer Research in Ethiopia

Since 1967, agricultural extension in Ethiopia has been organized under series of package technology transfer programs within the Ministry of Agriculture (MoA) mainly to demonstrate farmers the positive effects of fertilizer use on yields. Among them, the *Freedom from Hunger Campaign (FFHC)* assisted by the FAO Fertilizer Program is the pioneer that did a large number of simple fertilizer demonstration trials on major cereal crops from 1967 through 1969. Then, during 1971-74, more than 1500 unreplicated fertilizer trials were conducted on selected and fenced Extension and Project Implementation Department (EPID) sites. As a joint project of the Institute of Agriculture Research and the Agricultural Development Department (IAR/ADD), fertilizer and variety trial program has also tested newly released crop varieties in a wide range of agro-ecological zones of Ethiopia with or without mineral fertilizers. National Field Trials Program (NFTP) that was launched by ADD with the assistance of National Fertilizer Input Unit (NFIU) has also conducted replicated trials in prioritized agro-ecological zones and soil units at the ADD sites in early 1986.

The results from these series of fertilizer demonstrations and experiments depicted significant positive responses to nitrogen (N) and phosphorus (P) at almost all locations (IAR, 1969).The results further showed that the yield increase due to fertilizer for the improved varieties was found to be by far higher than for the local varieties. The studies have also established foundation to further initiate Dispersed Simple Fertilizer Trials (DSFT) in 1988 under small farmers' conditions and showed variable productivity index of N and P for different soils and crops (IAR, 1989; Lemma *et al*., 1990 in Hailu *et al.,* 1991).

Based on the ADD and NFIU 1988-1991 Fertilizer Demonstration and Crop Response Trials, application of chemical fertilizers was seen as the most effective way of improving agricultural productivity. Mineral fertilizer use, hence, remained among the main yield-augmenting technologies being aggressively promoted by the government and institutions, through its adoption rates remained, minimal in earlier times (Byerlee *et al*., 2007) with recent promising improvement. In addition to the aforementioned attempts, substantial soil fertility research efforts have been made for major cereal crops since 1990s by the National Agricultural Research System (NARS) that include the Ethiopian Institute of Agricultural Research (EIAR), Regional Agricultural Research Institutes (RARIs) and the Higher Learning Institutions (HLIs). The major focused research area includes response of different crops to N and P fertilizers and determination of optimum rates, times and methods of fertilizer application to increase productivity with alternative fertilizer sources. Accordingly, recommendations have been drawn, however, they were yet blanket both to some soil types and crop varieties. Hence, efforts to develop soil test based crop response fertilizer recommendations started quite recently for some crop varieties.

Most of the results of soil fertility research conducted in the country indicated high response of cereal crops to N and P fertilizer applications. Accordingly, blanket recommendation of 64/20 kg N/P ha^{-1} in the form of urea and DAP (i.e., 100 kg of urea and 100 kg of DAP ha^{-1}) has been used irrespective of soil and crop types (NFIU, 1988). Later on, with further research, progressive but variable increase of grain yield to increased level of N and P applications have been observed for different crops and soils types. Hence, the blanket recommendation was updated with respect to soil order /color and crop type as indicated in Table 1 below for major cereal crops (NFIU, 1993).

Recently, different phosphate fertilizer sources (Mijingu organic, Mijingu mazo, Yaramilla, Togo 1 and Togo 2), potassium and micro nutrient requirement of major crops were also studied by the NARS on major soils throughout the country under the coordination of EIAR. The result showed that most of the P sources were not superior to the existing DAP fertilizer and found to be non-effective to recommend, except Yaramilla and Togo at few locations (Negash and Sofia, 2015). Other experiments on potassium fertilizers showed importance of potassium application to wheat, tef, maize, and soybean crops in most locations with some variations particularly on Vertisols. In most acid soils, where available potassium is expected to be lower than in Vertisols, liming was required to get good response of crops. Some micronutrients, such as Zinc (Zn) at Ada'a, and Zn and Copper (Cu) at Minjar were also shown to be important for tef production (Bereket et al., 2011; and Negash and Sofia, 2015). A field experiment conducted in Tigray at Ofla testing site with slow release urea (SRU) fertilizer and the conventional urea (CU) fertilizer for tef production also showed increasing trend with increasing N rate, where the maximum record were obtained at the highest rate of SRU (69 kg N ha^{-1}). It was observed that application of 46 kg N ha^{-1} of SRU fertilizer has yield advantage of 462 kg ha^{-1} over 46 kg N ha^{-1} of CU fertilizer for tef crop (Okubay *et al.*, 2014).

Inorganic Fertilizer Recommendations for Different Crops

Currently, the proportion of cultivated land under chemical fertilizer has reached 46% of the total cropped area in the country (CSA, 2014/15). Research in fertilizer management has continued throughout the country, as several high yielding crop varieties were released and further new crops were considered important in the agricultural production system of the country. The results generally showed higher response of the new varieties to fertilizer application as compared to the old and local cultivars (Tolessa *et al*., 2007).

Table 1. Fertilizer recommendations for major cereal crops by soil order/colour and crop

Soil color	Fertilizer recommendation (N/P kg ha^{-1})			
	Wheat	Maize	Tef	Barley
Red	41.00, 20.07	71.82, 20.07	83.20, 26.09	67.60, 24.09
Black	41.00, 20.08	73.20, 20.07	83.20, 26.09	NA, NA
Brown	41.00, 20.09	74.80, 32.12	64.00, 20.07	32.00, 10.04
Gray	75.50, 20.07	41.00, 20.07	64.00, 20.07	NA, NA
Vertisols	64.00, 20.07	42.44, 21.68	83.20, 26.09	NA, NA
Country	41.00, 20.07	64.00, 20.07	64.00, 20.07	64.00, 20.07

Source: NFIU (1993); NA = Data not available

Cereal crops

Maize: Among cereal crops, maize stands second interms of area coverage and land area treated with chemical fertilizers in the country (CSA, 2014/15). The response of various maize varieties to application of chemical fertilizers (N and P) in different parts of the country in different periods was reviewed and summarized by Kelsa et al. (1993), Tolessa et al. (2002) and Wakene et al. (2012). Progressive increase in maize yield was observed with increasing levels of N and P application in all locations. The effect was particularly more pronounced with the first increment in N and P than with subsequent levels.

In the earlier period, the review work by Kelsa *et al*. (1993) recommended 75/33 kg of N/P ha^{-1} for maize production with a potential yield around 7.47 tones ha^{-1} in Bako and Didessa areas whereas 46/33 kg ha^{-1} N/P was found to be sufficient for average grain yield of around 4.66 tons ha^{-1}in Jimma area that produces. In Hawasa area, including Hallo, Arsi Negelle and Sinkile, 92/44 kg/ha N/P was recommended with P application only once in three to four years due to its residual effect. In dry land areas such as in the rift valley, rates of 69/30 kg ha^{-1} N/P were advised for application in wet seasons or when the rainfall amount and distribution is good enough. The more detail and recent recommendation of N and P rates for maize crop are summarized in Table 2 below.

Hybrids and improved composites showed higher response to nitrogen and phosphorus application than did local varieties. Application of 100 kg N and 100 kg P_2O_5 ha^{-1} for hybrids, improved composites and local varieties gave 24.0, 22.6 and 15.6 kg grain per kg N and P_2O_5. The N use efficiency (grain kg per applied N) of hybrid maize genotypes at Bako also showed higher values (20.8 to 16 kg ha^{-1}for 46 to 92 kg ha^{-1} of N) as compared to open-pollinated (15 to 10 kg ha^{-1}) for the same rate of N application (Tolessa *et al*., 2007).

Table 2. Optimum N and P fertilizer recommendations for major maize growing regions and soil types in Ethiopia

Region	Locations and soil type	Soil Types	N/P (kg ha^{-1})	Variety	References
Oromia	Bako	Alfisol	75/20; 92/20	OPV; BH 660	Tolessa *et al*. (2002)
	Bako, Jimma, Holetta	Alfisol, Vertisol, Nitisol	119/30	Maize Hybrid	Wakene *et al*. (2012).
	Melkassa,	Andosol	41/20	OPV	Tolessa *et al*. (2002); Wakene *et al*. (2012).
	Gimbi	NA	96/30	Hybrid	Wakene *et al*. (2012).
	West Showa (Gudar, Mutulu, Toke and Babichi)	NA	75/22	Hybrid/OPV	Tolessa *et al*. (2002)
	West Wallega (Gimbi, Guliso and Jarso area)	NA	75/33	OPV	Tolessa *et al*. (2002)
	Haramaya	Vertisol	87/20	OPV	Wakene *et al*. (2012).
	Arsi highlands	NA	138/40, 92/30	(Argene, AMH 850)	Bayisa and Endale, 2013
	Jimma zone	Vertisol	69/20	Hybrid/OPV	Tolessa *et al*. (2002)
	Ambo	Vertisol, Fluvisol	110/20	Hybrid	Wakene *et al*. (2012).
Gambella	Abobo	NA	23/20	OPV	Anon. (1999-2000)
	Gambella	Alisol	41/20	OPV	Tolessa *et al*. (2002); Wakene *et al*. (2012).
SNNPRS	Hawassa	Vertisol, Fluvisol	110/20	Hybrid	Wakene *et al*. (2012).
	Areka/Kokate	Alisol/Nitisol	46/20	Hybrid	
Amhara	Bure	NA	100/35	Hybrid	
	Pawe	Nitisol	69/0	Hybrid	Aseffa *et al*., 2009
	Adet	Vertisols	119/30	Hybrid	Wakene *et al*. (2012).
	Basoliben, Mecha and Yilmana, Densa and Ankesha, Jabi Tenan woredas	Nitisols	60/20	Hybrid	Tilahun *et al*. 2007a
	Bure and Huleteju Enebsie	Vertisol	120/20	Hybrid	
	Achefer	Nitisol	180/60	Hybrid	

NA= Data not available; Source: Mandefro et al. (2002); Worku et al. (2012).

Tef: Tef covers the major share of both the cereal-cropped area and chemical fertilized cereal area (CSA, 2014/15). Site-specific fertilizer experiments conducted throughout the country revealed significant response of tef to N fertilizer application, while its response to P fertilizer application is absent or minimal for some Vertisols, where tef is widely cultivated in the country and particularly in the central highlands of Ethiopia (Tekalign et al., 2001; Wakene and Yifru, 2013). For maintenance purpose, P application at a rate of 10 kg ha-1 was recommended for tef in various agroecologies of the country (Table 3).

Table 3. Optimum N and P fertilizer recommendations for major tef growing regions and soil types in Ethiopia

Region	Location	Soil Type	N/P rates (kg ha^{-1})	Reference
Oromia	Ada'a, Akaki	Vertisols	60/10-15	Tekalign *et al*. (2001)
	Ada'a	Andosol	90/15	Teklu (2003)
	Melkassa	Andosol	23/10	Olani *et al*. (2005)
	Wolenchiti, Wonji	Andosol	23/10	Olani *et al*. (2005)
	Holetta	Nitisols	40/26	Balesh et al. (2008)
	Holetta	Vertisol	60/26	Balesh et al. (2008
	Arjo, Shambu	Nitisol	15/10	Abdenna *et al*. (2006)
SNNPRS	Humbo, Jinka	Nitisol	23/30	Abay *et al*. (2010) (unpublished)
	Areka	Nitisol	18/20	Kelsa (1998)
	Areka	Alisol	9-18/10-20	Abay (2011)
	Bobicho (Hossana)	Luvisol	9-27/10-30	Abay (2011)
Tigray	Tahtay Koraro and	Cambisol/Luvisol/ Vertisol	46/10	Abreha and Yesuf (2008)
	Asgede Tsimbela	Vertisol	46/46 (P from Orga fertilizer)	Fissehaye et al., 2009
Amhara	Yilmana Densa, Estie, Ebinat	Nitisol	40-41/18-26	Minale *et al*. (2004) Alemayehu *et al*. (2007)
	Achefer, Gozamin	Nitisol	60/26	Alemayehu *et al*. (2007)
	Dembecha, Dangila, Bure	Nitisol	20/18	Alemayehu *et al*. (2007)
	Dejen, Belesa	Vertisol	41/20	Alemayehu *et al*. (2007)
	Bichena	Vertisol	80/9-18	Minale *et al*. (2004)
	Huleteju-Enebssie, Awobel, Simada, Dembia	Vertisol	60-80/18-26	Alemayehu *et al*. (2007)
	Kelela, Tenta (Wata), Tehulederie, Habru, Wadla	Brown soil	46/0-20	Sirinka progress report (2007)
	Sayint, Kalu (Adamiya)	Red soil	46/10-30	Sirinka progress report (2007)
	Mekdela, Kobo Zuria, Sayint (Waro), Kalu (Harbu)	Black soil	46/0-30	Sirinka progress report (2007)

Source: Fissehaye et al. (2009); and Wakene and Yifru (2013).

Wheat: Currently, wheat stands forth after sorghum in area coverage and total production. Earlier blanket recommendation adopted by EPID in the 1970s was 41/20 kg N/P ha-1. This rate has been used as a sole fertilizer recommendation for a long period in wheat producing areas. Based on input and output (i.e. fertilizer and open market wheat grain) prices in 1986, NFIU proposed the application of 25-25-0 on black soils and 30-35-0 NPK on reddish brown soils. Later on, the Joint Project of IAR and Agricultural Development Department (IAR/ ADD) and then National Field Trials Program (NFTP) have come up with revised fertilizer recommendations (Table 4) (NFIU. 1989).

Table 4. Fertilizer recommendations (kg ha^{-1} N/P) for major wheat producing areas in Ethiopia

Soil unit	Shewa	Arsi/Bale	National
Vertisol	60/13.0	35/23.9	60/17.4
Nitisol	75/32.6	25/34.8	40/23.9
Black soils	60/13.0	20/26.0	60/17.4
Red soils	70/28.3	30/34.8	40/23.9
Brown soils	55/26.0	-	50/21.7

Source: Asnakew et al. (1991)

Asnakew *et al*. (1991) reviewed different fertilizer trials conducted on wheat by various organizations since 1966 and the results showed significant response of the crop to NP fertilizers in major wheat growing areas of the country. Most fertilizer experiments of wheat on Vertisol showed minimal response to P as was also found for tef. Hence, maintenance level of as low as 10 kg P ha^{-1} was advised for Vertisol in general.

An N source study consisting of large granular urea (LGU), standard urea prills or ammonium sulfate was conducted on Vertisols at Akaki and Robe in 1990 and 1991 (Tilahun *et al*., 1996). In this experiment, it was observed that using LGU as source of N enhanced wheat grain yield, total N uptake, apparent N recovery and agronomic efficiency of N, particularly under severe water-logging conditions. Major recommendations are summarized in Table 5.

Table 5. Optimum N and P fertilizer recommendations for major wheat growing regions and soil types in Ethiopia

Region	Location	Soil type	N/P rate (kg ha^{-1})	Source
SNNPRS	Hosanna, Kokate, Hagereselam	Nitisol	46/40	Abay et al., 2010 unpublished
	Chencha (Dokotsida and Gindogembela Kebeles)	N.A	78/20	Bekalu and Arega, 2016
Oromia	Debrezeit & Akaki	Vertisol	120 N	Bemnet et al, 2006
	Bekoji, Asasa	Nitisol	46 P_2O_5	KARC, 2004
	Kulumsa	Nitisol	90 N	Genene, 2003
	Central highlands (Holetta and Ginchi)	Nitisol & Vertisol	60/ 26	Amsal et al, 2000
	Akaki & Chefe Donsa	Pellic vertisol	92 to 115/15	Teklu et al, 2000
	Central highland Vertisols	Vertisol	60/10	Teklu, 2003
	Arjo and Shambu	Alfisol	23/23	
	Debre zeit & Akaki	Vertisol	64/20.9	Workneh and Mwangi, 1994
	Eteya-Gonde Bekoji	Nitisol	123 and 82; 0	Yesuf and Duga, 2000
	Central highlands		40- 64 N & 5-20 P	Getachew et al., 2015
Amhara	Farta & Lai-Gaint, NW Eth	Luvisol	123-138/30	Minale et al, 2006
	Bichena	Vertisol	138/20 with BBF	Minale et al, 1999
	East Gojam (Goncha Siso Enebssie and nebssie Sarmidir districts)	Nitisol	92 /20	Asmare et al, 1995
Tigray	Hawzen	Sandy soil	46/20	Bereket et al., 2014
Afar	Melka Werer, irrigated wheat	Cambisol	30/0	Kassahun, 1996

Barley

Traditionally, barley is cultivated with no or little external inputs such as fertilizer or agro-chemical application. The practice of minimum- or no-replenishment to nutrient removal with barley grain harvest and soil erosion has resulted in soil fertility depletion. To this end, fertilizer trials have been conducted since 1980s for sustainable barley production. The results have indicated that fertilizer had a significant effect on barley grain and straw yields and yield components (Chilot *et al*., 1998; Woldeyesus and Chilot, 2002).

Efforts have been made to determine the economic optimum nitrogen and phosphorus fertilizer rate for local food barley cultivars in major barley-growing areas of North West Ethiopia and to determine the optimum levels of N and P fertilizers for acceptable levels of grain protein in malting barley (AARC, 2003). In most of the studies, progressive increases in barley grain yields and yield advantages ranging from 37 to 100 % were recorded with increased levels of N and P fertilizer. The highest grain yields were obtained from the applications of 60/13, 60/26, 45/26 or 30/26 kg N/P ha^{-1} at Laie-Gaient. The analysis of malt quality was also to the standard of first-grade barley (suit for malt making) with application of 30/26, 60/0 or 60/26 kg ha^{-1} N/P in Laie-Gaient area (AARC, 2001 and 2003).

Results of on farm experiment on early maturing local food barley cultivars depicted that application of 62/20 kg N/P ha^{-1} in the form of urea and DAP, at sowing time gave the highest mean grain yields of 1797 and 1635 kg ha^{-1} at Yilmana-Denssa and Huleteju-Enebssie, respectively (AARC, 1996). Unlike this finding, application of chemical fertilizers for barley production in Banja area of Awi zone was reported to be uneconomical (AARC, 2000–2002), probably due to the acidic nature of the soil in the area. Yet, 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 under high-input production conditions. These landraces are preferred by small-scale farmers, as they are less demanding in terms of soil fertility and are more competitive with weeds. The potimum N and P fertilizer recommendations for major barley growing regions and soil types in the country is summarized in Table 6.

Table 6. Optimum N and P fertilizer recommendations for major barley growing regions and soil types in Ethiopia

Region	Location	Soil Type	N/P(kg ha-1)	Type	Sources
Oromia	Arjo and Gedo	Alfisol	10/30	Food barley	BARC, 2006.
	Shambo	Alfisol	20/30	Food barley	BARC, 2006.
	Arsi Agricultural Development Enterprise	NA	40/17	Malt barley	Amsal et al. (1996)
SNNPRS	Hosanna.	Nitisol	23/20	Food barley	
	Kokate and Bule	Nitisol	41/20; 0/0	Food barley	WADU, 1977; Areka Agricultural Research Centre, 2000; Awassa Agricultural Research Centre, 2005.
Tigray	ofla and Enda Mehoni districts of Southern Tigray	Vertisol	46/20	Food barley	Assefa, 2015
Amhara	Farta	Luvisol	69/10	Local food barley	Minale et al., 2001.
	Geregera and Kone areas	Moderately acidic soil	60/46 and 120/46	Malt barley	Amare and Adane, 2015.
	Huleteju-Enebssie	Vertisols	46/10	Local food barley	Minale et al., 2001.
	Laie-Gaient (Gondor)	Red soil	92/20	Local food barley	AARC, 2001.
	Laie-Gaient	Red soil	30-60/26	Malt barley	AARC, 2003.
	Enarge-Enawga, Machakel and Debay-Tilatgin	NA	46/20	Malt barley	AARC, 2000–2002.
	Gozamen and Chillga	Nitisol	69/30	Malt barley	AARC, 2000–2002.
	Estie	Red soil	69/10	Malt barley	AARC, 2000–2002.
	Wogera	NA	69/20	Malt barley	AARC, 2000–2002.
	North Wollo Estayesh	Black to brown	46/10	Food barley	Getachew and Tekalign, 2003.

Rice

Rice is produced only to a very limited extent in Ethiopia, because it is a newly introduced crop. The grain yield of rice is reported to be responding more to N fertiliser than to P; however, maximum grain yield and N uptake were obtained with combined application of N and P fertilisers. In the Fogera plain vertisols, farmers are advised to apply both 60 kg N and 13.2 kg P ha^{-1} (Mulugeta and Heluf, 2006) in order to improve the grain yield and nutrient uptake by flooded rice. For the upland rice production, the agronomic and economic optimum application was found to be 92/10 kg N/P ha^{-1} under Vertisol conditions of Pawe (Aseffa *et al.*, 2009). Future fertiliser rate determination under flooded rice production condition may be required plant to account soil-water-environment related factors that affect the availability of nutrients and for evaluation of different sources of nitrogen that improve yields of rice in different potential areas of the country.

Sorghum

An experiment conducted in the Central Rift Valley of Ethiopia indicated that applications of fertilizer beyond 49/23 kg N/P ha^{-1} could not give any significant yield advantage and, thus, would not be economically feasible (Worku *et al*., 2006). Hence, 41/20 kg N/P ha^{-1} is recommended for sorghum production along with in-situ moisture conservation. Further research has shown that moisture deficit can limit the response to applied N and P even with tied-ridging particularly in the drier environments of northern Ethiopia and central rift valley of the country. Hence, the authors recommended that application of N and P should be considered if mean yield levels are above 2.5 tones ha^{-1} (Tewodros *et al*., 2009). The optimum N and P fertilizer recommendations for major sorghum growing areas in the country is summarized in Table 7.

Table 7. Optimum N and P fertilizer recommendations for sorghum growing areas in Ethiopia

Region	Locations	Soil type	NP (kg ha^{-1})	Sources
Amhara	Ambasel, Kalu, Habru	Black soil	46/23 - 69/46	Adet Agricultural Research Center
Oromia	Melkassa, Welenchiti	Andosol	41/20	Worku et al., 2006

Legume Crops

For cool season legumes 18/20 kg N/P ha^{-1} and 27/30 kg N/P ha^{-1} was recommended for faba bean and field pea on Dila (reasonably fertile) and Dimile soils (low fertility status), respectively, of Nitisol in Welmera area (Getachew *et al*., 2006). Even with P application, response of lentil and chickpea to fertilizer application on Vertisol was none or minimal (Tekalign *et al*., 1998). Another study on response of field pea to phosphorus fertilizer at Holetta and Bekoji depicted significant increase of seed yield. At Bekoji the most economical P rate was 20 kg P ha^{-1} for cv. Tegegnech, 10 kg P ha^{-1} for G22763-2C and 5 kg P ha^{-1} for cv. Cheffa local (Amare *et al*., 2005).

Only few experiments have been conducted and thus, limited information is available on fertilizer requirement of low land legumes. Among them, common bean is relatively most researched and grain yield advantages of 36% and 23.7 % over the control were obtained from application of 46 kg N ha^{-1} and 40 to 46 kg P ha^{-1}, respectively, on Andosol of Melkassa in the Central Rift Valley of Ethiopia. Economic analysis using partial budget procedure for the grain yield showed that 23/0 kg N/P ha^{-1} and 23/20 kg N/P ha^{-1} are economically superior (Birhan, 2006). For intermediate maturity soybean, application of only 23 kg N ha^{-1} was found enough for soils under Awassa condition. However, responses to different levels of NP fertilizers were found different depending on the inherent soil fertility status (Girma *et al*., 2003).

Vegetable Crops

Potato: A blanket recommendation of three hundred kg ha-1 of DAP (54/60 kg N/P) was drawn in the mid-1970s irrespective of soil type, variety and location (Hailemichael, 1977). This had been used for over 15 years until a detail study was done at Holetta on Nitisol in 1988 and 1989 for N, P and K using a medium maturing variety, Sissay. Yields as high as 36.5 and 36.3 t ha-1 were reported in 1988 for NPK (165/90/110 kg ha-1) and N and P (165/90 kg ha-1) applications, respectively. Unlike the result of this experiment that indicated very little effect of K on yield of potato at Holetta on Nitisols, recent study showed a clear evidence of the requirement of potato to K fertilizers application up to 75kg ha-1, either in the form of K2SO4 or KCl in the highlands of Ethiopia, particularly in acid soils, where Nitisol is dominating (Getachew et al., 2015). At Adet, the economically feasible rates were found to be 81/0 and 81/30 kg/ha of N/P with 1418% and 1316% marginal rates of return, respectively. Hence, the rate 81/30 kg/ha of N/P was recommended for potato production in Adet and Injibara areas (Gebremedhin et al., 2008; Gizaw, 2011).

