Ethiopian Journal of Crop Science

Special Issue Volume 6 Number 3 (2018) ISSN: 2072-8506

A Special Volume Dedicated to the 3rd Decadal National Conference on Food and Forage Legumes in Ethiopia
6 - 9 November 2016, EIAR, Addis Ababa, Ethiopia

An Official Journal of the Crop Science Society of Ethiopia (CSSE)

2018
Addis Ababa, Ethiopia

Ethiopian Journal of Crop Science

Current Members of the Ecxcutive Committee of the Crop Science Society of Ethiopia (CSSE)

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Ethiopian Journal of Crop Science

Published by the Crop Science Society of Ethiopia (CSSE)

Special Issue Vol. 6 No. 3 (2018) ISSN 2072-8506

Ethiopian Journal of Crop Science (EJCS)
Special Issue Volume 6, Number 3, 2018
ISSN 2072-8506
Addis Ababa, Ethiopia

Ethiopian Journal of Crop Science

Current International Advisory Board Members of Crop Science Society of Ethiopia (CSSE)

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Foreword

Ethiopia has a large land base that is well suited for growing a wide range of food and forage legumes. In particular, the food legume industry in Ethiopia is significantly and ecologically influencing sustainability of the farming system through soil fertility restoration. Now, with an area of some 1.8 million ha and production volume of more than 2.7 million MT annually, the country contributes a significant amount of legumes globally.

Among the major grain legumes are: faba bean, common bean, chickpea, field pea, lentil, and soybean. Research works done on legumes over the last four decades have improved productivity, quality, marketability and use values of these crops. The national grain yield average for the dominant legumes recently reached 2 t ha^{-1} from less than a ton a few decades ago. Legumes are major source of income and foreign currency earnings, nutrition, farm fertilization and farming system sustainability to about 8.5 million (70% of all) small holder agrarian households in Ethiopia.

Up until now, we have been able to release more than 160 varieties of food legumes holding unique traits of interest preferred by the farmers, the market and other beneficiaries. Likewise, Ethiopia is a centre of diversity for herbaceous forage legumes such as the genera *Trifolium, Vigna, Lablab, Neonotonia,* and others. Currently 2076 accessions from 140 species and 35 genera are systematically collected and conserved. Yields of improved herbaceous forage legumes range from 3–5 DM ton ha^{-1} and for tree legumes 10–12 DM ton ha^{-1}.

So far, 20 varieties from 10 species that belong to seven legume genera have been registered and/or released.

Local studies during the past three decades revealed that, there is a good opportunity for integration of pasture and forage crops in the existing farming system, wherein, heavy emphasis is put on the use of forage legumes in cropping systems (through under-sowing, improvement of fallows and establishment of tree legumes hedges) to partly address the major problems of long-term sustainability of crop production.

However, there have still been challenges to tap the potential of the sub-sector. The role of key institutions in the sub-sector is of paramount importance. The future dimension needs even far more innovative approaches and applications of advanced techniques for the sub-sector to remain competent.

The Ethiopian Institute of Agricultural Research (EIAR) in collaboration with its longstanding CGIAR partners like ICARDA, ICRISAT, CIAT, IITA and ILRI, including national research and development institutions, has been making utmost research and development efforts in food and forage legumes that resulted in the development and promotion of improved technologies. The hitherto scaling up of these technologies by different stakeholders not only revealed the superiority of the technologies over the existing ones but also made farmers aware of the importance of applying improved production packages, including improved seeds of the crops.

In order to ensure the research is delivering the required outputs, it is of paramount importance that reviews are carried out on regular basis. On this perspective, like periodically revising the research progress, it become eminent to EIAR and its aforementioned partners, to have a forum whereby, “Decadal Performances” of the national food and forage legumes research and development are reviewed by researchers and stakeholders. Accordingly, as part-and-parcel of the celebration of the International Year of Pulses in Ethiopia, the Third Decadal National Conference on Food and Forage Legumes in Ethiopia, themed: 'Legumes for Healthy Food, Feed, Income and Sustainable Agriculture in the Face of Rapidly Changing Climate' was held from 6 - 9 November 2016, on the premises of the EIAR, Addis Ababa, Ethiopia. Concurrently, for us, the International Year of Pulses 2016 thus offers an opportunity to celebrate the major impacts that our research has registered so far, and also to call on donors and partners for renewed support. Their commitment is critical for translating the remarkable achievements of recent years into new rounds of improvement for the future.

At this juncture, it is gratifying to note that national and international support for the legume research and development sub-sector continue to realize the desired impact for which EIAR expresses its appreciation.

Therefore, on behalf of EIAR and on my own behalf, I would like to acknowledge the many individuals and organizations that have directly or indirectly contributed to the success of this conference. In particular, the organizers of the conference should be deeply commended for their wonderful job in organizing this successful conference and undertaking the conscientious task of facilitating the editing of all manuscripts presented at the conference for publication in this Special Volume of the Ethiopian Journal of Crop Science. I am thankful to the Ethiopian Society of Crop Science for kindly dedicating this Special Issue of the Ethiopian Journal of Crop Science for publication of the papers presented at this conference, as this kind of publication provides a measure of continuity of research and development within the sub-sector, and guides decisions of policy makers.

Let me also extend my sincere acknowledgements to the sponsors: EIAR, ICARDA and CIAT for their financial support to the conference and the publication thereof.

Ultimately, I wish ever success to the Ethiopian Food and Forage Legumes Research, and Development Decadal Forum in the future.

Mandefro Nigussie (PhD)
Director General, EIAR

Part I. CGIAR Experiences in Legumes Research and Development

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Advances in Food Legumes Research at ICRISAT

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Abstract

The mandate grain legumes of ICRISAT include chickpea, pigeonpea and groundnut which are important crops of Asia and Africa. The grain legumes improvement program of ICRISAT has access to the largest collection of germplasm of these crops (20,602 accessions of chickpea, 13,771 accessions of pigeonpea, and 15,446 accessions of groundnut) available in ICRISAT genebank, state-of-the art genomics lab, Platform for Translational Research on Transgenic Crops (PTTC), precision phenotyping facilities for abiotic and biotic stresses, controlled environment facilities and a global network of research partners. The major objectives of grain legumes improvement include high yield, early maturity, resistance/tolerance to key abiotic and biotic stresses, and market preferred grain traits (size, shape and color). The crop-specific breeding objectives include suitability to machine harvesting and herbicide tolerance in chickpea, development of hybrids in pigeonpea, and enhanced oil yield and quality (high oleic content) and tolerance to aflatoxin contamination in groundnut. The crop breeding programs have been making extensive use of the germplasm, including wild species. The advances in genomics include availability of draft genome sequences, large number of molecular markers, high density genetic maps, transcriptomic resources, physical maps and molecular markers linked to genes/quantitative trait loci for key traits. There are successful examples of introgression of traits through marker-assisted backcrossing in chickpea and groundnut. Transgenics events are available for pod borer resistance in chickpea and pigeonpea and drought tolerance in groundnut. Advances have also been made in use of secondary metabolites for promotion of plant growth, control of insect pests and plant pathogens, and biofortification. The breeding materials and germplasm supplied by ICRISAT have led to release of 160 varieties of chickpea in 26 countries, 91 varieties/hybrids of pigeonpea in 19 countries and 190 varieties of groundnut in 38 countries. Many of these varieties have been adopted widely by farmers and benefitted them in sustainably improving their livilihoods.

Keywords: Breeding, chickpea, groundnut, pigeonpea, pulses

Introduction

The mandate food legume crops of ICRISAT include chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* L.) and groundnut (*Arachis hypogea* L.) which are globally grown on over 47 million ha. Over 94% of the area of these crops is in Asia and Africa. These legumes are important sources of protein and calories for millions of people in several of Asian and African countries. These legumes are an integral part of cropping system in the semi-arid tropics mainly because of their ability to produce something of economic value (food or fodder) under extreme conditions and soil ameliorative properties.

The partnership of ICRISAT with the National Agricultural Research Systems (NARS), Advanced Research Institutes (ARIs) and other Research and Development organizations globally has contributed significantly to research and development of grain legumes. This article provides an overview of the research progress made on improvement of grain legumes during recent years.

Genetic resources

Plant genetic resources are the key to the success of crop improvement programs. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India has global responsibility to collect, assemble, conserve, characterize, evaluate, distribute and document the wealth of chickpea, pigeonpea and groundnut genetic variation, for use in crop improvement programs. Therefore, ICRISAT genebank has the largest collection of chickpea (20,602 accessions from 59 countries), pigeonpea (13,771 accessions from 74 countries) and groundnut (15,446 accessions from 92 countries) germplasm. Accessions are conserved as active collection at 4^{o}C and 30% RH to maintain the seed viability above 85% for 15-20 years and base collection at -20^{o}C for about 50 years. ICRISAT also established regional genebanks in Nairobi, Kenya, Niamey, Niger and Bulawayo, Zimbabwe, to conserve germplasm of regional importance and core and mini core collections, reference sets, etc., to meet the research needs of NARS in Africa. As a safety backup, 90% accessions were duplicated at Svalbard Global Seed Vault, Norway.

Germplasm collections were characterized for various morpho-agronomic traits. Wide variation was observed for almost all traits. To enhance use of germplasm in crop improvement representative core (10% of entire collection) and mini core (10% of core or 1% of entire collection) (Upadhyaya *et al*., 2001, 2002, 2003, 2006, Upadhyaya and Ortiz 2001) were formed. The mini core collections are now International Public Goods (IPGs) and 131 sets have been shared with NARS partners in 25 countries. Mini core collections have been used to identify multiple trait-specific, genetically diverse and agronomically desirable germplasm lines in chickpea, groundnut and pigeonpea (Upadhyaya *et al*., 2013; 2014). Composite collections (1000-3000 accessions) were formed and genotyped with 20-50 SSR markers and genotype based reference sets have been developed in chickpea, pigeonpea and groundnut (Upadhyaya *et al*., 2008 a, b, c).

Crop wild relatives harbor genes for adaptive, agronomic and nutritional traits and resistance to pest and diseases. Using a synthetic amphiploid TxAG6, involving three diploid species of *Arachis*, high yielding cryptic introgression lines with exceptionally high 100 seed weight (up to 130 g) spanish types have been developed (Upadhyaya, 2008). Crosses involving *Cajanus cajan* × *C. scarabaeoides* resulted into a line, ICPL 87162, with high seed protein (up to 32%) compared to control, C 11 (23%) (Reddy *et al*., 1997). Initial characterization of cultivated (8000 accessions at ICRISAT and 6300 in China) and wild *Arachis* (304 accessions of 41 species) germplasm revealed abundant variation in oil content. Using high oil lines identified from mini core collection (Upadhyaya *et al*., 2002), lines with exceptionally high oil content (> 60%) have been identified (Upadhyaya, 2016). Further research on systematic characterization of wild relatives for seed nutritional traits is in progress to identify nutritionally dense types for use in breeding new cultivars.

Some elite germplasm lines were released as cultivars - 22 chickpea, 11 pigeonpea and 17 groundnut accessions were released for commericial production in a number of countries. A chickpea landrace, ICC 11879, was released as a variety in eight Mediterranean countries and ICC 13816 was released in seven countries. ICG 12991, a groundnut accession was released in Mozambique, Malawi, Uganda and Zambia. A vegetable pigeonpea landrace from India (ICP 7035) was released as a cultivar in India, Fiji, Nepal, China and Philippines. Wilt resistant pigeonpea landrace, ICP 8863, was released as *Maruti* in India with a benefit of US$ 75 million in 1996 with 73% internal rate of return (Bantilan and Joshi 1996).

Seeds of germplasm accessions are available free of cost at ICRISAT genebank under Standard Material Transfer Agreement (SMTA) of International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), for research and training purpose. To date, ICRISAT genebank provided 151, 972 samples of chickpea to the researchers in 88 countries, 74, 830 samples of pigeonpea to 113 countries, and 101, 109 samples of groundnut to 96 countries. A total of 375, 217 samples were provided to the researchers within ICRISAT.

Pre-breeding

Like other major crops such as rice and wheat, grain legumes have narrow genetic base which hinders the genetic improvement of these crops. In contrast, wild species are the reservoirs of many important genes and can be utilized for the genetic improvement of grain legumes. Although high levels of genetic variability for important traits such as morpho-agronomic and nutrition-related traits and high levels of resistance/tolerance to biotic/abiotic stresses is available in wild species, these are not being utilized adequately in breeding programs. The major limitation is due to the linkage drag, differences in ploidy levels, and different incompatibility barriers between cultivated and wild species. Under such situations, pre-breeding provides a unique opportunity to expand primary genepool by exploiting genetic variability present in wild species and cultivated germplasm, and will ensure continuous supply of new and useful genetic variability into the breeding pipelines to develop new cultivars having high levels of resistance and a broad genetic base.

Pre-breeding involves identification of desirable traits and/or genes from unadapted germplasm (exotic landraces and wild species) that cannot be used directly in breeding populations, and to transfer these traits into well-adapted genetic backgrounds resulting in the development of an intermediate set of material which can be used readily by the plant breeders in specific breeding programs. Thus, pre-breeding offers a unique tool to bridge the gap between the germplasm conserved in genebanks and utilized in crop improvement programs (Sharma *et al*., 2013).

Chickpea

Precise evaluation of wild *Cicer* species had identified accessions having high levels of resistance against ascochyta blight (AB), botrytis grey mould (BGM) and dry root rot (DRR). These accessions are being utilized to transfer resistant genes for AB, BGM and DRR into popular chickpea cultivars following interspecific hybridization. The major focus of these activities is to combine heat tolerance with DRR resistance and short duration with BGM resistance. To meet these objectives, the development of AB-QTL populations is in progress. Using complex 3-way crosses [C. arietinum × (*C. reticulatum* × *C. echinosperumum*)], advanced backcross populations have been developed in desi and kabuli chickpea genetic backgrounds (Sharma *et al*., 2016). Considerable variability for morpho-agronomic traits has been observed in these populations (Sharma *et al*., 2016). These populations will provide new and diverse variability for important traits for further use in chickpea improvement programs.

Pigeonpea

Pre-breeding activities are in progress by utilizing the wild *Cajanus* species from secondary and tertiary genepools for pigeonepa improvement. One major achievement of using wild *Cajanus* species is the development of cytoplasmic nuclear male sterility systems (CMS). These CMS systems have been developed with cytoplasm derived from different wild *Cajanus* species (Saxena *et al*., 2010). Besides this, pre-breeding activities involving wild *Cajanus* accessions as donors and popular pigeonpea varieties as recipients are in progress to develop new genepools for resistance/tolerance to important biotic/abiotic stresses as well as for agronomic and nutrition-related traits. The focus is on the development of advanced backcross populations to minimize the linkage drag associated with utilizing wild species in crop improvement programs. Using secondary genepool species -*C. cajanifolius* (ICPW 29), *C. acutifolius* (ICPW 12 and ICPW 004), *C. scarabaeoides* (ICPW 281); and tertiary genepool species, *C. platycarpus* (ICPW 68) having useful traits such as tolerance to salinity and pod borer resistance (Srivastava *et al*., 2006; Sujana *et al*., 2008; Jadhav *et al*., 2012); and two pigeonpea cultivars (ICPL 87119 and ICPL 85010) advanced backcross populations have been generated at ICRISAT, Patancheru, India (Sharma and Upadhyaya, 2015). The evaluation of these populations for agronomic traits revealed considerable variability for days to flowering, growth habit, pod and seed traits. Promising introgression lines (ILs) having high number of pods per plant, seeds per pod, and 100 seed weight (>20.0 g) have been identified from the population derived from ICPL 85010 x ICPW 004 cross. High yielding ILs derived from *Cajanus acutifolius* and *C. cajanifolius* have been shared with NARS for multilocation evaluation. Preliminary evaluation of different populations has resulted in the identification of ILs having combined resistance against sterility mosaic disease and wilt, and ILs having moderate resistance against phytophthorablight (Sharma and Upadhyaya, 2015). Recently, efforts were initiated to introgress pod borer resistance from two wild species, *Cajanus acutifolius*, and *C. scarabaeoides* into two pigeonpea cultivars, ICPL 87119 and ICP 8863, following simple and complex crosses (Sharma and Upadhyaya, 2015).

Groundnut

Enormous genetic variability is present in genus *Arachis* comprising 80 wild species and cultivated groundnut. Wild *Arachis* species offer significant variability particularly for biotic and abiotic stresses that can be utilized to develop cultivars having enhanced levels of resistance to key stresses and broaden the existing narrow genetic base of cultivated groundnut. The utilization of wild *Arachis* species following interspecific hybridization has resulted in the development of many elite germplasm lines and cultivars with improved level of resistance to diseases and insect-pests. At ICRISAT, several elite lines have been developed with desirable characters transferred from wild *Arachis* species, such as ICGV 86699 (Reddy *et al*., 1996) with resistance to multiple pests, ICGV 87165 (Moss *et al*., 1998) with multiple disease and insect resistance; ICGV 99001 and 99004 with resistance to late leaf spot

(LLS); and ICGV 99003 and 99005 to rust. Besides this, varieties such as ICGV-SM 85048 (Nigam *et al*., 1998), and ICGV-SM86715 (Moss *et al*., 1998), having genetic base from wild *Arachis* species, were released for cultivation, mostly in USA.

Recently, for efficient utilization of diploid wild species from section *Arachis*, several synthetics (amphidiploids and autotetraploids) have been developed by using various A- and B-genome species. These synthetics are being utilized in crossing programs with cultigens to develop pre-breeding population/introgression lines (ILs) having high frequency of useful genes/alleles and good agronomic background.

Evaluation of two such populations derived from ICGV 91114 x ISATGR 1212 (a synthetic derived from *A. duranensis* × *A. ipaensis*) and ICGV 87846 x ISATGR 265 (*A. kempf-mercadoi* × *A. hoehnei*) has led to the identification of ILs having high levels of late leaf spot (LLS) and rust resistance and sufficient genetic variability for morpho-agronomic traits.

These ILs are being genotyped using linked-markers for LLS and rust resistance to identify novel alleles from different wild species other than the commonly used *A. cardenasii* for further use in peanut improvement programs.

Genomic Resources

Chickpea

For faster genetic gains, the availability of genomic resources and their deployment in breeding is a prerequisite. Towards this direction, during the last decade, ICRISAT, in collaboration with several partners at national and international levels, developed several thousands of molecular markers (Nayak *et al*., 2010), high density genetic maps (Thudi *et al*., 2011; Kale *et al*., 2015), transcriptomic resources (Varshney *et al*., 2009; Hiremath *et al*., 2012; Kudapa *et al*., 2014) and physical map (Varshney *et al*., 2014a). Both linkage and linkage disequilibrium mapping based approaches were adopted for understanding the genetics of drought and heat tolerance. As a result, a "*QTL-hotspot*" harbouring quantitative trait loci (QTLs) for several drought tolerance related traits (Varshney *et al*., 2014b), and more than 300 significant marker-trait associations for drought and heat have been identified. In addition, QTLs for key production constraints like fusarium wilt, ascochyta blight (Sabbavarapu *et al*., 2013) and salinity (Pushpavalli *et al*., 2015a) have been mapped. In addition, several functional genomics approaches such as RNA-seq, Massive Analysis of cDNA Ends (MACE) with parental genotypes of mapping populations as well NILs have provided some candidate genes for drought tolerance that are being validated through genetical genomics and/or TILLING approaches.

For deploying SNP markers in chickpea breeding programs, cost effective SNP genotyping assays like VeraCode and KASPar assays (Roorkiwal *et al*., 2013) were developed. In addition to unravelling the draft genome sequence of chickpea (Varshney *et al*., 2013a), several germplasm lines have been re-sequenced, for instance, parental genotypes of chickpea mapping populations (Thudi *et al*., 2016), 129 released varieties (unpublished), chickpea reference set (unpublished) and multi-parent advanced generation intercross (MAGIC) population (unpublished). Very recently, ICRISAT, along with its partners, has launched the large scale re-sequencing initiative "The 3000 Chickpea Genome Sequencing Initiative" to re-sequence 3000 lines from chickpea composite collection. This initiative enabled identification of several million SNPs, Indels, copy number variations (CNVs), and presence absence variations (PAVs) that can be deployed in chickpea improvement programs. A precise and cost-effective SNP genotyping platform with 50,590 high quality non-redundant SNPs on Affymetrix® Axiom® genotyping array was developed. This array will be useful for fingerprinting the released varieties as well as assessing their adoption in addition to genetics and breeding applications. The genomic resources have been successfully deployed for developing superior lines with enhanced drought tolerance (Varshney *et al*., 2013b), and fusrium wilt and ascochyta blight resistance (Varshney *et al*., 2014c). This success story has led to the introgression of the "*QTL-hotspot*" region into several elite varieties in India as well as Kenya and Ethiopia. Further, the available genomic resources also enabled the successful deployment of modern breeding approaches like genomics selection for faster genetic gains.

Pigeonpea

To exploit full potential of genomics for pigeonpea improvement, a significant amount of genomic resources have been developed. For instance, a draft of the nuclear and the complete mitochondrial genome sequence (Varshney *et al*., 2012; Tuteja *et al*., 2013), large repertoire of molecular markers (Saxena *et al*., 2014), high throughput genotyping platforms, transcriptome assembly (Kudapa *et al*., 2014) and genetic maps (Bohra *et al*., 2012) have been developed. The draft genome sequence at the very first instance enriched pigeonpea with information on protein coding genes, more than 54,000 Simple Sequence Repeat (SSR) markers and more than 12,000 high quality Single Nucleotide Polymorphisms (SNPs). Further, the availability of draft genome sequence has allowed implementing advanced methodologies such as whole genome re-sequencing (WGRS), genotyping by sequencing (GBS) and high density SNP array in pigeonpea. A number of WGRS projects initiated and sequencing data have been generated for more than 400 pigeonpea lines representing the reference set (unpublished), parental lines of hybrids (unpublished) and parental lines mapping populations segregating for economical important traits (Kumar *et al*., 2016). The detailed analyses of WGRS data in three different sets have provided long awaited genome-wide variations to overcome the low level of marker polymorphism in pigeonpea. In summary, WGRS data analysis provided unique accession signatures, targets of domestication and human selection associated genetic sweeps, information on centre of origin and marker trait associations (MTAs) for days to 50% flowering, days to 75% maturity, number of seeds per pod, 100 seed weight, etc. Apart from these, GBS has been deployed to generate high density genetic maps for many inter- and intra-specific populations (unpublished). These high density genetic maps along with multi-year trait phenotyping data will provide MTAs for sterility mosaic diseases, fusarium wilt, fertility restoration, yield related traits, etc. All these genomic resources along with the above mentioned approaches will be used for strengthening the pigeonpea breeding.

Groundnut

Genomics-assisted breeding (GAB) has demonstrated promising results in improving few traits in several crops with high precision leading to the accelerated development of improved lines. However, the availability of an optimal level of genomic resources is must for deploying GAB in any crop species including groundnut. This crop suffered for several years for achieving an optimal level of genomic wealth for conducting genetic and molecular breeding studies. The overview presented below is regarding the development of genomic resources and their deployment in groundnut breeding.

Quick evolution innext-generation sequencing (NGS) technologies have drastically reduced cost of sequencing, encouraging researchers to develop good quality genome assembly for crops with large sized genome such as groundnut. Since cultivated groundnut is tetraploid containing two sub-genomes (A and B), draft genome assembly has been developed for diploid progenitors i.e., *Arachis duranensis* (A subgenome) and *A. ipaensis* (B subgenome). ICRISAT collaborated with International Peanut Genome Initiative (IPGI) for decoding draft genome for both the diploid progenitors, while co-led another initiative -Diploid Progenitor Peanut A-genome Sequencing Consortium (DPPAGSC) for sequencing the A-genome progenitor. The above collaborative effort made available two genome assemblies for A subgenome (*A. duranensis*, accession V14167 and PI475845) and one assembly for B subgenome (*A. ipaensis*, accession K30076) in 2016 (Bertioli *et al*., 2016; Chen *et al*., 2016). The genome size of A subgenome and B subgenome were found to be 1.1 and 1.38 Gb, respectively. The availability of these assemblies together with re-sequencing data of limited genotypes will provide much needed boost to the several ongoing genetic and breeding studies in groundnut. Such resources also opened possibilities to deploy several modern genomics studies for faster gene discovery and trait improvement in coming years. Till very recently, only ~5,000 simple sequence repeat (SSR) markers were available in public domain (Pandey *et al*., 2012, Varshney *et al*., 2013c). ICRISAT in collaboration with DArT Pty Ltd, Australia, developed diversity arrays technology (DArT) arrays with 15,360 features and Kompetitive Allele Specific PCR (KASP) assays for 90 SNPs in groundnut (Varshney 2015; Janila *et al*., 2016a; Pandey *et al*., 2016). Due to the availability of genome sequence for both the ancestors of cultivated tetraploid, now a large number of SSR markers and millions of single nucleotide polymorphisms (SNPs) have become available for use in genetics and breeding applications. More recently, ICRISAT has developed 58K SNP array using Affymetrix SNP platform covering the entire genome whith a very efficient and high throughput genotyping tool for conducting high resolution trait mapping and modern breeding such as genomic selection (Varshney 2015; Pandey *et al*., 2016).