Increased rate of K fertilizer was also reported to significantly improve the shelf life of potato. Increasing the rate beyond 30 kg ha^{-1} K_2O did not bring a significant effect on potato yield, while up to 150 kg K ha^{-1} was recommended on acid soils of Chencha and Hagereselam (Wassie and Shiferaw, 2011), where the soils are highly weathered and available K is expected to be low.

In relative terms, recently, developed varieties such as Tolcha and Wechecha were more benefited from increased N rates as compared to Awash. For the above N, P and K requirement study, results of the partial budget analysis based on the open market prices of fertilizer and potato tuber at that time, showed that the maximum profit was estimated to be 12768 EB ha^{-1} from application of 140 kg ha^{-1} N and 56 kg P ha^{-1}.

Onion, Tomato and Pepper : In east Belesa woreda, 60 kg N and 11 kg P ha-1 was advised for onion (Adama Red), tomato (Roma VF) and pepper (Mareko Fana) production with smallhloders drip irrigation system (Selamyihun et al., 2009). According to Sirinka Agricultural Research Center (SARC), 55/20 to 60/11 kg N/P ha-1 was recommended for onion, tomato and pepper production. The economic dose of N and P for pepper production under furrow irrigation at Jari Research sub center of South Wello was found to be 55 and 20 kg ha-1, respectively, with an optimum yield of 3020 kg ha-1. In the central rift valley, the commonly used rate by the research was 150 kg urea and 200 kg DAP (105/40 kg N/P ha-1). Unlike the common trend of cereal farmers' fertilizer application, which is sub optimal of the research recommendation, vegetable producing farmers apply well above the research recommendation (i.e. from 184-368/80-160 kg N/P ha-1) for onion and tomato production. This may require future research focus to recheck the existing recommendations, if there is a need to revise depending on the current soil fertility status, price of inputs and the produce and environmental sustainability.

Root Crops

Results of some experiments on the effect of NP and NP + lime on taro in Areka area showed that application of 110 kg N and 40 kg P ha^{-1} gave significantly higher yield as compared to the control and FYM received treatments (Abay *et al*., 2010 unpublished). This rate was, hence, advised for the farmers in the area who use only chemical fertilizers. Similarly, an experiment conducted by Abay (2013) to determine rate and frequency of N and P fertilizers application for Enset production at Areka, Wolaita, in Southern Ethiopia indicated that application of N and P fertilizer increased Enset production. Application of 138 kg N and 20 kg ha^{-1} P per year two times in the life of the crop gave the highest Enset production. Beside increasing Enset production, application of the above rate of N and P per ha per year for two consecutive years caused the Enset plant to mature three years earlier as compared to the farmers practice in the area, which takes five years to mature. In general, application of N and P fertilizers more than once in the life of Enset is important to increase its production and reduce its maturity period. Therefore, application of 138 kg N and 20 kg ha^{-1} P per year for two consecutive years was recommended for better production of Enset in Areka area.

Oil Seed Crops

Oil crops fertilizer requirement studies have not been given adequate focus by the research in the past. The response to NP fertilizer application was not also promising for some oilseed crops and some varieties. For instance, there was only trend of increased seed yield of linseed with application of none to 35.5 kg N ha^{-1} that has no significant improvement to be considered at Holetta, Arjo, Gedo and Shambu research stations (Shiferaw *et al*., 2011). Recently released varieties of Noug, on the other hand, showed considerable improvement (67.5% seed yield advantage) with application of 23/10 kg N/P ha^{-1} at Tefki, while the yield advantage was only about 21 to 26.5 % at Gohatsiyon, Weldiya and Bichena (Getachew, 2011). Sesame seed yield increase was obtained with application of 28/24 to 38/29 kg N/P ha^{-1} at Bako research center and on farmers' field in the surrounding (Shiferaw *et al*., 2011). Yield of rapeseed or Gomenzer was reported to be influenced by application of NP fertilizer, 23/46 to 46/30 kg N/P ha^{-1} was recommended in Bekoji, Robe, Dabat (Gonder), Mota, Bure, and Shambu are as (Getinet and Nigussie, 1997)

Coffee

Coffee farming systems in Ethiopia are conventionally divided in to four categories: forest coffee, semi-forest coffee, garden coffee and modern plantation. The bulk of coffee soils in the southwestern region are classified as Nitisol, which are highly weathered, deep, well drained, having a PH of 5-6 and low base saturation (Paulos, 1994). Extensive fertilizer trials have been carried out since 1978/79 by Jimma Agricultural Research Center (Melko) and its sub centers (Gera, Metu, Tepi, Bebeka, Wonago and Bedessa) that represent major coffee growing agro-ecologies of the country. The results showed significant coffee yield increment with increasing level of nitrogen, except at Bedessa (Fisseha *et al*., 1993; Tesfu *et al*., 2011; Anteneh *et al*., 2015). The optimum NP rate recommended at Wonago was 200/66 kg N/P ha^{-1}. In some trials involving potassium fertilizer, significant coffee yield improvement was also depicted when the level of potassium was increased from zero to 62 kg ha^{-1} at Melko, but not significant at Gera, Metu and Tepi (Anteneh *et al*., 2015). Results of previous fertilizer trials at different coffee growing areas of south-western Ethiopia are summarized by Tesfu *et al.* (2011) and Anteneh *et al*. (2015) (Table 8).

Table 8. Location-specific NPK fertilizer recommendations for coffee

Location	Recommendation Domain	Recommended Rates (Kg ha^{-1})		
		N	P	K
Melko	Jimma, Manna, Seka, Gomma, and Kossa	150 - 172	63	0
Gera	Gera	No fertilizer	No fertilizer	No fertilizer
Metu	Metu, Hurumu, Yayou, and Chora	172	77	0
Tepi	Tepi	172	77	0
Bebeka	Bebeka	172	77	0
Wenago	Wonago, Dale, Aleta Wondo, and Fiseha Genet	170 - 200	33 - 77	0
Bedessa	Habro, Kuni, Darolebu	150 - 235	33 - 77	62

Source: Tesfu et al. (2011) and Anteneh *et al.* (2015)

Soil Test Based Phosphorus Determination

In soil fertility management research, attempts have been made recently to provide phosphorus fertilizer recommendation based on the results of soil test and crop responses. The critical values and requirement factors of phosphorus are the two important decision criteria whether to apply phosphorus or not and how much to apply if application is indispensable. Accordingly, experiments have been conducted since 2010 through 2014 on P calibration for major cereal and pulse crops in different agroecologies and soil types. The critical P values and P requirement factors have been developed (Table 9) and can be used by soil analytical laboratories to give need based recommendations for different crops and soil types after analyzing the soils coming from the producers.

Rate of fertilizers to be applied (kg P ha^{-1}) = (Pc-Po) x Pf

Where:

- P_c = Critical P concentration (mg/kg)
- Po = Initial P values for the site
- Pf = P- requirement factor ((kg P/ha)/ (mg/kg))

Table 9. Critical P concentrations and P requirement factors determined for different crops and soils at various locations.

Crop	Soil type	Location/Districts	Extraction Method	P- Critical Value (Pc) (mg kg^{-1})	P-requirement factor (Pf)	Responsible Center
Bread wheat	Nitisols	Holetta area	Bray II	13.5	10.7	Holetta
Bread wheat	Nitisols	Kulumsa/Bekoji area	Olson	12	9.34	Kulumsa
Bread wheat	Nitisols	Yilmana Densa and Debre Elias	Bray-II	10	6.89	Adet
Tef	Vertisols	Ginchi and Becho	Olsen	7.5	12.91	Holetta
Tef	Vertisols	Bichena	Olsen	8	7.20	Adet
Tef	NA	Laylay Maichew	NA	8	9.10	Alamata
Tef	Nitisols	Dangilla & Yilmana Densa	Bray II	10	5.97	Adet
Tef	Nitisols	Welmera	Bray II	10	5.4	Holetta
Malt Barley	Nitisols	Welmera and Jeldu	Bray II	10 .5	8.7	Holetta
Food Barley	Nitisols	Welmera	Bray II	11	5.6	Holetta
Soya bean	Nitisols	Jimma	Bray II	6.4	7.04	Jimma
Soya bean	Nitisols	Asossa	Bray II	8.5	6.55	Asossa
Haricot bean	Andosol	Meki to Adami Tulu	Olson	8	3.82	Melkassa
Maize	Nitisols	Jimma & Illubabor	Bray II	7.5	5.87	Jimma
Maize	Nitisols	Pawe/Metekel	Bray II	9	2.81	Pawe
Maize	Andosol	Meki, Zeway, Adami Tulu & Bulbula	Olson	10	1.41-4.68	Melkassa

Source: EIAR Soil and Water Research directorate progress report

Timing and Method of Inorganic Fertilizer Application

Studies on the method of fertilizer application showed that band or row application with thorough mixing to soil is the most preferred and economical method. With regard to time of N application, split application in general is reported to improve N-use efficiency of crops by synchronizing the availability of N with the crop stage for maximum N demand. It has been reported to increase cereal grain yield predominantly under higher application rates unless other factors such as moisture or pests are not limiting the yield (Asnakew *et al*., 1991; Tekalign *et al*., 2001; Tilahun *et al*., 2007b; and Bekalu and Arega, 2016)

Three splits of N for high potential highland areas (1/3rd at planting, 1/3rd at knee height i.e. 30-35 days after emergence and the remaining 1/3rd at flowering or tasselling); and two splits for medium potential mid altitude sub humid agro ecologies (half at planting and half at knee height or 1/4th at planting and 3/4th at knee height) was reported to improve the grain yield of maize (Tolessa *et al*., 1994). Similar split application was recommended for wheat production (1/4th at planting, half at mid-tillering and remaining 1/4th at anthesis) and has improved grain yield and N use efficiency for improved varieties in potential growing areas. Split application of N to bread wheat was also recommended for marginal rainfall zones of Ethiopia, primarily as a means of minimizing the economic risk for farmers. Similarly, studies of N application time on Nitisols at Holetta and Vertisols at Ginchi showed that application of 50% of the total N at sowing and the rest at full tillering stage significantly increased grain yield as well as the protein content of wheat.

Two split-applications of N, half at planting and the remaining half at tillering or booting stage were recommended in order to increase the grain yield of tef (Tekalign *et al*., 2001; and Teklu, 2003). Smaller N fertilizer rate applied once at active growth stage of tef was found to increase N use efficiency when soil moisture is low. No statistically significant yield difference between split and basal applications of N fertilizer was reported for barley. However, split application is important to save some N fertilizer, particularly when barley fails at the early vegetative stage due to water logging, or aphid or barley shoot fly infestation

Challenges of Inorganic Soil Fertility Management Research

Sub optimal application of fertilizer that has resulted in gradual decline of soil productivity is among the major challenges (Kefyalew, 2011), as crop production continues to be increasingly reliant on nutrient stocks from soil reserves. Nominal nutrient use efficiency may be very high under this circumstance, but it is clearly a non-sustainable scenario.

The increased fertilizer use and use of improved high yielding varieties in the past decades has resulted in significant improvement in the productivity of major crops. But the yield increase has not been adequate suggesting that other constraints limit crop yield improvement. This could be attributed mainly to nutrient imbalance due to the use of only DAP and urea fertilizers that may aggravate depletion of other essential macro and micronutrients (Asgelil et al., 2009). This is also supported by research findings in which fertilizers containing potassium and micronutrients have significantly increased crop yields of some crops such as potato (Wassie, 2011). To this end, new fertilizer products containing both macro and micronutrients are under evaluation throughout the country by EIAR in collaboration with regional research institutes and ATA. On the other hand, most of the recommended fertilizer rates are old enough and hence need to be updated for the crop varieties existing in the production system and for the current soil fertility status.

Low fertilizer use efficiency is the other major constraint to improve agricultural productivity in Ethiopia. The nutrient use efficiency (NUE = kg yield per kg nutrient) is very low in Ethiopian farms using fertilizers compared to other East-African countries, which is probably caused by interactions between chemical and physical soil quality, improper management and limited supply of fertilizers.

As indicated in the main text of this document, some crops have shown good response to application of potassium on some soils including acid soils. Similarly, appreciable response of crops was reported on soils having adequate or even higher amount of K (Negash and Sofia, 2015). Hence, this may also require further research that may include the analysis methods for different forms of K in soil and any synergic process with the application of K fertilizers. The issue of P (less response of crop to its application), particularly in Vertisols needs good understanding with regard to soil-plant-water relationship.

Poor laboratory capacity, field facilities and lack of well-equipped greenhouse are among the major challenges to conduct some fertilizer experiments to get reliable data. For instance, most of the soil fertility management technology generation activities require full engagement of soil testing laboratories to determine, for example, the critical levels for the key nutrients, and based on that, scale up the soil-test based fertilizer advisory services to farmers.

Despite the many inorganic fertilizer rate studies conducted across the country, availability of information is limited. Hence, lack of strong database, and permanent research or trial plots and information exchange system is another big gap. Had it been in place, we could have accessed the soil data for the whole country and, hence, works done before would have not been repeated. Previous research findings, at least some could have provided relevant information that can be extrapolated to other similar areas with decision support tools and could have generated invaluable information about long-term effects of different forms of fertilizer application on the nutrient pool of the soil.

The impacts of climate change have been continuously growing at a rate that often exceeds human and ecosystem tolerance levels. The increase in temperature aggravates water problems by causing additional loss of moisture from the soil that would have positive implication on soil biological activity and soil fertility. The frequent extreme weather events (NMSA, 2001; and Kidane *et al*., 2010) have also considerable negative impact on soil physic-chemical properties and biological activities. Consequently, many traditional adaptive knowledge and livelihood strategies are unsatisfactory to the existing stress. Hence, the linkage between soil fertility and climate change adaptation must be well understood for our soil fertility management technologies to help and adapt to the changing climate.

Progress In Biofertilizer Research In Ethiopia

Biofertilizers are provisions containing live or latent cells of efficient strains of nitrogen fixing, phosphate solubilizing or cellulolytic microorganisms used for application to seed, soil or composting areas with the objective of satisfying plant nutrient needs. It could be done by increasing the number of such microorganisms and accelerate certain microbial processes to augment the extent of availability of nutrients in a form which can be easily assimilated by plants (Yami, 2009). Research on biofertilizers in Ethiopia started in the early 1980s (Amare, 1982). Since then, studies have been conducted in different parts of the country. However, most of these research findings are found either in the form of reports or within the hands of researchers as unpublished data. This section, therefore, tries to review the extensive researches that have been carried out in the past three decades in Ethiopia and stresses the need for more intensive research in this field.

Rhizobial Inoculants

Brief Description of Rhizobium Research in Ethiopia: In Ethiopia, research work on selection of efficient rhizobia strains for inoculation started in 1982 at Nazareth (Melkasa) Research Center, Institute of Agricultural Research (Tekalign and Asgelil, 1994). Accordingly, 110 strains of Rhizobium leguminosarum from Pisum sativum, Vicea faba, and Lens esculenta; 20 strains of Rhizobium phaseoli from Phaseolus vulgaris; 328 strains of R. japonicum /cowpea type Rhizobium from Glycine max and Cicer areietinum; and 34 Strains of R. trifoli from Trifolium Sp. were isolated in microbiology laboratory at Melkassa Research Station (Amare, 1986).

Later, the Department of Soil Science of the Institute of Agriculture Research (IAR) has established a Soil Microbiology Unit at Holetta Agricultural Research Center, which was responsible for coordinating all the research activities on biological nitrogen fixation (BNF) in Ethiopia since 1986 (Tekalign and Asgelil, 1994). The Unit fulfilled some laboratory facilities and linked itself with the International Atomic Energy Agency (IAEA) in Austria, International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria, and Nitrogen Fixation by Tropical Agricultural Legumes (NifTAL) in the USA for possible financial and technical backstopping. The major items considered at the limited phase were evaluation of symbiotic effectiveness of the isolates on the legumes, particularly highland pulses. (Desta and Angaw, 1986).

Since then, many studies have been conducted on different food, forage and woody legumes by different universities, students and research centers. Subsequently, different rhizobia strains of economically important legumes in Ethiopia have been isolated from nodules of host legumes grown in the major producing areas. Currently, commercial inoculants are available in Ethiopia for soybean, faba bean, field pea, chickpea, lentil and common bean.

Most recently, genetic diversity and phylogenetic relationships of rhizobia isolated from root nodules of perennial (tree/shrub) and annual (crop) legume species were studied by some researchers (Desta *et al*., 2004; Endalkachew *et al*., 2004a, b, c; 2005; Aregu *et al*., 2012a, b, and Tulu *et al*., 2013). The findings of these studies strongly support the view of Odee *et al*. (2002) indicating that this sub-Saharan region might be a center for rhizobia biodiversity.

Yield Response of Legumes to Rhizobia Inoculations: A field experiment conducted during the 2006/07 growing season to assess the effects of inoculation on the performance of chickpea (variety" DZ-10-11") in Shoa-Robit area, Ethiopia revealed that inoculation of Sinorhizobium ciceri, EAL 001 +Pseudomonas sp + 18/20 kg N P ha-1 as urea and with the cheap source of phosphorous as dried and crushed bone resulted in 57.02% yield increase over the uninoculated control (Birhanu and Pant, 2013).

On the other hand, a study conducted in the Regosols of Hararghe highlands showed that inoculation with mixed granular inoculants and starter N increased yield and nodulation of different haricot bean varieties under intercropped condition (Shibru and Mitiku, 2002). Besides, a field study using Melkassa-I variety (locally developed haricot bean variety) also indicated that inoculation with HB 429 isolate resulted in 17.6% yield increase compared to the control (Hawassa University Technical report, 2013 unpublished).

Table 10. Response of different legumes to rhizobia inoculation under field condition.

Crop	Isolate/Strain used	Yield increase over the control	Location	sources
Soybean	Legumefix	88.8	Metahara	Tesfaye (2015)
	SB6 B1	112%	Metahara	Tesfaye (2015)
	Legumefix	74%	Jimma	Getahun (2013)
	MAR 1495	86%	Jimma	Getahun (2013)
	UK isolate	46.3% (TGx-1336424)	Shinille	Anteneh (2014)
	UK isolate	72% (GIZA)	Shinille	Anteneh (2014)
	TAL 379	53.2%	Bako	Tamiru *et al*. (2012)
	TAL 378 + PSB	36.3%	Assosa	Anteneh (2012)
	TAL 379	15.07 - 27.92%	Haru	Workneh and Asfaw (2012)
Faba bean	# 18	44%	Holetta	Angaw (1995)
	# 51	13%	Holetta	
	# 18, 51 and 64	32-45%	Holetta	IAR (1990)
	HUFBR4	55%	Haramaya	Anteneh (2011)
	HUFBR5	51%	Haramaya	Anteneh (2011)
	EAL 110, EAL 120	61%, 68%	Bulie	Wassie *et al*. (2008)
	EAL 110, EAL 120	52%	Chencha	Wassie *et al*. (2008)
Field pea	HUFPR1	31%	Haramaya	Anteneh Argaw (2011)
Haricot bean	HB 429	17.6%	SNNP	Hawassa University Technical report, 2013 unpublished

Tamiru *et al*. (2012) have reported that an increase of 53.2% seed yield of soybean was realized due to inoculation of TAL 379 as compared to the uninoculated control in Nitisols of Bako area. Similarly, Getahun (2013) has reported 74 and 86 % yield increase of soybean on Nitisols of Jimma because of inoculation with Legume fix and MAR-1495, respectively. Furthermore, Anteneh (2014) reported a yield increase as high as 46.3 and 72% on TGx-1336424 and GIZA varieties of soybean, respectively, due to inoculation by local isolate in the irrigated agricultural field of Shinille Agricultural demonstration site, Somali region. Tesfaye (2015) has also observed an increase in grain yield of soybean (intercropped with sugarcane) by 88.8% and 112% and protein content by 20.3% and 15.3% due to inoculation of soybean by legume fix and SB6 B1, respectively, at Metahara sugar estate. A study conducted at Haru, western Ethiopia, to identify appropriate inoculation method and optimum phosphorus level for soybean showed that grain yield increased by 26.12, 15.07 and 27.92 % for seed, soil and seed plus soil inoculation respectively, compared to the control (Workneh and Asfaw, 2012). On other hand integration of minimum tillage with 10/20 kg NP ha^{-1} without the application of rhizobium strain is recommended for faba bean and field pea production in Horro and Gedo highlands (Tolera *et al*., 2011).

Production of Inoculants: Unavailability or high cost of the already established carrier material such as peat hinders limits its use as a carrier for rhizobia inoculants in Ethiopia. In line with this, Asfaw (2003) has studied the ability of four locally available carrier materials, namely: filter mud, bagasse, charcoal and lignite, to support prolonged rhizobia survival as compared to South African peat. His study proved that lignite, which was provided by the Coal and Phosphate Project found around Bedele and was found to be equally effective for maintaining high (1.1x1010) population of rhizobia for periods of 180 days, followed by charcoal, which maintains 1.3x106 rhizobia, indicating the suitability of these materials as an inoculant carrier (Table 11).

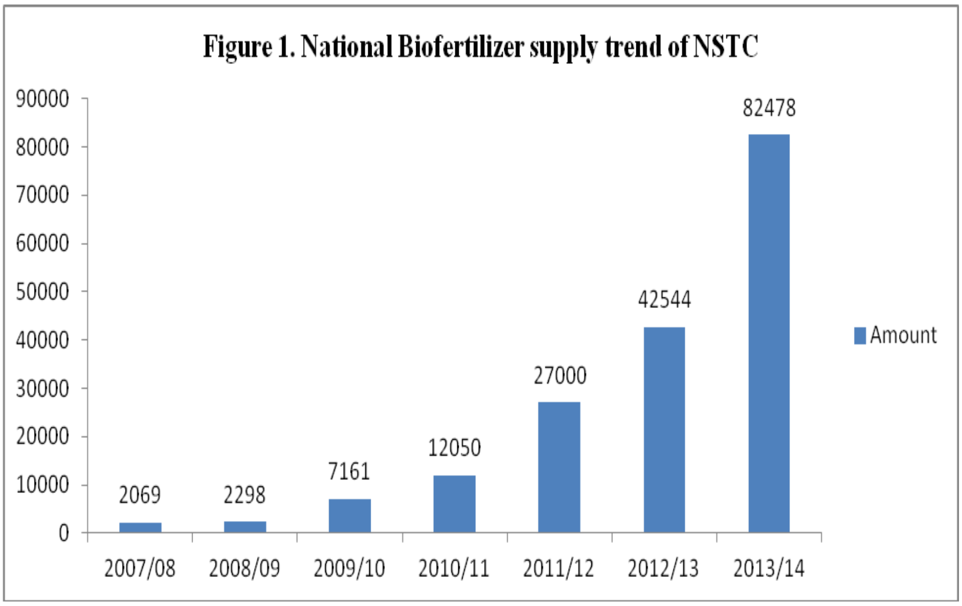
Table 11. Population of *Rhizobium leguminosarum*/g of carrier material at respective time.

Materials	Population of *Rhizobium leguminosarum*							
	3 days	15 days	30 days	60 days	90 days	120 days	150 days	180 days
Filter mud	$1.42x10^{10}$	$1.3x10^{9}$	$1.5x10^{9}$	$1.1x10^{8}$	$1.6x10^{7}$	$1.2x10^{5}$	$1.8x10^{3}$	1.5x10
Bagasse	$1.2x10^{4}$	1.42x10	Nill	Nill	Nill	Nill	Nill	Nill
Charcoal	$1.5x10^{10}$	$1.2x10^{10}$	$1.4x10^{10}$	$1.1x10^{9}$	$1.3x10^{8}$	$1.5x10^{8}$	$1.8x10^{7}$	$1.3x10^{6}$
Lignite	$1.4x10^{10}$	$1.6x10^{10}$	$1.1x10^{10}$	$1.3x10^{10}$	$1.4x10^{10}$	$1.2x10^{10}$	$1.2x10^{10}$	$1.1x10^{10}$
Peat	$1.8x10^{10}$	$1.4x10^{10}$	$1.3x10^{10}$	$1.4x10^{10}$	$1.6x10^{10}$	$1.2x10^{10}$	$1.5x10^{10}$	$1.4x10^{10}$

Source: Asfaw (2003)

This result suggests that high quality rhizobia inoculants may be produced with these locally available materials where peat is not available. According to the same author, in an attempt to replace imported mannitol sugar for mass production of rhizobia, Molassess-D, a sugar industry byproduct has showed good result for growth of rhizobia in broth culture.