ICRISAT has been the pioneer in developing genetic maps and conducting QTL analysis for identification of linked markers in groundnut. For example, ICRISAT developed five SSR based genetic maps using recombinant inbred line (RIL) populations, and one DArT/DArTseq based genetic map using F_2 mapping population with 1,152 loci in addition to the first SSR based genetic map (Varshney *et al*., 2013c; Janila *et al*., 2016a; Pandey *et al*., 2016). Moreover, ICRISAT also developed a consensus genetic map for the first time with 897 marker loci which was then improved to 3,693 marker loci. In addition, ICRISAT has also collaborated with USDA-ARS, Tifton and developed two improved genetic maps for two RIL populations (Varshney 2015; Pandey *et al*., 2016). Further, using linkage mapping and genome-wide association studies (GWAS), a large number quantitative trait loci (QTLs)/marker-trait associations (MTAs) were identified for drought tolerance related traits, late leaf spot resistance, rust resistance, oil content, oil quality, yield related traits, physiological traits and seed dormancy (Varshney *et al*., 2013c; Varshney 2015; Janila *et al*., 2016a; Pandey *et al*., 2016). Linked markers for rust resistance, late leaf spot resistance and high oleic acid were validated successfully and deployed in molecular breeding. The first example of molecular breeding at ICRISAT was improvement of three popular varieties, namely ICGV 91114, JL 24 and TAG 24, for rust resistance using the marker-assisted backcrossing (MABC) approach (Varshney *et al*., 2014d). The field evaluations of these MABC lines recorded increased pod yields (56–96%) and also retained early maturity duration. Of these lines, six best MABC lines, namely ICGV 13192, ICGV 13193, ICGV 13200, ICGV 13206, ICGV 13228 and ICGV 13229, were picked with 39–79% higher mean pod yield and 25–89% higher mean haulm yield in comparison to their respective recurrent parents (Janila *et al*., 2016b). Some of these MABC lines have now been nominated to the special trial on Near Isogenic Line (NIL) of the All India Coordinated Research Project on Groundnut (AICRP-G) for evaluation and release. The second successful example of molecular breeding in groundnut was improvement of three groundnut varieties, namely ICGV 06110, ICGV 06142 and ICGV 06420, for oil quality (high oleic acid, low linoleic acid and low palmitic acid) using two approaches, namely MABC and marker-assisted selection (MAS). Linked gene-based markers were used to introgress two mutant alleles from the SunOleic 95R carrying two FAD2 mutant alleles responsible for oil quality traits. These lines showed elevated oleic acid (62 to 83%), i.e., oleic acid increased by 0.5–1.1 folds along with reduced linoleic acid by 0.4–1.0 folds and palmitic acid by 0.1–0.6 folds (Janila *et al*., 2016c). Several of these lines were selected for further multilocation yield trials in order to select promising lines for nomination to the AICRP-G for further evaluation and release.

Physiology

Much progress has been made over the last decade or so in our understanding of the adaptation of grain legumes to major abiotic stresses such as water deficit (‘drought’) and soil salinity.

Drought

Much of the efforts have been focused on chickpea and groundnut, involving a cross-species comparison between bean and cowpea in some aspects, and only recently has some work been initiated in pigeonpea.

In the case of chickpea, initial work had involved the screening of chickpea for long and profuse rooting system to allow plants to extract more water from the soil profile. This work has started by the identification of a large genetic variation for root traits (Kashiwagi *et al.*, 2005), followed by the development of mapping populations and the identification of a major QTL for root traits on linkage group 4 of chickpea (Varshney *et al*., 2013b). Building up on this work, a lysimeter system has been developed (Vadez *et al*., 2008) allowing to go beyond measuring roots and allowing to measure water extraction from the soil profile. The system has been used in chickpea germplasm contrasting for their “drought tolerance” based on seed yield under terminal stress (independent of flowering time) and this work has shown that tolerant and sensitive material did not extract different amounts of water from the soil profile (Zaman-Allah *et al*., 2011a). Rather, tolerant materials were able to extract somewhat less water at vegetative stage than sensitive germplasm, and then had more water left for reproduction and grain filling stages. Additional research showed this was possible because of: (i) a canopy that developed slower; (ii) lower canopy conductance at vegetative stage, especially under high vapor pressure deficit (VPD) conditions (Zaman-Allah *et al.*, 2011b). This work has been backed up by crop simulation work that has shown indeed that an early water extraction by a more vigorous phenotype could be detrimental in certain situations, but not under short cycle environments like South India (Vadez *et al.*, 2012c). The current focus of that work is to identify QTL for the canopy conductance and development characteristic, using a high throughput phenotyping platform developed to that end (LeasyScan – Vadez *et al.*, 2015), the basic idea being to fit ideotypes to specific environments on the basis of their water requirements.

In the case of groundnut, much of the work of the last three decades or so has focused on the identification of genotypes with high transpiration efficiency (e.g. Rao *et al.*, 1993; Wright *et al.*, 1994). This work has relied mostly on the use of surrogate traits for TE, i.e. SPAD chlorophyll meter readings – SCMR, specific leaf area – SLA, or the carbon isotope discrimination-CID. However, a recent evaluation of TE in a large set of groundnut germplasm, using a lysimeter system–therefore a gravimetric assessment of transpiration efficiency (TE) with no surrogate use–led to an important finding: surrogate traits were not related to TE in any way, regardless of water treatment or sampling time (Vadez and Ratnakumar, 2016). The ruling hypothesis in the past two decades was that higher TE would be driven by a higher photosynthetic rate in groundnut and each of these surrogates, SCMR, SLA, or CID, indirectly proxies for differences in the photosynthetic rate. The finding of an absence of a relationship between a gravimetric/robust TE measurement and the surrogates is an indication that high TE is driven by something else.

According to the theory (Condon *et al.*, 2002), high TE is driven either by a high photosynthetic rate or by a low stomatal conductance. Genetic variation has been recently found in groundnut for the capacity to restrict transpiration under high VPD (Devi *et al.*, 2010). The TE differences identified in the large germplasm assessment are likely explained by differences in the transpiration control under high VPD (see discussion in Vadez and Ratnakumar, 2016). As in the case of chickpea (and other crops), the current research on groundnut adaptation to water deficit therefore focuses on fitting ideotypes to water availability (Halilou *et al.*, 2015). Research has also been carried out to identify genetic variation for adaptation to intermittent drought (Hamidou *et al.*, 2012).

Crop simulation is also used as an important entry point to characterize the environments with regards to stress intensity. Then research focuses on analyzing genetic variation in traits that contribute to the plant water budget, those involved in the dynamic of canopy development as in chickpea and those involved in the regulation of stomata opening, using the LeasyScan platform to measure these traits in a high throughput manner (Vadez *et al*., 2015).

Soil salinity

Much of the efforts have been focused on chickpea, where initially a large variation for salinity tolerance was identified (Vadez *et al*., 2007), from which donor parents were chosen for breeding and used to better understand salinity tolerance traits. Two major finding helped in this search: (i) the first was an absence of relationship between the seed yield under salt stress and vegetative growth at about flowering time - this finding dismissed the idea that early screening at germination or vegetative stage could be carried out, and also implied salinity tolerance had a close link with the reproductive biology of the plant; (ii) the absence of a relationship between the sodium (Na) accumulation in the shoot tissue at vegetative stage and the degree of tolerance based on seed yield under stress – a finding that dismissed the hypothesis of a Na toxicity. In follow up research, it was found that salt tolerance was related to the capacity of tolerant genotypes to maintain a higher number of fertile pods (Vadez *et al*., 2012a), something that was confirmed later (Pushpavalli *et al*., 2015a).

Among the germplasm that was tested, parents of a mapping population showed contrast under salt stress and screening of the population led to the first QTL for salinity tolerance in chickpea (Vadez *et al*., 2012b). Another population was later used and additional QTLs were identified, with a particular interest on two genomic regions harboring a high number of genes involved in the response to salt stress (Pushpavalli *et al*., 2015a). One pending aspect has been the focus of the last few years of research: the fact that Na had no toxicity effect led us to hypothesize that chloride (Cl) anions could have such a toxic effect.

Research was undertaken to test this hypothesis, testing also ions (Cl, Na, K) level in different plant organs, including the reproductive parts and no relationship was found between tolerance and ion level in any of the plant part (Turner *et al*., 2013; Kotula *et al*., 2015; Pushpavalli *et al*., 2016).

Therefore, there is still quite a bit of “mystery” around the reasons for salinity tolerance in chickpea, although it is now well established that it involves tolerance of the reproductive biology, independently of any ion toxicity, and that large variation in the tolerance exists and genomic regions involved in that tolerance have been identified.

Pathology

Chickpea

The production and productivity of chickpea is severely constrained by diseases such as Fusarium wilt (FW, *Fusarium oxysporum* f sp *ciceris*), dry root rot (DRR, *Rhizoctonia bataticola*), Ascochyta blight (AB, *Ascochyta rabiei*) and Botrytis gray mold (BGM, *Botrytis cinerea*). These diseases have been reported to cause huge losses in susceptible cultivars under favorable environmental conditions (Choudhary *et al*., 2013; Ghosh *et al*., 2013). Advances have been made in the areas of host plant resistance, host x pathogen x environment interactions and pathogenomics to understand the resistance mechanism in these diseases in chickpea. Stepwise screening procedures for these diseases (greenhouse and field) have been reported by Pande *et al*. (2012a).

Recent studies have indicated changes in the race scenario of pathogen and existence of multiple races (Sharma *et al*., 2014). Stable and broad based sources of resistance to wilt (ICCV 05527, ICCV 05528 and ICCV 96818) have been identified through the multi-year and multi-location evaluation (Sharma *et al*., 2012a). Genetics of resistance against different races has been studied in detail, and contradicting results have been reported (compiled by Choudhary *et al*., 2013). Progress has been made in molecular breeding for wilt resistance and tagging of wilt resistant genes through molecular markers (Varshney *et al*., 2014). Dry root rot is found to be an emerging disease in chickpea particularly and is predisposed by high temperature and soil moisture stress (Sharma and Pande, 2013; Sharma *et al*., 2015a). Recent surveys conducted during 2010–2013 in India indicated widespread and increased incidence of DRR in the central and southern states of India (Ghosh *et al*., 2013). Cultural, morphological and molecular variations in 94 isolates of *R. bataticola* collected from various agro-ecological zones of India have been reported by Sharma *et al*. (2012b & c). Lack of resistance in the available germplasm and breeding lines is a biggest challenge in managing this disease. Search for specific resistance to DRR in chickpea is continued and few moderate sources of resistance have been identified (ICCV 08305, ICCV 05530 and ICCV 05529). Efforts are underway to develop improved breeding lines/introgression lines (ILs) with enhanced level of resistance to dry root rot and share these promising lines with NARS for use in chickpea breeding programs

Considerable progress has been made in understanding the AB and BGM diseases in chickpea. Moderate resistance to AB has been found in chickpea and breeding for resistance is making progress by identifying new resistance genes. Molecular markers associated with major QTLs conferring resistance to AB have been located on linkage maps, and these markers can be used for efficient pyramiding of the traits of interest. Pande *et al.* (2012b) identified five genotypes with consistent resistant reaction to AB (EC 516934, ICCV 04537, ICCV 98818, EC 516850 and EC 516971) in multi-environment. In BGM also, only moderate sources of resistance are available (ICCV 96859, ICCV 96853, ICCV 05604, ICCV 96852 and ICCV 05605) (Sharma *et al*., 2013). *Cicer echinospermum* and *C. reticulatum*, the only two compatible annual wild species, have been reported to have resistance to BGM. Hence, interspecific populations were developed with susceptible cultivars as female parents and *C. echinospermum* accession IG 73074 and *C. reticulatum* accession IG 72937 as the pollen donors to transfer and assess the nature of genetic control for BGM. Screening the progeny indicated that resistance to BGM was controlled by a single additive gene/allele (bgmr1cr and bgmr1ce), which can be introgressed through a backcross breeding programme (Ramgopal *et al*., 2013).

Pigeonpea

Fusarium wilt (FW, *Fusarium udum*) and sterility mosaic disease (SMD) caused by pigeonpea sterility mosaic virus (PPSMV) are the most important diseases of pigeonpea and can cause yield losses up to 100% (Saxena *et al*., 2010). Apart from wilt and mosaic, Phytophthora blight (PB, *Phytophthora cajani*) is another important disease that got the status of economic concern (Sharma *et al*., 2006 and 2015b). FW and SMD incidence differs from place to place due to variability in pathogen. Considerable variability have been observed using 73 isolates and 11 differentials collected from seven states in India (Sharma *et al*., unpublished). Three distinct strains (Bangalore, Patancheru and Coimbatore) have been characterized for PPSMV in India (Kulkarni *et al*., 2003). So far, no confirmed information regarding pathogen variability is available for *Phytophthora cajani*.

Reliable greenhouse and field screening techniques are available for FW and SMD to identify resistance sources (Pande *et al*., 2012c). Recent advances in FW and SMD research have facilitated the selection of high-yielding varieties with durable resistance to FW and SMD. Lines derived from crosses with *C. acutifolius* and *C. platycarpus* have shown resistance to the Patancheru isolate of PPSMV under field conditions (Mallikarjuna *et al*., 2011). Recently new sources of resistance to FW and SMD were identified in a mini-core collection of pigeonpea germplasm (Sharma *et al*., 2012d). In multi-environment field testing, four genotypes (ICPLs 20094, 20106, 20098 and 20115) have been identified as the most stable and resistant to SMD (Sharma *et al*., 2015c). Three genotypes (ICPLs 20096, 20107, 20110) showed moderately stable performance against SMD. All these lines have medium duration of maturity and could be valuable sources of resistance for a pigeonpea breeding programs to FW and SMD. Recently, Sharma *et al*. (2015b) developed a reliable and repeatable zoospore screening technique for PB screening. Using this zoospore bioassay, over 800 pigeonpea genotypes including released cultivars, earlier reported PB resistant lines, breeding lines and water logging tolerant lines have been screened. Repeated screening of promising genotypes has so far identified four genotypes with a moderate resistance to PB (ICPLs 99004, 99008, 99009 and 99048) (Sharma *et al*., unpublished).

Saxena *et al*. (2012) reported dominant suppressive epistatic effect of a dominant gene over the recessive one for wilt resistance in a cross of a FW susceptible cytoplasmic male-sterility line with four FW resistant fertility restorers. The nature of inheritance of SMD was studied in the segregating population of two crosses, Gullyal white (susceptible) X BSMR 736 (resistant) and BSMR 736 (resistant) X ICP 8863 (susceptible) (Bhairappanavar *et al*., 2014;), indicating that the resistant trait was governed by two independent non-allelic genes, designated *SV1* and *SV2*, with inhibitory gene interaction (Bhairappanavar *et al*., 2014). The limited reports available on genetics of PB resistance in pigeonpea suggest that a few major genes may control resistance in the host to PB.

Groundnut

Foliar fungal and viral diseases

Foliar fungal diseases in groundnut such as leaf spots (early and late) and rust and viral diseases such as groundnut bud necrosis disease (GBND), and groundnut rosette disease (GRD) are economically important yield limiting biotic constraints with worldwide significance. Host plant resistance is a cost-effective and sustainable management option for smallholder farmers in fighting these important diseases. Recently ICRISAT scientists identified several groundnut lines from mini core germplasm accessions such as ICGs 4389, 6993, 11426, 4746, 6022 and 11088 with combined good levels of resistance and yield to rust and late leaf spot (Sudini *et al.,* 2015b). Efforts in breeding resistant varieties to groundnut rosette disease (GRD), an important virus disease in sub-Saharan Africa, were successful and lead to the release of several varieties in Africa. For example, ICGV-SM 90704, ICG 12991, ICGV-SM 99568, ICGV 93437, SAMNUT 23, SAMNUT 21 and SAMNUT 22 (Waliyar *et al.,* 2007b).

Aflatoxin contamination

Aflatoxin contamination in groundnut is the most important qualitative problem affecting its profitability, trade and health of humans and animals. ICRISAT has given top priority since 1990’s and made tremendous progress in understanding and mapping the occurrence of aflatoxin contamination in groundnut value chains in various countries in sub-Saharan Africa (SSA) and Asia, identifying pre-harvest and post-harvest interventions to better manage this menace, cost-effective diagnostics to quantify aflatoxins from agricultural commodities and capacity building of NARS of SSA and Asia.

Aflatoxin diagnostics: ICRISAT scientists devised a simple and affordable testing assay using in-house developed antibodies that helps identify aflatoxin-free grains to meet international market standards and ensure higher returns for farmers, and provide safer products for consumers. The test uses a competitive enzyme-linked immunosorbent assay (cELISA) to detect the presence of aflatoxins. The assay has drastically reduced the cost of testing crops from $25 to $1 per sample and can be used with minimal laboratory facilities (Waliyar *et al.*, 2005; Waliyar *et al.*, 2009). Its advantage is that most of the required chemicals are locally available in developing countries and it allows the analyses of up to 200 samples per day. Further we transferred this technology to several NARS partners in Asia and sub-Saharan Africa and significantly contributed to the capacity building of scientific staff and organizations. For example, the National Smallholder Farmers' Association of Malawi (NASFAM) has successfully used the new technology, in conjunction with HPLC, as part of a broader effort to regain its once-lucrative European groundnut export market. ICRISAT recently developed a low cost (<2 USD) rapid test kit too based on lateral flow immunoassay principle for the estimation of aflatoxins in groundnuts. Adding a mobile sample extraction kit to this device will make it the first on-site testing kit for aflatoxins.

Progress in breeding for resistance to aflatoxin: Researchers at ICRISAT were able to identify resistant sources and combine resistance to pre-harvest seed infection and/or aflatoxin contamination into improved genetic backgrounds (Waliyar *et al.*, 1994; Upadhyaya *et al.*, 2001; Upadhyaya *et al.*, 2003; Nigam *et al.*, 2009). In spite of high genotype by environment interaction, a number of germplasm with high levels of resistance across environments, for example, ICGs 1326, 1859, 3263, 4749, 7633, 9407, 9610, and 10094 (Nigam *et al.*, 2009), have been identified in cultivated groundnut. More importantly, some of the germplasm lines such as ICGs 7, 23, 1323, 2925, 5158, 5195, 6760, 9610, 10094, 10609, 10615, 11480, and 11682 were reported to contain very low aflatoxin (0.4 -1.0 ppb) in comparison 171.4 to 304.6 ppb in susceptible controls (Fleur 11 and JL 24). Further a number of breeding lines showed much less pre-harvest aflatoxin contamination levels (0.2 – 4.1 $\mu g\ kg^{-1}$ seed) than susceptible control under ambient conditions. Terminal drought predisposes groundnut to *Aspergillus flavus* infection and aflatoxin contamination (Waliyar *et al.*, 2005). Current breeding research at ICRISAT is focused on development of breeding lines combining early maturity, tolerance to terminal drought and resistance to seed infection and aflatoxin contamination. Genetic crosses were made to generate appropriate breeding populations to select for tolerance to terminal drought and resistance to seed infection and resistance to aflatoxin contamination into improved early maturity genetic background. A number of breeding lines combining short duration and aflatoxin resistance were identified for further evaluation. Some of these varieties in advanced trials were significantly superior (2.8-4.8 t ha^{-1} pod yield) over the control J 11 (2.1 t ha^{-1} pod yield). ICGV 10038 (4.5 t ha^{-1}, 5 µg kg^{-1} aflatoxin content and 5% *A. flavus* infestation), and ICGV 10043 (4.0 t ha^{-1}, 15 µg kg^{-1} aflatoxin content and 2% *A. flavus* infestation) were the best performing entries for pod yield and aflatoxin contamination. Furthermore, ICGVs 13142, 13125, and 13127 combined short duration and resistance to aflatoxin contamination into improved genetic background (ICRISAT Legumes Archival Report 2012/2013).

Agronomic practices for aflatoxin management: Tremendous progress has been made by ICRISAT scientists in identifying pre- and post-harvest cultural practices and testing on-farm which significantly reduce pre and post-harvest aflatoxin contamination. For example, soil amendments (eg. farmyard manure, lime, and gypsum), moisture conservation techniques, pod drying methods and storage methods (Waliyar *et al.*, 2007a; Sudini *et al.*, 2015a).

Monitoring aflatoxin contamination: Continuous monitoring of aflatoxin contamination in food commodity value chains is essential in safeguarding public health. In this direction, ICRISAT conducts regular surveys and map the risk of aflatoxin contamination in target countries of Asia and sub-Saharan Africa. Our findings inform policy makers about the options to best contain this important food safety menace (Monyo *et al.*, 2012; Waliyar *et al.*, 2015; Njoroge *et al.*, 2016).

Integrated Breeding

Chickpea

The major breeding objectives in chickpea include: (1) Enhanced yield potential, (2) Early to extra-early maturity, (3) Tolerance to terminal drought and heat stresses, (4) Resistance to root (fusarium wilt, dry root rot) and foliar diseases (ascochyta blight and botrytis grey mold) and pod borer (*Helicoverpa armigera*), (5) Improved physical (size, shape and color) and nutritional quality (protein and minerals) of grains, and (6) Suitability to machine harvest and tolerance to herbicides.

The chickpea breeding program has been making extensive use of the genetic resources available in ICRISAT's Genebank. Over 20,000 crosses have been made in chickpea so far utilizing over 4,000 unique germplasm accessions (about 20% of the germplasm accessions available in ICRISAT's genebank). ICRISAT is taking three crop cycles per year for rapid generation turnover and accelerating genetic gain. Selection for simple traits is carried out in early segregating generations and for complex traits in F4 and later generations.

We need to improve the precision and efficiency of breeding programs by integrating novel approaches for enhancing genetic base of the breeding populations, genomics-assisted breeding, precision phenotyping, rapid generation turnover and efficient data management system, such as Breeding Management System (BMS) of integrated Breeding Platform (https://www.integratedbreeding.net/)

Tolerance to abiotic stresses

The major abiotic stresses to chickpea production include terminal drought and temperature extremes (low and high). One of the strategies for managing terminal drought and heat stresses is to develop early maturing varieties that can escape these stresses (Gaur *et al*., 2008c, 2015c). Excellent progress has been made in development of early maturing varieties with high yield potential and resistance to fusarium wilt.

Efforts are being made to develop varieties with improved drought avoidance (dehydration postponement) and/or drought tolerance (dehydration resistance) for improving grain yield under drought stress (Gaur *et al.*, 2008b). It was found that partitioning coefficient provides an effective selection criterion for grain yield under terminal drought condition (Krishnamurthy *et al*., 2013). Several studies conducted at ICRISAT demonstrated that a prolific root system contributes positively to grain yield under terminal drought conditions (Kashiwagi *et al*., 2013, 2015). However, it is challenging to breed for improved root traits because the screening for root traits is a destructive and labor intensive and difficult to use in large segregating populations. Marker-assisted breeding is ideal for improving such traits. Remarkable progress has been made in development of molecular markers and expansion of genome map of chickpea in recent years (Gaur *et al*., 2012a, 2014c). A genomic region, called QTL-hotspot, carrying several QTLs that are associated with several drought tolerance related traits including some root-traits was located on LG04 (Varshney *et al*., 2014b). This genomic region has been introgressed in several cultivars (JG 11, ICCV 10, JAKI 9218, JG 6) using marker-assisted backcrossing (MABC) (Varshney *et al*., 2013b, Gaur *et al*., 2013b). Several of these lines are being evaluated in the trials of All India Coordinated Research Project (AICRP) on Chickpea.