In view of the fact that inoculation with efficient strains of rhizobia has been found to increase the yield of food legumes in different parts of the country, the demand for rhizobia inoculants increased from time to time. The supply of rhizobia inoculants by National Soil Testing Center (NSTC) in the past seven years is shown in figure 1.



Source: Mesfin *et al.* (2015)

The production capacity of the MBI also showed increasing trend across years from 30,000 packets (125 grams each, which is enough for quarter hectare) of inoculant in 2012 (establishment year) to 50,000, 70,000, and 102,000 packets in 2013, 2014 and 2015, respectively.

Demonstration and Popularization Activities of Inoculants: Several field demonstrations have confirmed that legume crops have showen remarkable growth and yield response to rhizobia inoculations in different agroecologies in Ethiopia. In an effort to demonstrate and popularize the use of rhizobia inoculants, EIAR in collaboration with COMPRO-II and N2-Africa projects disseminated the technology to plenty of farmers for the past three years (Abere, 2015). This activity considerably increased the interest of farmers to use biofertilizer technology for improving the productivity of legume crops.

Nevertheless, many countries using biofertilizers have regulatory authorities supported by appropriate legislations. So far, Ethiopia has no appropriate legislation for the registration of biofertilizer and biopesticides owing to the infancy of the technology. But, EIAR in collaboration with MoANR has currently developed quality standards and registration guidelines for commercial biofertilizers and biopesticides in the country and now it is waiting for approval by concerned bodies.

Mycorrhizal Fungi

Research on mycorrhizal fungi in Ethiopia has probably started in late 1980s. However, the progress is very slow. Some research works conducted in Ethiopia showed the importance of mycorrhiza in plant growth and production (Tekalign and Killham, 1986; 1987; Michelsen, 1993b; Ararsa and Selvaraj, 2013).

Different researchers (Michelsen, 1992; 1993a; Tesfaye *et al*., 2003; Diriba *et al*., 2007; 2008; Tadesse and Fassil, 2013; Zerihun *et al*., 2013; 2015; and Moges, 2015) have studied the distribution and diversity of VAM in different land use systems. These studies show that VAM fungi colonized the roots of many plants.

Phosphate Solubilizing Microorganisms (PSM)

Studies conducted on PSM are limited. However, some phosphate-solubilizing microorganisms were isolated from various soils in Ethiopia and characterized (Wassie *et al*., 2002; Asfaw, 2003; Assefa *et al*., 2010; Fekadu, 2013; Dereje *et al*., 2014). Some greenhouse and field experiments also showed promising results especially when combined with rhizobia (Asefa *et al*., 2008; Yifru *et al*., 2008; Anteneh, 2014).

Blue Green Algae (Cyanobacteria) and Azolla

Not much work has been done in the field of blue green algae in Ethiopia. Recent survey of water bodies in Ethiopia has revealed the occurrence of Azolla in Lake Ziway (DZARC, 2015). Field inoculation experiment at Fogera plain, northwest Ethiopia with *Azolla microphylla* and *Azolla filiculoides(* imported from India) incorporated once into the soil resulted in 15 and 19% increase in yield of rice, respectively (Tesfaye *et al*., 2013).The other study conducted under greenhouse condition using *Anabaena* spp. of cyanobacterial strain E3, isolated from soil sample from pigeon pea field of Ziway, indicated that application of dried cyanobacteria increased number of leaves, leaf area, leaf length, fresh weight of leaves, leaf dry weight and root dry weight of the lettuce by 159.5, 112.4, 80.8, 48, 137.5 and 110%, respectively, over the control (Muluneh and Zinabu, 2013)

Prospects of Biofertilizers

In the context of increasing cost of chemical fertilizers to improve productivity of crops, the future use of biofertilizers seems bright. This is despite some of the challenges, which restricts wider adoption of the technology.

Issues and Challenges

- Adaptation of the technology is very slow and difficult as some of the microbial inoculants are host specific.
- Increases in crop yield due to response to inoculation are not always reproducible and vary from place to place.
- Stiff competition between indigenous strains and inoculated efficient strains.
- Lack of access to the technology and quality control of the inoculants

Biofertilizer and Future Research

Research on biofertilizer so far focused mainly on rhizobia. Future research should also give due emphasis to other important beneficial microbes like phosphate solubilizing microorganisms, mycorrhiza, other symbiotic, free living and associative microbes. Moreover, future efforts must incorporate a systematic research program on biofertilizers to tackle the following:

- Biosafety of biofertilizers
- Host- stain specificity of some symbiotic microbes like rhizobia
- Compatibility studies between inoculants and pesticides
- Study of microbial persistence of biofertilizers in soil environments under different farming systems.
- Factors confounding the use of biofertilizer inoculants

Integrated Soil Fertility Management In Ethiopia

Integrated Soil Fertility Management (ISFM) combines the use of both inorganic and organic fertilizer to increase crop yield, rebuild depleted soils and protect the natural resource base in association with other complementary practices such as tillage, rotation and moisture conservation with due attention to timing and placing of the inputs to maximize nutrient use efficiency. The basic concept of ISFM is the judicial and efficient use of organic and inorganic fertilizers to meet crop needs based on a nutrient budget. Among the integrated soil fertility management practices, integrated use of chemical fertilizer with farmyard manure (FYM); compost; green manure; and lime; were the common practices that have been studied in most parts of Ethiopia following different crop rotation systems. Integrated nutrient management is an approach that seeks to both increase agricultural production and safeguards the environment for future generations (Gruhn *et al*., 2000)**.** Mugwira and Murwira (1998) have reported that the use of organic manure is more beneficial when combined with inorganic fertilizers. Higher crop yields were achieved with the same amount of nutrients when used in combination (organic and inorganic) than mineral fertilizer alone is applied (Charreau, 1995). Sayre (1999) has indicated that sustainable crop production practices involve use of break crops and optimum fertilizer application that minimize nutrient losses. This could be owing to the improvement in soil fertility status with different crops compared to continuous monocropping.

Integrated Use of NP with organic fertilizer sources

Integrated use of NP and FYM has resulted in higher yield than application of either NP or FYM alone for maize production (Wakene *et al*., 2004). Sole application of FYM at the rates of 4-12 t ha^{-1} is also recommended for resource poor farmers with relatively fertile soils. Application of FYM every three years at the rate of 16 t ha^{-1} supplemented by NP fertilizer annually at the rate of 20-46 Kg N-P_2O_5 ha^{-1} was recommended for sustainable OPV maize production around Bako area (Tolessa, 1999a). Besides integrated use of coffee byproducts and N, fertilizer also increased N uptake and grain yield of haricot bean and maize at Hawassa, southern Ethiopia. Similarly, coffee residue along with N fertilizer positively influenced soil moisture, soil nitrogen and organic matter, grain yield and water use efficiency of maize (Tenaw, 2006). Integrated use of 23/20 kg N /P ha-1 with 20 t FYM ha^{-1} or 46/40 kg N /P ha^{-1} with 10 t FYM ha^{-1} were recommended for wheat around Hagerselam, and barley and Potato producers around Chencha. Furthermore, integrated use of 4.53 t FYM ha^{-1} and 37 kg N ha^{-1} was also recommended for tef production on Vertisols of central highlands (Teklu *et al*., 2009).

Integrated use of 5 tons ha^{-1} of compost either with 55/10 or 25/11 kg of N/P ha^{-1} was found to be economical for maize production in Bako Tibe district. Applications of the full-recommended doses of NP fertilizers integrated with five ton per hectare crop residue was advised to improve fertility status of the soils for sustainable maize production in Haramaya area. Combination of cereals + 75% legume plant materials showed a curvilinear increase up to 25% dry biomass yield of tef (Yihenew *et al*., 2010). In line with this, composting time of up to 7.5 months linearly increased grain yield of tef, whereas extending the compositing period to 8.5 months showed adecline in tef grain yield. Increasing the proportion of legume plants in compost preparation increased the quality of compost and shorten the period of compositing. On the other hand, application of orga (mixture of manure, bone meal and blood meal) significantly increased tef yield in southern Ethiopia, whereas it showed non-significant effects in Tigray, Nothern Ethiopia. This result indicates less solubility of orga in neutral to alkaline soil reaction of Tigray than under acid soil condition of southern Ethiopia. Tef was most responsive to FYM and compost on Vertisols and Nitisols; and to mustard meal for both soil types (Balesh *et al*., 2007). Agro-industrial byproducts from coffee, brewery, sugar, oil food cakes and sisal can be potential fertilizer sources in Ethiopia as revealed by their elemental compositions and effects on soil quality parameters (Wakene *et al*., 2010, 2011a, 2011b).

Integration of biogas slurry and NP fertilizer produced significantly higher grain yield of maize and improved soil properties. Biogas slurry at eight t ha^{-1} with 50 % recommended N/P kg ha^{-1}(100/50 kg ha^{-1} of Urea/DAP) or 12 t biogas slurry ha^{-1} alone was recommended for maize production (Tolera *et al*., 2005).

Minimum tillage with residue retention increased mean grain yield of maize by 6.6 and 12.2 % as compared to minimum tillage with residue removal and conventional tillage. Therefore, use of minimum tillage with residue retention was recommended for sustainable maize production, productivity, and soil fertility improvement in Ethiopia. Tie ridging is better moisture conservation technology and used for producing increased maize grain yield in moisture stress regions of Ethiopia. It has been observed that tie ridging effectively conserved moisture and resulted in higher maize grain yield; especially, in moisture stressed areas of Ethiopia.

Integrated use of cover crops and multipurpose, woody and herbaceous legumes with different cropping systems increased the availability of organic resources and consequently improved crop yields. It could be applied at green succulent condition by chopping to small pieces to facilitate its incorporation.

Integrated use of green manure (*mucuna pruriens*) as improved fallow with low doses of inorganic fertilizer or FYM increased maize grain yield and yield components, and improved important soil properties. Supplementing improved fallow mucuna for soil fertility restoration with low doses of NP fertilizers or Farmyard manure could be recommended for maize production in the various areas. Similarly, integrated use of *Dalichos lablab* as green manure with 50 % of the recommended NP fertilizer rate gave proportionally comparable grain yield of maize with the application of recommended inorganic fertilizers.

Green manure legumes such as *Dolichose lablab, Mucuna pruriens, Crotalaria ochralueca* and *Sesbania sesban* enhanced soil fertility and resulted in grain yield increases of 30–40% over plots that received an optimum mineral N-fertilizer from a urea source and further realized that green manure of sole legumes had potential to substitute for more than 70 kg urea N ha^{-1} in Jimma area. Application of *Sesbania* biomass and dry FYM greater than five t ha^{-1} gave comparable or greater mean maize yield than 69 kg N ha^{-1} from urea fertilizer. Green manure of intercropped legumes could at least offset the cost of 46 kg N ha^{-1} from urea for smallholder farmers who do not have sufficient land. N-fixed by Soybean, sesbania and crotalaria had 50% yield advantage over the plot of continuous maize without N-application and produced comparable yield to plots of continuous maize with recommended N. The mean yield advantage of N from five ton per hectare dry biomass of sesbania, soybean and crotalaria was 49 % over the control and it resulted in comparable yield to plots of continuous maize with recommended N. Integrated application of 5 ton Tithonia with 30 kg P ha^{-1} gave comparable maize yield as the recommended NP fertilizers of 64/20 kg NP ha^{-1} did and could be advised for low cost and sustainable maize production in Areka area. Combined application of *Erythrina* biomass (10 t ha^{-1}) with 23/20 kg N/P ha^{-1} increased the grain yield of wheat by 189% over the control and by 30% over the recommended N/P rate for the location (46/40 kg N/P ha^{-1}), implying that the use of *Erythrina* biomass can reduce the recommended rate of chemical fertilizer by half.

The combined applications of *Delicos lablab* and 23 kg N ha^{-1} significantly increased the grain yield by 70 and 117% over the control at Kokate and Hosanna, respectively. The highest yield was achieved by applying *Delicos lablab* green manure in combination with 46 kg N ha^{-1} fertilizers at Kokate (Wassie *et al*, 2010). Lupine and vetch green manures increased tef grain yield by 15 and 23% over the control at Adet, Amhara region. The result revealed that there is a possibility of growing and incorporating green manure crops within a time gap between onset of rainfall and tef planting for improving tef grain yield. Besides, integrated use of mustard meal with N fertilizer also highly increased tef N use efficiency (Balesh *et al*., 2005).

Integration of Vermicompost with NP fertilizer improved grain yield of different crops and soil properties. Application of vermicompost at 20 % of the recommended NP level had significantly improved growth and development of tomatoes and soil properties at Jima Research Center (Reshid *et al*., 2014). Use of vermicompost also increased growth, yield and chemical compositions and pH of the soil.

Integrated use of lime with organic and inorganic fertilizer

Sources for acid soil management: In Ethiopia, acid soils are rampant and occupy about 40.9 percent of the country (Mesfin, 2007). They extend from south-west to north-west with east-west distribution. Out of the 40.9 percent total coverage, 27.7 percent are moderate to weakly acidic (pH of 5.5 - 6.7); 13.2 percent are strongly to moderately acidic (pH < 5.5) and nearly one-third have aluminum toxicity problem. The combined use of lime with some type of organic matter is a superior treatment to increase pH and yield of crops. The reason for this is that organic matter has been shown to reduce Al toxicity, as well as enhance plant growth through improvement of physical properties and fertility of the soils (Lungu et al, 1993). Currently, research has shown that the addition of organic wastes and green manures to acid soils reduce Al toxicity and increase crop yields. Integrated use of compost and lime has increased yield of barley by 3.7 t ha^{-1}.

The different soil properties of acid soils were improved. Higher yields of faba bean, barley, maize, finger millet and soybean were obtained from integrated application of lime and phosphorous. Integrated use of 92/20 kg NP ha^{-1} and 4 t lime ha^{-1} could increase mean grain yields of maize and common bean by 23 and 10 % and recommended to obtain better yields of intercropped maize and common bean in Bako areas. Integrated use of 110/ 40 kg NP ha^{-1} with 3.5 t lime ha^{-1} gave better tuber yield of potato and recommended for Hagereselam and Chencha areas. Barely yield can be increased from 2.5 t ha^{-1} to 4.5 t ha^{-1} by applying 1.5 to 3.5 t ha^{-1} lime (according to the exchangeable acidity level of the soil) and 46 kg P_2O_5 ha^{-1}

Integrated use of cropping sequence with N and P and farmyard manure: Intercropping of maize with climbing bean with integrated application of 69/10 kg NP ha-1 and 4-8 t FYM ha-1 gave better grain yields and recommended for sustainable production of component crops. Physio-chemical properties of the soil were improved with integrated use of NP and Farmyard manure in intercropping of maize with climbing beans (Tolera et al., 2010).

Maize following Niger seed and haricot bean with recommended N-P fertilizer application was recommended for sustainable maize production in Bako area. Production of maize following Niger seed as a precursor crop with 46/5 Kg N-P and eight t FYM ha^{-1} or recommended fertilizer (110/20 Kg N-P ha^{-1}) was recommended for Bako area (Tesfa *et al*., 2012; Tolera *et al*., 2009a). Production of maize and sorghum following sole haricot bean with recommended fertilizer rate gave higher mean grain yield and recommended for sustainable production of maize and sorghum in Bako area. Wheat following Niger seed, faba bean and field pea with recommended rate of fertilizer was recommended for sustainable production of wheat in Horro and Arjo highlands. Wheat grain yield responses to N were minimal or non-significant; and P occasionally enhanced after a faba bean break crop and in the first wheat crop after any precursor crop.

Improved soil NO_3 and soil structure was observed following legume break crops with application of lower amounts of nitrogen fertilizers at Kulumsa. Bread wheat after pulses produced a higher grain yield with a yield advantage of 8-14% over application of 41-46 kg N-P_20_5 ha^{-1} at Sinana. Wheat following lupine exhibited no response to N fertilizer, suggesting that the enhanced productivity of wheat following lupine may be due to N- fixation by the lupine precursor crop (Minale *et al*., 2001). Faba bean and Ethiopian mustard increased the mean grain yield of wheat by 59% over the cereal precursors. Rotation of wheat with faba bean was found to be the economically optimal system of wheat production, even without fertilizer application for the central highlands (Amsal *et al*., 1997). N fertilizer requirement of wheat as a result of using faba bean and field pea as a precursor crops was reduced to 60 and 80%, respectively, compared to N requirement of wheat after wheat (Yesuf, 2006). Therefore, the use of legume precursor crop significantly reduced the application of nitrogen fertilizers for different cereal production systems.

Challenges

- Organic materials are required in bulk
- Most of the organic materials such as crop residues and FYM can be used as sources of energy and income instead of being used for soil amendment.
- Open grazing of animals
- Slow release of nutrients
- Little knowledge of farmers in integrating organic and inorganic fertilizer sources
- Little knowledge of farmers in preparing and keeping organic fertilizer sources

Oppourtunties

- Conducive policies and strategies for agriculture development,
- Due attention given by the government to agricultural research,
- Establishment of NARS and existence of good link with local, regional and international research and funding organizations and Universities,
- Establishment of research centers in different parts of the country/agroecologies,
- Development of soil fertility map for most parts of the country
- Availability of funding organizations for capacity building and technology generation.

Hence, in the future research must move beyond the concept of managing single nutrients. Actually, there is already good move by the EIAR in collaboration with regional research institutes and MoANR/ATA to support production of high nutritional quality and sustainable economic and biological yield levels by providing multi-nutrient fertilizer products.

- Identification of sustainable, environmentally friendly and profitable fertilizer technology packages under the changing climate and site-specific nutrient management with the help of decision supporting tools are also a prerequisite for soil fertility management in the country.
- Introduction of different organic and inorganic fertilizer sources (campanies) in the country
- Establishement of fertilizer blending plants in various parts of the country

Future Research Directions

Cropping system-based research is required for soil fertility management to offer reliable recommendations for different agroecology. Due attention should be given to integrated use of different fertilizer sources for sustainable crop production. Studies of rhizobia inoculation of legume crops intercropped with cereals in different agro-ecologies of Ethiopia should be emphasized. Emphasis should be given to the use of inorganic soil ameliorants in conjunction with slow release minerals. Due attention should be given to integrated use of crop rotation, inorganic and organic fertilizers for crop production. Due attention should also be given to scaling up of integrated soil fertility management practices on farmer's field. Due attention should be given to cost effective nutrient cycling; micronutrient and blended fertilizer application following EthioSIS (Ethiopian Soil Information System) soil fertility maps.

Conclusion

Sustainable land management plays a vital role in producing sufficient food for the rapidly expanding population with reducing land degradation and improving soil fertility in Ethiopia. Using various combinations of legume rotations, ground covers, green manures, animal manures, and other locally available resources in addition to adequate, affordable amounts of inorganic fertilizers, it is possible to improve soil fertility and thereby increase the productive potential of soils in Ethiopia. Integrated use of different fertilizers sources improved soil health and crop productivity and contributed for sustainable crop production. Besides, integrated use of all soil management practices also helps to save considerable amount of money which would otherwise be invested for inorganic fertilizers. Organic fertilization enhances the responses to mineral fertilizers, thereby increasing the efficiency of fertilizer use. These technologies ensure replenishing of soil organic matter as well as essential plant nutrients.

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Research Achievements, Gaps and Directions in Irrigated Agriculture

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Introduction

Ethiopia has a total area of 112 million hectare and a total population of 104 million (CSA 2007). The country is heavily dependent on rain fed agriculture with about 12 million ha currently under cultivation. This area can be substantially increased if the necessary infrastructure is put in place. Irrigation is one the means by which agricultural production can be increased to meet the growing food demands of the fast growing population of the country. The Increasing demand for food can be met in one or a combination of three ways: (i) increasing agricultural yield, (ii) increasing the area of arable land, and (iii) increasing cropping intensity by growing two or three crops per year using irrigation. However, expansion of the area under cultivation is a limited option and hence, increasing yields through cropping intensity system in irrigated areas with various mitigation methods and technologies are the most viable options for achieving food security in the shortest time span.

Traditional irrigation has been practiced in the highlands for centuries, particularly for producing subsistence food crops. In the early 1950s modern irrigation was introduced to Ethiopia in the Upper Awash Valley with the objective of producing industrial crops such as large-scale sugarcane plantations. Following the development of irrigated agriculture in the Awash Valley, research on irrigation started in Werer Agricultural Research Center in 1964 focusing on large commercial plantations of cotton and horticultural crops in the valley. The main activities during the initial era were determining frequency of irrigation and water closure dates, experiments to determine optimum combination of irrigation frequency and depth of application, and experiments to evaluate sensitive stages of growth for moisture stress, moisture depletion patterns and the effect of water logging on yield. Later following the expansion of research coverage and number of research actors, the targeting started to consider small-scale, medium and large scale irrigation schemes. Currently, the irrigation research is expanding to almost all research centers both under the federal and regional research Institutes and some universities. However, the research has been focused on plot-based studies than looking into integrated water management for agriculture. Investigations on alternative irrigation systems and an assessment of indigenous knowledge were conceived only recently.

The need to expand the coverage and depth of irrigation research emanates from the huge potential in the country in terms of surface, groundwater and rainwater resources. In terms of surface water, the country has 12 river basins that provide an estimated annual run off of ~125 billion m^3, with the Abbay basins (in central and northwest Ethiopia) accounting for ~45 percent of this amount. In terms of groundwater**,** Ethiopia has barely exploited its groundwater resources, especially for agriculture, which is estimated from 2.6 to 13.5 billion m^3, and while Ethiopia has abundant annual rainfall, the rainfall varies spatially (different parts of the country), temporally (different times of year) and inter-annually (yearly cycles). This synthesis presents the major achievements, gaps, constraints and future research in irrigated agriculture.

Research achievements

Given the focus of the research, the main research achievements are in terms of agricultural water management and drainage, reclamation, and amelioration. The key achievements are presented in detail below:

Irrigation water use studies

The water use studies were conducts in six irrigation locations namely Middle Awash, Lower Awash, Arba Minch, Gode, Debre Zeit, and Gerado in Wollo. The studies in Middle Awash were for Alfaalfa, Onion, sweet pepper, banana, maize, wheat, sesame, groundnut, kelaf, and cotton. In Lower Awash and Arba Minch, the studies considered only cotton whereas in Gode, water use management was studies for groundnut and sesame. at Debre Zeit area for chickpea and lentil, and in Wollo around Gerado irrigation scheme for tef. In addition, there were Lysimeter and furrow evaluation study at Middle Awash targeting cotton and wheat.

Middle Awash (Melka Werer and Melka Sedi areas)

Cotton:

- The optimum sowing dates for cotton in the Middle Awash region is between 1 to 15 May.

- Optimum irrigation regime for cotton in the Middle Awash has been found to be 75 mm per application every 2-weeks or 125-mm per application every 3-weeks.
- Suitable irrigation system is furrow irrigation with one establishment irrigation of 150 mm.
- Cotton water yield relations were established with 150- mm irrigation water at squaring, flowering and boll formation stages each with two establishing irrigation of 150 mm under Middle Awash condition.
- Pre-irrigation (150 –mm) practice for cotton was justified as an important practice for weed control, germination, and high crop yield.
- Irrigation regimes recommended for cotton at Gewane was 175 mm irrigation water every 3-week intervals.

Kenaf:

- Usual planting time for kenaf in the Middle Awash region is around Mid-May.
- Estimated crop water requirement is 839.6 mm seasonally.
- Irrigation amount of 125 mm every 2 weeks a total of six irrigation gave high yield and water use efficiency.
- Suitable irrigation system is furrow irrigation

Groundnut:

- It has been found to grow during the main and off-season in the Middle Awash region but the crop doesn't perform well during the off season.
- The optimum irrigation regime of 3-weekly application of 125 mm gave a net seasonal irrigation requirement of 775- mm comprising 150 mm at planting followed by five irrigation up to 120 days.
- Recommendations: Three irrigations at; Pre-flowering; Peak flowering; Pod development
- Recommendation was 150 m at plant establishment and 125 mm every 21 days up to 105 days.
- Suitable irrigation system is furrow irrigation

Sesame:

- Early July and early November planting were optimal for the main and minor seasons respectively in the Middle Awash Valley.
- With an irrigation regime of 100 mm every 3-weeks the net seasonal irrigation requirement is 450 mm , comprising a 150 mm application at planting followed by 3-irrigation up to 63 days from planting sesame irrigation system.
- The most suitable irrigation system for sesame is: 10 m wide X 140 m long border irrigation; Slope 0.1 of along the flow
- Recommendation was 100 mm every 21 days until 63 days after sowing

Wheat:

- Recommendation was given for wheat as 100-mm irrigation water every 10 days.
- Three irrigation with 125 mm each at squaring, booting and grain filling period; or Tillering, jointing and grain filling period, or Tillering, anthesis and grain filling period is recommended for wheat crop under Middle Awash condition.