Heat stress at reproductive stage is increasingly becoming a serious constraint to chickpea productivity because of large shift in chickpea area from cooler long-season environments to warmer short-season environments, increasing chickpea area under late sown conditions due to increasing cropping intensity, and high fluctuations in temperatures due to climate change (Gaur *et al*., 2014a,b; 2015b). A simple and effective field screening technique for reproductive stage heat tolerance in chickpea has been developed (Gaur *et al*., 2012b, 2014b). A large genotypic variation for reproductive stage heat tolerance has been observed in chickpea (Krishnamurthy *et al*., 2011a, Gaur *et al*., 2014a,b, 2015a) and several heat tolerant genotypes have been identified (ICC 1205, ICC 1356, ICC 4958, ICC 6279, ICC 15614, ICCV 07104, ICCV 07105, ICCV 07108, ICCV 07109, ICCV 07110, ICCV 07115, ICCV 07117, ICCV 07118, ICCV 98902, JG 16, GG 2, JG 130, JAKI 9218, JGK 2 and KAK 2). A heat tolerant breeding line ICCV 92944 has been released as JG 14 in India, Yezin 6 in Myanmar, Chania Desi 2 in Kenya and BARI Chola 10 in Bangladesh.

Tolerance to biotic stresses

Among diseases, fusarium wilt (FW), dry root rot (DRR), and collar rot (CR), are the important root diseases of chickpea in areas where the growing season is dry and warm, while ascochyta blight (AB), and botrytis grey mold (BGM), are the important foliar diseases in the areas where the growing season is cool and humid. Development of FW resistant cultivars is one of the greatest success stories of chickpea breeding and all breeding lines developed at ICRISAT have high resistance to FW. Dry root rot (DRR) has emerged as a major disease under high temperature (>30^0 C) and dry soil conditions (Sharma *et al*., 2015a), but development of varieties with high level of resistance continued to remain a challenge due to lack of high level of resistance available in the germplasm.

AB is a highly devastating foliar disease as its pathogen is highly variable and has capability to change and infect newly introduced resistant cultivar (Pande *et al*., 2005). Methods for AB resistance screening have been standardized (Pande *et al*., 2010). Several cultivars with moderate to high levels of resistance have been developed and some breeding lines from multiple crosses (e.g. ICCV 04512, ICCV 04514 and ICCV 04516) have shown high levels of resistance to multiple isolates (Gaur and Gowda, 2005). BGM is another major foliar disease of chickpea (Pande *et al*., 2006). A major constraint in breeding for BGM resistance is the non-availability of high level of resistance in chickpea germplasm. High level of resistance to BGM has been observed in wild *Cicer* species *C. echinospermum* and efforts are being made to utilize this species.

Pod borer (*Helicoverpa armigera* Hubner) is the most important pest of chickpea in all growing environments. Moderate levels of resistance is available in some germplasm accessions (e.g. ICC 506 EB) of cultivated (Lateef and Pimbert, 1990), while higher levels of resistance were observed in some wild species (Sharma *et al*., 2005) and efforts are being made to combine the non-preference (antixenosis) mechanism of resistance identified in the cultigen (e.g. ICC 506 EB) and antibiosis mechanism of resistance identified in *C. reticulatum.*

Improving yield potential

Efforts are being made to develop genotypes with short internodes and erect growth habit as such plant type may resist excessive vegetative growth in high input conditions. Two brachytic mutants, one spontaneous (E100 YM) and one induced (JGM 1), with short internodes and compact growth habit have been used in ideotype breeding and promising progenies with compact growth habit have been obtained (Gaur *et al*., 2008a).

Labor-saving varieties

Mechanization would play a key role in modernization of chickpea production. The farmers need chickpea varieties which can be directly harvested by combine harvesters. Recent efforts in India through ICRISAT-NARS partnership have led to release of three machine harvestable cultivars, namely Dheera or NBeG 47 (ICCV 05106), Phule Vikram (ICCV 08108) and RVG 204 (ICCV 08102). Several other breeding lines are in pipeline for release.

Another labor-saving trait desired in chickpea is tolerance to post emergence herbicides. Weed management by herbicides will not only be economical but also facilitate no-till methods, which help preserve topsoil, and help in reducing drudgery on farm women. Genetic variability has been identified for herbicide tolerance in chickpea germplasm/breeding lines/cultivars (Gaur *et al*., 2013a) and efforts are being made to develop chickpea varieties with desired level of herbicide tolerance.

Pigeonpea

Pigeonpea or red gram [*Cajanus cajan (L.) Millspaugh*] is an important food legume of the semi-arid tropics of Asia, Africa and Americas. It occupies a prime niche in sustainable farming systems of smallholder rainfed farmers. The productivity of pigeonpea has remained low and stagnant over the last few decades, thus this prompted scientists to search for novel ways of crop improvement. To tackle this challenge, Pigeonpea breeding unit at ICRISAT working on number of innovative ideas like, development of CGMS hybrids with 30 to 40 % yield advantage over traditional varieties, development of photo insensitive super early maturing lines, introgression of cleistogamous flower structure to maintain genetic purity of elite lines, use of obcordate leaf shape as NEP to assess genetic purity of hybrid parental lines and development of disease resistant hybrids and integrated breeding approaches.

Inadequate genomic resources together with narrow genetic diversity in cultivated pool caused serious impediment to applying genomics assisted breeding (GAB) in pigeonpea (Pazhamala *et al*., 2015). To overcome this, several research groups were engaged in developing genomic and genetic resources. As a result a number of traits associated markers have been developed e.g. fusarium wilt (FW), sterility mosaic diseases (SMD), fertility restoration, days to 50% flowering, growth habit etc. Marker-assisted backcrossing (MABC) is being utilized to introgress resistance to diseases (FW and SMD) in susceptible cultivars as well as for pyramiding superior alleles into a single cultivar. Additionally, trait mapping using bi-parental crosses and multi-parental crosses such as MAGIC and NAM populations are in progress which will provide additional loci for GAB in pigeonpea. For complex traits which are governed by many genes/minor QTLs, genomic selection (GS) has been planned to implement. In order to assist pigeonpea hybrid breeding markers for cytoplasmic male sterility and fertility restoration have been identified. Simple sequence repeat (SSR) markers based hybridity purity assessment kits have also developed. Above mentioned markers are in routine use of pigeonpea hybrid breeding and providing quick and accurate solutions to breeders (Saxena *et al*., 2015).

Super early Lines

Day neutral and photo insensitive elite lines which mature in less than 100 days are recently developed in pigeonpea. These lines provide number of opportunities like expansion of pigeonpea on non-traditional area like rice fallow, could fit the pigeonpea-wheat cropping system, contribute to reduce environmental degradation, attractive option to grow the crop on stored soil moisture, can escape diseases, drought and pod borer attack (Kumar *et al*., 2015a).

CGMS hybrids

Hybrid breeding technology has been successfully developed in pigeonpea. The male–sterile lines carrying A4 cytoplasm from *C.cajanifolius* (Saxena *et al*., 2005) exhibits perfect male-sterility with absolutely no pollen production. This system has been reported to be highly stable under diverse environments (Dalvi *et al*., 2008). The hybrids ICPH 2671, ICPH 3762 and ICPH 2740 were released in India for commercial cultivation by the farmers. These hybrids are resistant to major diseases in pigeonpea viz. fusarium wilt and sterility mosaic disease and possess yield advantage of 30 to 40 percent over varieties (Kumar 2015 *et al*., 2015b).

Obcordate hybrids

To develop a stable and robust hybrid seed production technology, a novel idea of incorporating naked eye polymorphic marker [NEP] of obcordate leaf shape was introduced in already established male sterile lines by back crossing scheme to track the purity of female parental lines. Since obcordate leaf shape is governed by single recessing gene, all the hybrids will be having normal lanceolate leaves in Ax R hybrid seed production and obcordate leaf shape in A x B maintenance programme. ICPA 2203 and ICPA 2204 are identified as stable male sterile lines with good general combining ability and ICPL 20116 is identified as fertility restorer which yielded disease resistant high yielding hybrids (Patil *et al.*, 2014).

Cleistogamous trait

Pigeonpea is an often cross pollinated species and out crossing extent up to 25-30 % (Saxena *et al*., 1990) and it is considered to be a prime constraint in maintaining genetic purity of cultivars and genetic stocks . To maintain a variety true to type especially in partially out-crossed species, it needs lot of resources in terms of isolation distance, installation of insect proof cages and labor charges for rouging and seed cleaning operations. Considering these facts attention was paid on natural mutant with wrapped flower morphology or cleistogamy. Stable lines are developed with this trait and are being used in crop improvement (Kumar *et al.*, 2015c).

Groundnut

Groundnut or peanut, an important oilseed and food legume crop is cultivated in 25.44 million ha with 45.22 m tons of production (FAOSTAT, 2014), of which Africa and Asia account for 95% of area and 91% of production. Groundnut breeding programs in various countries and ICRISAT (International Crops Research Institute for Semi-Arid Tropics) have contributed to release varieties to meet the needs of the producers, processors, and consumers. ICRISAT has supported the groundnut breeding programs in several countries in Africa and Asia and the partnerships led to release of ca. 130 improved varieties in 38 different countries that contributed to enhanced production and productivity.

Groundnut is a self-pollinated crop and pedigree method of breeding has been the choice. At ICRISAT, the groundnut breeding pipeline has successfully adopted 'single seed decent' method of breeding to optimize resources and improve traits with low heritability. Phenotyping for various agronomic and quality traits, yield evaluation trials, and early generation testing in target sites have largely contributed to enhance selection efficiency in breeding and testing pipelines (Janila and Nigam 2012). With the advent of molecular markers, genomic tools have been deployed in breeding pipelines to enhance selection efficiency in early generations and optimize resources. More recently, market-traits such as, oil content, oleic acid content and blanchability are focused in addition to production traits to meet end-use needs and demand from food industry.

Marker Assisted Backcross (MABC) breeding was used to combine early maturity with foliar fungal disease resistance the resulted in selection of introgression lines with 39–79% higher mean pod yield and 25–89% higher mean haulm yield over their respective recurrent parents (Janila *et al.*, 2016d). A major effect QTL region explaining 80% Phenotypic Variance (PV) for rust resistance and 68% for resistance was targeted following the MABC approach is given in Varshney *et al.* (2014d). Marker Assisted Selection (MAS) and MABC breeding approaches were used to breed 'high oleic' lines in the background of Spanish and Virginia bunch types (Janila *et al.*, 2016c). Under HTGP (High throughput genotyping platform) project supported by BMGF, we are using SNP-based markers for cost-effective genotyping with a turnover time of two weeks. In 2017 we have genotyped 18,000 plants and another 10,000 will be genotyped by end of 2017 using 10-SNP panel for three traits, viz., high oleic, and resistance to LLS and rust diseases. As we embark upon large scale genotyping, field logistics for collection of leaf samples, decision support tools for selections based on genotype, and rapid generation advancement need to be put in place to achieve the expected gains.

Transgenics

ICRISAT has recognized importance of the application of the genetic engineering technologies for the genetic enhancement of its mandate grain legumes owing to their narrow gene pool. Extensive efforts have been made at ICRISAT to develop efficient and reproducible tissue culture and transformation systems for production of transgenic pulses (Dayal et al., 2003; Sharma *et al.*, 2006, Bhatnagar-Mathur *et al.*, 2009a&b). Tissue culture and transformation methods based on *Agrobacterium*-mediated gene transfer for groundnut, pigeonpea, and chickpea, are now available for routine applications.

The successes with genetic transformations have resulted in developing transgenic grain legumes carrying genes for resistance to insect pests, fungal pathogens, tolerance to drought stress and nutritional enhancement (Bhatnagar-Panwar *et al.,* 2015). Since resistance to *Helicoverpa armigera,* or the legume pod borerin chickpea and pigeonpea germplasm has so far been found to be low to moderate, transgenic resistance using insecticidal genes has been developed to achieve sustainable levels ofresistance to this insect pest (Gopalaswamy *et al.*, 2008). Transgenic progenies have been screened based on the molecular data, ELISA, and detached leaf and pod bioassays showing significant reduction in damage rate and larval weights in comparison to the untransformed controls. While several events using single *cry* gene have been selected for event selection trials under confined fields, a number of transgenic events have been developed using *Bt* gene stacks for achieving durable resistance for this pest as well as the pod borer complex. For abiotic stress tolerance, particularly drought, genetically engineered desi-type chickpea has been engineered to ectopically overexpress an osmoregulatory gene *P5CSF129*A for the overproduction of proline (Bhatnagar-Mathur *et al*., 2009a) and At*DREB1A*, driven by the stress-inducible *rd29A* promoter (Anbazhagan *et al*., 2015). Four Transgenic events in advanced generations (T6) with single copies were evaluated under water stress in lysimeters in a biosafety greenhouse under progressive water stress. While, one event reduced its transpiration in drier soil and higher vapor pressure deficit (VPD) range (2.0–3.4 kPa), two of these showed increased biomass partitioning into shoot, denser rooting in deeper layers of soil profile and higher transpiration efficiency than the untransformed controls, indicating the implicit influence of *rd29A:DREB1A* on mechanisms underlying water uptake, stomatal response, transpiration efficiency and rooting architecture under water stress (Anbazhagan *et al*., 2014, 2015). Similarly, for inducing herbicide tolerance in chickpea, transgenic interventions have been made towards developing resistance to PSII targeting herbicides (unpublished data). Transgenic events of chickpea expressing P450 cytochrome genes from soybean and artichoke have been developed and screened for herbicide tolerance using pre-emergence herbicides such as Linuron and Chloroturon that are photosynthesis inhibitors. Several events have shown resistance against linuron and are being characterized in advanced generations. Gene expression studies with key genes involved in photosynthetic as well as antioxidative machinery indicated up regulation of APX and CBP genes in the transgenic events as compared to the controls. More recently, genome editing tools for large-scale genome engineering in legumes are being developed to accelerate trait development and understanding the gene functions and their interactions. These toolkits/ platforms are being developed for testing several key genes to reveal the efficiency of these systems in grain legumes. A repository of pre-integrated Cas9 lines is also under development for making these available to the larger research community for facilitating both forward and reverse genetics towards enhancing genetic gains in these pulse crops.

Groundnut transgenics have been developed for economically important viruses such as Indian Peanut Clump virus (IPCV), groundnut rosette assistor virus (GRAV), an important component of the virus complex causing groundnut rosette disease in sub-Saharan Africa, Tobacco Streak virus (TSV) and PBNV, Peanut Bud necrosis virus (Sharma and Anjaiah, 2000; Rao *et al*., 2013). Similarly, transgenic groundnut events expressing the rice chitinase gene

(Rchit) were generated and evaluated for their tolerance to foliar fungal diseases including LLS and rust. Overexpressed chitinases imparted enhanced protection by degrading the chitin in hyphae, thereby retarding fungal growth, and by releasing pathogen-borne elicitors that induced defense reaction in plants (Prasad *et al*., 2013). Besides, abiotic constraints like drought are being addressed in groundnut using rd29A driven DREB1A, where selected events have been comprehensively tested in green house and confined field trials in various water stress regimes under varying vapour pressure deficits (VPDs). Several transgenic events had significantly higher seed filling under drought and displayed 20–30 % lower pod yield reduction than their untransformed counterparts under drought stress without displaying any yield penalty under irrigated conditions (Bhatnagar-Mathur *et al*., 2007, 2009b, 2014).

To address more complex and important aspects like pre-harvest *Aspergillus flavus* infection and resulting aflatoxin contamination, ICRISAT has developed high level of resistance in groundnut by over expressing (OE) antifungal plant defensins and through host-induced gene silencing (HIGS) of aflatoxin biosynthetic pathway genes. While the former improves genetic resistance to *A. flavus* infection, the latter inhibits aflatoxin production in the event of infection providing durable resistance against different *Aspergillus flavus* morphotypes and negligible aflatoxin content in several groundnut events/ lines well (Sharma *et al*., unpublished results).

Microbiology

Use of secondary metabolites for promotion of plant growth, control of insect pests and plant pathogens, and biofortification

There is a growing interest in the use of secondary metabolites, such as toxins, proteins, hormones, vitamins, amino acids and antibiotics, from microorganisms, particularly from actinomycetes, for promotion of plant growth, control of insect pests and plant pathogens and biofortification as these are readily degradable, highly specific and less toxic to nature. Actinomycetes are a group of Gram-positive bacteria with high G + C content belonging to the order Actinomycetales, which form branched mycelium and hence have sometimes been classified as *fungi imperfecti*. These are found most common in soil and compost and play an important role in the decomposition of organic wastes and produce secondary metabolites of commercial interest. Actinomycetes isolated from compost and rhizosphere soil have been reported to promote plant growth and inhibit phytopathogens including *Sclerotium rolfsii*, *Fusarium* *oxysporum* f. sp. *ciceri* (FOC), *Rhizoctonia bataticola*, *Macrophomina phaseolina* and insect pests including *Helicoverpa armigera* and *Spodoptera litura*. The Microbiology unit of ICRISAT has identified 26 bacteria (of which 19 were actinomycetes) that has been demonstrated under field conditions for their usefulness and mechanisms such as plant growth-promotion (PGP), biological control on both insect pests and pathogens and biofortification potentials. From these promising microbes, ICRISAT has also identified few novel secondary metabolites that are responsible for mortality/inhibition of insect pests and pathogens, which can be further exploited for PGP/biocontrol applications under on-farm conditions. The following are ICRISAT's contribution in the field of Microbiology:

Role of bacteria on plant growth promotion (PGP)

A total of 137 bacteria were screened for their antagonism against important fungal pathogens of chickpea such as *S. rolfsii*, FOC, *R. bataticola* and *M. phaseolina* by dual culture and metabolite production assays. Nineteen most promising action-mycetes and seven other bacteria were evaluated for their physiological and PGP properties under *in vitro* and *in vivo* conditions. All the isolates exhibited good growth at temperatures from 20─40^{o}C, pH range of 7─11 and NaCl concentrations up to 8 %. These were also found highly tolerant to Bavistin, slightly tolerant to Thiram and Captan but susceptible to Benlate and Ridomil at field application levels and were found to produce siderophore, cellulase, lipase, protease, chitinase, hydrocyanic acid, indole acetic acid (IAA) and β-1,3-glucanase. When these actinomycetes and other bacteria were evaluated for their PGP properties under field conditions on chickpea, all exhibited increase in nodule number (up to 25%), shoot weight (up to 20%) and yield (up to 16%). The actinomycetes treated plots enhanced total N (up to 15%), available P (up to 18%) and organic C (up to 15%) over the un-inoculated control plots. The scanning electron microscope (SEM) studies exhibited extensive colonization by action-mycetes and bacteria on the root surface of chickpea. The expression profiles for IAA, siderophore and β-1,3-glucanase genes exhibited up-regulation for all three traits. The actinomycetes were identified as *Streptomyces* but different species in the 16S rDNA analysis. It was concluded that the selected actinomycetes have good PGP potentials on chickpea. The actinomycetes and bacteria were also demonstrated for their PGP potentials on other crops including pigeonpea, rice and sorghum (Gopalakrishnan *et al.*, 2012a; 2012b; 2013a; 2013b; 2014a; 2014b; 2015a; 2015b; 2016a; 2016b; Sreevidya *et al.*, 2016a).

Role of bacteria and their metabolites on biological control of insect pests

Helicoverpa armigera (Hübner) and *Spodoptera litura* (Fabricius) are an important insect pests causes serious damage to grain legumes. Microorganisms produce a range of metabolites with varying pest control properties. With this concept in mind, we had identified 15 *Streptomyces* strains with insecticidal activity against *H. armigera* and *S. litura*.Among the 15 isolates identified, SAI-25 (*Streptomyces griseoplanus*), CAI-155 (*Streptomyces sp.*) and BCA-698 (*Streptomyces sp.*) were found to be promising candidates as broad-spectrum biocontrol agents. We evaluated an insecticidal compound purified from the extracellular extract of *S. griseoplanus* SAI-25 by bioactivity guided fractionation against *H. armigera*. Spectral studies confirmed that the purified compound was cyclo(Trp-Phe) of the diketopiperazines class. Cyclo(Trp-Phe) exhibited antifeedant (70%), larvicidal (67%) and pupicidal (59%) action against *H. armigera* in a dose-dependent manner. The LD_{50} and LD_{90} values for larvicidal effect were 619 and 2750 ppm, respectively. In addition, the purified compound prolonged larval (10.3-11.1 days) and pupal (10.9-11.8 days) periods as compared to the untreated control (larval duration - 9.8 days; pupal duration - 10.6 days). This is the first report on the presence and biological activity of cyclo (Trp-Phe) isolated from the genus *Streptomyces*. One more metabolite was also purified from the culture filtrate of *Streptomyces* sp. CAI-155. The culture filtrate of CAI-155 was extracted using Diaion HP-20 and the active fractions were fractionated on Silica and C18 column chromatography. The C18 active fraction was further fractionated on Silica gel 60 F_{254} thin layer chromatography (TLC). The most active fraction (Rf 0.64) purified from TLC led to the identification of a novel metabolite *N*-(1-(2,2-dimethyl-5-undecyl-1,3-dioxolan-4-yl)-2-hydroxyethyl)stearamide by spectral studies. The purified metabolite showed 70─78% mortality in 2nd instar *H. armigera* by diet impregnation assay, detached leaf assay and greenhouse assay. The LD_{50} and LD_{90} values of the purified metabolite were 627 ppm and 2276 ppm, respectively. Both of these novel metabolites can be exploited for pest management in future (Gopalakrishnan et al. 2016a; Sathya *et al*., 2016a; Vijayabharathi *et al*., 2014).

Role of bacteria and their metabolites on biological control of plant pathogens

A total of 137 actinomycetes, isolated from 25 different herbal vermin-composts, were characterized for their antagonistic potential against FOC by dual-culture assay. Of them, five most promising FOC antagonistic isolates (CAI-24, CAI-121, CAI-127, KAI-32 and KAI-90) were further characterized for antagonistic potential against *Macrophomina phaseolina* (*Rhizoctonia bataticola*), which causes dry root rot in chickpea and sorghum. In the dual-culture assay, three of the FOC antagonistic isolates, CAI-24, KAI-32 and KAI-90, inhibited *R. bataticola*, while two of them inhibited *M. phaseolina* (KAI-32 and KAI-90). When the FOC antagonistic isolates were evaluated further for their antagonistic potential in the greenhouse and wilt-sick field conditions on chickpea, 45−76% and 4−19% reduction of disease incidence were observed, respectively, over the control. The sequences of 16S rDNA gene of the isolates CAI-24, CAI-121, CAI-127, KAI-32 and KAI-90 were matched with *Streptomyces tsusimaensis*, *S. caviscabies*, *S. setonii*, *S. africanus* and *Streptomyces* spp., respectively, in the BLAST analysis. This study indicated that the selected actinomycete isolates have the potential for biological control of *Fusarium* wilt disease in chickpea (Gopalakrishnan *et al*., 2011).

In a study against *Botrytis cinerea*, causing Botrytis Gray Mold (BGM) disease in chickpea, ten bacteria and one fungus were found promising. The culture filtrate of the most promising isolate, VFI-51, was further purified by various chromatographic techniques and identified as “citrinin” by spectral studies. The efficacy of citrinin was demonstrated to control BGM in chickpea under greenhouse conditions. The sequences of 18S rDNA gene of the VFI-51 matched with *Penicillium citrinum* in BLAST analysis. Under greenhouse and field conditions, VFI-51 significantly enhanced the nodule number, nodule weight, rootand shoot weight and stover and grain yield over the un-inoculated control. In the rhizosphere, VFI-51 also significantly enhanced total N, available P and OC over the un-inoculated control. Scanning electron microscopy analysis revealed that VFI-51 colonized on the roots of chickpea. This study concluded that VFI-51 have the potential for biocontrol of BGM and plant growth promotion in chickpea. VFI-51 was also demonstrated to have antagonistic potential against charcoal rot disease in sorghum (Sreevidya *et al*., 2015, Sreevidya and Gopalakrishnan, 2016b).

Role of bacteria on biofortification

A study was done to test the potential of plant growth-promoting actinobacteria in increasing seed mineral density of chickpea under field conditions. Among the 19 isolates of actinobacteria tested, significant ($p < 0.05$) increase of minerals over the un-inoculated control treatments was noticed on all the isolates for Fe (10─38%), 17 for Zn (13─30%), 16 for Ca (14─26%), 9 for Cu (11─54%) and 10 for Mn (18─35%) and Mg (14─21%). The increase might be due to the production of siderophore producing capacity of tested actinobacteria, which was confirmed in our previous studies by q-RT PCR on siderophore genes expressed up to 1.4 to 25 fold increased relative transcription levels. The chickpea seeds were subjected to processing to increase the mineral availability during consumption. The processed seeds were found to meet recommended daily intake of FDA by 24–28% for Fe, 25–28% for Zn, 28–35% for Cu, 12–14% for Ca, 160–167% for Mn and 34–37% for Mg. It is suggested that, microbial inoculum can serve as a complementary sustainable tool for the existing biofortification strategies and substantially reduces the chemical fertilizer inputs (Sathya et al. 2016b).

Concluding Remarks

Recent years have witnessed impressive progress in research and development of grain legumes. Impressive yield growth has been seen in some countries where adoption of improved cultivars and production technologies was high. The integration of novel tools and techniques provides opportunity for accelerating process of development of improved cultivars. Enhanced investments are needed in research on grain legumes and developmental activities for enhancing adoption of improved cultivars and technologies. In addition to increasing productivity of grain legumes, other aspects of increasing profitability to farmers from grain legumes, such as enhancing mechanization, reducing post-harvest losses, developing value-added products and linking to markets, should be considered.

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Advances, Challenges and Opportunities in Cool-Season Food Legumes in Dry Areas

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Abstract

Cool-season food legumes (CSFL) such as chickpea, lentil, faba bean, field pea, and grass pea are an integral part of subsistence farming in dry areas and the major sources of nutritious food for human, feed for livestock, and income for smallholder farmers. These crops also fix atmospheric nitrogen into usable form and thus contribute to soil fertility in the cereal based cropping systems. The area, production and productivity of these crops are 26.1 million ha, 31.3 million tones and 1197 kg ha^{-1}, respectively. Cool season food legumes cover 33 and 45% of global pulse area and production, respectively, indicating better yield compared to warm-season food legumes. Past research and development efforts have resulted in development of improved varieties with medium to high levels of resistance to key diseases such as Fusarium wilt/root rot complex in chickpea and lentil; Ascochyta blights in chickpea, lentil and faba bean; rust in lentil and faba bean; and chocolate spot and parasitic weeds in faba bean. The most significant improvement in yield stability has resulted from the genetic improvement to develop appropriate phenology so that the durations of the vegetative and reproductive phases are well matched with the expected water supply. Expansion of chickpea in Central and South India, Myanmar and Ethiopia is an example of such development. With increasing pace of climate and farming system changees and reduced genetic diversity at farm levels, intensity and frequency of abiotic stresses especially heat and drought and emergence of new diseases and insect pests have increased manifold with serious yield losses. This drives the demand to produce more crops per drop of water and per unit area to enhance crop and water productivity. The yield potential of pulse crops is still low and requires substantial improvement in source-sink equilibrium to fit in various cropping systems. To achieve this goal, appropriate changes in phenology and plant type that can be grown in conjunction with cereals or fit within the short-season windows available between major cereal crops and are amenable to machine harvest, disease and pest resistance, and post emergence herbicide application to control obnoxious weeds are required. Thus, enhancing economic competitiveness and stability in performance of CSFL crops under climate and farming system changes require a three-pronged research strategy involving stress characterization, trait/gene discovery using high throughput platforms, and trait deployment through precision breeding in the desired agronomic and quality background along with a variety of specific production technologies. This strategy looks promising, particularly for developing more nutritious, input efficient varieties for enhancing food and nutritional security in developing countries.

Keywords: Cool season food legumes, genetic improvement, pre-breeding, production technologies, varieties

Introduction

Cool-season food legumes (CSFLs) *viz.*, chickpea, lentil, faba bean, field pea, and grass pea are an integral part of subsistence farming in the dry areas. These crops are the preferred choice among the smallholder farmers as their cultivation needs external inputs. Legume seeds are a rich source of protein and micronutrients, almost 2-3 times more than the major cereals, and the straw is a valued animal feed (Iqbal *et al*., 2006). Because of their vital role in human and soil health, these crops have been grown with cereals not only for meeting the diversified food systems but also for maintaining favorable equilibrium in agricultural production system. Together, these crops occupy 26.1 million ha area with production of 31.3 million tones and average productivity of 1197 kg ha^{-1} globally during 2011-13 (FAOSTAT, 2015). Chickpea contributes 39% to total CSFLs production followed by dry pea (33%), lentil (15%), and faba bean (13%).

South Asia grows CSFLs on 12.85 million ha and produces 10.52 million tons of grains with India as the major producer, importer and consumer. Chickpea (10 million ha) followed by lentil (2.0 million ha) and dry pea (0.5 million ha) are the major crops in the region (FAOSTAT, 2015, Figure 1). Food legumes in West Asia mainly in Turkey, Syria, and Iran are grown on 0.97 million ha area with production of 1.28 million tones and average yield of 1319 kg ha^{-1}. Chickpea (0.55 million ha) followed by lentil (0.39 million ha) and faba bean (0.03 million ha) are the major crops in the region. North Africa grows these crops on 1.05 million ha area with 1.12 million tones production and an average yield of 1060 kg ha^{-1}(FAOSTAT, 2015). Faba bean accounts for 52%, followed by chickpea (8%) and lentil (4%).

During the last five decades, area under CSFLs in East Africa has almost doubled from 0.76 to 1.58 million ha while the production has increased more than three times from 0.56 to 1.84 million tones (FAOSTAT, 2015), showing a positive yield gain over time (Fig. 1). Ethiopia is the largest producer of food legumes in East Africa with extensive area under faba bean (0.50 million ha), field pea (0.30 million ha), chickpea (0.25 million ha), grass pea (0.14 million ha), and lentil (0.11 million ha) (FAOSTAT, 2015).

In the past, CSFLs production could not keep pace with population growth resulting in drastic reduction in the per capita availability in developing countries. To bridge the demand-supply gap, a paradigm shift is needed in research strategy which supports the overall development, delivery, performance and impact of research on food legumes. Its focus should be on high-priority challenges and new opportunities based on the past successes and recent progress in science and technology. Systematic researches for their improvement are underway in several national and international institutions. The International Center for Agricultural Research in the Dry Areas (ICARDA) has a global mandate for improvement of faba bean, lentil and grass pea and a shared mandate with ICRISAT for chickpea to address specific needs of different agro-ecological regions in the dry areas.

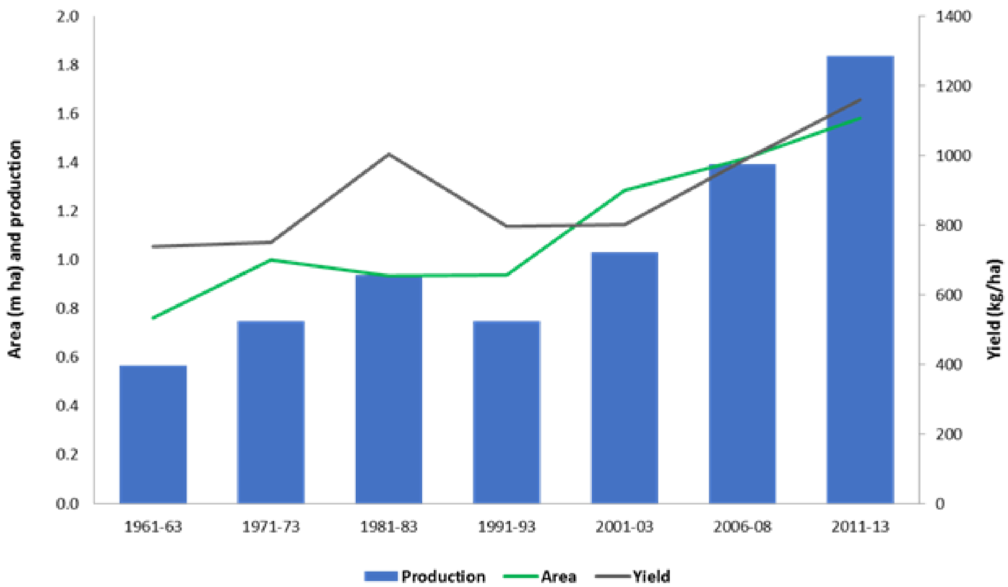

Figure 1: Trends in area, production and yield of cool-season food legumes in East Africa (FAOSTAT, 2015)

Major production constraints

Major constraints that limit the realization of potential yield of CSFLs which include biotic and abiotic stresses; besides socio-economic and policy factors (Table 1). Fusarium wilt/ root rot complex, Ascochyta blight in cool and wet areas and Botrytis grey mold in warm and humid climate are important diseases of chickpea. In lentil, wilt/root rot diseases, rust, Ascochyta blight and *Stemphylium* blight cause considerable damage in many countries. Powdery mildew and Ascochyta blight are the two most important and widely spread foliar diseases of dry pea whereas faba bean suffers great yield losses due to chocolate spot, rust, black and foot root rots, faba bean gall, and viral diseases. In grass pea, diseases limiting its productivity include powdery mildew and root rots. Among key insect pests, pod borer (*Helicoverpa armigera*) and leaf miner on chickpea, aphids on lentil, field pea, and grass pea and stem borer in faba bean cause severe damage (Sharma and Crouch, 2004). Besides annual weeds, parasitic weeds

(*Orobanche* and *Phelipanche* spp.) and dodders have emerged as major threats to CSFLs in West Asia, North Africa and East Africa, leading to substantial reduction in area and production (Sarker and Kumar, 2011). New diseases are appearing because of climate and farming system changes like *Stemphylium* blight, Botrytis gray mold and downy mildew on lentil and faba bean gall disease on faba bean.

Among abiotic stresses, terminal drought, heat, waterlogging and frost during reproductive stage; cold sensitivity during the flowering stages; and salinity/alkalinity throughout the crop growth period in irrigated areas inflict yield variation. All these stresses make the production of these crops low and unstable. Consequently, legume crops are perceived as marginal crops laden with high risk and poor yield. This perception discourages farmers to invest in requisite inputs vital for its successful cultivation. In the technological front, food legumes still need major yield breakthrough through morpho-physiological changes in plant type and development of multi-stress resistant varieties. In the cold-prone highlands of Turkey and Iran, lentil and chickpea are traditionally grown in spring to avoid the harsh cold climates in winter season. Local cultivars are of spring types that do not have winter-hardiness and so are unsuitable for winter cultivation. Frost at vegetative and reproductive stages and water logging in black soils are key constraints in the highlands of East Africa.

Research Advances

Genetic improvement

Food legumes improvement program at ICARDA is built upon the foundation of its vast germplasm collections (cultivated and wild relatives) and its use to breed new varieties better adapted to different agro-ecological conditions. ICARDA gene bank holds 38,000 accessions of chickpea, faba bean, lentil, field pea and grass pea. Except for a few traits, sufficient variability for important economic traits is reported in the existing germplasm. To increase the use of germplasm in breeding programs, the Focused Identification of Germplasm Strategy (FIGS) is recently being pursued at ICARDA with robust geographical datasets and core and minicore collections by ICRISAT. The FIGS strategy has proven successful for various adaptive traits such as tolerance to heat, drought, cold, and salt, besides resistance to insect pests and diseases. Such FIGS sets in chickpea, lentil and faba bean are now available to NARS partners to discover and deploy the useful genes into desired agronomic background.

Table 1. Production constraints of cool-season food legumes in different regions

Production Constraints	South Asia	East Africa	West Asia	North Africa
Chickpea				
Drought stress	x	x	x	x
Heat stress	x	x	x	x
Cold stress			x	x
Fusarium wilt	x	x	x	x
Root rot	x	x		
Ascochyta blight	x	x	x	x
Botrytis gray mold (BGM)	x			
Pod borer	x	x		
Faba bean				
Heat and drought stress	x	x	x	x
Cold stress			x	
Ascochyta blight		x	x	x
Chocolate spot	x	x	x	x
Rust	x		x	x
Viruses		x	x	x
Parasitic weeds		x	x	x
Lentil				
Drought stress	x	x	x	x
Heat stress	x	x	x	x
Cold stress			x	x
Fusarium wilt	x	x	x	x
Root rots	x	x		
Rust	x	x		x
Ascochyta blight		x	x	x
Stemphylium blight	x			
Aphids	x	x		
Parasitic weeds			x	x

Source: CRP-Grain Legumes (2013-16)

ICARDA breeding program generally uses parents of diverse origin with an aim to combine traits contributing to yield, appropriate phenology, adaptation to major biotic and abiotic stresses and market preferred traits. Following a selection-hybridization-selection cycle, ICARDA constructs new breeding lines to deliver to the NARS partners in the form of international nurseries (INs). These nurseries comprise a range of genetically fixed materials and segregating populations to provide opportunities to NARS partners for selection. Based on phenotypic performance, resistance to prevailing stresses, quality parameters and farmers' preference, NARS partners identify and select promising lines/single plants for eventual release as variety for commercial cultivation. Over 368 varieties have been released in lentil 137, kabuli chickpea 162, faba bean 75, and grass pea 7 for cultivation in target countries. During the last ten years, NARS partners have released 85 varieties of these crops using ICARDA material (ICARDA, 2016) (Figure 2).

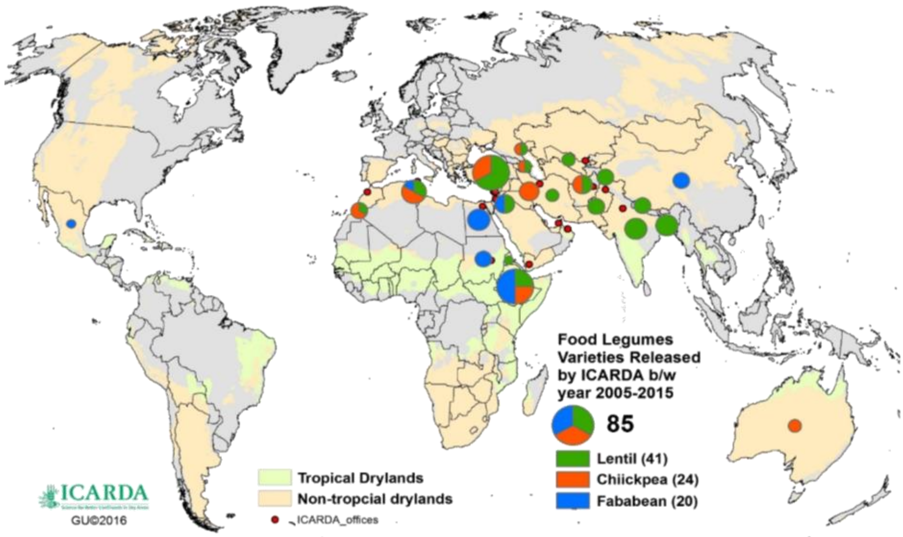

Figure 2. Improved varieties of food legumes released in different parts of the world using ICARDA germplasm

Focused programs on breeding and refinement of production and protection technologies have shown profound effect on production and productivity. The maximum production gain is observed in chickpea (6.32 million tons) and lentil (2.18 million tons). These gains become more spectacular when viewed with markedly reduced crop duration of these varieties. This has increased the per day productivity comparable to any rainfed crops besides making them suitable for introduction in new niches and diversification of the existing cropping systems. Some of the specific success stories of ICARDA partnership with NARS are well documented.

East Africa: Ethiopia is a major producer of cool-season food legumes in sub-Saharan Africa. In Ethiopia, several varieties of faba bean (22), field pea (26), chickpea (19), lentil (14) and grass pea (1) have been released (Yigezu *et al*., 2015). For example, the red lentil variety *Alemaya* is grown on about 10% of lentil area with average yield of 2 tones ha^{-1}. This variety has high level of resistance to rust, Ascochyta blight and wilt/root rot diseases, excellent phenological adaptation in new cropping niches, attractive seed traits, and high in iron and zinc. In chickpea, three kabuli varieties, *Arerti*, *(*FLIP 89-84C) *Ejere (* FLIP-97-263C), and *Habru* FLIP 88-42C *)* , that can yield up to 4 tones ha^{-1}, compared to only 1.7 tones ha^{-1} from landraces. These varieties with combined resistance to Ascochyta blight and Fusarium wilt/root rot complex have great potential due to their suitability for early planting to take full advantage of moisture during growing period. The regional agricultural research institute recently released a rust resistant lentil variety *Derso* and *Jiru* and being under scaling-out. Among faba bean varieties, *Moti*, *Gebelcho*, *Obsie*, and *Walki* are prominent. *Walki* is gaining popularity in waterlogged areas of the central highlands. An Orobanhce tolerant faba bean variety *Hashenge* was released recently and being out-scaled by NARS. In grass pea, low-toxin variety *Wasie* is a good example of successful collaboration with NARS partners and can be scaled out in cereal (wheat, barley, Tef and rice) based cropping systems in the mid highlands of the country. This partnership is reaping rewards over the past decade in Amhara and Oromiya regions where yields of faba bean, chickpea and lentil have increased and production is steadily growing, as is the cultivated area. In Ethiopia, the average rate of increase in grain yield potential of lentil over the 30-year period was estimated at 27.82 kg ha^{-1} at Debre Zeit and 18.02 kg ha^{-1} at Enewari (Bogale *et al*., 2015). Similarly, in faba bean, the annual rates of genetic progresses were 8.74 kg ha^{-1} (Tolessa *et al*., 2015).

The diffusion of improved varieties of faba bean, chickpea and lentil has been estimated at 11, 19 and 15% in Ethiopia (Yigezu *et al*., 2015). A study on faba bean showed higher adoption rate of 19% (Bishaw and Alemu, 2017). An IFPRI impact study in 2010 showed that the release and uptake of high yielding, rust and wilt resistant lentil varieties in Ethiopia has increased the growing area and harvest at an annual rate of 15% from 1994 to 2009. This resulted in 105,956 ha cropped with lentil, and 123,777 tones of production in the 2009/10 cropping season. As a result, food legumes have emerged as the third-largest crop export of Ethiopia after coffee and oil seed and represent a US$ 90 million export industry.

South Asia: In South Asia, one of the major achievements is the breaking of an ancient bottleneck of narrow genetic base in lentil. Genetic base has been broadened through introgression of genes from ICARDA germplasm in local landraces of the region. In Bangladesh, adoption of improved varieties like *BARImasur-4, BARImasur-5, BARImasur-6 BARImasur-7* and *BARImasur-8* has helped in improving lentil productivity in the country. Impact study showed that these improved varieties are cultivated over 110,000 ha in Bangladesh, delivering an annual extra production gain of some 55,000 tons, and valued at US$ 38 million annually (ICARDA, 2012). In grass pea, two varieties *BARIKhesari-3* and *BARIKhesari-4* are recently developed for rice systems.

West Asia and North Africa: In the highlands of West Asia and North Africa, kabuli chickpea and lentil suffer from low temperature at seedling stage. To overcome this problem, long duration varieties with winter hardiness, cold/frost tolerance and Ascochyta blight resistance have been developed.

The first winter-sown chickpea variety released in Syria was *Ghab 1* in 1982 followed by *Ghab 2, Ghab 3, Ghab 4, Ghab 5* and *Ghab 6 (*ICARDA, 2016*)*. Winter-sown chickpea area is expanding particularly in drier regions that do not traditionally grow chickpea in Syria, Turkey, and Iran. Winter hardiness has also been incorporated in lentil varieties such as *Kafkas, Uzbek* and *Cifci* in Turkey; *Gachsaran* in Iran; *Shiraz-96* in Pakistan; and *Bichette* and *Zaria* in Morocco. The winter-hardy variety *Kafkas* is getting ground in Central Anatolia. Winter technology in chickpea and lentil has significantly increased productivity compared to traditional spring-grown crop in these countries. Similarly for spring sowing, drought-tolerant chickpea variety *Gokce* released in Turkey was once grown on over 350,000 ha, almost 85% of the chickpea area in the country. Now it is being replaced with new releases because of their better yield and stability. The variety *Gokce* was introduced in Ethiopia and farmers are growing the crop in limited scale in East Shoa.

Like-wise, in lentil, *Firat-87,* locally known as *Commando* and *Syran-96* are popular in South-East Anatolia in Turkey, a major hub of red lentil production. In Morocco, *Bakria*, an early maturing green lentil with resistance to rust has been adopted by farmers in low-rainfall areas. *Idlib-3* is suitable to low rainfall areas (<280 mm) in Syria. Multiple disease-resistant faba bean varieties in Egypt have substantially increased productivity and production in the recent past. The release of Orobanche tolerant varieties, *Misr1, Misr3,* and *Giza843* has encouraged farmers to take up faba bean production in orobanche infested areas in Egypt. Recent efforts made for dissemination of these varieties combined with integrated pest management packages has increased farmers' grain yield by 256 kg ha^{-1} and reduced production costs by 350 USD ha^{-1}. Results from 1997-2014 shows that even with the decrease of faba bean cultivation area (from 135290 to 51680 ha), total productivity with improved varieties has gone up from 2 to 3.53 tones ha^{-1}. Egypt's self-sufficiency in faba bean production saw a downfall in 2011-12, but with the technology package, it improved in 2014-2015 and is on a continuous rise since then.

Supplemental irrigation:

Depleting soil moisture in rainfed areas often occurs during the most sensitive growth stages (flowering and grain filling) of CSFLs. supplemental irrigation (SI), with a limited amount of water applied, especially during the critical crop growth stages, results in a substantial improvement in yield and water productivity in chickpea (Acharya *et al*., 2015), lentil (Oweis *et al*., 2004) and faba bean (Girma and Haile 2014). A four-year (1996–2000) study on supplemental irrigation has identified significant improvement in yield and water productivity for chickpea, lentil, and faba beans (Oweis and Hachum 2003). However, lentil and faba bean are more responsive to supplemental irrigation than chickpea. In Ethiopia, drought period is likely to occur when the crop is at flowering and grain filling stages resulting in premature drying of leaves which in turn result in reduced assimilatory capacity and lower grain yields much below the potential yield of the crop; and SI would help improve yield of faba bean (Girma and Haile 2014).

Integrated pest management

The level of resistance in faba bean, chickpea and lentil for some of the diseases (*Stemphylium* blight, Botrytis Gray mold, wilt/root rots, Ascochyta blights, faba bean gall and rust), insect pests and parasitic weeds ranged from low to high and additional control measures are required. For foliar diseases caused by necrotrophic pathogens of food legumes, a combination of adjusting planting dates, crop rotation, seed treatments, pesticide sprays and uses of pathogen free seeds are used to reduce their impacts. For soil born pathogens, resistant/partially resistant cultivars, adjusting planting date, seed bed preparations to avoid excess water and seed treatments are commonly employed as management strategies. For biotrophic pathogens like rust and powdery mildew, resistant/partially resistant cultivars are mainly used. Parasitic weeds are mainly controlled by application of 1-2 sprays of sub-lethal dosage of Glyphosate on partially resistant cultivars (mainly faba bean) at flowering stage of the crop coupled with 1-2 hand weeding. Since the levels of resistance for insect pests is very low or non-existent, application of pesticides with adjusting planting date is widely used by farmers. For example, losses from leaf miner and pod borer in winter planted chickpea are very low compared with spring planted chickpea in Mediterranean region.

Major Challenges

Climate variability and farming system changes

Predicted climate change brings many challenges and opportunities to farmers and legume scientists. In the past, it may have been sufficient to develop a variety well adapted to a agro-ecological region, taking into account the well understood abiotic and biotic constraints and end-product quality. With climate and farming system changes becoming a reality, a dramatic shift in production base is expected to take place. Being climate smart crops, CSFLs will gain ground in these new niches. This requires development of varieties adapted to environments with larger variability in temperature and water availability and new cropping systems like conservation agriculture, intercropping, double/relay cropping etc. Drought stress, especially after the onset of flowering, is of common occurrence, causing substantial yield losses in South Asia, West Asia and North Africa. Drought research at

ICARDA is conducted at various locations to capture the expression of genotypes under low, medium and high moisture conditions screening a large number of lines for drought include delayed planting of germplasm/improved materials to coincide the critical growth stage with high moisture stress. Additionally, the conventional methodologies are being supplemented with better and automated phenotyping facilities and molecular tools to understand the complex nature of drought tolerance. Similarly, heat stress during the reproductive phase adversely affects pollen viability, fertilization, pod set and seed development leading to abscission of flowers and pods, and substantial losses in grain yield (Gaur *et al*., 2015). Pollen-based screening methods have been useful for evaluating genotypes for tolerance to heat stress in both lentil and chickpea. We also evaluate our germplasm of faba bean, chickpea and lentil in Sudan, where the crops experience heat stress throughout its reproductive phase. Genetic variation for heat tolerance has been identified in these crops. The precision and efficiency of breeding programs for climate smart varieties have been enhanced by integrating novel approaches, such as high throughput phenotyping, rapid generation turnover, marker-assisted selection, and genome wide selection. Efforts are underway to mainstream these tools into routine breeding programs.