Maize:

- During the main and minor-cropping seasons the optimum date of planting during the main season was June and November respectively in the Middle Awash Valley.
- November planting was found to be optimum for the cool season.
- It was found that there was no advantage in extending the irrigation beyond 84 days after planting.
- With an irrigation application of 75 mm every 2 weeks the net seasonal irrigation requirement is 600 mm, comprising a 150 mm application at planting and 7 to 8 irrigation.
- The gross irrigation requirement for maize planted in November in the Middle Awash region ranges from 840 to 900 mm.
- Three irrigations of 150 mm at vegetative, tasseling and grain development is also recommended.

Banana:

- The water use efficiency and fruit yield were the highest for an irrigation regime of 2-week frequency and 100 mm application in the middle Awash Valley.
- The irrigation requirement under this regime is 1700 mm for a period of 10 months (April to January) resulted in an annual irrigation requirement of 2028 mm. With an effective rainfall of about 430 mm /year, the annual total water use will be around 2450 mm.
- Based on the modified penman method, the seasonal crop water requirement for banana is 1843 mm / year and, with 75 % irrigation efficiency and an 8 % leaching requirement, the gross irrigation requirement is about 3071.7 mm per annum.

Sweet pepper:

- Sweet pepper is well adapted for growing in the Middle Awash Valley
- The highest yields and water use efficiencies were obtained under an irrigation regime of 6 days intervals and 40 mm application.
- With this regime, a total of 810 mm of water is required for one cropping season.
- The estimated crop water requirement of the crop during August to December is 802.78 mm and the gross irrigation requirement assuming 8 % leaching requirement and 75 % irrigation efficiency is 1090 mm.

Onion:

- Under Middle Awash condition, Onion can be grown successfully during the major and minor cropping seasons.
- Maximum fresh bulb yield was recorded for an irrigation regime of one- week frequency and 50 mm application.
- The crop water requirement of onion, as estimated using the modified penman method, is 516.87 mm for crops planted in October and growing for 120 days.
- With irrigation regime of 50 mm applied weekly the net irrigation requirement ranges between 850 and 900-mm and the gross irrigation requirement ranges between 1100 and 1200 mm.

Alfalfa:

- Alfalfa is well adapted as a lowland pasture and can be grown under irrigation in the Middle Awash region.
- Alfalfa was found to respond best to shorter irrigation intervals and at higher rates of water application.
- The maximum yield was obtained with an irrigation regime of one-week and 100 mm application.
- In terms of water use efficiency, both one week and 50 mm application and 2-week frequency and 100 mm application are equally important.
- From the management point of view, 2-week frequency and 100 mm application is optimum regime.
- Using modified penman for a growing period of 365 days the crop requirement is 2273.65 mm.
- The net irrigation requirement for an irrigation regime of 2-weeks and 100 mm application is 2700 mm.

Lower Awash Valley (Tendaho): Cotton

- At Tendaho, yield declined progressively as irrigation frequency was increased from 2 to 4 weeks and increased with an increase of water application.
- Yield depression was also observed when irrigation was prolonged beyond 120 days.
- Weekly irrigation application gave the highest yields. This is because of high evapotranspiration.
- Recommendation was 100 to 125 mm of irrigation water every week.

Arbaminch:Cotton

- Recommendation 125 mm every three weeks at Arbaminch.

Gode

Groundnut:

- Maximum yield of Groundnut was obtained under an irrigation interval of 6 days and 150 mm per application at Gode
- Recommendation was 100 mm every 6 days

Sesame:

- At Gode, shorter irrigation intervals (7-14 days) were better than longer ones
- Heavier water applications (10 –15 cm) were better than application of 5 cm.
- Maximum yield of 13.6 q/ha was obtained for an irrigation regime of 2 weeks and 15 cm application.
- Recommendation was 100 – 150 mm every 14 days

Debre Zeit area

Chickpea: the crop water requirement of Chickpea at Debre Zeit was estimated from long-term weather data using Penman-Montieth. The estimated CWR for January planted chickpea in Debre Zeit was 452 mm. The crop could be irrigated every 2 weeks in absence of Belg rainfall.

Lentil: The ETo, effective rainfall and CWR of lentil for Selgie irrigation scheme were estimated using Penman-Monteith as 509.4 mm and the crop could be irrigated every 13 day in absence of rainfall (Menelik Hailu, 2008).

Gerado area in Wollo

Teff: Solomon Zeberga (2006) estimated the CWR of teff for February planted crop in Gerado irrigation scheme. The estimated CWR of tef using Penman-Montieth for February planted crop in Gerado irrigation scheme has ranged between 434.6 and 439.0mm.

Lysimeter study at Middle Awash

Study of crop Water requirement and irrigation scheduling of Cotton and Wheat using lysimeter, FAO computer program and Water balance yield the following crop coefficient which tell the crop water requirement in each growth stages (Table 1).

Table 1: Crop coefficient, KC of cotton and wheat under drainage type Lysimater and FAO computer program

Crop type	Crop coefficient - Kc			
	initial stage	mid season stage	crop development stage	late season stage
Cotton	0.68	0.98	1.4	0.9
Wheat	0.996	1.3844	0.9381	0.85

Furrow Evaluation:

As per the furrow evaluation research, the optimum rates of stream flow and furrow lengths in the Middle Awash Valley are indicated in Table 2.

Table 2: Optimum rates of stream flow and furrow lengths

Characteristics	Location		
	Werer center	Melka Sedi	Amibara
Optimum initial stream flow rate (liters/sec.)	3.44	2.34	3.50
Cut-back stream flow rate (liters/sec)	0.72	1.72	1.42
Optimum furrow length(m)	205.00	190.00	210.00
Application efficiency %	97.00	78.00	62.00

Drainage, Reclamation and amelioration

- Leaching trial was conducted by Fentaw and Girma, 1996 on saline-sodic soils of Melka Sedi area where subsurface drainage system was already installed. Intermittent leaching method with single application of 200-mm water depth every recession period could be applied for cotton crop as a free leaching practice for reclaiming salt-affected soil with sub-surface drainage pipe under Middle Awash condition.
- Sub-surface drainage system is effective in controlling ground water table depth and soil salinity level under Middle Awash condition. Based on measurement of discharge and hydraulic head, values of hydraulic conductivity computed using the Hooghoudt equations were in the range 2-5 m day^{-1}. For a medium textured alluvial soil as found throughout the Middle Awash Valley, the following drainage criteria could be used;
- Minimum depth to water table 1.3 m with a corresponding hydraulic head of 0.7 m midway between the drains
- Hydraulic conductivity = 2.0 m day-1
- Drain discharge q = 2 mm day-1
- The tests on the hydraulic properties of the pipes and filter materials indicated that the best combinations were perforated corrugated plastic pipe (PVC) with 60 and 80 mm nominal diameter, surrounded with an envelope of red-ash and with a minimum pipe grading of 0.1%.
- Drain spacing of 40 to 60 m
- Drain depth of 1.7 to 2.0 m
- Fentaw (1995) has studied the effectiveness of subsurface drainage system in controlling ground-water table, reducing soil salinity level and increase crop yield in Melka Sadi pilot drainage scheme during 1986 to 1990. The groundwater depth after drain installation was deeper than before. The average water table depth after drain installation was constantly maintained above 1.3 m below ground surface over the years of monitoring period. Hence, under Middle Awash condition, the drainage system maintained the water table depth between the "drainage criteria" (1.3 to 1.5 m). Comparing to the initial ECe of 1983 with that of the Electrical conductivity (ECe) in 1989 and 1990, the average values of 66% and 78%, respectively of the initial ECe of the whole soil profile had reduced due to the subsurface drainage system.
- In the Middle Awash Valley, where evapotranspiration is greatly exceeding precipitation, it is advisable to keep the land wet under continues cropping to avoid movement of salt to the surface from shallow ground water in course of alternate wetting and drying.
- *Cinchrus* spp., *Panicum antidotale*, sudan grass and *Chloris gayana*, and Desmodium spp, triflorum spp, *Medicago sativa* (Alfalfa) and *Sesbania sesban*, were evaluated for their ameliorative effect under salt affected soils condition. Looking into the plant height, biomass yield and dry matter yield parameters of all grass species, they all performed well in the salt-affected soils of Werer research center. This shows that these grass species and legumes could tolerate the salinity effect and can survive in the salt affected soils environment.

Research gaps

The main gaps in irrigation research are related with the scope the research. In this regard, the scope of the research has been confined to irrigation agronomy trials to recommend irrigation regimes and less attention was given to the engineering aspects. Priority areas for irrigation and drainage research, based on studies of the country's problems, have yet to be identified.

Research in water resource development could enable the development of low-cost structures and irrigation systems for handling water. Where research information is lacking, there is a danger of over-design, which could results in high cost or under-design. Specific research has not yet been conducted to address problems related with flow structures (canals, ditches, flumes etc.); water storage facilities (farm ponds, irrigation reservoirs) and sediment traps. Agricultural water management research should, therefore, be accompanied with the water resource development and research activities to have a significant impact on the future development of irrigated agriculture.

Moreover, the research was focused only on research center and plot-based studies than looking into integrated water management for irrigated agriculture. The research does not exercise piloting research system i.e. on-farm irrigation plots at already developed irrigation schemes in the country for exchanging research and farmer practices and directly release the irrigation technologies. There is limited exercise on Problem identification and situation analysis on the status of AWM on irrigated agriculture. Furthermore, Lack of strong linkage with watershed management (WSM) interventions to irrigation development is of the main concern

In addition to these, the current research system does not target the nationally identified potential investment for Agricultural Water Management (AWM). The AWMs were identified on the basis of (i) where water is physically available (without water AWM is impossible), (ii) where the target beneficiaries are mostly located based on rural population density and poverty rate, and where water is key for livelihoods i.e. the extent to which livelihoods depend on secure access to sufficient water and where lack of water is a major constraint for rural populations.

Future research needs and direction

The agricultural water issues and related drainage and salinity problems in the irrigation areas of arid and semi-arid low land areas of the country are complex, and are not well described at the current time. So it will be critical to understand this complex processes and frame future agricultural water management options within this context to ensure that farming becomes and remains sustainable. Obviously there is no straight forward solution to the complex problems of salt-induced soil and water resources degradation. The research commodity with its overall goal of addressing the management of irrigation and drainage management will follow multidimensional approach through taking into account the biophysical and environmental conditions of the target area as well as livelihood aspects of the associated communities.

The future research direction and strategy combine continuity with change – addressing the current fast growing irrigation development and problems while expanding the focus to emerging challenges such as climate change and desertification in the country. There is a need to work closely with national agricultural research systems and government ministries. The research program will built a network of strong partnerships with national and regional research institutions, universities, agricultural organizations, private institutions, industries and manufacturers for effective technology generation/adoption and dissemination that synchronized with possible changing scenario.

Technical

- Improving agricultural water management for climate resilient irrigated agriculture: The role of irrigation on the Climate change // Variability in adaptation and mitigation measures. The role of Agricultural water management for climate resilient rainfed and irrigated Agriculture (agro-hydrological studies etc). Assessing water demand under climate change for major crops in rain fed and irrigated agriculture at different AEZs
- Assessing future irrigation water demand and enhancing irrigation water productivity for major crops and develop adaptation options under irrigated agriculture. Pre-irrigation practices for large-scale irrigated agriculture.
- Improving water management in small, medium and large-scale irrigation schemes establishing engineering design parameters and design criteria. Development of irrigation technologies on deficit irrigation, Engineering economics and conjunctive use of water resources. Most basic research works on water resource engineering research would be supported by physical models and hydraulic laboratories.
- Prevention and control strategy for salinity and water logging; Soil and surface water sources quality (Assessment, prevention, control, reclamation etc..): Urban irrigated agriculture and waste water treatment for irrigation; drainage water recycling techniques. promotion of saline agriculture techniques: Indigenous knowledge and knowledge management on irrigation and salinity management ; Magnetic treatment for Reducing salinity problems in irrigated agriculture;
- Agricultural drainage Management-Drainage agronomy; Drainage water treatment and reusing; Enhancing bio-drainage techniques-promotion-scaling up; Surface drainage, Mole drainage, BBF in highland drainage scenario;
- Groundwater management; potential and quality for irrigation, conjunctive use of water resources; Water balance study and Groundwater recharge techniques in climate change scenario. Groundwater:
    - potential,
    - quality for irrigation
    - Groundwater recharge techniques
- Improving water harvesting management: Water harvesting techniques In-situ / Ex-istu; Research on spate irrigation; Research on rain-fed and irrigated Rangeland management
- Watershed and environmental management must be integrated into all irrigation development projects, particularly in lowland areas that prone to salinization from poor soil quality. Integrated study with watersheds management

Social, economical and environmental

- Problem identification and situation Analysis
- Investigation into environmental, economic, and social factors affecting soil salinity and sodicity be made and their relationships must be established.
- Environmental and socio-economical influence must be assessed to establish system to sustain agricultural production and protect the environment
- On-farm verification and demonstration of water management technologies (small-scale / micro sprinkler and Localized irrigation system
- Technological impact assessment
- Adoption and up-scaling of small=-scale agricultural water management (AWM) interventions
- Raising awareness level of smallholder farmer and the community for improved agricultural water management practices and techniques. Awareness creation forum to prevent newly developed irrigated land
- Validating high water saving technologies, Drip and Sprinkler systems and Piloting of the best bit irrigation technologies at on-farm based irrigation schemes
- Validation and suitability of water lifting, soil moisture and flow measurement devices and solar energy for pumping irrigation water

- Establishing water resource management information hub

Policy, Institutional and capacity building
- Identify policy issues and policy set up (policy for irrigated land protection)
- Assessing water resource management policy issues
- Establishment of autonomous institution (Agricultural water management research)
- Extension system for irrigated agriculture
- Capacity building for researchers, development workers and users

Situation Analysis of AWM
- Existing environmental, hydrological and climate conditions
- National institutional and policy frameworks related to AWM
- Typologies of existing AWM practices and their geographical spread
- Key actors who are supporting the development of AWM in each region
- Promising AWM solutions that merit further detailed study

Implementation strategy
In addressing the identified future directions, the following strategic approaches need to be considered:

- Action research
- Monitoring and evaluation and learning
- Impact assessment
- Technology promotion and dissemination
- Promotion of research networking and partnership

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Agricultural Mechanization Research in Ethiopia: Challenges and the Way Forward

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Introduction

Agricultural mechanization embraces the use of tools, implements, and machines for agricultural land development, crop production, harvesting, preparation for storage, storage, and on-farm processing. It includes three main power sources: human, animal, and mechanical. The manufacture, distribution, repair, maintenance, management, and utilization of agricultural tools, implements, and machines is covered under this discipline with regard to how to supply mechanization inputs to the farmer in an efficient and effective manner. The paper presents the overall need for agricultural mechanization research, the key areas of research and achievements, organizational setup, current status at regional level, key challenges facing along the way forward. The paper is based on review of literature and secondary data sources.

Need for Mechanization and Productivity-enhancing Technology

Farm power—consisting of manual labor, agricultural tools, draft animals, tractors, implements, equipment, and machinery—is an essential farm input. In almost any agricultural production system, the annual expenditure on farm power, whether on labor, draft animals, or fuel and depreciation of machines, greatly exceeds the costs of other inputs such as agrochemicals and seeds. In many developing countries, agricultural production and food security are adversely affected because of insufficient use of farm power, low labor productivity, or labor scarcity. The need to improve agricultural labor productivity is increasingly recognized. In a case such as pump sets for irrigation, the need for machinery is undisputed. Rather than agricultural mechanization, it would be preferable to use the term farm-power or labor productivity–enhancing technology to recognize not only the importance of manual labor and hand tools, draft animals, and mechanical power, but also other issues related to labor scarcity, such as cropping and farming systems. Finding solutions to environmental problems in agriculture requires improved agricultural tools and machinery, including tools for soil tillage and pesticide application. Similarly, machines are required to assist with postharvest loss reduction and on-farm processing. Thus, it is now (again) recognized that agricultural mechanization is crucial in the fight against hunger and poverty, and at the same time it is crucial to address environmental and health concerns. The term mechanization unfortunately is often very narrowly perceived, while its real purpose, namely, enhancing the productivity of land and labor, often is not well understood. In this context, three principal purposes of mechanization may be summarized as follows:

a) **To increase labour productivity**: The introduction of machinery to substitute for labor ("labor-saving") is a common phenomenon associated with the release of labor for employment in other sectors of the economy or to facilitate cultivation of a larger area with the same labor force.
b) **To increase land productivity**: The purpose of mechanization is here to produce more from the existing land. Machinery is a complementary input, required to achieve higher land productivity, for example, through the introduction of pump sets, or through faster turnaround times to achieve higher cropping intensity. In labor surplus economies, net labor displacement or replacement should be avoided.
c) **To decrease cost of production**: Introduction of a machine may lower production costs or offset increased costs of draft animals or labor. Usually, in various degrees, a combination of the three objectives will be achieved. Additional benefits to the user may be associated with a reduction in the drudgery of farm work, greater leisure, or reduction of risk. These are subjective benefits and difficult to translate into cash. Frequently, mechanization increases an individual's workload, can be hazardous to health, and may reduce the social interactions associated with farm work.

With the above mentioned perspectives, the then Institute of Agricultural Research (IAR) established the Department of Agricultural Engineering comprising of Farm Power and Machinery, Soil and Water Engineering, Energy, Home Science and Food Technology sections in 1977. Later on the Soil and Water Engineering division was amalgamated to the Soil and Water Management program, the Food Science section was dissociated from the department, the Energy program was de-emphasized. The only remaining engineering division has been the Farm Power and Machinery section, which was then named Appropriate Technology for Farmers (ATF). This division was strengthened as the result of the signing of a project document, between the Ethiopian government and UNDP to establish an Agricultural Implements Research and Improvement Center (AIRIC) in July 1984. Prior to the signing of this agreement, the department was running two projects; one on Enset processing devices and another one on chain and washer pumps.

The Agricultural Implements Research program now called Agricultural Mechanization Research Process was then one of the seven national commodity programs operating under the then IAR. The program was organized in research, testing and evaluation and workshop divisions. The workshop supports both the research and evaluation divisions. The Melkassa

Research Center has handled all the necessary administrative works like finance and general service. The program operated informally as Agricultural Mechanization Research, Food Science and Post-Harvest Research Program in 2005 till the program was reorganized as Agricultural Mechanization Research Process in 2008. Through the years, a number of technologies have been generated and some have reached the end users though a steady supply of implements is not in place yet.

Key areas of research and achievements

The agricultural mechanization research has been engaged in the design and development of agricultural tools and machineries, testing and evaluation, promotion and multiplication of tested tools and machineries, and documentation of generated knowledge and experience through publication.

Design and development

The design and development of agricultural tools and machineries is looked considering six phases since the start of research in early 70s.

The beginning years

The ***Enset*** and pump research works, which started in the late 1970s, were followed by small works on development of land preparation implements, wheat and barley threshers till the UNDP supported project came into being in July1984.

The year 1985 was an establishment period. During this period a country wide survey was conducted in six administrative regions to identify crop production techniques and farm machinery related constraints. Based on the survey, land preparation, harvesting, weeding, crop establishment and transport in that order were singled out as the production constraints which needed the research's attention and helped the program set the research agenda (Pathak 1988). During this period, the necessary workshop, field and laboratory equipment were procured and installed. Some of the research staff were given long term training (MSc) and others were sent for short term training ranging from six months to one year to develop their skill in testing and manufacturing of agricultural equipment. Besides the infrastructure and capacity building, some outstanding works were done in research and development. Testing procedures for different agricultural equipment were developed and put to use. Besides basic crop physical parameters (Dereje Adugna 1987), methods and equipment for measuring the degree of soil aggregation through the tilth depth were availed during this period (Friew and Dereje 1989). Basic design data for the moldboard board plough were generated using the profilograph technique, which was the basis for the design and manufacturing of the moldboard part of the present animal drawn soil turning and inverting plough. Besides the works on hand tools, the wheat-barley thresher was modified to accommodate maize shelling during this period.

The shape of the moldboard part of the moldboard plough was generated using the profiliograph technique, which later helped generate the shape from a cylinder of 60cm diameter rolled from 3mm sheet metal. The moldboard pattern was pasted on the cylinder, and the moldboard was cut around the pattern using a cutoff disc. Up to ten moldboards were prepared from the cylinder (AIRIC Progress Reports, 1987 and 1988). Using this technique the department developed the first local moldboard plough, then called Nazareth plough, with a less draft power requirement and ease of operation based on the surface configuration of Nardi and Danish ploughs (AIRIC test report II 1988).

The years 1990-1995

In the early and mid-1990s, more works continued on land preparation implements. At this time the tie ridger was availed, more work was done on threshers (AIRIC progress Reports 1990, 1991). A hand metered row planter, manual maize sheller, a safe tomato transporting box harnessing system for horses, groundnut lifter, improved sickles and groundnut decorticator were developed and modification on donkey cart especially on the wheel axle assembly and raised bed were done during this period The wheat and Barley thresher was modified to accommodate maize shelling (Friew et al 1994) and a manual maize sheller was also delivered during the same period (Zelalem, 1994). On the other hand, information generated in the period also shows that operation on vertisol was proved to be better when handled during the second week of June under the then condition of Ginchii (National Agricultural Mechanization Progress Report, 1997)

In this period significant information on available animate power was generated. Accordingly, anthropometry information on the Ethiopian agricultural work force was generated (AIRIC Progress Report 1990, 1991) and basic studies on the effect of draft force on speed and work output of the draft oxen were carried out. .Information on the draft capacity of local oxen and cross bred animals was availed. based on the study the average working speed of Ethiopian oxen was recorded as 0.4 to 0.5 $m.s^{-1}$ while 1.1 $m.s^{-1}$ is a commonly reported speed for draft oxen. Under the conditions of the study the local draft oxen performed best at a pull level of 15% of their body weight contrary to reports of 10% elsewhere (Adugna Kebede et.al 1990). The oxen performed better at higher altitude. These were the basis for the design of suitable land preparation implements within the draft capacity of the local oxen. Studies on transport capacity of donkey carts (Adugna Kebede and Demeke Bekele 1990) and. Introduction of the low draft tillage implement together with the single animal harness believed to be beneficial for the large number of farmers, owning only single ox. Therefore, low raft implements and single animal harness was developed for single animal. Recorded results show that v-yoke was found to be better than the neck-yoke as a single animal harness (Adugna Kebede et.al 1990). A comprehensive documentation describing the division's experience on an international forum (Melese Temsgen 1990) and on the IAR newsletter (Friew Kelemu 1991) were presented during this period.

The years 1995- 2000

A set of pre-harvest implements like, winged plough, tie ridger row planter inter row weeder and groundnut lifter were developed and studies on small horse power tractors were conducted during this period (Melese Temesgen, 1995, Melese Temsgen and Mengistu Geza, 1999, Muluken Tilahun and Mengistu Geza, 1995). Studies on the improved planter and weeder showed a remarkable yield advantage over the conventional practice. During this period a ***Mofer*** attached plough, a single row maize and a four row small cereal planter were also developed and tested at Assasa and favorable response was received from farmers.

The single ox field capacity was 32hr.ha^{-1} and 21hr.ha^{-1} for primary and secondary tillage respectively. The planter draft requirement was 87.9 kgf and its field capacity was 10 hr.ha^{-1} and the depth of operation was adjustable between 4-7 cm (Agricultural Mechanization Progress Report, 1996).

The years 2001-2005

Works on grain storage, reengineering work on the Assela and IITA threshers (Seyoum et al 2008) were conducted during this period. A pedal driven maize sheller, cotton planter, milk churner (Minwyelet Nigatu, 2008) and honey extractor were developed. The work on ***Enset*** processing devices was restarted. Studies on draft capacity of camels, feed choppers, onion storage (Laike Kebede and Shimeles Aklilu, 2008) tomato seed extractor, papaya harvester, groundnut decorticator (Laike Kebede, 2008) and trials on using harvesters for *tef* were conducted and pertinent information and technologies were also generated (National Agricultural Mechanization Research Progress Report 2002). Besides, more work on land preparation implements and conservation tillage works on Maize and land suitability studies for maize production (Friew Kelemu and Girma Mamo 2002) were done and presented at the second National Maize workshop (Shilma Goda, 2002, Friew Kelemu, 2002). Works on donkey utilization as a power source were conducted during this period (Fisseha et al 2004).