Farming system and climate variability, as well as germplasm movement led to emergence of new diseases and insect pests which are becoming new challenges in food legume production. For example, new faba bean gall disease in Ethiopia is damaging the crop for the last five or more years and expanding its area coverage. This disease is threatening both the welfare of farmers and genetic diversity of the crop. On the other hand, parasitic weeds are expanding in East Africa which has never been known in the past. Collar rot has emerged as major disease of lentil with the introduction of relay planting of lentil in standing rice crop in South Asia. In zero tilled cropping with the introduction of lentil in the rotation has resulted in a serious outbreak of downy mildew, which is a minor disease on lentil in Syria. The breeding program and integrated pest management practices should be developed or fine-tuned to address new biotic threats.

Large yield gaps

Combined effect of insect pests, diseases and weed infestations on food legumes is estimated at 37-70% losses in grain yield (Kumar *et al.*, 2016). A great progress has been made in solving individual diseases and now the major challenge is to manage new spectrum of diseases and insect pests under climate change and variability and develop multiple disease resistant varieties. Since the value of resistance sources depends upon levels and stability of their resistance, a complete understanding of resistance-associated factors for critical traits in the available germplasm has the potential to bring them together in a selection index, and ultimately use them in pyramiding using molecular tools in breeding programs. Among major insect pests, pod borers and leaf miner in chickpea, and aphids and Sitona weevil in lentil and faba bean and stem borer in faba bean are the major challenges. The levels of resistance to pod borers in the cultivated germplasm are quite low, and hence, little progress in developing resistant cultivars. Good sources of resistance against pod borers and leaf miner in chickpea and Sitona weevil in lentil have been reported in wild relatives but its transfer into the cultivated germplasm poses a challenge (Kumar *et al*., 2011).

Development of insect-smart production systems integrating various components including rational application of bio- and synthetic pesticides will guide decision-making in pest management. Integration of transgenic plants with high levels of resistance to pod borers and management approaches will act as a major game changer to provide a sustainable solution to these intractable pest problems. For biological control, our approach is ‘discovery-to-deployment’ pipeline involving identification of better-adapted natural enemies against this pest, and efficient system for rearing of the natural enemies.

Harvest losses

Manual harvest of legume crops is becoming increasingly uneconomical because of the rising cost and shortage of labor at the peak harvest time. In order to use combine-harvesters, legumes varieties need to be modified for machine harvestability. This requires development of varieties with erect and tall plants with strong stem, top pod bearing habits, synchronous maturity, and tolerance to lodging and pod shattering. Utilization of available genetic variability for these traits has led to the development of improved breeding lines suitable for mechanical harvest. A large number of breeding lines with upright growth habit and suitable for mechanical harvesting is under field testing and would soon be available for cultivation. Past efforts at the Center have produced new varieties suitable for mechanical harvesting - such as the *Idlib 2* to *Idlib 5* in Syria and *’Sayran 96’* in Turkey. On-farm trials and demonstrations indicate that on average mechanical harvesting combined with improved cultivars reduces harvest costs by 17-20% in lentil (Sarker and Kumar, 2011).

Mono-cropping of cereals

Expansion of area under irrigation and availability of more productive cereal varieties and production inputs have resulted in substantial reduction in area under legumes especially in the Indo-Gangetic plains and North Africa (Ali and Kumar, 2004). With cereal yields projected to double over the next 30 years, legumes would likely to be further pushed out, unless extra-early varieties of food legumes are developed that can fit in the short season windows of the existing cereal-based systems. Extra-early varieties (<90 days) escape end-of-season drought and heat stresses in addition to fitting the crops in available short windows of these cropping systems. In addition, increased adaptability to marginal soil conditions and matching water availability during the critical growth stages will also be required. In Ethiopia wheat mono-cropping is a major problem in medium and highlands of the country and recently large seeded high yielding kabuli chickpea and faba bean with resistance to foliar diseases and wilt/root rot are showing high acceptability to be included in the rotation.

Non-availability of quality seeds

Neither the public nor the private sector is involved in legume seed delivery due to various reasons. Non-availability of quality seeds of improved varieties in legume crops remains a challenge to transfer agricultural innovations to farmers and realize the impacts of investments in agricultural research. The present seed delivery systems have been constrained by policy, regulatory, institutional, and technical issues or a combination of these factors superimposed by complexity and diversity of farming systems, and socio-economic conditions of farmers. Many countries are grappling with establishing sustainable legume seed delivery and looking into a combination of options including formal (public or private) and innovative alternative informal approaches to ensure availability and access to new technologies.

Opportunities

Different approaches like genetic, management and developmental options are available for improving productivity. Besides restructuring the plant as per the environmental requirements and cropping systems, efforts are needed to design varieties with appropriate growth habit and efficient source-sink relationships. Except faba bean, introgression of unexplored genes from the wild relatives could be rewarding for broadening the genetic base of important traits such as yield, yield attributes and resistance to biotic and abiotic stresses in pulses. We need varieties which are amenable to machine harvest and to commercially available post-emergence herbicides. We also need varieties which provide opportunity of planting in the short-season windows available in the existing cropping systems. Thus, enhancing economic competitiveness and stability in performance of food legume crops under climate change requires a three-pronged Research for Development strategy involving environment characterization using GIS tools, trait discovery using a high throughput phenotyping and genotyping platforms, and trait deployment through precision breeding tools in the desired agronomic background. Some of the opportunities are as follows:

Pre-breeding for widening the genetic base

There is a growing concern on limited genetic diversity due to frequent use of limited germplasm in breeding improved varieties. Genetic enhancement through pre-breeding is proposed for increasing the extent of useful diversity available to breeders through introgression of desirable traits from exotic material and wild species. ICARDA in collaboration with NARS partners in India have initiated a pre-breeding program on chickpea and lentil which has been instrumental in introgressing useful genes in the mainstream breeding. With rapid generation advancement and recent successes and availability of new biotechnology tools have brightened the prospects of transferring useful traits from exotic materials as well as primary and tertiary gene pools into pulses.

Improving plant type

Food legumes are grown under varying agro-ecological conditions and cropping systems and each set of conditions needs a specific plant type for higher productivity. Most of the food legumes still have wild traits like indeterminate growth habit, pod shattering, pre-harvest sprouting and sensitivity to photoperiod and temperature regimes. It is presumed that the determinate types under good management would partition photosynthate to yield components with greater efficiency. Similarly, photo and thermo insensitive varieties will be able to have wide adaptability with minimum seasonal and regional effects on their phenology and yield potential besides a more synchronous reproductive ontogeny and greater harvest index. Breeding objectives need to be directed keeping in mind the impact of altered plant types on the yield of the component crops. Simulation models developed recently for some of the legume crops offer the potential to interpret and predict the performance of individual genotypes in different environments thus offering a possible role in decision-making regarding suitability of the proposed plant type in the target environment and prevailing cropping systems.

Intensification and diversification of cereal based cropping systems

By virtue of atmospheric nitrogen fixation, food legumes can play an increasingly important role in rainfed production environments, especially in soils with low N content. After the harvest of wheat, fields are commonly left fallow as insufficient moisture prohibits the reliable production of rainfed summer crops in the Middle East and North Africa. The use of food legumes to replace the summer fallow phase of the traditional fallow-wheat system is one of the key components for obtaining a reduced or negative carbon footprint besides increased wheat yields, enhanced soil fertility, increased water use efficiency, as well as decreased losses in yield and quality from weeds and soil borne diseases. Typical rainfed wheat-based cropping rotations include food (chickpea, lentil, faba bean, field pea) and forage (*Medicago sativa* and *Vicia sativa*) legumes. In the highlands of Ethiopia, food legume crops are often grown in rotation with cereals or as intercrops, mixed crops to minimize the risks of biophysical stresses and to manage soil fertility. In Ethiopia, in a two-year cropping system, wheat after faba bean significantly out yields wheat-wheat and wheat-barley rotations (Tadesse *et al.*, 2016).

Growing crops in mixtures or as intercrop is a common practice in traditional agriculture. Despite this, a recent recourse by farmers in northern Ethiopia from growing a pure wheat crop to mixed intercropping of wheat with a small population of faba bean and field pea has attracted attention from research and development stakeholders. The farmers' reason for such a practice is land shortage coupled with the need to produce a cereal as the main crop and some legumes as an additional benefit. In South Asia, systematic research on inter/mixed cropping of wheat + legumes with emphasis on genotypic compatibility and spatial arrangement has led to identification of efficient intercrops, such as chickpea/lentil with wheat (Ali and Kumar, 2001). These intercrops, in a particular row ratio significantly increased total productivity and land use efficiency besides improving soil health.

Simulation studies show that there is potential to further expand the geographical area of lentil in East Africa including Uganda, Kenya, Tanzania and Somalia (Ghanem *et al*., 2015). Delaying sowing alone or in combination with a long-season genotype can result in a high probability of crop yield increase in East Africa. For the long-season genotypes, an optimum sowing window was found between June and July (152–229 day of year) for areas to the north of the Rift Valley (Ghanem *et al*., 2015). Late sowing dates (229–243 day of year) were found to be optimal in southern areas of East Africa (Ghanem *et al*., 2015). These simulations indicated that selection and breeding for lentil accessions in East Africa should consider changes in plant phenology and/or sowing dates.

Conservation agriculture

Zero-tillage, together with crop residue management (mulches) and crop rotation are the pillars of CA. Inclusion of legumes in the cereal-based rotation improves the soil physico-chemical properties and provide opportunity to increase the legume area and production. The rotational soil fertility benefits of legumes to subsequent crops can be substantial increase in the yield of subsequent cereal crops. But often the crop residues are removed from the field at harvest, so they do not provide the mulch cover wanted for CA.

Cereal–legume rotations for CA should focus on multipurpose legumes, where expansion of their cultivation will depend on the availability of ready markets for the quantities of grain produced beyond the direct needs of the farming households and suitable machineries. ICARDA has introduced and sxcaled out CA (cereal-lentil rotation) in Syria and northern Iraq where the average grain yield increase with ZT compared to CT was 0.26 t/ha for barley (*n* = 278), 0.33 t/ha for wheat (*n* = 264), and 0.23 t/ha for lentil (*n* = 88). Since 2006/2007, the area under ZT has grown from zero to more than 30,000 ha in Syria and 10,000 ha in northern Iraq in 2012/2013 (Loss *et al.* 2015).

Diseases like downy mildew on lentil and Ascochyta blight on chickpea were more sever on ZT with early planting in Syria (Ahmed *et al.* 2012) and therefore, continue pest monitoring is important for better pest management practices

Bridging yield gaps

In recent years, cultivars resistant to one or other stress have been bred bringing stability to legumes production. Stable resistance sources for many diseases and insect pests besides precise information on important aspects such as identification and characterization of races/biotypes, rate of emergence of new races/biotypes, genetic control, etc., are now available for directed improvement in resistance breeding. In chickpea, varieties need to be developed with multiple resistance against Fusarium wilt, root rots, Ascochyta blights, and botrytis gray mold to succeed in farmers' fields in different regions. Besides, lentil and field pea varieties need to be resistant to root diseases and powdery mildew, respectively. The most significant improvements in yield stability have resulted from genetic modification to develop appropriate phenology such that the durations of the vegetative and reproductive periods are well matched with the expected water supply. From trait evaluation to gene discovery to its deployment into varieties for abiotic stress tolerance is long drawn process and requires the expertise in various disciplines. In the recent past, a great progress has been made in development of high throughput approaches in eco-physiology, genomics, phenomics, and geo-informatics which offer scope for tailor-made solutions to these stresses.

Managing weeds

Weeds (parasitic and non-parasitic) pose serious challenge to food legumes production. Non-parasitic weeds compete with crops for light and nutrients, often leading to significant yield losses of up to 40% in legume crops. Use of non-selective herbicides is effective in removing all types of weeds in a single application; however, herbicide resistant/tolerant varieties need to be developed. Recent progress in identifying herbicide tolerant germplasm within the cultivated species has shown promise for development of herbicide-tolerant varieties. For example, varieties with improved tolerance to herbicide metribuzin have been developed by screening the advanced breeding lines in faba bean, lentil and chickpea. Genotypic differences have been reported for tolerance to imidazolinone class of herbicides in chickpea, lentil and faba bean. Although, genetic variations have been reported in faba bean and lentil to Orobanche, integrated broomrape management practices that include herbicide and other control practices offer an opportunity to recapture the area under CSFLs crops in WANA and East Africa regions.

Improving nutrient use efficiency

Plants differ greatly in their ability to utilize nutrients and adapt in deficient nutrient conditions. It is, therefore, necessary to screen germplasm having better nutrient use efficiency to cut on external use of fertilizers. Manipulation of the production environment with fertilizer application has been the most preferred practice to meet plant requirements. However, the same may not be the most economical solution to all mineral deficiency and toxicity problems of the soils in future. Altering the plants to grow on soils with mineral deficiency without compromising on yield or quality has great potential. Lower input requirements, reduced production costs and less pollution could be some of the benefits expected to accrue with nutrient use efficient plants. Information about genetic aspects of plant mineral nutrition should be derived to augment research strategy for developing nutrient use efficient genotypes for cultivation of legumes in degraded soils.

Enhanced nutritional quality

Over two billion people in the developing world are malnourished and are affected especially by micronutrient malnutrition, the “hidden hunger” (FAO, 2015). Legumes are one of the key food components of daily diet of the people, and valuable source of digestible protein, minerals and vitamins, and low-glycemic carbohydrate. Biofortification, under the Harvest Plus Challenge Program of CGIAR, has led to enrich lentil varieties with micronutrients. More than 1700 germplasm including wild species, breeding lines, and released cultivars from about 20 countries were analyzed for iron and zinc contents. Iron and zinc were found to be present in the range of 43-132 ppm and 22-90 ppm, respectively in these materials. This high presence of iron and zinc contents in wild accessions (ILWL74 and ILWL80) encouraged scientists to proceed further for genetic enhancement through cross breeding.

Conclusion

Systematic and concerted research efforts over the years have resulted in increasingly more productive technologies in CSFLs, which have brought about wider adaptability, higher and stable yield, and better market price due to market specific characteristics like seed size and color besides early maturity, and tolerance to biotic and abiotic stresses. Focusing on improved plant type, widening the genetic base, pyramiding of resistance genes for key stresses, and identifying remunerative cropping systems and intercrops, besides efficient production and protection technologies, can help improve the production on sustainable basis. Looking ahead, escalating costs of producing inorganic nitrogen fertilizer, reducing availability of water for agriculture, climate change, food insecurity and an increasingly nutrition-conscious consumer society collectively give a bright future for CSFLs. There is a need to employ a more integrated approach to use the existing genetic and genomics resources for uplifting the current yield level in lentil, faba bean and chickpea. Application of molecular approaches for legume improvement is expected to be the part of mainstream breeding programs in the international and national programs which will contribute immensely for developing improved cultivars with higher yield and stability. Improving the seed system is critical expand the scale of adoption and impact of improved crop varieties. ICARDA is collaborating with national program of West and South Asia, and East and North Africa to promote improved technologies to increase smallholder legume production, strengthen food and nutritional security, and improve soil fertility and health.

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Part II. Breeding and Genetics Research in Food and Forage Legumes of Ethiopia

Pages 69 - 178

Harnessing Modern Breeding Tools, Techniques and Approaches to Improve Yield and Quality in Legume Crops

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Abstract

Climate change and the associated problems have limited crop productivity and quality in Ethiopia. In order to meet the fast growing demand for providing quality food, feed and industrial raw materials, breeding strategies should foster for faster and more reliable methods. The potential application of marker-assisted breeding and genomic-driven legume crop improvement is well recognized. Little efforts have been made to employ biotechnological tools in national legume breeding programs in Ethiopia. Genome wide association studies (GWAS), multi-parent advanced generation intercross (MAGIC), and genomic selection (GS) are among the modern approaches for improving the efficiency of conventional plant breeding. The current advancement in next-generation sequencing and high throughput genotyping has also created huge potential to improve the untapped crop genetic resource in developing countries. The adoption of these approaches and integration in the conventional breeding process is a critical step to revamp the current effort in breeding of many important crops using the existing wide genetic diversity. Identification of novel genes associated with biotic and abiotic stresses resistance/tolerance and their subsequent introgression into elite crop varieties should be followed as one of the best strategies in the future. In this review paper, different approaches of the potential application of marker-assisted breeding and genomic driven-crop improvement with the achievements in different crops including legumes so far have been discussed.

Keywords: Conventional breeding, genome wide association, genomic driven-crop improvement, marker-assisted breeding

Introduction

Due to the ever-growing population and the impact of climate change, many developing countries are experiencing the grand challenge of getting enough food, feed and industrial raw materials. Research efforts to improve productivity of food, feed and industrial crops using the conventional breeding methods were found to be ineffective in some cases. This necessitated the application of modern genomics tools together with the conventional approaches. The rapid identification and introgressions of novel genes to adapted crop cultivars has been the key step towards the genetic improvement of our major crops (Haung *et al*., 2015) and this approach has been applied for incorporating important physiological and morphological traits including biotic and abiotic stresses resistance and compositional traits for added food and industrial values.

The limitations of the existing designs have led to new types of complex experimental designs such as genomic selection (GS), genome wide association study (GWAS) and multi-parent advanced generation inter-cross (MAGIC) designs which are superior in terms of power, diversity, and resolution. Besides, the recent introduction of new methods like Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated (Cas) genes for genome editing will be a good opportunity to integrate into the conventional breeding approaches, in order to mutually complement or supplement drawbacks of each method.

The role of 'omics' approaches for the improved efficiency of marker-assisted selection (MAS) of crop plants has recently attracted global interest. The term omics refers to the comprehensive analysis of biological systems involving high-throughput measurements of collection of protein in a cell (proteome), the collection of RNA transcribed from a gene (trancriptome) or collection of metabolites (metabolome). In proteomics, the protein identification is done in serial fashion and it is an excellent measure for early identification of traits like disease resistance, where as in transcriptomics the gene expression level which has a direct influence on trait is assessed simultaneously. Transcript profiling based on micro/macro-arrays offers the candidate genes responsible for various developmental stages and/or agronomically important traits. Metabolomics quantitatively measures the complete set of small molecule metabolite such as hormones, signaling molecules, metabolic intermediates and secondary metabolites, to produce a metabolic profile.

The advancement in next generation sequencing (NGS), high-throughput marker genotyping and high-throughput phenotyping technologies have also created an excellent opportunities for many breeders to exploit this emerging technologies in improving productivity, quality and nutritional values of the major crops by speeding up the identification of desirable genes and delivery of improved cultivars.

In this paper, the status and potential application of the emerging molecular plant breeding approaches ranging from diversity analysis to the recent advances of genomic driven-crop improvement to contribute to increased major legume crop productivity and to improving food and nutritional security have been discussed.

Marker-Assisted Breeding Efforts in Legumes of Ethiopia

Ethiopia has diverse crop genetic resources; however, the productivity of legume crops in the country is limited by a number of biotic and abiotic stresses. Among the biotic factors, fungi, bacteria, viruses, weeds and insect-pests are the major ones that are severely affecting the yield of the crops. Some of the recently emerged legume pests in Ethiopia include faba bean gall (*Olpidium viciae* Kusano) on faba bean, pea weevil *(Bruchus pisorum)* on field pea, and Broomrape (*Orobanche* sp.) on chickpea, faba bean, lentil and field pea.

Similarly drought, heat, water logging, salinity and frost are some of the major abiotic stresses that could result in extensive yield losses of the legume crops. The application of biotechnological tools/approaches to the crop plays significant role towards the development of superior varieties that can tolerate/resist these stresses.

Despite these constraints and significant contribution of the crops towards food and nutritional security program of the country, the majority of legume crops in Ethiopia, have received very little research attention. Most of the researches are focused on conventional based crop improvement strategy. In recent years, however, attempts have been made to complement molecular tools to exploit and utilize the existing natural variation in the legumes gene pool for various traits. Sufficient variation within and between species is desirable in breeding programs to ensure adequate sources of novel traits and, hence, marker based genetic variability studies play significant roles as the starting point for effective marker-assisted breeding, which reduces the time and resource investment. Some of the biotechnological based effort in exploiting natural variation in the legumes gene pool and their subsequent application in legume crops improvement program are summarized in Table 1.

Similarly, the intervention of biotechnological tools to study some of legume-associated pathogens plays significant role in race identification and disease control efforts. In this regard, attempt has been made to employ biotechnological tools to identify and characterize the various microbes/races associated with legume crops using germplasm collected from Ethiopia. Some of the studies are focused on nucleotide sequences of the Ethiopian isolate pathogens such as chickpea chlorotic stunt virus (Abraham *et al*., 2006; 2009), lentil stunt virus (Abraham *et al*., 2008), soybean dwarf virus (Abraham *et al*., 2008) and faba bean necrotic yellow virus (Katul and Vetten, 1999).

Table 1. Some of the molecular marker based studies using selected legumes in Ethiopia

Crops	Type of study	Marker type	References
Chickpea	Diversity analysis and population structure	SSRs	Kenani *et al*., 2012;
	Marker-assisted back crossing	RNA-Seq analysis	Jarso, 2017
	Genetic variability	SSR and morphological	Keneni *et al*., 2016
	Genetic dissection for drought and heat tolerance traits	DArT- GWAS and Candidate gene	Thudi *et al*., 2017
Common bean	Diversity analysis	ISSR	Dagnew *et al*., 2014
	Diversity analysis	EST-SSR	Teshome *et al*., 2015
	Diversity analysis and population structure	SSR	Fisseha *et al*., 2016
Field pea	Diversity analysis	SSRs	Negisho *et al*., 2017
Lentil	Diversity analysis and population structure	SSRs	Mekonnen, 2015
	Diversity analysis and population structure	ISSRs	Fikiru *et al*., 2007
	Comparative study	Morphological and ISSR	Fikiru *et al*., 2010
Ethiopian lupine	Diversity analysis and population structure	SSRs	Atnaf *et al*., 2017
Grass pea	Genetic Diversity	EST-SSR	Shiferaw *et al*., 2012
	Marker development and cross-species amplification	EST-derived	Shiferaw, 2013

Global Trend on Application of Biotechnological Tools in Legume Improvement Program

The huge amount of genetic variation within the legume genetic resources demands significant effort to exploit and employ in breeding program. In order to explore all the possible opportunities, the scientific community is trying to improve the existing approaches to advanced levels. Several molecular tools were developed and used in the study of parental selection, population genetics, linkage analysis, association studies and QTL analysis. Determining the relative positions of traits on various chromosomes of an organism are key towards efficient breeding for the trait in question. Different kinds of populations (bi-parental, backcross or association mapping) are used to determine the likely positions of the traits of interest. Besides, there are a number of emerging genomic tools that are proofed to be promising in improving the speed and effectiveness of the conventional plant breeding approach. Some of the commonly practiced molecular/genomic tools in legume breeding program are discussed as follows:

Linkage or family mapping

There are many ways to identify economically important quantitative traits in crop plants. Most of the past research has largely been undertaken based on linkage or family mapping of quantitative trait loci (QTL) which involves the generation of mapping populations, identification of polymorphism and linkage analysis of markers (Collard *et al*., 2005). However, nowadays bi-parental based

QTL mapping is considered as one of the conventional approaches. This type of mapping requires the generation of at least one type of mapping populations from a number of possible populations (Paterson, 1996) such as recombinant inbred lines (RILs), near isogenic lines (NILs), double haploid (DH), back cross (BC) and second filial generation (F2). A number of studies have been carried out regardless of its limited application in crop improvement program, because of a limited representation. Even though most of these studies have focused on major cereal crops, significant effort on identification and mapping of important traits using major pulse crops have been also carried out to improve crops for several biotic and biotic stresses tolerance traits. Some of the examples of QTL mapping using bi-parental mapping population of major pulse crops are summarized in Table 2.

Linkage mapping based QTL identification is limited by small population size or polymorphism and low resolution power because only two alleles per locus can be sampled in any given bi-parental population and a few recombination events are considered to estimate the genetic distances between marker loci and identify the causative genomic regions for QTL (Soto-Cerda and Cloutier, 2012). Due to these limitations, there is a need to look for a better mapping approach that can give better resolution power using existing natural populations.