The tomato seed extractor was able to pulp 12 kg of tomato and extract seed in a minute (Friew Kelemu and Amdom G/Medhin, 2008). The papaya harvester was able to detach papaya from a height of 3 meters in 2 sec without imparting any mechanical damage to the fruit. (Agricultural Mechanization Research Progress Report 2003 and 2004). Tef harvesting using combine harvester was found superior if the *tef* is grown on a leveled land and harvested by adjusting the cutter bar very low to the ground and the pickup reel has numerous spring type pick up fingers (National Agricultural Mechanization Research Program progress Report 2001, Friew Kelemu and Laike Kebede 2012). The pedal driven maize sheller shelled 12.5 quintals of maize per hour and the Enset processing device pulverized corm at a rate of 20kg/hr and received a favorable response in Koffele area (Friew Kelemu et al 2008). The study on camel showed that camels can generate a draft force of 568.23 N, moving at a speed of 1.14 m.s^{-1} ,which is equivalent to 0.65 KW power and can work comfortably in hot climate without any physiological stress (Workneh Abebe et.al 2008).

The years 2006-2010

Three two wheel tractors models DF15 DF 12 and VARI of 15, 12 and 6 hp and associated equipment were purchased and tested in 2008 and 2009. Among the three tractors the DF 15 showed better field performance and lower fuel consumption followed by the DF12 model, VARI was inferior to the two (Unpublished report). Manufacturers were trained extensively on the manufacturing of proven and potential technologies. Works on extruders was also picked up during this period.

The years 2010-2015

Studies were conducted on wheat and *tef* planters; single axle tractor based conservation agriculture, appropriate mechanization system post-harvest handling of horticultural crops, , metal silo, cassava processing devices. The works at this time included collaborative and externally funded projects (Eastern African Agricultural Productivity Project (EAAPP), McKnight, Evaluation, participatory demonstration of metal silo storage units in four major regions of Ethiopia supported by FAO, Farm Mechanization and Conservation Agriculture for Sustainable Intensification (FACASI) supported by the Australian Government and being jointly conducted with CIMMYT).

A four row *tef* seed drill with and without fertilizer application provision are developed. The seed rate ranges from 5-10 kg.ha^{-1}. A six row wheat planter with a seeding rate of 125-150 kg.ha^{-1} was also developed during this period. A cassava grater and chipping machine and metal silo of hermetic storage type of capacity of 300 kg to 1 ton were developed and distributed.

Conservation tillage types and planting techniques were evaluated. The study showed that the performance of ripping followed by manual planting tillage system was superior to the other four tillage treatments in tillage time, and weeding time, except the conventional tillage system. Ripping once and planting is a better in saving tillage time, avoiding delayed planting and drudgery to animals and human beings compared to reduced tillage system in areas where the rainfall pattern is erratic in nature as rift valley. It is also recommended that the right time of planting with uniform seed placement can be achieved if there is an efficient row planter that can be attached to the ripper.

Participatory evaluation of implements was undertaken with farmers on pre-harvest implements and 18 technicians were trained on manufacturing technique in 2010 (EIAR, 2010). In the same year around 200 implements were multiplied and distributed. An animal drawn Broad Bed Maker with a marker was developed during this period (EIAR, 2010). A total of 296 implements were multiplied and distributed to users,18 people from different micro enterprises were given practical training on manufacturing of implements, 139 lead farmers and 70 experts were trained on the use of different implement in the 2011 season (EIAR, 2011).

Testing and Evaluation

Testing and evaluation of all types of imported and local implements has been the mandate of the center. A number of implements collected from the country and produced by the program were tested and series of test reports were produced from 1986 till the early 1990s following standards developed elsewhere. A test guideline was developed as part of the testing and evaluation program in 1990, discussed by concerned groups and was approved as a test procedure. Using this test procedure different agricultural implements and equipment brought by the Ministry of Agriculture and the Ministry of Industry were tested and performance reports were written at different times. Twenty four Bulgarian made tractor drawn implements brought in by the Ministry of Industry were tested (Progress report, 1990) and found unsatisfactory by the center after two seasons of on station and field testing at Awassa and Adele.

Agricultural and Industrial Pre-extension Achievement

The research does not end, when the researcher generates a technology or comes up with a successful prototype. The researcher should help the extension worker at the popularization phase and the manufacturer at the initial stage of manufacturing for the successful diffusion of the mechanization technology in to the user community).

AIRIC has batch produced and popularized its successful prototypes around Welenchiti and Bofa in collaboration with the research extension department and the ***woreda*** Ministry of Agriculture offices to other parts of the country as well (Table 1) The ***Erfe*** and ***Mofer*** attached plough, planter have been distributed to the farmers around Bofa and Wolencheti and favorable response were received on the performance of these equipment. With the first cycle grant money from the Science and Technology Commission farmers from Welencheti area were trained on the operation of improved plough thresher and donkey carts, Also the local artisans were trained on the manufacturing of the plough. in the early 1990s. Besides, a substantial number of the plough were distributed to the farmers in the Merahabete area with the Menschen for Menschen group. Every year threshing-shelling services are given to the local farmers using the threshing-shelling machine developed by the center. The hand operated Sheller was distributed to farmers around the country through the Sasakwa Global 2000 program. A small number of donkey carts and an ox- cart were given out for Wolencheti farmers and feedback was collected accordingly.

As part of the pre-extension activity, training were given to the Rural Technology Promotion Centers of different Regional States on the manufacturing of ploughs, ridge-tiers, weeders, hand maize sheller and carts at different times. Besides, the rural technology centers, local artisans from the different parts of the country were given training on the manufacture technique of ploughs and ridge-tiers.

Table 1. Implements distributed to users

Year	Plough	Tie ridger	Maize planter	Wheat planter	Tef planter	Decorticators	Dectoticator Blades	Metal silos	Carts	Diff implements	Threshers/ shellers	BBM	Total
1994	20	20							3				43
1997	26								1				27
2007										50			50
2008										22	1		23
2009	27		3			20	40						90
2011*	694	2200	4								4	65	2967
2012	169	40									1		210
2013	50	50						50					150
2014	400	150		8	15		46	50			3		672
2015		50		20	20			8					98
Total	**1386**	**2510**	**7**	**28**	**35**	**20**	**86**	**108**	**4**	**72**	**9**	**65**	**4330**

Note: * the 2011 data is based on the collaborative work with FAO

Source: Progress reports 1994 - 2014 and Agricultural Mechanization 4th quarter reports of 2013 - 2015

Multiplication of Agricultural Equipment

Research generates the technology and once tested on station, the workshop produces in batch for verification on farmers' field (Table 2). If the equipment are found satisfactory on farmers' field, they have to be multiplied in larger quantity for popularization work. This later stage work has been handled to a limited extent by the regional rural technology promotion centers. Once this work is done, the manufacturing sector be it private or government has to pick it up and commercialize the technology.

Accordingly, AIRIC has previously given the drawings as well as prototypes of plough, ridge-tier, donkey cart and threshing and shelling machine to Tateke Engineering and Akakai Spare Parts and Hand Tools factory as a result of the protocol agreement reached between the IAR and the Ministry of Industry. Tateke produced the first batch, and Akaki produced some ploughs but both did not pursue the work further.

Table 2. Training s given to different users through the years

Year	Plough		Tie ridger		Wheat planter		Tef planter	Enset	Metal Silo	BBM	Total
	use	fabrication	Use	fabrication	use	fabrication					
1994	20		20								40
1997	15										15
1998	279	6			15						300
2007	40	20									60
2009	370	10						120			500
2011	38	11	479					34			562
2012	234				198			34			466
2013	406				180						586
2014	408				284		229	165			1086
2015	408										408
Total	2218	47	479		662		229	188	165		4023

Source: Progress reports 1994 2014 and Agricultural Mechanization 4th quarter reports of 2013 2015)

Publications

The Agricultural Mechanization Research program has documented its works in different forms for monitoring purposes and to avail information to fellow researchers, higher learning institutes, the extension group and the end users. The publications include; progress reports, test reports, technical manuals, newsletter articles, invited papers published in proceedings and journals (Table 3).

The progress reports are prepared annually and constitute the research works on progress, papers published at that particular year, list of staff members, weather condition and problems encountered during that period. This is an important document, which shows the progress of the research works, helps in planning and for the follow up of the work. This has been consistently documented till 2008 and some gaps are observed thereafter. This gap has created a problem in the follow up of the work.

The technical manuals deal on working methods like machinery and equipment testing, prepared working documents were discussed by working groups comprising of pertinent stake holders and are published as accepted guidelines for testing equipment. Besides many test reports of different agricultural implements; starting from land preparation, crop establishment, harvesting and post-harvest handling are prepared and documented, which contain useful information for designers, importers and training institutes. The staff has also published a number of articles in proceedings and journals as a means of communicating the works of the departments to different stakeholders.

Table 3. Papers produced by the department staff

No.	Category	Quantity
1	Research Reports	2
2	Newsletters	6
3	Seminar Papers	4
4	Manuals	8
5	Test Reports	22
6	Proceedings	21
7	Journals	4

The Organizational Structure

The Agricultural Mechanization Research Program has never had any defined structure. As mentioned above in the earlier period, it was seen as a support giving section to the research center till the period it started as a project. Later on towards the end of the 1970s it was a division under the then Department of Agricultural Engineering. The department started to take shape after the launching of the UNDP project signed in 1984 .Then it was informally organized as Design, Testing and evaluation and workshop. During that period a lot of testing and evaluation works were conducted, but the staff was working across the two streams, except the workshop which was limited to the fabrication work and has its own defined job. Then the department was then called Agricultural Implements and Improvement Center, had the status of a commodity and it was one of the seven national research commodities run by EIAR. At that time, the commodity personnel were categorized as Researchers, Technical and Field Assistants following the general category in the research system.

Agricultural Mechanization Research in the Regional States

Currently, there are Regional Mechanization Research Centers in Oromia, Amhara, Tigray, Afar and Somalia, besides the Federal Agricultural Mechanization Research Center operating at Melkassa. Most of these centers have long years of experience as Rural Technology Promotion Centers. It is just recently that they have been restructured as Mechanization Research Centers. The ones in Oromia, Amhara and Tigray are fairly strong, the one in Afar is relatively young and has a strong workshop, but is short on personnel; the one in Somalia is just at infant stage.

Unlike the many crop and livestock research centers in the different parts of the country, the mechanization research program was conducted mainly from Melkassa even after the establishment of the Regional Agricultural Research Institutes. Handling the country's mechanization related constraints from one center was difficult and some pertinent problems remained unaddressed. Issues related to crops like rice, root crops have now started to be addressed with the coming of the Regional Agricultural Mechanization Research Centers like Baher Dar, Jimma, Bako, etc., which are near or in the Agro ecology zone of these zones. Besides the establishment of these centers has expedient effect on the development adoption and dissemination of agricultural mechanization technologies in the respective regions.

Oromia Agricultural Research Institute, Agricultural Mechanization Process: In Oromia, there are four Agricultural Mechanization Centers (Assela, Bako, Jimma, and Fedis). In all the centers there are pre harvest; harvest and post-harvest divisions. Bako started as a technical school in 1968 and the others were Rural Technology Promotion centers, doing mainly demonstration and multiplication of agricultural implements and equipment. They were integrated to the Oromia Agricultural Research Institute (OARI) as rural technology research centers in 1994 E.C and are now transformed to Mechanization Research Centers. The centers are responsible for undertaking research in Agricultural machinery, implements, Small scale industry, small scale energy, food and feed processing. They also provide training to farmers, manufacturers, dealers; offer hiring service and are also involved in multiplication of technology. Some of the implements developed by these groups include: ARDU Moldboard plough (625-800m2. hr-1), Single donkey plough, winged plough, wheat row and water lifting technologies (treadle pump, rope and washer pump).

They have developed hand shellers (100kg.hr^{-1}), ground nut lifter, manual operated maize sheller, Engine and p.t.o operated shellers (0.5-0.6 ton.hr^{-1}) and produce 30 pcs a year, Assela wheat and barley thresher (0.3-0.6 ton.hr^{-1}), ground nut decorticator, winnowers transport and storage technologies, *Enset* decorticators, milk churner, bee hives, feed choppers, grass balers , different type of fuel saving stoves, biogas plants, water powered flour mill, solar cooker civet cage trap, poultry house are also some of the other technologies . The group has done some work on evaluation of votex thresher on black cumin (Lelliso Eddoshe and Birhanu Atomsa, 2007) and has modified the IAR model hand maize sheller with a smaller weight fly wheel, the weight concentrating on the outer rim of the fly wheel (Zelalem Biru, 2007) .

The Amhara Agricultural Mechanization Food Science Research Directorate: The Amhara Regional State Agricultural Mechanization and Food Science Research Center started as Bahir Dar Rural Technology promotion Center in 1985 with the responsibility of multiplying and popularizing agricultural implements around the north and western part of the country. It was reorganized as a mechanization research, technology multiplication, production and maintenance center in 1996.It started to conduct full-fledged research with the responsibility of generating, selecting, developing and adopting and promoting agricultural mechanization technologies in 1999. Later, in 2007/08 the Food Science research has been included and now operates as the Bahir Dar Agricultural Mechanization and Food Science Research Center. The center is mandated to do research and development works on agricultural mechanization and processing constraints with the responsibility of developing, testing and introducing effective appropriate technologies suited to the region.

The center has so far developed modern bee hives, treadle pumps, drainage and moisture conservation technologies, which are being widely popularized in the region. Improved plow, weeder, planter, harnessing technologies are already in use. Crop threshers, sheller, grain storage, potato storage, carts, wheel barrow, hay press, churns are also availed. Poultry houses, hatchers, feed processing, feeding equipment, milking equipment are addressed in the livestock sector.
Milling, size reduction, preservation and shelf life enhancement technology, churns , small scale possessing technologies for perishable products, improvement of traditional food, product safety and quality are addressed in the processing and food science category. The center also renders technical back stopping.

Currently, the Amhara Mechanization Research has been transferred to the Metal and Engineering Corporation (Amhara METEC).Although there are developments on the reorganizing the divisions with the inclusion of the agricultural mechanization as part of their main programs, it is difficult to guarantee the research will continue as it was before, since the new enterprise is working for profit and may not be subsidized to conduct public research.

Tigray Regional State: The Tigray Rural technology promotion center was established during the Derg era. Like the other enters, this center was also responsible for promotion of implements, rural energy and rural industry technologies. There was also an attempt to establish an implements research center at Mekele in 1967 by FAO, but could not materialize because of the then situation. After the fall of the Derg, Mekele Rural Technology Center was established in 1995. It was meant to demonstrate, multiply and popularize technologies developed elsewhere. After 2004 this department was reorganized as an agricultural mechanization research center. The center since its establishment has been focusing on pre-harvest, post-harvest, agro processing, biomass energy, fuel saving technologies, alternative sources of energy and water lifting technologies. Since its establishment the center has promoted similar technologies in the region like the other regional research centers.

When the regional mechanization research centers were established the main reason was to give solutions to the farmers problems depending in the crops, livestock available and the agro-ecologies and the source of power available in the vicinities. For example, the maize crop mechanization related problems were addressed by Bako mechanization research center of Oromia, Coffee beans mechanization related problems were addressed by the Jimma mechanization research center of Oromia, wheat crop mechanization related problems were addressed by Assela mechanization research center. Due to lack of mechanization research in the southern region, the federal mechanization research had tried to address enset mechanization related problems. All the mentioned efforts were made with the available resources but it does not mean that they all were done efficiently. What has been tried was to show that the mechanization issues were not addressed in the scale that is required by the farmers. The major reason was lack of adequate fund for research from the regional governments, lack of skilled researchers and workshop machines for producing prototypes.

Key Challenges facing agricultural mechanization research

The limited attention accorded

The Agricultural Implements and Improvement program had to face many ups and downs in its forty years journey. In the beginning years, it was not considered as an important research sector by the EIAR management, faced the challenge of proving its importance to every management group which has come at different times. At the establishment period, it was taken as a support system, more of a garage and an irrigation service center. Later on when the Agricultural Engineering division was dissociated and the implements section got the support of the UNDP first phase project, it was strengthened with workshop, laboratory facility and had the chance to train its staff on long term and short term basis.

At the beginning, the program was designed to follow the crop research program working division where the staff was categorized as researchers, technical and field Assistants, despite the major difference in the manufacturing workshop set up, which did not exist in the crop research program. The category was based on education level (high school, diploma and degree) rather than the kind of works being handled in the different sectors. One important problem was the staff working gear and cloth. Under the IAR system, all field assistants were given a pair of boots and boiler suits for field works, and the workshop technicians being categorized as field assistance were given a pair of rubber boots in the workshop, which is actually prohibited on the shop floor. It took a whole lot of energy and time to explain this to the management and was not settled before a new job description and title was studied and got approved by the then Civil Service office, which took more than two years. The IAR tuned mainly on crop research, could not appreciate the difference of the research system in the engineering sector and has failed to render the necessary support. It can also be easily indicated that the number of crop researchers with that of mechanization researchers. Even later, there are more than 650 researchers in EIAR who were engaged as a full time researchers whereas less than 25 researchers are available in the mechanization research. This further can be elaborated by the budget that is allocated by the government to these research directorates. The best way to justify how the program was given less attention is that an institute which is the same age with that of EIAR mechanization research in India, Indian Central Institute of Agricultural Engineering (CIAE), now has a remarkable progress by becoming one of the leading in mechanization technology development and innovation in the world. Despite the same age, the CIAE has transformed into an independent institute with 5 core divisions on Agricultural Engineering by improving the early mandate of the institute, which was to address the areas of farm machinery, post-harvest technology and energy in agriculture. However, the range of activity was later extended to cover Agro Industrial Extension, Instrumentation and Irrigation and Drainage Engineering. Thanks to the contribution of CIAE, now India becomes the second largest next to China in agricultural output at market exchange rates according to International Monetary Fund (IMF) in 2014 (IMF, 2014).That was the vision and progress that the program should have followed since its inception.

The other major challenge to the sector is lack of professionals on the sector. There are only two Universities that have BSc and MSc program in Agricultural Engineering or Agricultural Machinery Engineering and their current annual average uptake is about 65 students. There is no university which has a program at PhD level in the country. One can see that the sector is struggling with all those challenges mentioned.

Although there are efforts here and there by the government and other stakeholders, it need to be thoroughly thought about the future destiny of the country on the sector. We can also see that even most of EIAR research centers are not fully equipped and mechanized as a standard research center due to lack of focus to mechanization. Currently, mechanization is organized as a directorate with one case team and few staff and cannot say it is to the degree of the country's expectation to deliver the solutions to the multitude of mechanization problems the country is facing.

The coverage of the research program

At this time, when Agriculture is at the crossroad, where direct biological inputs alone cannot meet the challenges of sustained increased production in a resource dwindling and deteriorating environment. The biological efforts should be supplemented with effective, efficient and environmentally friendly mechanization technologies. The current Mechanization Research system is not tuned to this line, but was mainly engaged on farm implements powered mainly on animate power sources and small mechanical powered harvest and post-harvest technologies. The program was not consistently supported and did not keep pace with the march of time. The development sector is introducing different power units and implements, which is difficult to tell their efficiency, effectiveness and whether they are in tune with the principle of environmentally friendliness. The research system needs to move fast and be in tune to capture the order of the day.

Personnel and staff attrition

The Agricultural implements research program started its work with one BSc in the 1970s, never had more than five people at the MSc level and had never been joined by any person with a PhD level except the FAO project manager, an expatriate who stayed till the end of 1990. The staff turnover has been high and the people employed with BSc stay with the program for some time till they get their MSc (table 4). The program has never trained any personnel at the PhD level in Farm Power and Machinery area or have not tried to train the ones who thrive to get a PhD in the area of the program's mandate. The program after the UNDP program has never had a human resource development plan for many, years till the last three cycle MSc training programs run at Haramaya and Adama Science and Technology University, which has a bearing on its current and future research undertakings. One of the main reason for high staff attrition was the negligence of the program by the institute and lack of subsequent progress of the program like any other research program.

Table 4. Human resource of the Federal Agricultural Mechanization Research Program on a five year basis starting the beginning years.

Category	-1985	1986-90	1991-95	1996-99	2000-04	2005-2010	2011-2014	2015
PhD								
MSc	1	5	5	5	2			7
BSc	2	6	6	4	2			7
Dip(Agr)		4	3	3	3			3
Dip(Mech)	10	8	8	8	8			7
others		7	6	4	4			3
Total		**29**	**28**	**24**	**19**			**27**

The EIAR management started to take the program seriously after the Bulgarian implements testing episode. Despite these, the program failed to get the UNDP second phase program, and support culminated at the establishment period.

This created a grave consequence on the staff morale, which thought the program could be there for at least two phases, where well trained staff and facility will be there to get the program get going.

The staff at this time started to look for alternatives, and started to apply for scholarships on their own and not necessarily in the farm and power machinery sector. As the original staffs were strong and competent, they did not find it difficult to win scholarships and who ever got the training did not come back or if some have returned did not stay with the program.

There was a second attempt to get a foreign support to boost the program through Japanese aid. A Japanese expert worked with the program for three years with the objective of a long term cooperation program with the Japanese government. A five year project proposal was prepared and was approved by JICA office, unfortunately could not get the support from the Ethiopian side, which was another blow for the project.

There after the program has been running on government budget and some collaborative fund from some donors and bilateral programs, which was mainly a running cost and did not do much for staff upgrading and training.

Limited research facilities

The workshop equipment brought in through the UNDP program and some equipment through JICA equipment aid have not been efficiently utilized because of the non-availability of technical backstopping. Even those, which are the key device for conducting mechanization laboratory equipment were obsolete and old.

The Way Forward

Agriculture still remains a very important sector as it should be more productive from day to day as the number of mouths to feed increases continuously, contrary to the continuous dwindling resource as the farm lands are being squeezed from competition from the other sectors of the economy. Cities are expanding to farm lands, industries and infrastructures are expanding to these areas as well. Improved varieties and agronomic practices have shown remarkable yield increase, but sustainable increment without compromising soil health and water resource requires proper utilization of Agricultural Mechanization techniques. These techniques rely on proper soil cultivation, where the land is ploughed to the proper depth and pulverized to the required degree. The required amount of seed is deposited to the right depth and the degree of fertilizer application does not affect the soil health and expose the water to contamination. Besides, the crop protection practices are critically implemented, where the applied chemical address only the intended target. This requires properly designed and manufactured machinery at the disposal of the farmers, who are also trained and made ready to handle the required machinery accordingly. The Agricultural Mechanization Research program should be ready to meet the above challenges if the country has to meet the future food demands of its people on sustainable basis. It is also very prudent to see the experiences of fast growing countries like China and India. The mechanization sector in China is led by Chinese Academy of Agricultural Mechanization Sciences (CAAMS). Similarly, the mechanization sector in India is led Indian Central Institute of Agricultural Engineering (CIAE). Such kinds of organizational arrangements and focus given to the mechanization sector made the countries very successful in technology transfer. During the past few years a remarkable increase in transfer of technology between less industrialized countries has occurred. In this case, transfer of technology is practiced by exporting agricultural machinery from countries like Brazil, India, China, and Egypt to neighboring countries or overseas markets. These exporting countries are not considered industrialized, but they have succeeded in developing their own manufacturing industry for agricultural machinery. Low costs of producing agricultural machinery in combination with advanced technology and affordable investments in the low industrialized countries have contributed to this successful approach to transfer of technology. Apart from that, the imported technology is likely to be taken as more appropriate than the high-level technologies from the industrialized countries. But even between less industrialized countries basic prerequisites must be fulfilled for successful transfer of technology. To this end the following need to be given due consideration.

Strengthening and Supporting the Program

Increasing productivity in resource dwindling environment is possible by deploying efficient, effective and environmentally friendly production system. Food production in this country is adversely affected not only by the low level of production, but by high values of post-harvest losses, which need serious attention as well. This requires a continuous program for strengthening the Mechanization system in the country, where the Mechanization Research plays the pivotal role. The Agricultural Research system must recognize that the program is at least as important as the other sectors even priority need to be given taking its current status and the challenges it has to meet today and in the years ahead. With open market and globalization all categories of tractors and machinery are being introduced into the country, these different machineries are of varying weight and horsepower category. Thus due attention must also be paid to possible detrimental effects of mechanized farming on the environmental sustainability and correct technologies must be applied in order to avoid soil compaction/erosion and chemical pollution. The program should orient itself to address these issues as well.

Thus strengthening the program in terms of highly trained staff, facility and on collaborative works on research and development with strong institutes and organizations should be high on the agenda. It will be imperative to work on collaborative projects, which contain design, fabrication and evaluation not limited to scale out with well-known Institutes like Auburn Alabama on Soil Related works, with big Companies like John Deere on field machines and Australia on precision farming if we like to have a viable confident Agricultural Mechanization Research System which can leap to the Global Status rather than trailing at snail’s pace all the time.

The research program is currently organized as a directorate comprising three programs by changing the name ‘Mechanization’ into ‘Agricultural Engineering Research’, it is one step to the road at which it will be an independent institute like Central Institute of Agricultural Engineering.

Operation Modalities

The work need to be pursued by upgrading the Agricultural Mechanization Research Program in the technology generation training, and dissemination activities. Also due consideration will be given to the collaboration and coordination of their mechanization undertaking scheme. The center is expected to work in its areas of responsibility on a complete package starting from the pre-harvest, harvest and post-harvest category in the entire three power source category. Working on the lower power source level is discouraged unless the particular situation of the target area dictates that. In all the areas, the aim is to deal with the mechanical power technology. In all cases, resource mapping, precision and efficiency are the prime consideration.

The research undertaking to date on mechanization has been dictated more by the local problems with limited national picture and some iteration are done before a working prototype is worked out. Here after it is a group work where the design office, workshop and testing have stake in the generation of the technology. Thus every team member is accountable and should plan, debate, modify and execute accordingly. Besides as the design capability is built, simulation should be used to reduce the number of iterations before a prototype is worked out.

Strengthening the human resource in design and development

People coming from universities are novice in research undertaking a grooming training focused on design fabrication, Computer Aided Engineering, research methods and evaluation should be in place at least for the first six months of their stay in the research system. This should be followed by annual short term training, to update the staff on the current state of the art in Agricultural Mechanization Research as deemed necessary.

It is not only formal training, but practical oriented training will be more helpful to grasp the new cutting age technology. In the previous years, institutes like Haramya were strengthened with collaborative programs with well-known Universities like Oklahoma, the research system is also collaborating with CGIAR centers, but is limited to scaling out and other field works. There has not been any collaborative program, which starts from need identification, design and development work, which encompasses the design office and fabrication work at the shop floor. Such programs help in the generation of the technology, skill and knowledge transfer to the national staff. This kind of work should be an integral part of the research system building process.

Long-term training: A critical number of research that can lead the program need to trained at a PhD level in the design and development of agricultural machinery equipment.Twice as many of the PhDs at least 25% of them should be trained on the MSc level on the engineering of precision agriculture, resource mapping and control machine guidance system.

Short term training: The staff at the different levels need to take short term trainings once every two years on CAE (computer Aided Engineering) to upgrade the staff design capability.
The workshop staff will be trained on modern manufacturing and workshop management at least once in a year as deemed necessary.

Physical Facility: The laboratory and workshop facility at the center are obsolete and poor and need major repair work. Machine shop equipment like lathe and milling, major sheet metal shearing, bending machines and major cutting and welding machines are lacking, where efficiency and precisions are sacrificed in the fabrication work. Thus a major equipment shopping and installation is required.

Laboratory Facility: The laboratory facility are of the classical type, besides their old age. Thus precise modern electronic and sensor based gadgets, data loggers with well trained staff for operation and maintenance of the gadgets is necessary and should be in place.

Design office: Though the usual facility for office are not lacking, but genuine design software which can be updated online, computers and printers, precision farming gadgets should be made available in the centers.

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Agricultural Research Extension Linkage: Approaches, Actors and Challenges

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Introduction

The main task of public Agricultural Research and Extension services is to develop and provide improved technical know-how and technologies for agricultural producers in order to improve their contribution to society's and their own wellbeing (Navarro, 1990). This requires efficient service provision of both research and extension systems and their linkages. The concept of linkage implies the communication and working relationship established between two or more organizations in both systems. In general, agricultural research and extension services are commonly considered as two systems, which are linked by information and technological flow and feedback (Agbamu, 2000).

In Ethiopia, the issue of research-extension linkage has given due attention, which is associated with the recognized role of improved agricultural technologies and practices in the transformation of the country's agricultural sector. Linked with this, improving the efficiency of the agricultural technology delivery systems mainly the national seed system is considered as one of the key interventions in the process. This implies the need to understand the different approaches and mechanisms put in place to ensure stronger research-extension linkages. Linkages in general are defined as mechanisms that help to hold institutional elements together and permit coordination and there are two types of linkages (Adesoji and Tunde, 2012; Navarro, 1990). The first types of linkages are administrative linkages that are related with fiscal, personnel practices, planning and programming, and administrative support services. The second category of linkages is direct service linkages that are more of outreach related activities that ensure transfer of information and technologies both ways. In general, the coordination process can be voluntary, voluntary with formal agreements, or mandatory. It can involve joint planning, actions or evaluation of outcomes. It can occur within a community, between organizations, across communities, and between different levels in the organizations.

The need for strengthening research-extension linkages can be related with the low level of technology adoption, which is in turn directly linked with the productivity gaps observed among achievements in research fields, model farmers' fields, and national average productivity levels (Walker et al., 2015; Yirga et al., 2013; and Dawit et al., 2010). This indicates the huge potential to boost production at national level. Obviously, the observed productivity gaps are not only associated with the weak research-extension linkages but also with the week capacity of technology multiplication and delivery systems prevailing in the country in addition to the natural factors related with challenges of climate change and rainfall patterns.

This paper presents the current agricultural research and extension linkage mechanisms by considering mode on implementation, actors, challenges, and opportunities.

Mechanisms and Approaches

The research-extension linkage mechanisms that the Ethiopian Institute of Agricultural Research (EIAR) has been following have evolved over years. The key mechanisms that are currently under implementation are:

- Institutional linkages with actors of formal agricultural technology delivery systems;
- Technology demonstration and popularization;
- Farmers' Research Groups (FRGs);
- Agricultural Development Partners' Linkage Advisory Councils (ADPLACs) as research-extension linkage platforms;
- Technology pre-scaling up approach, and
- ENATT initiative
- Promotion of Research Linked Community-based seed system to enhance New Technology Transfer
- Fruit nursery linked Participatory Transfer of Fruit Technologies, and
- Agricultural innovation through Value Chain Empowerment

Institutional linkages

The institutional linkages with actors of the formal technology delivery systems have two forms. The first is related with the delivery of initial/source/prototype technologies for actors of technology multiplication and distribution, and the second is related with the involvement of researchers in the preparation of extension packages and manuals.

Delivering initial technologies

All public and private institutions that are formally involved in agricultural technology multiplication and distribution have access to initial livestock technologies, source seeds, farm tools, and implements. Therefore, all research centers formally make available the initial, source, and/or prototypes of technologies they have generated. The demand for initial technologies in the country is tremendously increasing which is linked with the following issues

- Considerable recognition by policy makers about the domestic availability of improved agricultural technologies that can considerably improve productivity and the limited access of these technologies to farmers;
- Considerable improvement in the level of farmers' awareness about the use of improved agricultural technologies; and
- Expansion of the type and number of technology multipliers.
  Accordingly, the research centers of the NARS are required to boost their capacity of initial technology multiplication and delivery.

The amount of source seed i.e. breeder, pre-basic and basic seeds multiplied by the different research centers of EIAR over the GTP period (2010/11 – 2014/15) indicates a total production of with the range of 10 to 15 thousand quintals annually (Table **4**). Further analysis indicates that the coverage of the production in terms of varieties is very limited only to the most popular varieties that are demanded by the actors of the formal seed system. Realizing the need to align and coordinate the production of source seed with the demand for certified seed, an ad hoc committee (National Seed Production and Distribution Committee – NSPDC) was established in 2008 during the time of Crash Seed Multiplication Program (CSMP), which was initiated to address the critical shortage of source seed. The NSPDC is composed of experts from EIAR, MoA and ESE, which is still functional though the decision making power has been reduced and given to the Inputs Marketing Directorate of the MoA.

Table 4. Amount of source seed multiplied by EIAR (2010/11 – 2014/15)

GTP Year	Crop	Source seed type (q)			Total
		Breeder	Pre-basic	Basic	
2010/11	Pulse	107.80	588.80	1,207.50	1,904.00
	Cereals	584.40	2,517.30	4,896.80	7,998.50
	Oil crops	5.00	98.20	353.50	456.70
	Total	697.2	3,204.3	6,457.8	10,359.2
2011/12	Pulse	139.30	517.40	1,909.50	2,566.20
	Cereals	415.80	2,749.00	5,801.10	8,965.90
	Oil crops	8.10	128.20	336.70	473.00
	Total	563.2	3,394.6	8,047.3	12,005.1
2012/13	Pulse	175.00	860.00	2102.00	3137.00
	Cereals	418.00	2,963.00	3,940.00	7,321.00
	Oil crops	16.00	350.00	668.00	1,034.00
	Total	609.00	4,173.00	6,710.00	11,492.00
2013/14	Pulse	117.10	661.00	1365.50	2143.60
	Cereals	548.30	5060.40	5418.50	11027.20
	Oil crops	27.30	116.20	1287.70	1431.20
	Total	692.70	5,837.60	8,071.70	14,602.00
2014/15	Pulse	239.30	660.60	1384.50	2284.40
	Cereals	535.70	3825.10	3123.70	7484.50
	Oil crops	10.50	72.50	1343.40	1426.40
	Total	785.50	4,558.20	5,851.60	11,195.30
Total (2010/11- 2014/15)		3,347.60	21,167.60	35,138.40	59,653.60

The initial multiplication and distribution of other agricultural technologies in the area of horticultural crops, livestock, soil and water and farm mechanization is very limited and lack an organized system as it is for grain crops. For instance, in 2014/15 production season, the number of seedlings of different fruit crops was 373,083, among livestock technologies, 649,835 fish fingerings, 15 improved heifers, 10 dairy cows, 200 sheep and goat, 282,000 silk worms, and 504.11 quintals of forage seed, and among soil related technologies, only 3,441 packs of bio-fertilizers were distributed from the different EIAR centers.

The following are key challenges in delivering source technologies

- Limited capacity of initial technology multiplication liked with resource (land, finance) and technology limitation (outdated machineries and equipment);
- In adequate internal quality control system for multiplication of initial technologies specially quality control for basic seed multiplication; and
- Limited coverage of available technologies

Preparing extension packages and manuals

Extension packages are the key tools in information and knowledge transfer within the research-extension-farmers linkage. Preparation and revision of extension packages is an activity performed every year by the extension directorate of the MoA at federal level. In the preparation and/or revision of the different extension packages, a committee is assigned for each agricultural commodity and it is composed of MoA extension experts and senior scientists of the NARS. The involvement of researchers helps to make sure that new technologies and management practices developed by the research system are considered in the preparation or revision. In recent years, experts of the Ethiopian Agricultural Transformation Agency are also involved.

At region level, the extension packages developed at federal level are adjusted/customized for region specific issues and in the adjustment process experts of respective region bureaus of agriculture and region agricultural research institutes are involved. The packages are also translated to respective region working languages.

In this respect the key challenge include development agents often face challenges in terms of timely supply of the recommended technologies in the require amount and quality at it is stated in the extension package.

Technology demonstration and popularization

Technology demonstration is an approach that have been used by the research system to create awareness about newly released technologies to farmers/pastoralists and other end users; and extensionists, technology multipliers and other public and non-public stakeholders. It is often undertaken using few innovative farmers in potential production areas for the technology on smaller plots. There is relatively high involvement of researchers. In terms of input provision, the research provides all the inputs, and target farmers provide land and labor. The local extensionists facilitate and assist researchers in farm selection and associated follow up of its implementation. All demonstrations and popularization activities are linked with field days where all relevant stakeholders are involved. During field days, discussion forums are organized to discuss issues related with the technology itself and how it can be accessed.

Popularization activities are implemented for technologies for which adequate demonstrations have been done in previous years. The main objective of popularization is to create awareness and access to the wider stakeholders. The role of researchers in popularization activities is lower compared to demonstration and it is more followed by local extensionists with technical backstopping and technology provision from the research. In popularization activities, more farmers host the activity. Field days are also organized as part of the popularization, where the fields are visited by relevant stakeholders and follow up discussions are made to boost awareness about the popularized technologies.

Often both demonstration and popularization activities are done for technologies that are recently released. However, there are cases where old technologies are demonstrated and popularized in areas where the technologies are not known. In terms of operational procedure, there are different approaches followed depending on the type of technologies.

Table 2. Demonstration and popularization of improved varieties of crops (2010 – 2014)

Crop	Varieties demonstrated and popularized	Demo sites	No of field days	Centers
Tef	Kora, Boset	640	3	Debre Zeit
Food Barley	Cross # 41/98, EH 1493	66	2	Holetta
Malt Barley	Traveler, Grace, IBON 174/03, EH1847, Sabini, Bahati, Bekoji-1	761	5	Holetta and Kulumsa
Maize	Mh140, MH 130, MHQ 138, Melkassa-2	181	20	Melkassa
Sorghum	Dekeba	90	2	Melkassa
Durum Wheat	Mukiye	280	11	Debre Zeit
Bread Wheat	Biqa, Honqolo, Hulluka, Ogolcho, Hidase, Shorima, Hoggana, Gambo, Danda'a, Kakaba, nejmah-14, Adel-6 (SAMAR-13/Pastor-1)	1169	84	Holeta, Kulumsa, Werer
Finger Millet	Debatsi	253	2	Pawe
Total	30 varieties	3,440	129	

Table2 presents the different types of newly released varieties of cereal crops that have been demonstrated and popularized from 2010 to 2014 production seasons. The number of varieties to be demonstrated depends on the number of new varieties released and availability of source seed. In total, 3,440 farmers have host demonstrations for 30 different varieties of cereal crops released during the period from 2010 to 2014 production seasons. During this period, 129 field days have been organized. Assuming that a minimum of 100 stakeholders, i.e., farmers, extensionists, and development partners engage in every field day, there have been more than 12,900 relevant actors directly informed about the varieties and their performance under farmers' conditions.

For pulse and oil crops, 22 varieties released during 2010 to 2014 were demonstrated engaging 627 demonstration hosting farmers and 35 field days have been organized to show the performance the varieties (Table 3).

Table 3. Demonstration and popularization of improved crop varieties (2010 – 2014)

Crop	Varieties demonstrated and popularized	Demo sites	No of field days
Chickpea	Teketay, Dalota, Minjar	324	16
Faba bean	Tumsa, Hachalu, Dide'a, Gora	10	2
Field pea	Bilallo, Latu	3	1
Soybean	Nyala, Wegayen, Gizo, Gishama	49	6
Lentil	Dembi, Derso	131	6
Haricot bean	Ada (KAT B1)	16	1
Noug	Ginchi-1	30	1
Linseed	Bekoji-14, Kassa-2, Jeldu, Furtu, Bakalcha	64	2
Total	22	627	35

One of the major achievements in terms of releasing improved varieties mainly through adaptation was for aromatic and medicinal crops. During the period from 2010 to 2014, 16 varieties for different aromatic and medicinal crops were released. The demonstration and popularization activities for the released varieties were hosted by 550 farmers and 22 field days were organized. Given the special nature of these crops, field days targeted the involvement of stakeholders involved in the marketing and value addition (processing) of these crops in addition to other farmers, extensionists, local administrators, and development partners (Table).

Table 4. Demonstration and popularization of improved varieties of condiments and medicinal plants (2010 – 2014)

Crop	Varieties demonstrated and popularized	Demo sites	No of field days
Nardos Grass	Nardos Grass	32	3
Lemmon grass	WG-Lomisar-UA, WG-Lomisar-Java, LOMISAR-1	22	2
Peppermint	Liyu	1	1
Spear mint	WG-SPM-FRAN, WG-SM-03	22	2
Japanese mint	Wondo-1	22	2
Chamomile	Chamomile-I [American Type]; Chamomile-II [German Type]	1	1
Lemon verbena	Lominat-I	24	2
Stevia	Sekwar	317	3
Hibiscus	WG-HIBISCUS-SUDAN, WG-HIBISCUS-JAMAICA	1	1
Lavender	WG-Lavender-I	1	1
Sage	WG-SAGE-	107	2
Total	16	550	20

Farmers' Research Groups

Farmers' Research Groups (FRG) is a participatory research approach with considerable role in technology transfer and adaptation. The approaches and institutional arrangement in promoting FRG follows different steps. These steps are

- undertaking situation analysis and identification of needs;
- selecting FRG member farmers;
- selecting FRG leader/management;
- activity planning;
- implementing planned activities;
- capacity building;
- monitoring and evaluation; and
- sharing experiences to other FRGs and farmers.

FRGs are voluntary groups of farmers formed to undertake research and extension activities on their own fields. The formation of groups is based on farmers' production constraints as identified and prioritized by farmers themselves. An FRG may have a chairperson and secretary elected by members (the only proviso being that there must be women's representative), a membership, which consists of those people who register with the group for a particular season's activity. The membership of FRGs is not fixed. People flow in and out of them, although a core of members will always provide continuity from one season to the next. The groups, however, have a collective memory, which individuals, disaggregated, do not have. The essence behind the formation of FRGs is to make agricultural research and extension client oriented and thereby develop informal, collaborative relationship and partnership, which will enhance the impact of research and extension activities in the final analysis (Teklu, 2007). The main role of the multidisciplinary team of researchers and extensionists is building farmers' capacity of innovation in their farming activities.

Agricultural Development Partners' Linkage Advisory Council

Recognizing the complex nature of agriculture and the need to involve wider stakeholders, Agricultural Development Partners' Linkage Advisory Council (ADPLAC) at federal, region, zone and in most cases at woreda levels as a platform for creating linkages among relevant stakeholders was institutionalized within the MoA, which has been previously promoted as ad-hoc platform for agriculture-related stakeholders' linkage. The nationally approved "Organizational Structure and Operational Guideline of ADPLACs at federal, region, zone and woreda levels (MoA, 2011) guide the overall operation of the ADPLACs. The policy and strategic framework presented in the guideline underline that the platforms are expected to play the following roles:

- promoting the government policy of alignment of all relevant stakeholders' endeavors in the agricultural development such as how synergy can be created in the scaling up and out of best practices in the sector;
- updating the government main intervention agendas and prioritization of emerging issues and see to it that these emerging issues are properly addressed;
- identifying and prioritizing best experiences from public and private actors and NGOs;
- serving as mechanism of experience sharing across regions and actors in the country; and
- using the platform as one of the key monitoring and evaluation mechanisms.

The key mechanism of operation of ADPLACs is the bi-annual meetings at federal, region, zone, and woreda levels, and members of the National Agricultural Research System (NARS) are chairs, co-chair, or secretary of these platforms at different levels.

Overall, the ADPLACs are linked to each other across the different levels to ensure that the issues discussed at lower levels are also issues known and properly addressed at higher levels. To ensure this logical link, the executive committees and General Assemblies (GAs) at different levels are required to hold regular meetings. The meetings are held in a staggered manner such that first they will be held at woreda level, then at zone, region and finally at federal levels. The linkages are ensured through reporting of the regular meeting resolutions using official minutes. The focal persons at different levels then summarize the discussions, synthesize issues of strategic importance, and make presentations to the executive committees at different levels. The committees will meticulously analyse the issues presented by the focal persons, identify issues to be included in the agenda, and prioritize them for ADPLAC's planned regular meeting. The performance of ADPLACs as stakeholders' platform is described as follows:

- periodicity of regular meetings;
- major issues addressed in those meetings; and
- achievements that have registered based on the resolutions made in previous meeting by member actors of the platform.

At federal level, the DG of the EIAR serves as the co-chair of the Federal ADPLAC executive committee, and the coordinator for Agricultural Economics, Research-Extension and Farmers Linkage program serves as a co-secretary of the Federal ADPLAC executive committee. Similarly, the same actors of RARIs play parallel role at region level. At zone and woreda levels, the director(s) of research centers from either federal and/or research institutes serve as co-chairs and coordinator at research center level for agricultural economics, research-extension program serves as co-secretary of the executive committee. These arrangements are instrumental for a two-way communication of research and development, where issues relevant to research are transferred to respective NARS members as assignments and/or mechanisms of availing existing technologies and knowledge in one hand, and available technologies and knowledge from the NARS are introduced for development partners for wider extension and scaling up on the other hand.

Pre-scaling up of technology

The pre-scaling up approach started to be implemented by the research system to support the national initiative of the "scaling up of best practices" in general and the "scaling up of agricultural technologies" in particular in the country. In previous years, limited localized success stories have been recorded through demonstration and popularization of improved technologies by various research centers in their respective mandate areas. In recent years, however, scaling up of agricultural technologies has been tracked with the following objectives:

- reaching different agro-ecologies and unreached areas with limited access to available technologies;
- triggering both the formal and informal seed systems in these areas for these adaptable technologies; and
- creation of functional linkages among the different actors in the research-extension continuum (Dawit *et al*., 2011).

The pre-scaling up activities are managed at national level by a multidisciplinary technical committee composed of relevant research program directors and representatives from the region pre-scaling up technical committees. Similarly, the activities at region level are managed by a technical committees composed of chairperson (senior researcher), three additional researchers, and a region focal person appointed by respective region BoA.

Even though, the activities are managed and coordinated by the technical committees at different levels, a number of stakeholders are involved in the implementation process. The key roles and responsibilities of the stakeholders are as follows:

Region Bureaus of Agriculture/extension

- Take the responsibility of the overall implementation of the pre-scaling up activities in the respective region;
- Facilitate the participation of all relevant stakeholders in the planning, implementation and M&E of the intervention,
- Assign a focal person for the pre-scaling up activities at respective level (region, zone and woreda levels) to facilitate the planning, implementation and M&E activities,
- Facilitate the selection of target zones and woredas along specific technologies,
- Cover the cost other than the cost required to purchase/multiply technologies, transport them to respective target woredas and the cost of training of trainers,
- Collect relevant information and data and report to relevant stakeholders,
- Facilitate the implementation of the pre-scaling up activities at the woreda level

Agricultural research

- Undertakes the overall mapping of stakeholders relevant for the implementation and later for scaling up of experiences that will be gained and ensures together with the region Bureaus of Agriculture their participation;
- Provides the selected technology packages up until the selected woredas;
- Provides training of trainers for the selected experts from the target woredas in each region;
- Covers the cost of training for trainers;
- Provides necessary manuals and guidelines relevant for the pre-scaling up;
- Develops and provides data and information collection instruments;
- Participates in the monitoring and evaluation of the implemented activities; and
- Supports the organization of field-days and workshops

Participating farmers

- Provide required land (not less than a quarter of a ha);
- Willingly participate in the technology package training;
- Apply the provided technology package as per the recommendations;
- Participate in the field-days and if necessary allow visits to his farm;
- Return the amount of seed or other technology to revolve for other farmers; and
- Collect data and provide to relevant stakeholders

Local administrative entities

- Facilitate the overall implementation of the activities at their respective levels;
- Participate in field days and workshops;
- Facilitate the scaling up of the gained experiences to other areas in their respective administration;
- Facilitate the alignment of all stakeholders engaged in their respective administration; and
- Support emerging issues in the implementation process

Other stakeholders (NGOs, HLIs, ATVET etc)

- Provide required support in the implementation as per their intervention in the agricultural sector to create synergy;
- Participate in the field-days and workshops; and
- Facilitate the scaling up of the experiences that will be gained from the interventions

The created access to improved agricultural technologies through the pre-scaling up activities was not generally meant only for the target hosting farmers and beneficiaries. By design, there was an attempt to use the seed produced by host farmers as seed in the subsequent production season. In some regions like Tigray and Amhara, the seed produced by host farmers was linked with the actors of the seed system for the following production season. The coverage over the last three years of the pre-scaling up activities in improved crop technologies is summarized in Table .

Table 5. Coverage of the pre-scaling up activities (2011 - 2013)

Indicator	Region	Production season		
		2011(2003/04 EC)	2012 (2004/05)	2013 (2005/06 EC)
Quantity of seed of improved varieties (q)	Tigray	1,086	712	791
	Amhara	1,485	1,718	1,064
	Oromiya	2,840	1,015	839
	SNNPR	3,907	537	693
	Total	9,318	3,982	3,387
Area covered (ha)	Tigray	1,608	503	779
	Amhara	1,812	1,844	634
	Oromiya	2,454	1,171	998
	SNNPR	3,663	319	415
	Total	9,537	3,335	2,047
Number of host farmers	Tigray	7,510	2,073	2,571
	Amhara	10,989	5,798	3,742
	Oromiya	10,781	4,686	4,168
	SNNPR	10,020	1,248	2,284
	Total	39,300	13,805	12,765

Source: EIAR (2014)

During the 2014/15 production season, the pre-scaling up initiative was transferred to be implemented with the leadership of the Extension Directorate of the MoA with technical backstopping of EIAR. In the implementation stage, though the initiative was implemented at region level through formal engagement of respective region BoA and region Agricultural Research Institute. For instance, the Amhara Region BoA has signed a Memorandum of Understanding (MoU) with the Region Agricultural Research institute in April 2015 that clearly states the responsibility of the BOA from region to Kebele level, and ARARI along with target volume of seed of varieties of different crops. This is expected to institutionalize the approach as one of the research-extension linkage mechanisms.