Association mapping

Association or linkage disequilibrium (LD) mapping is relatively recent version of mapping that focuses on a non-random association of alleles at separate loci located on the same chromosome (Mackay and Powell, 2007; Soto-Cerda and Cloutier, 2012). It is a multidisciplinary field which requires adequate knowledge of genomics, genetics, molecular biology, statistical genetics and bioinformatics. It has several merits as compared to linkage mapping, including the shorter time required to carry out the study since natural population can be used to identify the genomic regions that are responsible for the trait of interest, a potentially large number of alleles per locus can be sampled, the possibility to detect complex combination between alleles, the prospect of simultaneous mapping and commercial variety development. On the other hand, the difficulty to screen SNP polymorphism in non-model organism and tedious nature of phenotyping large no of germplasm in multiple environments and years are some of the limitation of association mapping studies.

Table 2. Examples of bi-parental based QTL mapping studies in major legume crops

Crops	Traits	Markers	Mapping populations	Number QTLs	References
Chick pea	Drought tolerance	2717SSRs	Two RILs (288+264)	9	Varshney *et al*., 2014
	Grain yield under terminal drought	260 SSRs	155 RILs	15	Rehman *et al*., 2011; Hamwieh *et al*., 2013
	Drought tolerance and other phenology and yield related traits	77 SSRs	Two RILs (152+162)	93	
Peanut	Oil content and oil quality traits	215+ 390 SSRs	Two RILs (352 + 248)	88	Pandey *et al*., 2014; Wang *et al*., 2015; Ravi *et al*., 2011; Sujay *et al*., 2011
	Thrips resistance	318 +239 SSRs	94 F2 +158 F5	3	
	Tomato spotted wilt virus resistance			24	
	Leaf spot resistance			50	
	Drought tolerance traits	3,215 SSRs	318 RILs	53	
	Late leaf spot (LLS) resistance			28	
	Rust resistance	3,097 SSRs	Two RILs (188+181)	15	
Pigeon pea	Fertility restoration	339 SSRs	Three F2 (188 each)	4	Bohra *et al*., 2012
Common bean	Nutritional quality,	189 SNP	101inbredlines	17	
	Frost tolerance and fatty acid composition				Sallam *et al*., 2016; Casanas *et al*.,2013
	Seed chemical content	175 AFLPs 51 SSRs 30 SCARs 33 ISSR 12 RAPD	104 RILs	19	

Depending on the scope and focus of the research, either candidate-gene or genome-wide association study (GWAS) can be applied. In most cases, GWAS is the most frequently used methods as compared to candidate-gene mapping. While breeders are usually interested in a specific trait often to exploit candidate-gene association mapping, the majority of researchers might choose to conduct comprehensive genome-wide analyses of various traits by testing hundreds of thousands of molecular markers distributed across the genome for association.

Candidate-gene association mapping

The candidate-gene approach is a type of association mapping that focuses on specific traits and targeted genes with pre-defined biochemical pathways (Sukumaran and Yu, 2014). The comparative advantage of this type of mapping is that it associates polymorphisms in selected candidate genes that have purported roles in controlling phenotypic variation for specific traits. The candidate-gene approach has been mainly successful across taxonomic groups and offers the greatest opportunity for initial association mapping studies in non-model organisms (Nichols and Neale, 2010). It provides the greatest opportunity for tests of phenotype–genotype associations for non-model organisms with few genomic resources. In some cases, genome regions identified from QTL mapping studies in controlled crosses of the same or related species would provide information on candidate regions for association studies. The disadvantage of the candidate gene approach is that for some traits, it requires prior study of conducting genome-wide approaches such as whole genome expression or transcriptome studies (Nichols and Neale, 2010).

Genome-wide association mapping (genome scan)

As compared to the candidate-gene association mapping, it doesn’t require prior information of candidate genes. One of the limitations of genome-wide association mapping is the only application to model organisms for which significant genomic resources are available. The approach is also suitable to identify genes with previously unknown function using high genomic coverage of SNP markers (Sukumaran and Yu, 2014). In most cases, the position or order of these markers across the genome is known from linkage mapping or genome-sequencing efforts. A genome-wide scan, then, gives an overview of the patterns of genotype–phenotype associations along the chromosomes. In non-model organisms, the most promising approach for genome-wide association studies may come in surveying associations in large numbers of candidate genes or expressed sequences identified from transcriptome sequencing (gene-space scan).

Even though most of the association mapping studies focused on cereal crops, recently there are significant effort to utilize these modern approachs in pulse crops improvement program as well (Table 3). Most of these works targeted genome wide association mapping where as some of them are focused on candidate genes with known mutant phenotypes and are motivated by high resolution mapping and allele mining process.

Nested association mapping (NAM)

NAM or joint linkage association mapping is ideal method which integrates the advantage of linkage analysis and association mapping, with the ultimate goal of dissecting complex traits (Yu *et al*., 2008). Unlike association mapping, which assembles existing lines to form a population, NAM focuses on a diverse set of founders that are representative of the main breeding pools of the target species (Sukumaran and Yu, 2014). NAM is characterized by high resolution power, less sensitive to genetic heterozygosity, increased statistical power and lower SNP markers requirement in the progenies as compared to the commonly used association mapping approach (Sukumaran and Yu, 2014). Limited studies have been conducted in chickpea crops using NAM populations for different traits (Varshiney, 2016).

Multi-parent advanced generation inter-cross (MAGIC)

Most of the improved varieties developed so far are based on populations derived from bi-parental crosses that combine the genomes of two parents with different phenotypes. Attempts have also been made to make multiple crosses either using three-way cross involving three parents or double crosses involving four parents to increase the genetic variation in breeding populations (Acquaah, 2007). However, extensive use of these multiple crosses may be restricted by technical limitations like intensive labor for crossing and large population sizes required for recovering recombinants with all the desirable traits.

Recently, MAGIC strategy has been proposed to interrogate multiple alleles and to provide increased recombi-nation and mapping resolution (Cavanagh *et al*. 2008). This is a type of advanced intercross in which an intercrossed mapping populations is generated from a multiple parents, typically eight. These mapping populations can be used as preferred training populations for genomic selection due to its less structured populations and suitable to predict the breeding value. It inter-mates multiple inbred founders for several generations prior to creating inbred lines, resulting in a diverse population whose genomes are fine-scale mosaics of contributions from all founders. Similar to bi-parental populations, alleles occur at relatively high frequencies due to the limited number of founders, but the population encapsulates much higher diversity in polymorphisms.

Table 3. Examples of association mapping studies in major legume crops

Crops	Phenotype	Marker	Association Level	Association panel	References
Chickpea	Superior alleles for targeted traits	WGRS	GWAS	300 reference set & elite varieties	Varshiney *et al*, 2016
	Development of a high density genetic map and improvement of chickpea reference genome assembly	30000 SNPs	GWAS	92 RILs	Deokar *et al*., 2014
	Drought and heat tolerance	DArT	GWAS and Candidate gene	300 accessions	Thudi *et al*., 2014
Common bean	Frost tolerance	156 SNPs	GWAS	189 SSD	Sallam *et al*., 2016
Field pea	Partial resistance to *Aphanomyces euteiches*	13,204 SNPs	GWAS	175 RIls	Desgroux *et al*., 2016
Soya bean	Root-knot nematode	WGRS	GWAS	246 RILs	Xu *et al*., 2013
	50 agronomic Traits	154 SSRs + 4,597 DArT	GWAS	300 genotypes from 48 countries	Pandey *et al*., 2014
Pigeon pea	heterotic pool	WGRS	GWAS	292 reference set & 104 hybrid lines	Varshiney *et al*, 2015

SNPs : Single Nucleotide Polymorphisms; SSRs: Simple Sequence Repeats; DArT: Diversity Arrays Technology; WGRS: Whole-genome resequencing, GWAS: Genome Wide Association Atudy, SSD: Association Study Single Seed Descent

This type of mapping population also offers the use of both linkage and association mapping. Combined with the suitability for the generation of high density genetic maps, many factors make MAGIC populations ideal platforms for community-based resources for crop improvement, genetic dissection of QTLs, and the anchoring of physical-genetic maps. In general, MAGIC plays a significant role due to: (1) the developed mapping populations can be used as permanent mapping populations for a number of traits; (2) more targeted traits from each of the parents can be analyzed based on the selection of parents used to make the multi-parent crosses; (3) increased precision and resolution with which QTLs can be detected due to the increased level of recombination leading to greater genotypic variation (Cavanagh *et al*., 2008); (4) pyramiding of desirable traits; (5) varietal development through direct selection of promising breeding lines and maintenance of potential donors of new traits; and (6) MAGIC populations eliminate population sub-structure, producing stable, homozygous mapping lines by employing several generations of inter-mating following the initial crosses of the founder lines, and by avoiding selection during self–fertilization.

Multi-parent populations are now become attractive to breeders of different crops including legumes such as chickpea (Gaur *et al*., 2012; Varshiney, 2016), pigeon pea (Varshiney, 2016) and groundnut (Varshiney, 2016) due to the development of high-throughput SNP genotyping platforms and advances in statistical methods to analyze data from such populations (Bandillo *et al*., 2013). However, the method is restricted by intensive labor for crossing and large population size required for recovering recombinants with all the desirable traits (Bandillo *et al*., 2013). While a MAGIC population requires greater initial investment in capability and time than a bi-parental, careful selection of founders makes it more effective and ensures relevance as a long-term genetic resource panel. The principle of MAGIC population generation involves several steps as summarized in Figure 1.

Genomic selection

Marker-assisted selection involves identification of QTLs associated with a trait of interest followed by the use of these markers in the breeding program. However, MAS depends on segregating populations derived from two contrasting parents for the trait of interest. These populations are not representative of the given gene pool and variations controlled by many genes with minor effect cannot be detected. As the result, genomic selection was designed as a new approach to simultaneously estimate all loci, haplotypes, or marker effect across the entire genome to calculate genomic-breeding values (GEBVs). The GEBV is derived on the combination of useful loci that occur in the genome of each individual of the breeding populations and it provides a direct estimation of the likelihood of each individual to have a superior phenotype. Selections of new breeding parents are made based on the GEBV calculated from training and breeding populations. This leads to shorter breeding cycle duration as it is no longer necessary to wait for late filial generations to phenotyping quantitative traits. Training populations are those genotyped using high density markers and phenotyped over a range of environmental conditions whereas breeding populations are those with only genotypic data.

The Promises of Biotechnological Tools in Legume Improvement Program in Ethiopia

The application of MAS and genomics related approaches for crop improvement in Ethiopia seems to be very promising due to various factors. Some of the major reasons include; availability of huge crop genetic diversity, the current genome sequencing effort for the entire major legume crops, strong commitment of the country to invest in modern biosciences infrastructure including sequencing platform and partnership opportunities with many regional and international institutions to undertake collaborative research in the area of molecular/genomics-based crop improvement.

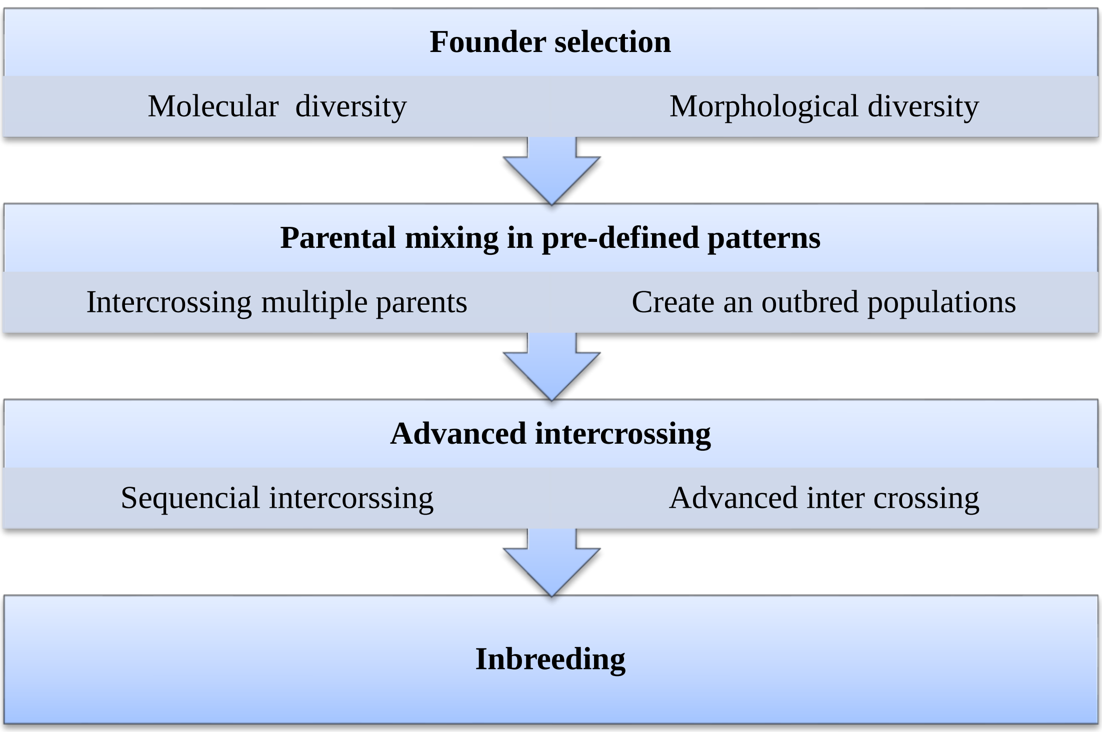

Figure 1. Summary of steps involved in multi-parent advanced generation intercross development

High legume crop genetic diversity in Ethiopia

Ethiopia is one of the primary centers of crop genetic diversity in the world and it is considered as one of the centers of secondary diversity for pulses (Vavilov, 1951). Legume crops like faba bean, field pea, chickpea, lentil, cowpea, fenugreek and grass pea have wide genetic diversity in Ethiopia. These important gene pool are useful sources of germplasm for economic traits. It is also important sources of genes resistance to abiotic and biotic stresses of many crops.

Given the importance of Ethiopian legume germplasm, long-term effective variety development for disease resistance and high yielding traits are becoming the priority area and the major agenda in agriculture sector of the country. We, therefore, need to focus on new breeding strategies that can address these biotic and biotic constraints of legume crops production. The high genetic diversity of these crops combined with potential sources of various desirable traits have the implication that the application of molecular/genomics-based crop improvement are likely to be very effective. This entails the potential contributions of Ethiopian genetic resources being inputs in its economic development.

Genome sequencing for most important legume crops

Availability of reference genome sequences for major legume crops and continued improvements in different genetic and genomic technologies would be an excellent resource and opportunity to realize the potential offered by biotechnological approaches in identifying new genes underlying complex traits for the improvement of legume crops in the country. As genomic technologies continue to evolve, more advanced approaches like genome-wide association analysis and CRISPR CAS will be expected to be conducted in different plant species to exploit the vast amount of available germplasm diversity in crops including legumes.

Establishment of modern bioscience facilities

The modern biosciences, particularly of molecular based genetics, genomics, proteomics and biochemistry promise in fine exploration of Ethiopian genetic resources and, thereby, capacitate the country in the exploitation and conservation processes of these resources. The employment of modern biosciences enables the country to generate high resolution data on its genetic resources, setting up of appropriate breeding and conservation strategies, and identification and isolation of products of high economic importance. Recently, there is tremendous interest in using agricultural biotechnology research as tool to improve the production, productivity and quality of crop plants including legumes in Ethiopia. This is evidenced by the current commencement of biotechnological researches and training in more than

25 higher education and research centers (Getu, 2011). In addition, a fairly equipped National Agricultural Biotechnology Research Center (NABRC) is built by the Ethiopian Institute of Agricultural Research (EIAR). The center is working on modernizing agricultural researches with special focus and genetic resource exploitations. These facilities will be a great asset for the country in order to identify important genes of interest using the emerging genomic tools.

Institutional linkages

EIAR has created many partnership opportunities to collaborate with various regional and international research organizations for the efficient utilization of genetic resources. The Consultative Group on International Agricultural Research (CGIAR) and many other institutions are currently conducting a collaborative research in order to address some of the constraints in agricultural and related sectors in the region. Besides, some institutes (eg. NABRC) serve as active node of the world class laboratory of the Bioscience for Eastern and Central Africa (BecA) as strategy of handling advanced molecular based researches. This will help the country in capacity building using multidisciplinary approach in the area of modern biosciences. It also allows domestic bioscience researches to be competitive enough meeting international standard. The collaboration would also enable the bioscience researches to have access to facilities and other resources that are missing domestically. It can also create chance to participate in cross nationally designed projects like genome sequencing of a particular crop plant, genomics based studies and many other molecular related researches. This ultimately contributes for the development of modern bioscience in the country to deal on national and international biological related challenges.

Conclusions

Molecular/genomics-based crop improvement has become one of the key approaches in gene discovery, complex trait dissection and development of superior genotypes in crop plants. As genomic technologies continue to evolve, the generation of genotypic data is no longer the limiting factor for further breeding studies. Besides, the current advancement in phenotyping strategy using high-throughput automated phenotyping methods will be another breakthrough research in improving productivity, quality and nutritional values of the major legume crops.

The rapid improvement of molecular/genomics-based crop improvement platform will benefit countries like Ethiopia due to its high genetic diversity of many cultivated crop plants including legumes. This is because high genetic diversity of crop plants has the implication that the application of modern approaches like association mapping, genomic selection and MAGIC are likely to be very successful. In addition, identification of candidate genes that are associated with drought tolerance, pest and disease resistance, and other beneficial nutrient traits and subsequent introgression into elite varieties will be among the sound strategies to be followed.

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Progresses of Faba Bean (*Vicia faba* L.) and Field Pea (*Pisum sativum* L.) Breeding and Genetics Research in Ethiopia

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Abstract

*Faba bean (***Vicia faba***) and field pea (***Pisum sativum***) are important crops in terms of both area coverage and volume of total national annual production. They are primary sources of protein, income for resource-poor farmers and foreign currency for the national economy. They also serve as "break" crops for cereal mono-cropping system en route to restrain pests and restore soil fertility through symbiotic nitrogen fixation. Despite the multiple merits of the crops, their productivity in Ethiopia is far below the potential at least in part because of biotic (biological limitations, foliar and root diseases, field and storage insects, parasitic and non-parasitic weeds) and abiotic (drought, water logging, soil acidity and frost) stresses. Genetic improvement of the crops to develop high yielding (quantity and quality) and stress resistant varieties has been underway since the 1950's and, as a result, a number of improved varieties have been released to farmers. Breeding progresses until 2003 have been reviewed in the proceedings of the first national food legumes workshop published in 1994 and the second workshop published in 2006. Breeding and genetics research efforts since then have gone some steps forward but the outputs and their implications for future breeding endeavors have not been reviewed and documented. In this paper, breeding and genetics research efforts have been reviewed in terms of both scientific information and technology outputs. Secondary information and results from analysis of available data were used as a basis for this review. Efforts made to create desirable genetic variation, develop basic genetic information and varieties identified for better and consistent performance and genetic progresses made from the hitherto breeding efforts, among others, have been reviewed. Finally, challenges, opportunities and future faba bean and field pea research directions have been discussed.*

Keywords: Faba bean, field pea, *Pisum sativum, Vicia faba*

Introduction

Ethiopia is a secondary origin and one of the Vavilovian centers of diversity for a number highland pulses including faba bean (*Vicia faba* L.) and field pea (*Pisum sativum* L.) (Vavilov, 1950; Frankel, 1973; Harlan, 1973; Westphal, 1974; Engels *et al*., 1991; Muehlbauer and Tullu, 1997). It is the largest producer of these two crops in Africa and the second largest for faba bean in the world next to China. The major producers in Ethiopia include: the mid and high-altitude areas of Amhara, Oromia, SNNPR and Tigray regional states (CSA, 2015). The crops are being produced in all regions for food, income and foreign currency, soil fertility restoration, and “break” crops to pests when rotated with cereals. The crops also serve in temporal and spatial intensification of production for product diversification, resource optimization, yield maximization and risk minimization (Keneni and Jarso, 2008 a, b and c). Faba bean and field pea are major source of dietary protein (25-40%) and staple food used in different forms by the majority of small-scale subsistence farmers in Ethiopia alleviating malnutrition in the country, and hence substitute expensive animal products like meat when consumed with cereals which are deficient in protein. These crops play an important role in management of soil fertility through crop rotation in cereal production, hence contributing to agricultural sustainability. The role of faba bean and field pea as soil fertility restorers in the highlands of Ethiopia will remain an integral part of the future farming system, among other reasons, because of rising price and negative side effects of commercial fertilizers and continuously increasing population pressure.

While playing a major role in the economic lives of the farming communities in the highlands of Ethiopia and, despite the huge potential of the country to grow these crops, the crops still suffer from numerous biotic and abiotic constraints at farm level. Production in Ethiopia is highly constrained by a number of biotic (biological limitations, foliar and root diseases, field and storage insects, and parasitic and non-parasitic weeds) and abiotic (terminal moisture stress, soil acidity, nutrient deficiency, water logging on Vertisols, frost in some pockets and low external inputs and poor management) stresses.

Faba bean and field pea breeding in Ethiopia was started in the 1950’s but strengthened with the establishment of the EIAR in 1966. The research was further re-strengthened and organized on a multidisciplinary basis since 1980’s through collaborated efforts with ICARDA. The objectives of faba bean and field pea breeding have been to improve yield, adaptation, biotic and abiotic stresses resistance/tolerance, and quality in terms of seed size and color. Investments in research have slightly but steadily been increased over the past decade but greater levels of support are still needed to meet the growing demands for the crops for local consumption and export markets. The central issue of this paper is to review the status of faba bean and field pea breeding and genetics research in Ethiopia, shade light on challenges and opportunities, future direction and projected needs for further efforts.

Production and Productivity Status

According to the Central Statistical Agency (CSA) of Ethiopia, the two crops together take the largest share (>50%) of area and production of pulses at main season, being grown by 76.5% of legume growers. In terms of production, closely 1.3 million tons of grain has been harvested from 813,845 ha of land (CSA, 2006-2016). As the result, the total annual national production of the two crops has been increasing during the last decade, closely by 43,000 tons every year for faba bean and 16,000 tons for field pea, which was mainly attributed to increment in productivity per unit area (Figure 1). On the average, area under faba bean has been increasing by not less than 3000 ha per annum during the last decade and field pea area has been increasing by not less than 1000 ha per annum during the same period. The total grain production of these crops was increased closely from 0.75 million to 1.30 million metric tons over the last one decade because of increased grain yield productivity from 1.2 to 1.9 t ha^{-1} in faba bean and 1.0 to 1.5 $^{-1}$ in field pea. About 78% of the increment in the total national annual production was merely due to the increment in productivity per unit area (Figure 1).

Breeding Approaches and Strategies

It is clear that under any situation the productivity per unit resources of a given crop could be boosted either through genetic manipulation (development of improved varieties) of the crop itself or manipulation of the growing environment (development of improved crop management and protection practices). Genetic manipulation of the crops through breeding of high yielding, stress tolerant/resistant and adaptive to the target production domain could be one of the stable alternatives to sustainably boost crop productivity. This is because of a number of technical reasons. First, improved seed is a prime background input through which other component technologies are siphoned to farmers. Second, once appropriate varieties are made available to farmers, on the existing cropping system and soil and water management practices, their adoption may involve no additional expense apart from the initial seed cost (Buddenhagen and Richards, 1988). However, technologies based on environmental manipulation must be repeated each season, are expensive and may not be affordable for resource-poor farmers (Keneni *et al.*, 2001). Third, experience also shows that seed based technologies are easier to transfer to farmers than more complex knowledge based agronomic practices (Edmeades *et al.*, 1998).

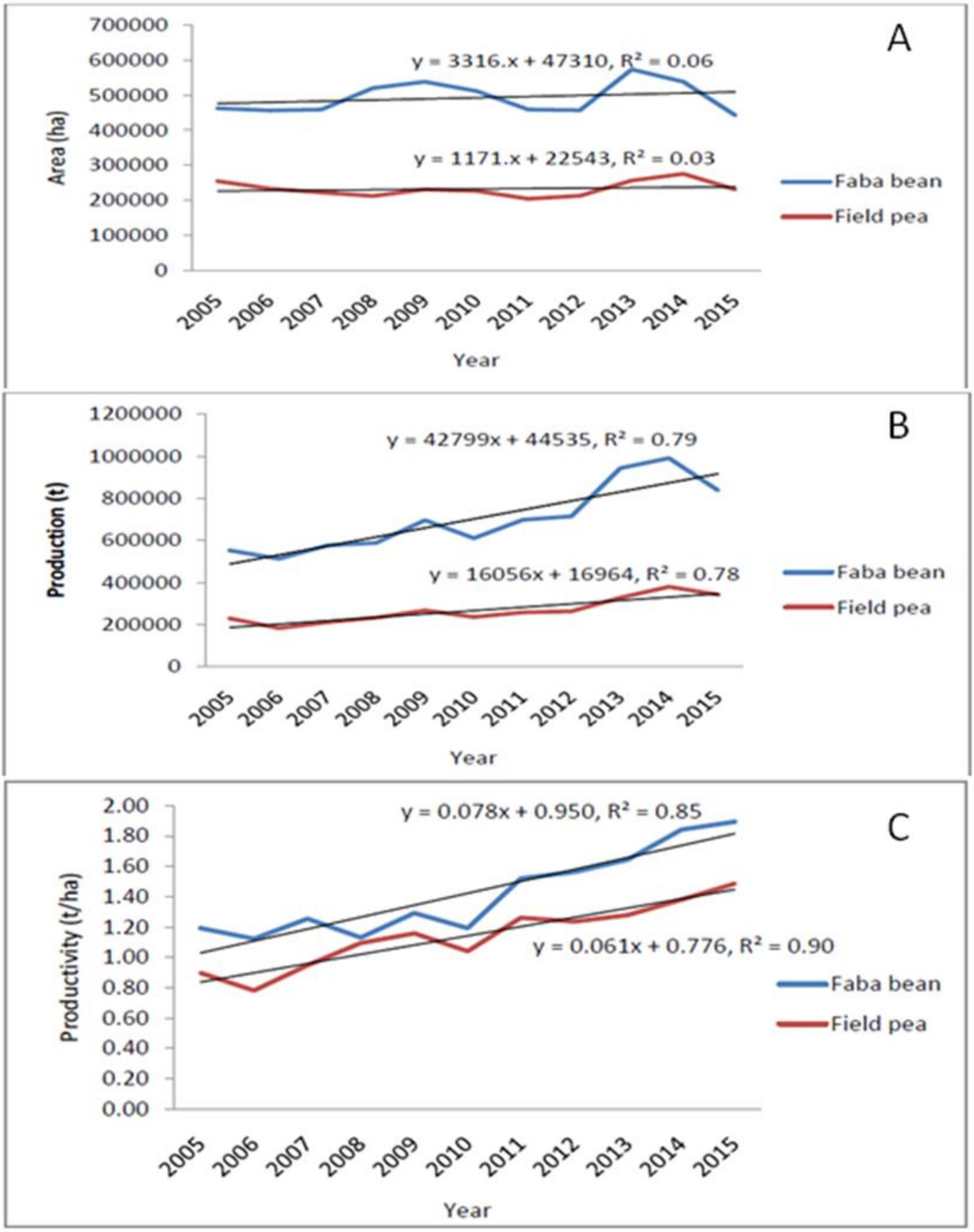

Figure 1. Area (A), production (B) and productivity (C) trend of faba bean and field pea in Ethiopia between 2005 and 2015 (Source: modified from CSA, 2006-2016)

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). So far, genetic variability has been created through introduction of exotic materials, collection of local landraces and hybridization of selected parents from the two sources (Keneni *et al*., 2006; Jarso *et al*., 2006). Crossing of genotypes from different sources and recombination of desirable characters was found to be more promising under the Ethiopian circumstances (Keneni *et al*., 2006). For instance, crossing of chocolate spot resistant or tolerant parents (ILB 4725, ILB 4426, ILB 4727 and ILB 938) and large-seeded parents (ILB 1563, ILB 2717-1 and ATOMA) sourced from ICARDA have been carried out with locally adapted genotypes. These resulted in new gene recombination for chocolate spot resistance with as double the seed size of the adapted parents.

Environment and the farming system for which breeding is undertaken, farmers' and consumers' preferences and traits of interest should be clearly defined as part of effective varietal development program. As it is practically difficult to come up with pest-resistant genotypes from selection in pest-free environments, selection for pest tolerance/resistance is commonly made under the hotspot areas for diseases like rust (*Uromyces viciae-fabae*), under artificial inoculation of the plants with inoculants of the causative agents for diseases like Chocolate spot (*Botrytiss fabae*), or under sick plots for soil born root diseases like the black root rot (*Fusarium sonani*).

A number of other basic genetic information on characterization and evaluation of germplasm (Keneni *et al*, 2005 a and b), choice of optimum selection environment (Keneni *et al*, 2001), secondary selection criteria (Keneni and Jarso, 2002), inheritance of primary and secondary traits (Beyene *et al*., 2016 a), genotype by environment interaction and performance stability (Tolessa *et al*., 2015), clustering of the test environments (Taye *et al*., 2000; Jarso and Keneni, 2004) and farmer's preferred traits (Keneni *et al*., 2002; Beyene *et al*., 2016 b) resulted in new basic knowledge, the sum total of which makes the whole background concepts and principles for effective breeding of the crops. The pictorial, tabular and graphical details of the basic studies are given in a number of other sources (Taye *et al*., 2000; Keneni *et al*, 2001; Keneni and Jarso, 2002; Keneni *et al*., 2002; Jarso and Keneni, 2004; Keneni *et al*, 2005 a and b; Temesgen, 2008; Keneni and Jarso, 2009; Tolessa *et al*., 2015; Beyene *et al*., 2016 a and b).

Breeding Achievements

Faba bean and field pea productivity has been augmented in the course of breeding since 1950's in Ethiopia with generation of productive cultivars. As the result, a number of faba bean and field pea improved varieties have been developed and released to farmers for their stable and high yielding performance, resistant to major diseases, good seed size/color and wider or specific adaptation during the last ten years. Seed size in faba bean, like grain yield, was also an economic trait that deserved the second priority as a prime objective of the breeding program (Tilaye *et al*. 1994). As a result, the seed size of faba bean improvement revealed the seed size increment up to 1069g thousand seed weight, which is three times the seed size of the older varieties Salale. The current Extension Package Program at the national level proved the superiority of these varieties at different levels (technical, policy and community) and made farmers aware of the importance of the improved seeds (Tables 1 and 2).

Nevertheless, it is hardly possible to say that these varieties have been made available, readily accepted, properly utilized and boosted faba bean and field pea productivity at farm level as desired. Wide gaps are observed between genetic potential under ideal condition and on-station performances, on-station and on-farm performances and between national average and on-farm performances. For instance, the current productivity of faba bean is 1.9 tons ha^{-1} and that of field pea is 1.50 tons ha^{-1} (CSA, 2015). On the other hand faba bean yields of 2.71-5.57 t ha^{-1} on the station and 2.18 -3.89 t ha^{-1} on farmers' fields and field pea yields of 2.45-5.01 t ha^{-1} on the station and 1.85-3.58 t ha^{-1} on farmers' fields have commonly been recorded from improved varieties with the associated proper crop management and protection conditions (Figure 2). This indicated that it is possible to double the annual national production if concerted efforts are made among research, extension and other development partners (Keneni *et al*., 2016).

Table 1. Performances of faba bean varieties nationally released and currently under production in Ethiopia

No.	Varity	Year released	Crude protein (%)	On-station (grain yield t ha^{-1})	On-farm (grain yield t ha^{-1})	Thousand seed wt(g)	Adaptation altitude (m a.s.l.)
1	CS20DK	1977	25	2.0-4.0	1.0.5-3	476	2300-3000
2	Degaga	2002	29.2	2.5-5.0	2.0-4.5	517	1800-3000
3	Wayu	2002	26	2.2-3.3	1.0-2.3	312	2100-2700
4	Salale	2002	28.2	1.8-3.2	1.0-2.3	346	2100-2700
5	Moti	2006	27	2.8-5.1	2.3-3.5	781	1800-3000
6	Gebelcho	2006	26.5	2.5-6.1	2.1-3.5	797	1800-3000
7	Obse	2007	26.9	2.5-6.1	2.1-3.5	821	1800-3000
8	Dosha	2008	26.5	2.8-6.2	2.3-3.9	704	1800-3000
9	Tumsa	2010	26.5	2.5-6.9	2.0-3.8	737	2050-2800
10	Walki	2007	27.5	2.4-5.2	2.0-4.2	676	1800-2800
11	Hachalu	2010	27	3.2-4.5	2.4-3.5	890	1900-2800
12	Gora	2013	24	2.2-5.7	2.0-4.0	938	1900-2800
13	Didia	2014	26	2.3-5.0	2.0-4.4	746	1900-2800
14	Ashebeka	2015	20.8	3.0-5.4	2.8-4.7	885	1900-2800
15	Numan	2016	26.5	3.6-5.1	2.2-3.8	1069	1800-3000

Table 2. Performances of field pea varieties nationally released and currently under production in Ethiopia

No.	Varity	Year released	Seed color	On-station (grain yield t ha^{-1})	On-farm (grain yield t ha^{-1})	Thousand seed wt(g)	Adaptation Altitude (m a.s.l.)
1	Tegegnech	1994	Creamy	2.5-3.5	1.5-3.0	215	2300-3000
2	Adi	1995	White	2.5-4.0	2.0-3.0	209	2300-3000
3	Wolmera	2000	White	2.5-4.0	2.0-3.0	143	2300-3000
4	Megeri	2006	Green	2.1-4.1	1.5-3.4	174	1800-2400
5	Gume	2006	Creamy	2.0-4.1	1.6-3.3	136	1800-3000
6	Burkitu	2008	White	3.5-6.2	2.0-3.8	201	1800-3000
7	Letu	2010	Gray	2.5-5.0	2.0-3.5	178	2300-3000
8	Bilalo	2012	Gray	2.6-5.6	2.0-3.5	209	1900-3000
9	Bursa	2015	Gray	2.0-5.4	2.0-4.0	189	1900-3000

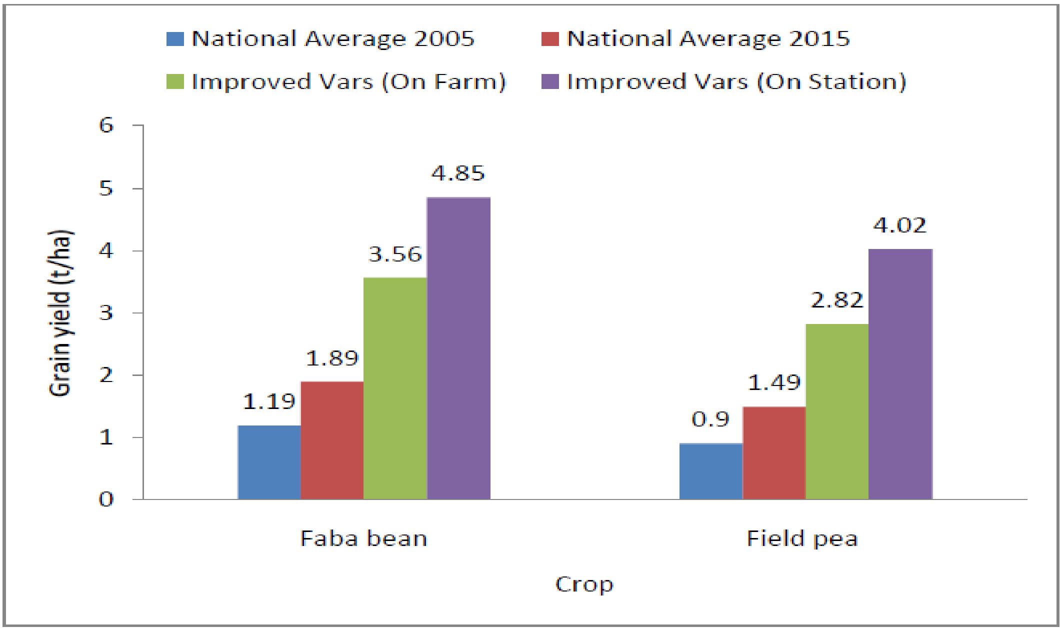

Figure 2. Comparison of faba bean and field pea national average yields (2005 and 2015) with performance of improved varieties under proper crop management and protection practices on the station and on farmers' fields

Genetic Progresses from Breeding

Genetic progresses made from breeding over the last decades were made to monitor the periodic advancement in the genetic gain of traits of interest particularly grain yield, seed size and chocolate spot disease in faba bean (Temesgen, 2008; Tolessa *et al*. 2015) and grain yield and seed size in field pea (Legese, 2011). The studies confirmed existence of modest levels of yield gains in both crops with tremendous improvement in seed size of faba bean during the last decade (Figures 3 and 4).

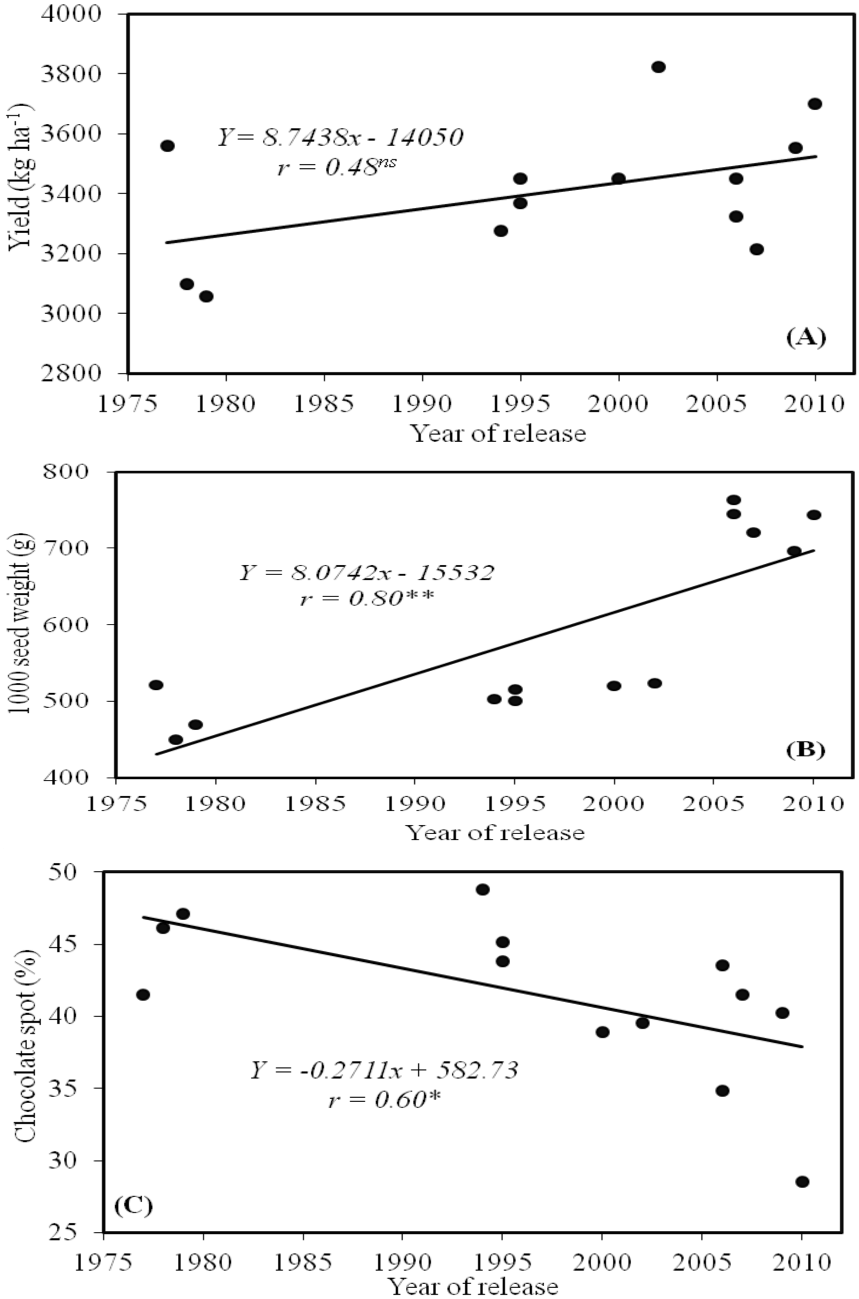

Figure 3. Regression of grain yields (A), seed sizes (B) and chocolate spot scores (C) of improved faba bean varieties over years of release showing the level of genetic gains from breeding during the last decades (Source: Tolessa *et al*. 2015).

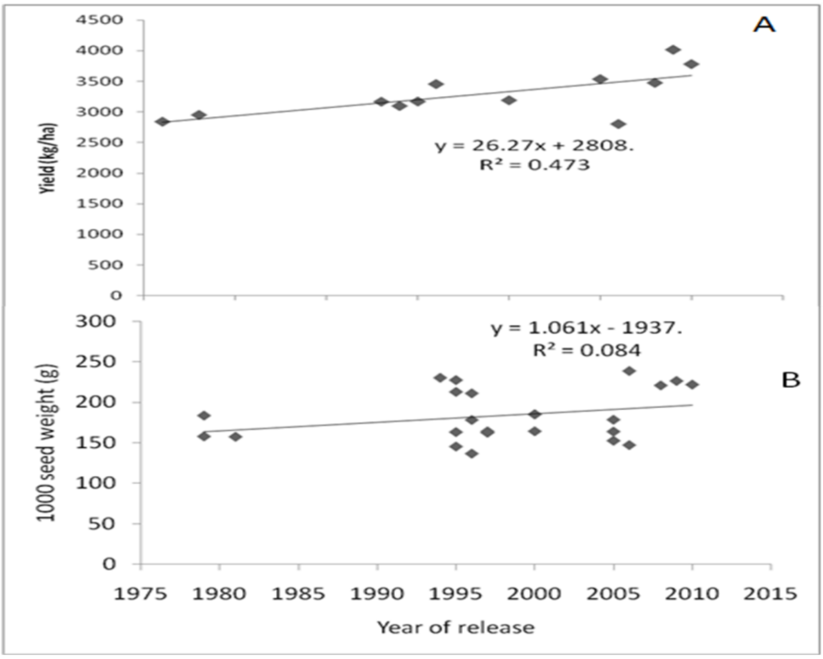

Figure 4. Regression of grain yields (A) and seed sizes (B) of improved field pea varieties over years of release showing the level of genetic gains from breeding during the past decades (Source: Legese, 2011).

Tolessa *et al*. (2015) reported the average cumulative genetic gain over 33 years of faba bean breeding to be 288.42 kg ha^{-1} for grain yield (an annual rate of genetic progress of 8.74 kg ha^{-1}), 266.3 g per 1000 seeds for seed size (1.55% 1000 seeds^{-1} year^{-1}) and -8.9% for chocolate spot severity (-0.27% per annum). Legese (2011) also reported that genetic progress of 22.23 kg ha^{-1} year $^{-1}$ was obtained from over 31 years of field pea breeding (Figures 3 and 4). Recently released faba bean varieties were found to be larger seeded and more resistant to chocolate spot because separate breeding programs were started for chocolate spot disease resistance and large seed size. This come up to competing breeding objectives since the year 2000 when artificial inoculation of aggressive inoculants started based on the details of the existence of pathogenic variability of *Botrytis fabae* by Gorfu (1996). Results from chick pea breeding in Ethiopia also showed similar trends in terms of increment in seed size (Keneni *et al*., 2011). The reason for slow genetic progress in seed size of field pea is that; this trait has not been so far deserved to be a research priority for separate breeding in this crop as it was in faba bean. Generally, it can be concluded that significant genetic progresses were made through decades of breeding faba bean and field pea in Ethiopia but obviously further efforts are needed to meet future demands.

Challenges and Opportunities

It was obvious that during the last decades, faba bean and field pea breeders in Ethiopia have successfully explored a large number of germplasm from which they managed to develop and release a number of improved varieties when applied with proper crop management and protection practices. In collaboration with other disciplines, they also contributed in terms of not only development of technology that potentially boost production and productivity but also generation of basic scientific information, availing initial technologies, ensuring demonstration, promotion, acceptance and proper utilization in production that changed livelihoods of small-scale farmers. However, the past successes were not immune of technical limitations and challenges. The most important challenges encountered, just to mention a few, include: the mismatch between selection and target production environments, appearance of new threats like pea weevil (*Callosobruchis pisorum*), broomrape *(Orobanche crenata*), faba bean gall (*Olpidium viciae*), at the top of lack of sources of resistance/tolerance and experience to overcome them, competition from the other sectors, difficulty of serving multi-dimensional interests, climate change and variability with all the associated complexities, and lack of effective technology multiplication and supply system (Keneni *et al*., 2016).

Remaining to their enormous value, all research for faba bean and field pea improvement has been done through conventional breeding resulted in releasing several high yielding varieties. With respect to productivity, however, substantial genetic gain has not been grasped. Unlike cereals, limited efforts have been directed towards undertaking molecular breeding worldwide and in Ethiopia in particular. One possible reason is the limited attention of the international research community to these crops. It is expected that molecular breeding will speed up the progress of genetic improvement of these crops.

Not only mere challenges but there are also opportunities for future exploitation, including: conducive policy environment for promotion of 'high value' crops, availability of “starter” technologies with strong phenotyping ability and partnership with others (universities, CGIAR centers and development organizations), successes of prior technology scaling up activities which made farmers realize the benefits of the use of improved technologies, realization of the risks of cereal-cereal monoculture both at technical and policy levels, the national plan to ameliorate acidic soils (note that legumes are highly susceptible to soil acidity) and improving local and foreign markets (Keneni *et al*., 2016).

Future Direction and Conclusion

The Second Growth and Transformation Plan (GTP II) of the Ethiopian Government was designed with much higher goals to be met in faba bean and field pea research and development. According to the plan, faba bean productivity will be increased from 1.89 t ha^{-1} of 2014 to 2.80 t ha^{-1} while field pea productivity will be increased from 1.49 t ha^{-1} to 22 t ha^{-1} in 2020 (MoANR, 2015).

In order to meet this demand, the first strategy is to effectively and efficiently utilize the readily available technologies from past research. Lack of effective seed multiplication and delivery system, no doubt, will be hindering better utilization of the available released varieties. In order to reverse the situation of critical shortage of early generation seeds (nucleus, breeder and pre-basic), the existing breeder seed maintenance and initial multiplication practices shall be critically examined and innovative and vibrant seed system need to be put in place (Keneni *et al*., 2016).

One of the bottleneck is that, currently, the maintenance, initial increase and multiplication of early generation seeds is excessively owned only by the national research coordinating centers (or centers that originally released the respective varieties) which have only a limited capacity to maintain and multiply early generation seeds in adequate amounts to meet the national demand. Strengthening the informal seed system, decentralization of the early generation seeds maintenance and multiplication system among the collaborative research centers by capacity building, supplying "starter" seed of adaptive varieties in the respective regions, putting mechanism for periodically replenishing seed stocks from the original releaser and linking the collaborative research centers with seed producers in their proximity may reverse this situation of chronic shortage of early generation seeds. The involvement of private investors in legume seed production and the technical efficiency of farmers should also be enhanced through policy and technical supports (Keneni *et al*., 2016).

The second strategy to meet the national demand is to strengthen the conventional breeding through capacity building, broadening the genetic basis of the source germplasm, application of modern and cutting edge science, defining resource base of primary breeding centers for better targeting of varieties, and use of irrigation to enhance generation advancement, thereby come up with more effective and efficient alternative technological options (Keneni *et al*., 2016).

It is obviously difficult for a single institute to overcome the production problems and challenges of faba bean and field pea production in Ethiopia. Therefore, concerted, integrated and consistent efforts are needed among the research and higher learning institution, CGIAR centers, development organizations and policy makers.

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A Decade of Research Progress in Chickpea and Lentil Breeding and Genetics

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This paper summarizes achievements of chickpea and lentil breeding during the last decade /2005-2015/ in Ethiopia. Gentic yield gains from decadal breeding efforts were 80 kg/ha/year for chickpea and 52 kg/ha/yr for lentil. The germplasm enhancment and subsequent variety evaluation verification programs during the decade resulted in releases of 17 chickpea and 2 lentil varieties. These advanced varieties, when applied in production system with proper crop managment and protection practices, almost doubled productivity per unit area at farm level.

Keywords: Chickpea, lentil, germplasm, geneticgain, variety

Introduction

Chickpea and lentil are among key market pulse products of Ethiopia. They account for 23% of total pulses produced in 2014 (CSA, 2014). The two pulses have recently played significant roles both in local and foreign markets. Farmers in Ethiopia produce chickpea and lentil mostly for market and agro-processing. According to the Ethiopian Revenue Authority, the two crops have been generating revenue of about 50 million USD per annum on last dates of the decade. It was also noticed that these pulses have lower production cost as compared to cereals and they also save a significant amount of nitrogen fertilizer for subsequent cereals.