The detail description of the scaling up approach in terms of technologies considered, number of farmers involved, extent of researchers' involvement, area coverage, and associated tools deployed is presented in Table 8.

ENATT initiative

Cognizant of the weakness of the different approaches presented above, EIAR and RARIs designed a new approach entitled "Enhancing National Agricultural Technology Transfer (ENATT)." ENATT is an integrated agricultural technology demonstration, which was started in 2014 production season. The main weakness in the above approaches was reported to be limited consideration of integration of different technologies i.e. crop, livestock, natural resources and farm implements along with input and value chain approach. In general, smallholder farmers are involved in a mixed crop-livestock production where their demand for technologies accordingly stretches over different crops, livestock, soil and water management, farm mechanization, natural resource management, marketing systems, and access to finance.

The main objective of the approach and associated activities focus on establishing integrated agricultural technology and knowledge demonstration centers with the following aims

- demonstrating, in an integrated manner, available and appropriate technologies to farmers in the target demo sites, which will be called Agricultural Technology Villages -ATV;
- creating mechanism for sustainable supply of provided technologies;
- facilitating institutional innovation for enhanced technology adoption;
- creating market linkages; and
- using the sites to demonstrate, to wider stakeholders, technologies and role of integrated approach mainly to policy makers, extensionists, and farmers.

The initiative started to be implemented in the 2014/15 production season and nine villages have been selected in six regions namely in Amhara, Benishangul Gumuz, Oromiya, SNNPR and Tigray (Promotion of Research Linked Community-based seed system

to enhance New Technology Transfer

It is well recognized that seed system is composed of the formal and informal seed systems. The recent evolution and increasing role of intermediate type of seed systems that have some of the characteristics of both the formal and informal seed system is being recognized in the seed development literature. It is often called intermediate seed system, which is dominantly associated with community based seed systems (CBSS). This has a crucial role especially for varieties and crop types for which there is limited commercial interest in their seed production and marketing. Thus, it is important that EIAR start empowering this section of the national seed system through different forms of capacity development and improved access to source seeds.

Table The target farmers and type of technologies to be demonstrated will be expanded every year. The detail description of the ENATT approach in terms of technologies considered, number of farmers involved, extent of researchers' involvement, area coverage, and associated tools deployed is presented in Table 6.

Promotion of Research Linked Community-based seed system to enhance New Technology Transfer

It is well recognized that seed system is composed of the formal and informal seed systems. The recent evolution and increasing role of intermediate type of seed systems that have some of the characteristics of both the formal and informal seed system is being recognized in the seed development literature. It is often called intermediate seed system, which is dominantly associated with community based seed systems (CBSS). This has a crucial role especially for varieties and crop types for which there is limited commercial interest in their seed production and marketing. Thus, it is important that EIAR start empowering this section of the national seed system through different forms of capacity development and improved access to source seeds.

Table 6. ENATT villages established during 2014/15 production season

Region	Zone/woreda	ENATT Site/ Kebele	Crop	Number of participating farmers
Afar	Gebiresu/ Amibara	Hassoba	Maize, sesame, onion and forage	70
BG	Metekel/Pawe	Village 23/45 & 9/10	Mung bean, Cassava, Sweet potato, Bio-fertilizer, maize, poultry, apiculture, conservation agriculture	132
	Assosa/Bambasi	Dabus	Soya bean, maize and potato	52
Tigray	K/Awulalo	Gemad	wheat, tef, and faba beans	140
Amhara	Mecha	Abiyot Fana	wheat, tef, chickpea, and faba beans	170
Oromia	S/W Shewa /Amaya	Tume	wheat, tef, chickpea, and lentil	264
	East Shewa/Fentale	Serewiba	Maize, sesame and forage	85
	West Shewa/Wolmera	Robu Gebeya	Potato, barley, wheat, faba bean, field pea, forage oats, improved dairy	226
SNNPR	Gurage/Meskan	Dobena Gola	wheat, tef, and haricot beans	220

In this regard, an initiative called "Promotion of Research Linked Community Based Seed System to enhance New Technology Transfer" was developed and its implementation has started in the 2014/15 production season. The main objective of the initiative is to enhancing the national seed system in general and community based systems in particular through timely transfer of newly released crop technologies. Specifically, it will create of sustainable institutional linkage among actors of CBSS in the major production belts of the respective crops; capacitating actors of CBSS; and create adaption, selection, and demonstration platforms at community level for newly released crop varieties.

The initiative started during the 2014/15 production season and depending up on the targets, the involved actors are of two types. The first ones are those that are already organized in the form of cooperative and are willing to be involved in seed production and marketing. The second ones are group of farmers organized by EIAR extensionists to produce seed, which will evolve into a formal entity into either a formal entity either in the form of cooperative or other formal entity. In the process, relevant public organizations will be involved like cooperative promotion offices. During the production season, 12 seed producing farmers' groups were established (Table 7).

The detail description of the approach in promoting community-based seed system to enhance New Technology Transfer in terms of technologies considered, number of farmers involved, extent of researchers' involvement, area coverage, and associated tools deployed is presented in Table 8.

Table 7. Community-based seed producing entities established during the 2014/15 production season.

Region	Farmers' cooperative / groups	Crops	Number of participating farmers
Tigray	Ambalaje farmers union	Wheat	100
	Atsbi farmers union	Wheat and barley	110
Amhara	Wonberima farmers' union	Wheat	60
	Gusha farmers union	Potato	120
Oromia	Adea	Wheat	120
SNNPR	Endegagn	Wheat	100
	Diyo Gena	Wheat	180
BG	23/45 kebele (Pawe woreda)	Rice, groundnuts, and soybean	25
	Hetsitsa (Mandura woreda)	Sesame	10
	Dangur (Dangur woreda)	Rice, groundnuts, sesame and soybean	38
	Parzait (Dibate woreda)	Groundnut, sesame, finger millet, and haricot beans	51
	Baruda (Bullen woreda)	Finger millet and haricot beans	30

Fruit nursery linked Participatory Transfer of Fruit Technologies

Ethiopia is endowed with diverse and favorable climatic conditions that allow the production of both tropical and temperate fruits year round. Recognizing this potential, the research system has adapted and developed numerous varieties for the different fruit crops. In the area of fruit sector development, there has been considerable investment in establishing a number of fruit nurseries that were expected to multiply and deliver seedlings of required varieties to the different parts of the country. With these all efforts, however, due to diverse bottlenecks access to improved fruit varieties not only to end users but also the different fruit nurseries is very limited, which is the main source of missed opportunity from domestic and international fruit markets. Rather the country is forced to import different types of fruits. Among the key bottlenecks is realized to be the weak linkage between fruit research and development. Considering the experience gained through a pilot activity in promoting mango technologies, EIAR has started in 2014/15 production seasons an initiative called "Fruit Nursery linked Participatory Transfer of Fruit Technologies". The main objective of the initiative is to enhance the transfer and availability of fruit technologies through

- creating sustainable institutional linkage among relevant stakeholders;
- facilitating capacity development of fruit technology multipliers; and
- creating efficient distribution system by developing viable business-models for planting materials supply.

The key components of this initiative are

- capacitating selected fruit nurseries in the target regions for multiplication of seedlings of improved varieties of fruit trees;
- facilitating the creation of efficient distribution system;
- facilitating the establishment of national and region stakeholders' platform to ensure sustainability; and
- documenting experiences, challenges and opportunities.

The detail description of the approach in fruit nursery linked participatory transfer of fruit technologies in terms of technologies considered, number of farmers involved, extent of researchers' involvement, area coverage, and associated tools deployed is presented in Table 8.

Agricultural innovation through Value Chain Empowerment

Technology transfer can enhanced if the value chains of the specific agricultural commodities become efficient. Previous pilot initiatives to empower value chains selected commodities as malt barley has demonstrated creation of increased demand for available technologies. The main intervention of the initiatives was creation of functional linkages among all relevant stakeholders within the value chain through value chain platforms ensures timely addressing emerging issues and sharing of responsibility and accountability among stakeholders. Given the successes and challenges observed, EIAR has initiated a national initiative entitled enhancing agricultural innovation through value chain empowerment for selected commodities especially those that are highly linked with domestic agro-industries and/or export markets like soybeans, durum wheat, cotton, and sesame. The detail description of the approach is presented in Table 8.

Key Challenges of Research-Extension Linkages

The key challenges of the research-extension linkage emanate from the overall limited access and use of available agricultural technologies of the national agricultural research system by the end users (farmers, pastoralists, and commercial farms). The main challenges are:

- limited capacity of the research system to multiply and deliver initial technologies;
- inefficient alignment of the technology transfer efforts of the research system with the national agricultural extension system;
- inadequate formal linkage with technology delivery systems like the national seed system; and
- insufficient application of business models in technology transfer (Dawit *et a*l., 2010, Dawit, 2010).

Limited capacity

Under the current situation, the research system is expected to multiply and deliver initial/source technologies like basic seeds/seedlings for crops and animal breeds for livestock etc. However, due to the limited resources available like facilities and land and the need for using researchers time for research rather than technology multiplication, the amount of initial technologies multiplied by the research system is often very small compared to the demand. Therefore, it will be important to capacitate the research system in initial technology multiplication and there is a need to design innovative approach like provision of exclusive right for technologies for improved multiplication.

Inadequate alignment

The different research-extension approaches promoted by the research system are not formally aligned with the extension system at different levels, which has reduced the possibility of wider scaling up of the demonstrated and popularized technologies. Through the pre-scaling up approach, attempt was made in aligning the activities with the extension programs, which was demonstrated in improved promotion of the technologies. Thus, it will be important in formally aligning all the research-extension programs of the research system with the national agricultural extension program.

Limited formal linkages

One of the constraints for the national technology delivery systems like the seed system is the limited interest of the different actors like the public and private seed companies in investing in demand creation for the newly released technologies. The different approaches promoted by the research system in ensuring technology transfer often create demand for technologies promoted. However, there is no mechanism of linking the activities with the technology multipliers like seed companies to the demands created.

Limited application of business models

The stated approaches are more of public push for transferring available technologies and there is not as such a business based technology transfer mechanism. Experiences in other countries indicate the use of business incubation approach to ensure the transfer of developed technologies. Thus, there is a need to expand the type of approaches by applying business models of technology transfer.

Conclusion and Recommendations

The application of agricultural technologies to boost production and productivity and to improve the sector's competitiveness in both domestic and international markets is one of the key measures. The national agricultural research system has been developing and availing agricultural technologies that have contributed the recorded agricultural development. However, considering the productivity gaps between available technologies under research condition and fields of model farmers and the national agricultural productivity levels, there is a need to do more. In this regard, further strengthening the research-extension linkage is crucial. Specifically, it will be important to consider the following:

- capacitating the research system to avail the required initial technologies in the required quantity, quality and time;
- strengthening the alignment of the technology transfer efforts of the research system with the national agricultural extension system;
- Creating formal linkages between the research-extension activities with technology delivery systems like the national seed system; and
- exploring different approaches including application of business models in technology transfer and the role of private sector in strengthening the research-extension linkage.

Table 8. Description of t research-extension approaches

Approach	Objective	Description of the approach	
		Indicators	Details
Demonstration	To demonstrate the performance of new technologies	Technology	New technology (s)
		No of farmers involved	Selected model farmers
		Involvement of Researcher(s)	Dominantly done by researchers
		Area coverage	Mandate zones of respective research centers
		Associated tools	Field days Pamphlets, leaflets, booklets
Popularization	To create wider awareness about demonstrated new technologies	Technology	Recently demonstrated new technology
		No of farmers involved	Wider number of farmers compared to demonstration
		Involvement of Researcher(s)	Technology supply and initial sensitization of farmers
		Area coverage	• Planned by each research center • Mandate zones of respective research centers
		Associated tools	• Field days • Pamphlets, leaflets, booklets
Pre-scaling up	• reaching different agro-ecologies, production areas and regions with limited access to available technologies; • triggering both the formal and informal technology delivery systems • creating functional linkages among the different actors in the research-extension continuum	Technology	All available technologies but one technology for each participating farmer
		No of farmers involved	Determined by availability of resources
		Involvement of Researcher(s)	• Technology supply, • Training for trainers (extensionists) • Technical backstopping • Monitoring and support
		Area coverage	Nationally planned in consultation with region BoA Priority for woredas with limited access to technologies
		Associated tools	Field days Annual stakeholders workshops Pamphlets, leaflets, booklets

ENATT	• demonstrating in an integrated manner available and appropriate technologies to farmers in the target demo sites; • to create mechanism for sustainable supply of provided technologies as a model; • to facilitate institutional innovation for enhanced technology adoption; • to create market linkages as a model; • To use the sites to demonstrate to wider stakeholders the technologies and role of integrated approach	Technology	Different technologies in an integrated manner
		No of farmers involved	All farmers in the target sites
		Involvement of Researcher(s)	• Supply of different technologies • Training for trainers (extensionists) • Technical backstopping • Monitoring and support
		Area coverage	One target site/watershed/Kebele
		Associated tools	• Organization of site visits in a continues manner to stakeholders • Field days • Annual stakeholders workshops • Pamphlets, leaflets, booklets
Promotion of Research Linked Community Based Seed System to enhance New Technology Transfer	• creation of sustainable institutional linkage among actors of CBSS in the major production belts of the respective crops, • capacitating actors of CBSS, and • creation of adaption, selection and demonstration platforms at community level for newly released crop varieties,	Technology	Improved varieties of crops for which there is limited commercial interest in their seed production
		Target beneficiaries	Cluster of member farmers of target cooperatives
		Involvement of Researcher(s)	• Supply of seed of appropriate crop varieties • Training for cooperative management staff and member farmers • Technical backstopping • Monitoring and support
		Area coverage	Cooperatives and organized farmers in different regions (Afar, Amhara, Benishangul –Gumuz, Gambella, Oromiya, SNNP, Tigray)
		Associated tools	Organization of site visits in a continues manner to stakeholders Field days Annual stakeholders workshops Pamphlets, leaflets, booklets

Fruit Nursery linked Participatory Transfer of Fruit Technologies	• Creation of sustainable institutional linkage among relevant stakeholders, • Facilitation of the capacity development fruit technology multipliers, • Creation of efficient distribution system by developing viable business-models for planting materials supply	Technology	Available varieties of both temperate and tropical fruits Fruit nursery management
		Target beneficiaries	Public fruit nurseries
		Involvement of Researcher(s)	• Supply of seedlings of appropriate varieties • Training for fruit nursery staff • Technical backstopping • Monitoring and support
		Area coverage	Public fruit nurseries in different regions
		Associated tools	• Organization of site visits in a continues manner to stakeholders • Field days • Annual stakeholders workshops • Pamphlets, leaflets, booklets
Enhancing Agricultural Innovation through Value Chain Empowerment	• Facilitation of the establishment of vibrant and sustainable institutional linkage through innovation platforms among stakeholders in the technology transfer • Facilitation of improved technology multiplication system; and • Facilitation of the creation of efficient dissemination and delivery mechanisms	Technology	Priority agro-industry commodities (malt barley, durum wheat, cotton, dairy and poultry
		Target beneficiaries	Farmers, extension workers, agro-industries, and other input providers
		Involvement of Researcher(s)	• Ensuring the availability of source technologies • Provision of training and technical backstopping • Monitoring and support
		Area coverage	Diverse areas that are potential for target agro-industry commodities
		Associated tools	Facilitation of the functioning of respective innovation platforms

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Adoption of Crop Technologies among Smallholder Farmers in Ethiopia: Implications for Research and Development

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Introduction

Enhancing rural households' income and food security through improving access to improved agricultural technologies is a key development strategy in Ethiopia. Consequently, successive governments of Ethiopia have taken a keen interest in establishing, supporting and nurturing a dynamic national agricultural research system (NARS) capable of adapting and developing improved agricultural technologies suited to the diverse agro-ecologies and socio-economic conditions of the country.

Over the years, in response to the political and socio-economic dynamics of the country, the NARS and the Agricultural Extension System (AES) have evolved in several respects including organizational structure, agro-ecological coverage, mandate as well as research and extension approaches followed. Currently, agricultural research in Ethiopia is based on a decentralized system of a network of institutions involving the Ethiopian Institute of Agricultural Research (EIAR), Regional Agricultural Research Institutes (RARI's) and Higher Learning Institutions. While the primary focus of NARS remained on agricultural technology adaptation and generation, it has also been involved in technology dissemination efforts, albeit with limited scale, with the intent of creating technology demand. Agricultural extension efforts pioneered by the research system include the package testing program of the Institute of Agricultural Research (IAR) in the 1980's, Pre-extension Demonstration and Popularization activities in the 1990's and early 2000's and the current agricultural technology pre-scaling up efforts run by the federal and regional agricultural research institutes (Tesfaye et.al., 1979; Kibebew et al., 2011).

Equally, the agricultural extension system evolved in response to smallholder farmers' reluctance to take-up recommended agricultural technologies and the resulting slow progress in agricultural productivity improvements. Formal national agricultural extension efforts started in the 1960s with the launch of the minimum package program one (MPPI). This was followed by a more comprehensive extension project known as minimum package program two (MPPII) under the Extension and Program Implementation Development (EPID) within the MoA in the early 1970's (Tecle, 1975; Aklilu, 197;Waktola, 1980). Focusing on accessible areas (along road sides), the MPPII program largely benefited resource rich and model farmers. Also, the MPPII was instrumental for the development of commercial private farmers. The majority of smallholder farmers, however, were largely neglected. In an attempt to redress the weaknesses of MPPII, the Peasant Agricultural Development Project (PADEP) was launched in 1983 amid at enhancing input distribution, promote the role of cooperatives in rural development, enhance linkage between research and extension, and improve the performance of extension based on Training and Visit (T & V) concept. Following the overthrow of the military government and in an attempt revive agricultural productivity that has suffered from misguided agricultural policy, a new extension program popularly known as participatory demonstration, and extension training system (PADETES) was launched in 1994/95. The PADETES was prompted by the success of the Sasakawa Global (SG) 2000 project (Belay 2003; Davis et.al, 2010). The new extension program is characterized by the introduction of recommended agricultural technologies commonly presented in the form of technology packages.

In spite of the extensive technology generation and dissemination efforts, however, yields of major crops such as wheat, maize and teff are still low averaging 2.45 ton/ha, 3.25 ton/ha, and 1.47 ton/ha, respectively, suggesting the county has not fully taped the benefits of the investments made on agricultural technology generation and dissemination efforts (CSA, 2014). The low crop productivity in one hand and availability of proven improved agricultural technologies that would increase productivity by a significant margin as well as the extensive extension efforts to get farmers adopt improved agricultural technologies on the other hand has triggered interest in crop technology adoption and analysis of factors that influence the adoption decision behavior of smallholder farmers in the country.

This paper, based on review and synthesis of crop technology adoption studies conducted in the country over years elucidates the level of use of improved crop technology adoption as well as the adoption decision behavior of smallholder farmers in Ethiopia. The report also identifies research and extension issues that deserve due attention in future crop technology development, promotion and adoption endeavors.

Methodology for measuring adoption

The synthesis is based on crop technology adoption studies conducted by various individuals and institutions affiliated with the national agricultural research system. The reviewed studies considered many commodities and employed several data collection techniques that suite the diverse nature of the commodities and hence the technologies considered. Overall, the studies that form the basis for the synthesis collected data in several ways. While household surveys form the basis for the adoption analysis, in some studies data were collected from community surveys through focused group discussions and assessment of expert judgments (Chilot et.al, 2015). The synthesis also considered a recent study that tracked the diffusion of improved crop varieties through DNA finger printing and compared with farmer adoption responses (Chilot et.al, 2016).

Several indicators are often used to illustrate the degree of use of improved agricultural technologies. In this synthesis, two adoption measures, namely rate of adoption and intensity of adoption are employed to summarize the level of use of improved technologies. While rate of adoption measures the proportion of households adopting improved seeds, intensity of adoption refers to the area share of improved varieties as percentage of total area under the commodity of interest or amount of input such as inorganic fertilizer applied per unit area often in terms of kg per ha.

Results and Discussion

Crop Technology Adoption among Smallholder Farmers

In view of providing a historical perspective of the agricultural technology use among smallholder farmers in line with the evolution of agricultural research and technology transfer efforts, the synthesis identified three time periods including the period prior to 1990 , the period from 1990 to 2010 and the years since 2010 to date. Agricultural technology assessments prior to 1990 were few in number, focused on documenting the efforts and lessons learned from the Comprehensive Integrated Rural Development Projects and the Minimum Package Programs (Tecle, 1975; Aklilu, 1977; Waktola, 1980). The period between 1990 and 2010 marked the proliferation of technology adoption studies following the intensified crop technology dissemination efforts by specialized projects such as SG 2000, outreach activities of NARS and the national extension system (Alene et.al, 2000; Abdissa et.al, 2001; Habtermariam, 2004; Binod Kafle, 2010; Motuma, et.al, 2010). Most of the studies during this period were highly location specific, pertain to few crops and conducted with the intent of demonstrating project impact. Technology adoption studies conducted since 2010 to date, however, have a national focus largely based on nationally representative samples and focus on broad range of crops (Chilot et.al, 2013; Yigezu et.al, 2015; Chilot et.al, 2016a; Chilot et.al, 2016b).

Crop Technology Adoption among Smallholder Farmers prior to 1990

The first technology adoption studies, in Ethiopia, were conducted in the 1980’s with the objective of assessing the successes of the Comprehensive Integrated Rural Development Projects and the Minimum Package Program (Tecle, 1975; Aklilu, 1977;Waktola, 1980). These early studies focused on the adoption of commercial fertilizers and to a lesser extent on the use of improved crop varieties. Most of the early adoption studies reported rather low awareness of improved technologies. Also, the studies reported limited adoption of improved varieties and chemical fertilizers among smallholder farmers who claimed to have knowledge of the technologies promoted. Weak research-extension linkage was singled out as a major bottleneck for the low awareness and use of improved agricultural technologies. Besides, timely unavailability of complementary inputs (mainly inorganic fertilizers and herbicides) and low grain prices contributed to observed dismal use of agricultural technologies among smallholder farmers. Consequently, various initiatives were tried to strengthen the research-extension-farmer linkage that would help bridge the gap.

Following regime change in 1991, a number of policies have been adopted by the Federal Democratic Republic of Ethiopia (FDRE) aimed at liberalizing the input and output markets thereby bring improvements in the input supply system (mainly improved maize seeds and chemical fertilizers). Also, various measures were taken to improve smallholder farmers’ access to institutional credit (MEDaC, 1999). Improvements in the input supply system were also matched with aggressive scaling up efforts of improved maize and wheat technologies involving high yielding varieties, agronomic practices such as row planting, application of recommended commercial fertilizers and crop protection practices. Among others the Sasakawa Global (SG) 2000 initiative and the subsequent scaling-up of improved crop technologies by the national extension system stand prominent in efforts to reach smallholder farmers in Ethiopia.

Crop Technology Adoption among Smallholder Farmers from 1990 to 2010

Following the intensified crop technology dissemination efforts by specialized projects such as SG 2000 and the national extension system, a lot of adoption studies were conducted to assess the use of improved crop varieties and inorganic fertilizer which were believed to have been widely demonstrated to smallholder farmers. Like its predecessors, these later studies focused mainly on improved maize and wheat varieties and the use of complementary purchased inputs (mainly inorganic fertilizer) by smallholder farmers (Chilot et.al, 1996; Alene et.al., 2000; Abdissa et.al., 2001; Habtermariam, 2004; Motuma, et.al. 2010). The studies reported quite variable adoption rates ranging from zero as high as 58% for improved maize varieties. In case of commercial fertilizer use, however, high adoption rates ranging from 42% to 97% were reported. Furthermore, the studies indicated that, although many farmers were using improved maize seeds, much of the improved seeds used were recycled and came from old varieties.

Contrary to these studies, farming systems diagnostic studies conducted outside the study areas indicated that while adoption of improved crop varieties are widespread around research centers and pilot project areas where most of the technology adoption studies concentrated, most of the smallholder farmers in non-project areas rely on traditional production technologies. It was then realized that farmers’ dependence on age-old traditional technology and its accompanying effect of low productivity is not simply a technical issue, rather complex including socio-economic and behavioral factors which necessitated a change in approach. Consequently, the need for a systems approach became apparent in order to deal with the complex nature of low and declining agricultural productivity that gave way for biophysical and social scientists to join hands to make agricultural research more relevant to the situation of smallholder subsistence farmers (Mekuria, *et.al*, 1992). The role of smallholder farmers in the technology generation and transfer process was formally recognized and took a new precedence known as participatory technology development and transfer; and the need to develop a better understanding of the conditions which encourage adoption of recommended agricultural technologies became a priority (Mekuria, *et.al*, 1992).

Crop technology adoption studies conducted after the change in technology generation and transfer approaches in favor of client oriented research reported higher adoption of improved crop varieties. For instance, adoption studies conducted in the major maize hubs of the country by Berhanu *et al.* (2007) found that improved maize variety use increased from 63% in 1999 to 69% in 2001. Similarly, a study by Getachew et.al. (2010) conducted in the rift valley of Ethiopia, reported about 53% of the well-endowed households adopted improved drought tolerant maize (IDTM) varieties and planted them on 23% of their cultivated land. On the other hand, 47% of the poorly endowed households adopted these varieties and planted on 20% of their cultivated land.

Almost all of the crop technology adoption studies conducted in Ethiopia up to 2010 primarily aimed at assessing project success were largely conducted either on pilot research and extension sites or in selected high potential but pocket areas where intensive project efforts had been conducted. Only few studies attempted to assess crop technology use at a national level. Even these latter studies were based on small samples which may not be useful for drawing policy recommendation. Furthermore, these studies focused on relatively few crops (largely wheat and maize) and limited component technologies (improved seeds and inorganic fertilizers).

Crop technology adoption since 2010 to date

Realizing the drawbacks of the previous crop related technology adoption studies and prompted by recent intensified technology transfer efforts, the Ethiopian Institute of Agricultural Research (EIAR) partnering with several International Agricultural Research Centers conducted adoption studies at national level focusing on three cereals crops (maize, wheat and barley), three cool season legumes (lentil, chickpea and faba bean) and one root crop (potato) under the auspice of the project "diffusion of improved varieties in Africa (DIVA)" in 2011 . (Chilot *et al*., 2013; De Groot, 2014; Walker *et al*., 2015; Chilot *et al*., 2015a; Yigezu et.al, 2015; Chilot *et al.*, 2016a; Chilot *et al*., 2016b). Besides the DIVA study, several assessments were conducted on wheat, maize and teff aimed at updating varietal use by smallholder farmers. Results of the studies are summarized on tables 1 and 2

Adoption of improved maize technologies. Defining rate of adoption as the proportion of households using freshly purchased (un-recycled) improved maize varieties, the DIVA study indicated about 31% of the farmers planted improved varieties (De Groot *et al*., 2014). The same study indicated, of the improved maize varieties promoted, BH660 was grown by 27% of households on about 21% of the maize area while BH54 was grown by about 6% of the farmers on about 9% of the maize area during the same season. Other less popular maize varieties among sample farmers include BH543, BHQP542, Morka, Melkassa-1, Melkassa-4, and AMH800. A more recent study by Chilot et.al (2016b) aimed at tracking maize varietal adoption comparing DNA finger printing techniques with household surveys revealed interesting results. While farmer responses suggest that 55.9% of the respondent used improved maize varieties during 2013 production season, the DNA fingerprinting indicated 61.4% of the respondents to have actually used improved maize varieties with a difference of 5.5 percentage points suggesting household survey based adoption estimates under estimate adoption levels. The same study further revealed that only 30% of the farmers know the variety they cultivated by name. When considering only adopters, the proportion of famers who identified the variety they grew by name increased to about 49%. Farmer knowledge of cultivars, however, are restricted to only four hybrid maize varieties, namely, BH-660, BH-540, BH-140 and Shone.

Adoption of improved wheat technologies: A study by Chilot *et al.* (2013) defining adoption as the use of improved wheat seeds recycled at most for not more than 5 seasons, estimated about 63% of the sample households found to have adopted improved wheat varieties on 52.8% of the wheat area across the country. The same study indicated that seed recycling is common across the study areas mainly due to the absence of formal mechanisms for supplying new improved varieties and farmers' lack of awareness of recently released improved varieties. Hence, appropriate mechanisms need to be devised to bridge the gap between new variety release and seed multiplication on one hand, farmer awareness and adoption on the other hand. The results also show that farmers believe yields of improved wheat varieties increase dramatically when properly fertilized. As many as 76% of sample farmers used inorganic fertilizer (DAP) at an average rate of 68 kg/ha, indicating the need to find ways to improve fertilizer use. Similarly, adoption estimates of improved wheat varieties based on the 2013 study of tracking wheat varietal adoption using DNA finger printing revealed a high divergence between farmer responses based estimates and DNA finger printing estimates (Chilot *et.al*, 2016b). While farmer responses indicated that about 63% of the farmers used improved wheat varieties, the DNA finger printing suggested that about 96% of the respondents cultivated improved wheat varieties revealing the household survey underestimated the economic importance of improved varieties in the wheat sector by about 33 percentage points. The result based on famer responses, however, is comparable with previous varietal adoption studies conducted in Ethiopia. Furthermore, the DNA finger printing identified some 23 improved wheat varieties are cultivated by smallholder farmers in the pilot areas revealing the household survey underestimated not only the level of use but also the diversity of the wheat varieties currently under cultivation.

Table 1: Summary of estimated adoption rate of improved varieties of cereals for various years, Ethiopia

Crop	Estimated adoption rate(%)	Indicator	Data Collection Method	Area coverage	Study Year	Source
Maize	31	HHs	HH Survey	National	2010	De Groot, 2014
	55.9	HHs	HH Survey	East Wollega, West Shewa and West Arsi zones of Oromiya	2014	Chilot et.al, 2016b
	61.4	HHs	DNA finger printing			
Wheat	62.5	HHs	HH survey	National	2010	Chilot et.al, 2013
	52.8	Area	HH survey			
	62.0	HHs	HH survey	East Wollega, West Shewa and West Arsi zones of Oromiya	2014	Chilot et.al, 2016b
	96.0	HHs	DNA finger printing			
Food Barley	39	Area	HH survey	National	2010	Yigezu et.al, 2015
Teff	76.0	HHs	HH survey	Central highland	2012	

Adoption of improved tef technologies. To date, national level teff varietal adoption estimates are unavailable in Ethiopia. A recent adoption study based on a sample of 450 randomly selected farmers in three major tef growing districts of East Shewa Zone (Ada, Lume-Ejere and Minajar-Shenkora), however, suggest Quncho and DZ-01-196 (Magna) as the most important improved teff varieties grown by 76% and 40% of the sample farmers, respectively (Setotaw, 2013). The study further indicated that while adoption of Quncho increased from 5% in 2009 to 76% in 2012, the proportion of households using DZ-01-196 (Magna) declined from 84% in 2009 to 40% in 2012 signifying the increased importance of the latter in the study area. In terms of intensity of adoption measured by the area share of improved varieties from total area under tef, Quncho stands first covering 66% followed by DZ-01-196 (Magna) accounting about 26% of the total tef acreage. Over the two time periods, the area share of Quncho increased from 4% in 2009 cropping season to 66% in 2012 cropping season. On the contrary, that of DZ-01-196 (Magna) has dropped from 71% to 26% in the respective cropping seasons. The survey result showed that high yield, marketability, seed color, lodging tolerance, good germination, panicle length and earliness were reported to be the most preferred traits of tef varieties.

Adoption of improved food legume technologies. Among the legumes, adoption studies concentrated on chickpea, lentil and faba bean (Walker et.al, 2015; Chilot et.al, 2015a; Yigezu et.al, 2015; Chilot et.al, 2016a). Results of recent adoption studies of these commodities are summarized on Table 2. A national chick pea varietal adoption study based on household survey revealed that about 17.4% chickpea growers used improved chick pea varieties on about 19.4% of the chickpea acreage (Chilot et.al, 2015a). Of the 9 most important chickpea growing zones included in the study, three zones namely North Shewa of Amhara region, East and West Shewa Zones of Oromia region has the highest holder and area weighted adoption rates of over 30%. The study further indicated that data collected form expert panel and community focus group discussions (FGDs) provide good estimates of adoption and diffusion patterns of chickpea varieties. Adoption estimates from the panel of experts' stands at 13.1% suggesting experts' belief that the use of improved chickpea varieties is not yet widespread. Likewise, the community-based estimates indicated that at national level, 13.9% of the households adopted improved varieties on 10.3% of the total national chickpea area. Hence, given reasonably good correspondence among the national estimates of adoption, in terms of area under the improved varieties derived from the expert panel and the household survey, using a panel of experts can provide a quicker, cheaper and reliable estimate. While the panel of experts did not attempt to estimate adoption rate, i.e., in terms of number of growers, the estimates obtained using the community FGD, though not very close to those from the sample household survey, can provide useful information if and when household surveys are not feasible.

Adoption of improved lentil varieties across the country is fairly low with 12% of lentil growers using improved varieties on about 15.6% of the lentil area, suggesting a lot remains to be done to raise both the number of households using improved varieties as well as intensity of area under improved varieties (Chilot et.al, 2016a). In terms of efficacy of approaches, estimates from the expert panel, community and household survey correspond fairly well with 10.8%, 13.4 and 15.6% of the area share of improved varieties, respectively, suggesting expert panel and community survey could be used to generate the desired information quickly and cheaply.

Table 2: Summary of estimated adoption rates of improved varieties of pulses for various years, Ethiopia

Crop	Estimated adoption rate (%)	Indicator	Data Collection Method	Area coverage	Year	Source
Chickpea	19.4	Area	HH survey	National	2010	Chilot et.al, 2015
	17.4	Households	HH survey			
	10.3	Area	Community survey			
	13.9	HH	Community survey			
	13.1	Area	Expert survey			
Lentil	12.0	HH	HH survey	National	2010	Chilot et.al, 2016a
	15.6	Area	HH survey			
	13.4	Area	Community survey			
	7.1	HH	Community survey			
	10.8	Area	Expert survey			
Faba bean	11	Area	HH Survey	National	2010	Yigezu et.al, 2015

Econometric Assessments of the Determinants of Crop Technology Adoption

Interest in establishing the underlying factors that determine the adoption decision behaviour of smallholder farmers in Ethiopia dates back to the early 1980's (Tecle, 1975; Aklilu, 1977; Waktola, 1980). Most of the adoption studies were motivated by the need to identify the factors (policy, institutions and infrastructure) constraining smallholder farmers benefiting from recommended technologies and suggesting ways of improving policy design. Doss (2003) based on a review of 21 micro level maize and wheat technology adoption studies conducted in Eastern Africa provide useful insight on empirical and theoretical issues. Research on farmers' adoption of improved crop varieties considered awareness of the technology, profitability of the production packages, household and farm characteristics and institutional factors such as land tenure, access to markets, information and credit. The review focusing on determinants of improved maize technology adoption indicates that the results from different studies are inconsistent precluding generalizations. Salient points of the review and synthesis are provided in the following section.

Household characteristics. Household characteristics considered to have an effect on maize technology adoption include age, education level of the household head and family size. Several studies considered the effect of age of the farmer on adoption decision as a composite of the effects of farming experience and planning horizon. Many equated short planning horizons with older, more experienced farmers who may be unwilling to switch to new maize technologies whereas younger farmers being more educated on the average and having longer planning horizons have a higher disposition to change are more likely to invest in new maize technologies. On the other hand, greater experience could lead to better knowledge of spatial variability of plots that could lead to more accurate assessment of the performance of the new technologies and hence likely improve adoption. Several studies in Ethiopia have shown a negative relationship between age of the household head in years and the adoption of improved maize varieties (Habtermariam, 2004; Getachew et.al, 2010). Studies by Shiferaw and Tesfaye (2006) and Alene et.al. (2000), however, found no statistically significant effect of age on improved maize variety adoption. Education is a human capital often considered as the best alternative of empowering farm households. Education is believed to improve access to information on improved technologies and help farmers better discern the productivity consequences of using complementary inputs such as commercial fertilizer and agrochemicals. Evidence from various sources indicates a positive relationship between the educational levels of the household head and improved maize technology adoption (Alene et.al, 2000; Abdissa et.al, 2001; Habtermariam, 2004; Binod, 2010; Motuma, et.al, 2010). Studies by Alene and Hassen (2006) and Nigussie (2001) also found evidence that education is positively related with production efficiency. Farmers with higher levels of education, therefore, are more likely to adopt improved maize technologies than those who do not.

Large family size is normally associated with a higher labor endowment that would enable a household to accomplish various agricultural tasks on timely bases. Evidence in Ethiopia suggest that a household with large family size are more likely to adopt improved maize technologies such as improved maize varieties and inorganic fertilizer (Alene et.al., 2000; Tesfaye et.al., 2001; Shiferaw and Tesfaye, 2006; Berhanu et.al., 2007; Getachew et.al., 2010; Motuma, et.al., 2010). Empirical evidence therefore suggests that the influence of household size on the decision to adopt improved maize varieties is unambiguously positive.

Farm characteristics. Farm characteristics considered to influence adoption in many of the studies are farm size and area allocated to maize. A number of studies provide evidence that farmers who own and cultivate larger farms are likely to use improved maize varieties (Alene et.al., 2000; Habtermariam , 2004; Getachew et.al., 2010; Motuma, et.al., 2010; Binod, 2010) and allocate larger areas to improved maize varieties (Motuma Tura, et.al., 2010; Getachew Legese et.al.,2009). Larger farm size is associated with greater wealth and increased availability of capital, which makes investment more feasible. Hence, the impact of farm size on maize technology adoption decisions in Ethiopia is unequivocally positive.

Institutional factors. Institutional factors often considered in maize technology adoption decisions to have differential impacts on adoption by smallholder farmers are access to information (often measured by the number of extension contacts the farmer had with development agents), institutional credit, off-farm employment and land tenure.

Access to information on sources of improved maize varieties and complementary inputs such as commercial fertilizer and herbicides is believed to contribute towards optimal use of scarce resources. In Ethiopia, agricultural extension services are mainly provided by the MOA, although non-governmental organizations (NGO) such as Sasakawa Global (SG) are also actively engaged in agricultural extension work. Various studies in Ethiopia reported a strong positive relationship between access to information and the adoption behaviour of farmers (Alene et.al., 2000; Getahun et.al., 2000; Tesfaye et.al., 2001; Abdissa et.al, 2001; Habtermariam, 2004; Shiferaw and Tesfaye, 2006; Binod, 2010; Motuma, et.al., 2010). One exception is Getachew et.al. (2010) who reported a negative and significant relationship between access to extension measured by the number of contacts a farmer had with extension agents and the likelihood of using improved maize varieties. The authors contend that extension agents are being used for purposes other than agricultural extension such as collecting taxes and loans rather than visiting farmers to advise on purely agricultural technical matters.

The role of off-farm income on the decision to adopt improved maize technologies has been considered in few studies in Ethiopia. It is observed that farmers with off-farm income are more likely to adopt improved maize varieties than farmers without sources of off-farm income. Off-farm activities may also reduce the management resources available for the adoption process, but access to outside information may have positive effects. Motuma, et.al. (2010), Getachew et.al. (2010) and Abdissa et.al (2001) found a positive association between off-farm income and adoption of improved maize varieties while Alene et.al. (2000) found no statistical significant between off-farm income and improved maize use in Ethiopia.

There is mixed evidence about the impact of land ownership on incentives to adopt a new technology. A number of studies showed that land ownership increase incentives by lengthening planning horizons and the share of benefits accruing to adopters while lowering the rates of time preference. Others argue that the effect of tenure on adoption depends on the type of technology in consideration. A technology with a high potential to conserve input use, reduce cost, and provide economic benefits such as conservation tillage could create incentives for adoption even among renters, part time renters and part time operators (Norris and Batie, 1987). In Ethiopia, despite the fact that land is a public property under the custody of the government, informal land markets have thrived where smallholder farmers either lease land in cash or on share cropping bases (Teklu and Lemi, 2004). Nevertheless, given past experience and the widely held view that land redistribution is a fact of life as long as land remains a public property, there still remains much uncertainty concerning tenure security and its effect on technology adoption.

Liquidity constraint (cash shortages) is a typical feature of smallholder farmers operating in developing countries. Availability of agricultural credit by easing the liquidity constraint allows smallholder farmers to have access to external purchased inputs such as commercial fertilizer and other new agricultural technologies, which ultimately improve farm productivity. Studies by Getahun et.al. (2000), Shiferaw and Tesfaye (2006), Motuma, et.al. (2010) and others found evidence in support of the role of credit in enhancing adoption of improved maize technologies. It is therefore concluded that improving access to credit are likely to have a positive impact on adoption of improved agricultural technologies in Ethiopia.

On-farm demonstrations of improved maize varieties with their associated cultural practices have been held to demonstrate the superiority of improved technologies over traditional practices. Demonstration plots and farmer trainings is believed to facilitate change in the behavior of farmers and ultimately bring behavioral changes in favor of improved maize technology adoption. Several studies reported a positive association between access to demonstration sites and trainings and adoption of improved maize technologies (Tesfaye et.al, 2001; Habtermariam, 2004). Hence, the contention that households who benefited from direct public intervention or participation in demonstrations and extension package programmes have developed a positive attitude towards improved maize technology is supported by many studies in Ethiopia.

Wealth. Wealth is believed to reflect past achievements of households and their ability to bear risk. Previous studies in Ethiopia used the type of house a household owns (corrugated or grass roofed) and the number of livestock as a proxy for the wealth position of a household (Yirga et al., 1996; Shiferaw and Holden, 1998). Livestock ownership affects maize technology adoption in various ways. In most parts of Ethiopia, livestock are the main store of value, which could be easily liquidated to meet a household's cash needs for both productive (purchase of improved seeds and other inputs) as well as household consumption. Besides alleviating liquidity constraints, oxen in the mixed crop-livestock farming systems, are the primary source of traction power. Oxen by facilitating timely land preparation and planting of crops would affect the adoption decision behaviour of farmers. Furthermore, livestock provides manure required for soil fertility maintenance which in turn affects variety choice. On the whole, all but one study reported a significant and positive association between the likelihood of using improved maize varieties and the number of livestock owned measured either in absolute number or in terms of tropical livestock unit (Getahun et.al, 2000; Tesfaye et.al, 2001; Getachew et.al, 2010; Abdissa et.al, 2001). Similarly, Berhanu et.al. (2007) reported the number of oxen owned has a positive and significant influence on the likelihood of improved maize adoption. As shown above, livestock are sources of cash, improves soil fertility through the manure it provides and serves as security against climatic uncertainties.

Agro-ecology. In Ethiopia, maize growing environments are classified into four, namely, mid-altitude sub humid, high altitude sub humid, low altitude sub humid and low moisture stress areas. Each of these growing environments could be further classified into various sub-agro-ecologies or farming systems based on variations in altitudes, rainfall, soil type, topographic conditions and type of associated vegetative cover. Earlier studies indicated that while the sub agro-ecologies are similar in some features they exhibit marked differences in terms of soil types, cropping pattern and soil management practices used by farmers that have a strong bearing on the adoption of improved maize technologies. Although maize is an important source of carbohydrates to tens of millions of people in the country at large, its importance is much more significant in the mid altitude sub humid areas of the country where maize productivity is not only high but also stable owing to the dependable rainfall. Much of the agricultural extension efforts, therefore, were largely concentrated in the more favorable maize growing areas of the mid altitude sub humid areas of the country. Despite the importance of ago-ecologies in the adoption decision behavior of farmers, only one study considered agro-ecologies in their studies. A study by Getahun et al, (2000) found a positive association between agro ecological zone (altitude) and the adoption of maize technologies in southern Ethiopia.

Risk. Risk resulting from rainfall variability such as late on-set, mid-season spells and early cessation as well as market related (inorganic fertilizer and seed availability and price) is an important factor affecting the choice of maize technology in Ethiopia. Despite its importance in influencing the adoption decision behavior of farmers, very few studies attempted to address risk. A study by Fufa and Hassan (2003) using a stochastic production function showed the importance of risk effects of factor inputs on production behavior of smallholder maize growers in Ethiopia. The study revealed that timely planting through the use of oxen or more labor for cultivation improve stability of yield on plots of maize farmers participating in the improved technology package. On the other hand, cultivation of larger plots of maize and use of fertilizer were found to be risk increasing for this group of adopters.

As indicated above most of crop technology adoption studies attempted to explain the adoption decision behavior of farmers focused on single commodities of project interest such as maize and wheat; relied on small samples that lack adequate variability; and emphasized on pilot project areas where intensive agricultural extension efforts had been conducted. Evidence elsewhere in the world, however, suggest that analysis of farmers decision making behavior focusing on single commodity or activity, while actually multiple commodities, activities or interdependent technological options are the norm than the exception, ignores the simultaneous nature of the decision making process and the self-selection of households into and out of activities (Winters et.al, 2002; Yunez-Naude and Taylor, 2001).

Nonetheless, in Ethiopia only very few studies recognized the interdependencies and endogeneity of activity/technology choice in the analysis of the determinants of agricultural technology adoption (Haile Mariam et.a, 2013; Chilot et.al, 2015). A recent study by Haile Mariam et.al. (2013), analyzed the determinants of interrelated sustainable agricultural practices (SAPs) adoption using data from multiple plot level observations using multivariate and ordered probit models. The results indicated a significant correlation between SAPs revealing that adoption of SAPs is interrelated. In another study by Chilot et.al (2015) aimed at analysing the synergies/trade-offs involved in the adoption of improved varieties of multiple crops (barley, potato, wheat and faba beans) using a multivariate probit (MVP) model attested the existence of endogeneity in the adoption decisions of improved varieties of the four crops. The area shares of improved varieties of potatoes and faba beans are found to have a positive and significant effect on the likelihood of adopting improved varieties of barley and wheat and vice versa - indicating synergistic effects among the adoption decisions of the two groups of crops. On the other hand, the area share of improved varieties of wheat negatively and significantly effects the chances of using improved varieties of barley and vice versa - suggesting the existence of trade-offs between the improved varieties of the two crops. The MVP results, therefore, provide evidence for the simultaneity and interdependence of the decisions and intensity of adoption of the improved varieties of the four crops.

Summary and Conclusions

This improved crop technology adoption review and synthesis paper revealed that numerous technology adoption studies dedicated to estimating the level and intensity of improved crop technology use among smallholder farmers and determinants of adoption exist in Ethiopia. Almost all of the technology adoption studies focused on improved seeds of a select of crops and chemical fertilizers. Information on the use of interrelated sustainable agricultural practices (SAPS) as well as impact of crop technology adoption on household wellbeing, however, is scarce in Ethiopia. The adoption studies conducted prior to 2010 were highly location specific thus limiting the usefulness of the studies for deriving policy recommendation. Recent studies conducted since 2010, however, involved many crops, employed several complementary data collection methods (household surveys, community group discussions, expert panels and DNA analysis) and quiet a good number of studies employed nationally representative samples. Furthermore, available studies besides providing adoption rates, illuminated many of the factors affect the adoption decision behavior of farmers. The synthesis has also brought into light methodological and empirical research gaps, if addressed, would likely contribute to enhanced technology generation, promotion and adoption by smallholder farmers.

Most of the econometric models employed for investigating the adoption decision behavior of smallholder farmers have low levels of explanatory power, although, long lists of explanatory variables were used. The common variables considered in adoption models as factors influencing adoption decisions were extension, education, age, family size/labor, credit and income. However, there are also other factors that influence adoption decisions, but are often missing in adoption models. For instance, variables that refer to climate change, policy, gender, farmer attitudes, marketing patterns, technology degeneration, taste, physical attributes of improved seeds (color, size, etc), agro-ecology and others were not adequately considered in the adoption models of previous studies. Furthermore, the results from different studies are often contradictory regarding the importance of any given variable mainly due to differences in variable definition, agro-ecology and socio-economic situations. This inconsistency of results, therefore, underscores the importance of agro-ecology based empirical adoption studies using well-specified adoption decision models.

Smallholder farmers in Ethiopia engage in multiple enterprises (livestock, crop and off-farm activities). And yet, with few exceptions, much of the studies have modeled the adoption of single commodities disregarding the effect of resource allocation decisions on adoption decision behavior of smallholder farmers. Also, smallholder farmers in Ethiopia not only manage multiple plots having different levels of soil fertility but also cultivate several crops. The decision to cultivate several crops on the same (intercropping) and separate plots of land involves choices among several technological options. Despite the fact that the adoption decision involves choices among several technological options (simultaneity of choices) and interdependent decisions (e.g. the decision to use improved maize and inorganic fertilizer), only few technology adoption studies considered these factors in the adoption modeling process.

Adoption is a dynamic process involving learning by doing. Almost all previous maize technology adoption studies, however, used static models that do not capture changes in the adoption decision over time mainly due to lack of micro level data over time. It is therefore important that future studies generate panel data and apply econometric models that appropriately account for, simultaneity of choices, interdependent decisions and time.

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