Chickpea and lentil share similar production geographies and over the last decade the total area has increased by 27% and 39% and production by 65% and 57 % for chickpea and lentil, respectively (CSA 2005-2014). Currently, 1.8 million households are producing chickpea and lentil combined on some 360, 000 hectares of land. On area basis, chickpea is mainly grown in Amhara (52.5%), Oromia (40.5%), SNNP and Tigry regions (Fikre, 2014). Whereas, 95 % of the lentil production is mainly concentrated in two regions; Amhara (52%) and Oromiya (43 %) (CSA 2016). Chickpea is largely grown in rainfed areas on residual soil moisture. Trials on optimum planting dates and associated crop husbandry practices have shown yield advantages of up to 100%. Advancing planting date by at least one month increased productivity significantly as it avoids terminal drought stress. However, advancing the planting date may lead to excess soil moisture at the early growth phase which needs to be properly managed.

The periodic profitability of chickpea production increased from 20,000 Birr ha^{-1} at the beginning of the decade to the current level of 90,000 Birr ha^{-1}, indicating positive and significant production gains. The periodic increment in profitability is, apparently attributed to the continuous technology flow into the farming system. Despite the profitability, however, the market potential, particularly of chickpea snacks/salads, green pea and *shiro*, is not yet fully explored.

Ethiopia is the largest producer, consumer and exporter of chickpea and lentil in Africa, and is among the top ten most important producers in the world (FAOSTAT, 2011). Ethiopian chickpea production is changing from traditional varieties to improved varieties and from the Desi type to the Kabuli type. The farmers have been increasingly using market-preferred varieties and adopting improved crop production practices recommended by researchers. Both crops are known for soil nitrogen enrichment and offer several integrative advantages with cereals. It is also an important source of diet and consumed in Ethiopian different preparations like snacks, curry, blend to bread/Enjera powder, green pea, and salad just to mention some. An assessment of producer's demand show that they are opting more for Kabuli chickpeas (Damte, 2009) tto Desi. The Kabuli types had negligible share two decades ago, but now is estimated to occupy above 1/3 of the total area (Fikre, 2014). This trend of area coverage increment is expected to continue, and Kabuli chickpea area may outsmart the Desi type in the near future. There is also a growing demand for extra-large seeded kabuli chickpea premium marketwise.

Chickpea production has shown steady increase during the past decade with currently reaching more than 400,000t year^{-1}. The major contributor to this increase in production is the remarkable improvement in productivity than the expansion in area. The average productivity, which is close to 2 t ha^{-1}, is now comparable to many cereals which are produced under intensive input system. The productivity in Ethiopia stands among the highest in the world and is almost double than the global average. The advantages recognized by farmers in chickpea cultivation include: (a) low input requirements and production cost compared to other crops, (b) low requirement of synthetic fertilizers, (c) improvement and sustainability of soil fertility, (d) growing chickpea demand due to increasing domestic consumption and export, (e) dependable feed protein source, and (f) increasing market prices. This report summarizes recent efforts and achievements that are not covered in our recent review paper (Keneni *et al*., 2016).

Achievement in Variety Development

The national chickpea and lentil research program came up with 17 superior varieties of chickpea and 2 varieties of lentil during the decade. The new chickpea varieties have comparative advantages in terms of earliness, Aschochyta blight tolerance, seed size, grain yield, suitability for mechanization and rust resistance among others (Table 1). The advance in release of chickpea variety for the last decade revealed that 9 Kabili type and 8 Desi tape chickpeas have been released for production. The release of the chickpea varieties so far was also based on product concepts and market oriented. Despite the release of several improved varieties, however, the variety replacement rate of both chickpea and lentil is reasonably low. The genetic gains from breeding is also low as compared to the expectation. This calls for improving breeding progress for economic attributes on one hand and effective promotion of the available technologies on the other.

Advances in Genetic Studies using genomic tools

A lot of information has been generated in the process of evaluation of available germplasm resources for different objectives during the decade. Close to 3000 germplasm resources including accessions have been employed under different breeding and evaluation schemes. Teshome (2014) conducted genotypic and phenotypic analysis of 1035 accessions of Ethiopian origin chickpea genetic resources using SNP markers and mapped into 6 phylogenic clusters of the 1035 accessions and 158 core derivatives, having 86% representation, for systematic exploitation in the breeding program. Based on the genogram map distances, existence of a sizable genetic diversity was confirmed in the Ethiopian chickpea accessions (Figure 1).

Keneni *et al.* (2011) profiled the genetic basis of 130 diverse germplams resources for response to infestation by adzuki bean beetle (*Callosobruchus chinensis* L.) and clustered them into three distinct groups. The same study found that there was a significant diversity in the genetic resources that could go through breeding-based enhancement. Heritable host diversity for Rhizobium association capacity among chickpea genotypes were also found with a good level of yield impact (Keneni, 2013; Girma, 2015) which are

Table 1. Description of chickpea varieties released between 2005 and 2016)

Official name of release	Year of release	source of the materials	Genetic background (parentage, pedigree, ancestry)	Area of potential coverage (ha)	Area of actual coverage estimate (ha)	Average yield potential kg/ha (on-farm)	Varietal driver traits(selected characteristics)
Hora	2016	ICARDA	X2000TH50FLIP98-52C X FLIP98-12C		New		Yield potential
Dimtu	2016	ICRISAT	ICCV-93954 X ICC –5003		New		Yield and big seed size
Dhera	2016	ICARDA	X98TH30FLIP-93-55C XS-96231		New		Quality and mechanical harvest
Teketay	2013	ICRISAT	JG-74 X ICCL-83105		200	2200	Potential yield
Dalota	2013	ICRISAT	ICCX-940002-F5-242PO-1-1-01		200	2300	Potential yield
Kobo	2012	ICRISAT				1800	Drought stress agroecology
Akuri	2011	ICRISAT	ICCV03402		1000	1850	Drought stress agroecology
Kassech	2011	ICRISAT	FLIP 95-31C		1000	1800	Drought stress agroecology
Minjar (D)	2010	ICRISAT	ICC97103		10000	1900	Aschochyta tolerance, drought resistance
Acos dubie(K)	2009	PVT/ Mexico	Monino	10000	2000	1800	Extra big seed size, best niche market
Natoli(D)	2007	ICRISAT	ICCX-910112-6	25000	20000	3000	Productivity, seed quality, root rot tolerance
*Mastewal(D)	2006	ICRISAT	ICCV-92006	5000	20000	2000	Better yield and seed quality
*Fetenech(K)	2006	ICRISAT	ICCV-92069		-	1750	Better yield and seed quality
*Yelibe(K)	2006	ICRISAT	ICCV-14808		-	1750	Better yield and seed quality
*Kutaye(D)	2005	ICRISAT	ICCV-92033		-	1640	Better yield and seed quality
Teji (K)	2005	ICARDA	FLIP-97-266c	2000	212	1750	Quality seed, better yield, root rot tolerance
Ejere(K)	2005	ICARDA	FLIP-97-263c	3000	5295	2250	Yield, aschochyta tolerance, earliness
lentil							
Dembi	2013	ICARDA	EL-142 X R-186-3	New			Yield potential and rust tolerance
Derso	2010	ICARDA	Alemaya X FLIP 41L AK-14		2500	2500	Yield potential and rust tolerance

*D = Desi type, K = Kabuli type

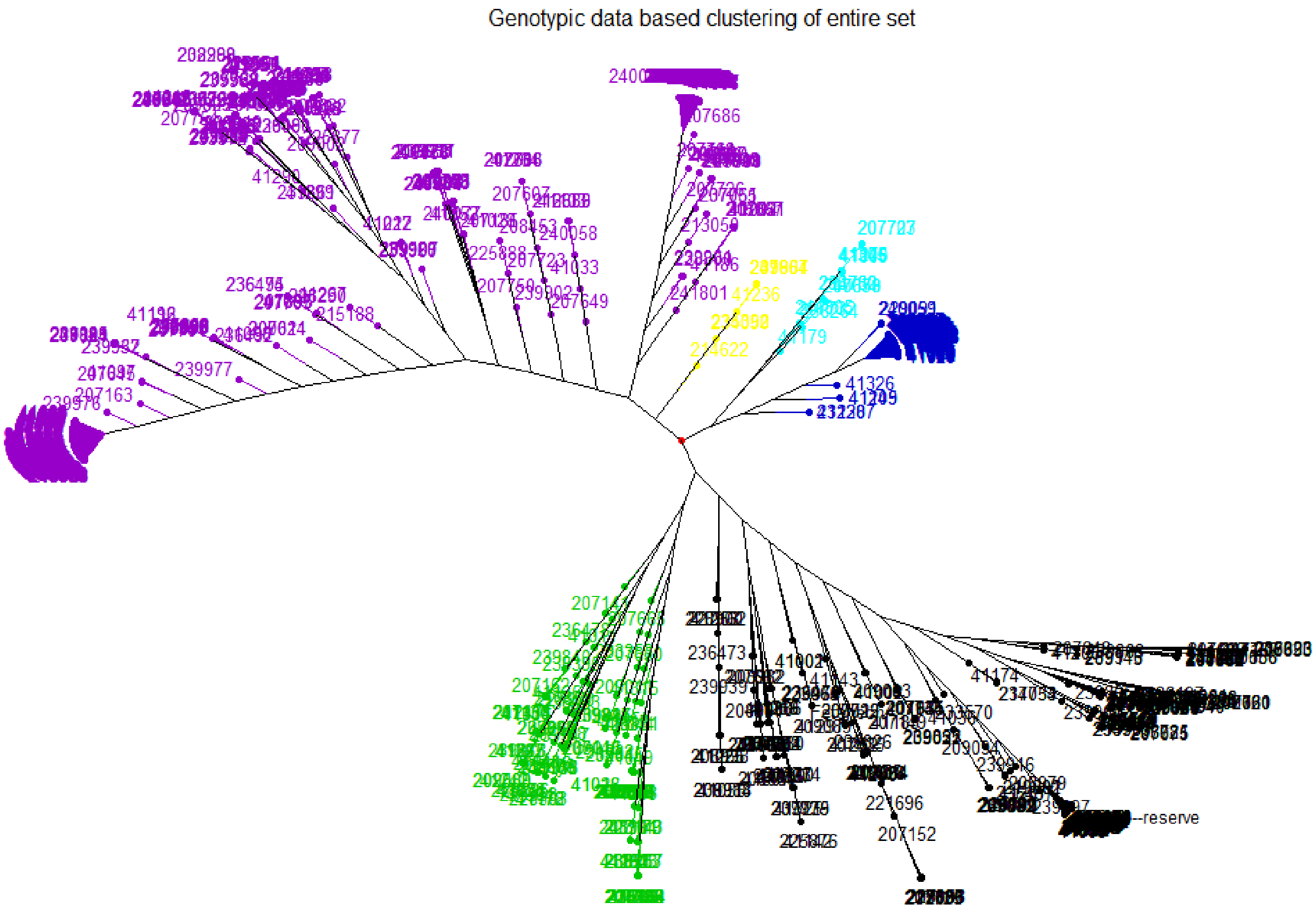

Figure 1. Genogram of Ethiopian chickpea germplasm collections (Source: Teshome, 2014)

important parameters in chickpea production. Genetic variability in germination power of some commercial cultivars with seed priming treatment was also examined. The result showed high differences for response to germination treatment among the tested genotypes (DZ-10-4, Arerti, Habru, DZ-10-11, Akaki and Natoli). Moreover, seedling vigor index in all varieties (except DZ-10-4 and Habru) and yield was improved (15%) using hydro-priming (Sori, 2014).

Farm level productivity for grain yield has been increasing by 80 kg/ha/yr for chickpea and 52 kg/ha/yr for lentil (Figure 2). This productivity gain is by far greater than improvements during the previous decades as reported by Fikre (2016), implying that the current decade demonstrated better progress to the previous decades. The productivity gain of chickpea and lentil was positive being almost closer to double during the last few decades (Admasu *et al*., 2015; Fikre, 2016). The increment is considered as the impact of the increased use of improved varieties with better biomass partitioning power and crop management and proper crop protection packages. Admasu (2015) estimated genetic gain of lentil varieties released during the last 3 decades to be 18.02 kg ha^{-1} $year^{-1}$ at Enewari and 27.82 kg ha^{-1} $year^{-1}$ at Debre Zeit, suggesting that the breeding effort does not have a similar effect over locations. There has also been information on nutritional quality differences of chickpea and lentil cultivars developed so far. Olika (2014) reported that the crude protein for Arerti (Kabuli) was 19.59 %, crude fiber was 3.87% and the fat content was 8.17%. The corresponding values for Natoli (Desi) were 16.78 %, 5.32 % and 6.59 %, respectively. The same study found that Arerti had better nutritional quality (in terms of low anti-nutritional factors) short cooking time as compared to Natoli variety.

Genotype by environmental interaction effects were found to be significant for germplasm lines evaluated in divergence agro-ecologies (Tilahun *et al*., 2015; Tadesse *et al*., 2016), indicating the need for multiple year multi-location yield trial. The national chickpea and lentil research program, in collaboration with key partners, has come up with the integration of modern breeding tools into the breeding system. In collaboration with the Tropical Legume III (TL III) project which is managed by ICRISAT, marker-based breeding (MABC,MARS) has been mainstreamed into the national chickpea breeding program since 2011. There have been attempts to improving drought tolerance capacity of otherwise well adapted varieties. To this effect one genomic region harboring quantitative trait loci for several drought tolerance traits has been identified (Thudi *et al*., 2014).

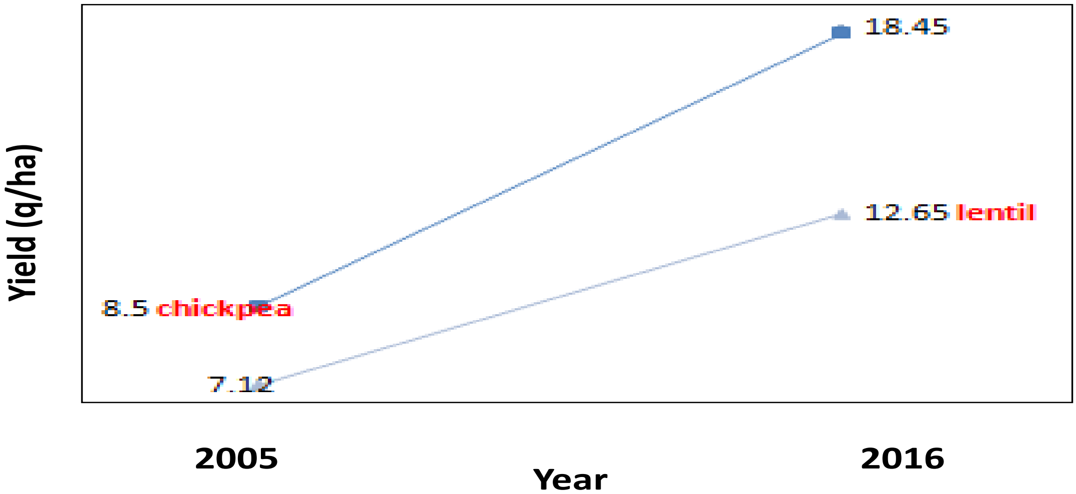

Figure 2. Trends in grain yield (q/ha) in chickpea and lentil during the last decade (Source: modified from CSA 2005-2016)

Advances in Germplasm Pool Enhancement

The identified QTL for drought tolerance was successfully introgressed using the marker-assisted backcrossing approach into three prominent chickpea varieties (JG 11, Chefe and KAK 2), Chefe being a released variety in Ethiopia in 2004. A multi-location evaluation of the lines developed through marker-assisted backcrossing exhibited 10–24% higher grain yield than their respective recurrent parents (Thudi *et al*., 2014). Currently, the national program is embracing marker-assisted breeding where lines developed reached at an advanced stage and soon the research program is expected to come up with a candidate variety for release.

On the other hand,) the recent development of wild x cultivated cultivar crossing as stated reverse introgression means to restore gentic diversity pools again, has been initiated since 2014 in collaboration with the University of California Davis through Feed the Future, Chickpea Innovation Lab (FtF), to further broaden the genetic diversity of the domesticated chickpea gene pool. Ecological mining of the gene pool was made and characterized (Eric *et al* 2018) to set inter-crossing to migrate desirable traits. The wild x cultivated introgression approach combines: (1) systematic survey of wild diversity, and (2) introgression of a representative set of wild genotypes. A total of 26 diverse wild donors of *C. reticulatum* (20) and *C. echinospermum* (6) were selected from 270 wild accessions based on their genomic sequence information and the ecology of their origin. Each of the 26 wild founders were crossed to two Ethiopian elite cultivars (Habru and Minjar), and the super early India genotype (ICCV-96029). Involving three parents (ICCV 96029, Habru and Minjar) in the crossing, a total of 43 F_1:F_2 introgressed lineages/families were created, which gave rise to more than 11,000 individual introgressed appreciably segregating individuals (Table 2 and Figure 2). At the F_2 stage, a subset of progenies within each lineage was intercrossed to increase chromosomal recombination and thus genetic power in the resulting populations. To this end, a total of 906 intercrossed first filial (iF_1) generation were created on top of the selfing F_2 populations. In parallel, F_2s were grown separately to establish early generation segregant (EGS) populations (F_2:F_4) and field phenotyping has been underway at Debre Zeit (Ethiopia) and ICRISAT (India).The wild x cultivated introgression is on its level of advancement as promising means of gene pool enhancement for the obvious narrow genetic bases in chickpea (Sharma *et al*., 2013), thereby enhancing genetic gain through the breeding program. Populations of extremely diverse make up have been generated and giving hope of sources to combat some standing challenges in chickpea. As part of the genetic base enhancement for favorable genes, there has also been Multi-parent Advanced Generation Inter-cross /MAGIC/ population development initiatives designed and proceeded since 2014/15 in the program using four way crosses which would go far un tapped genetic gains using 8 founder Kabuli released parents for crossing: (A). Arerti, (B). Habru, (C). Ejere, (D). Chefe, (E). Shasho, (F). Acos Dubie, (G). Teji and (H). Yelibe (Figure3). Besides, the national chickpea research program, with other partners, is making 50-100 crosses yearly on developing multiple trait target population, which enhance the germplasm enhancement leading to effective genetic gain. Along this, there are close to 2000 germplasm resources within the program that could be ready for variety development.

Table 2. Wild x cultivated introgression, introgressed (iF1) population advancement under three elite cultivars background

Parental combination	No of introgressed family (W x C)	No of individuals per family (F_1:F_2)	Total no of F_3 individuals established (F_3)	No of putative intercrossed seeds (iF_1)
Wild x Habru	14	125	2,875	218
Wild x Minjar	9	85	2275	281
Wild x ICCV 96029	20	321	6815	407
Total	**43**	**531**	**>11,000**	**906**

Figure 2. Appreciable morphological, phenological, ideotypical and color variability in *C.reticulatum/echinospermum* X *C. arietinum* introgressed resources

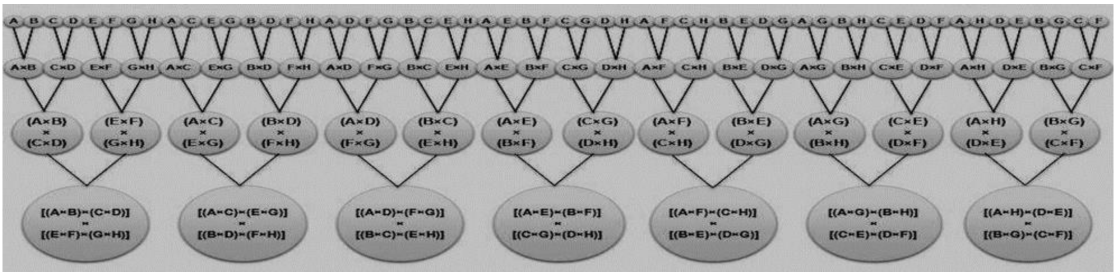

Figure 3. MAGIC population development design

Gentic Variability for Symbiotic Nitrogen Fixation

Niguse *et al*. (2016) reported that estimate of the magnitude of heterosis for host nitrogen fixation and yield and yield associated traits in chickpea from six F_1 crosses obtained from crossing of four parents (two nodulated and 2 non-nodulated) in a half-diallel showed significant ($P < 0.05$) differences among the entries for all traits studied. Considering key traits, relative to the mid-parent (MPH), better parent (BPH) and standard heterosis (SH), ranged from 0.01 to 59.80. The hybrid ICC5003 x ICC19180 scored the highest heterosis for number of nodules on the basis of MPH and BPH and demonstrated positive and significant Specific Combining Ability (SCA) effects for key economic traits including grain yield. Another study on the combination of four rhizobial inoculant (EAL-029, ICRE-025, ICRE-03 and ICRE05) and three chickpea cultivars (Natoli, Teketay and ICC-4918), indicated existence of significant genotype by strain interaction.

Food Quality Characteristics of Improved Varieties

The released varieties were evaluated for food quality characteristics including soak absorption and cooking time. The result showed varieties released over time demonstrate existence of considerable variability for these traits (Table 3). Cooking time among newly released varieties ranged from 22 to 37 minutes, indicating possibilities to shorted cooking time through selection thereby save fuel.

Table 3. Cooking time and associated parameters in recent released cultivars.

Chickpea varieties	TKW (g)	Soak absorption (%)	Cooking time (min.)
DZ-00155/08 (Minjar)	208.075	211.28	22
DZ-2012 CK-031/ICCV-10107 (Dimtu)	333.02	207.85	20.33
DZ-00156/08 (Ejere)	400.245	206.39	25.33
DZ-2012 CK-001/FLIP 04-9C (Hora)	413.105	204.01	24.67
DZ-10-4/DZ-00158/08	130.88	213.28	37
DZ-2012 CK-009/FLIP 0163 (Dehra)	387.74	206.97	25
DZ-00160-08 (local check)	128.67	207.89	22

Source: TLIII annual report (2017)

Nutritional studies on released cultivars also showed different nutritional compositions. Comparing two popular Kabuli (Arerti) and Desi (Natoli) varieties of chickpea through proximate analysis indicated the highest moisture content, ash, crude protein, crude fat, energy, zinc and iron respectively was 9.07%, 3.87%, 21.78%, 7.41%, 366.46 k cal/100 g, 7.15 and 10.88 mg/kg in Arerti (Olika, 2014). However, Arerti had lower crude fiber, total carbohydrate, calcium, tannin and phytic acid (4.71%, 53.16%, 1545.58 mg/kg, 0.13% and 84.61mg/100g, respectively). Moreover, the same variety exhibited higher bulk density, hydration capacity, swelling capacity, hydration coefficient and swelling coefficient (0.47 g/ml, 0.26 g/seeds, 0.34 ml/seeds, 1.94 and 1.96, respectively) and lower water absorption capacity, oil absorption capacity, solubility, swelling power, hydration index, swelling index, un-hydrated seeds and cooking time (1.43 g/g, 1.94 g/g, 25.19 % , 13.01% 0.28, 0.35, 1.64% and 21 min, respectively). Natoli was found to have higher crude fiber, total carbohydrate, calcium, tannin and phytic acid (6.91%, 58.65%, 1545.58 mg/kg, 0.19 %, and 91.95 mg/100 g, respectively). The main factors of variety by processing methods significantly influenced the proximate composition, mineral, anti-nutritional factor and functional properties of improved chickpeas (Olika, 2014). The results indicated that boiling was the most effective and recommendable technique in reducing ant-nutritional factors. Under different processing treatments, Arerti variety exhibited low ant-nutritional concentrations. Hence, it can be used as raw material in the food processing industries in production of quality food formulation especially conventional flours which are low in protein to increase utilization of improved chickpea flour, thereby alleviating protein malnutrition in developing countries like Ethiopia. Protein contents of two improved chickpea varieties exhibited significant ($p < 0.05$) difference with values of 15.63 % and 21.78 % for Natoli and Arerti, respectively

Another similar study by Admasu *et al*. (2014) on two popular varieties of lentil showed that the varieties Alemaya and Derso contained 4.64 and 3.14% total ash, 27.18 and 26.86% crude protein, 1.76 and 0.75% crude fat, 4.97 and 3.65% crude fiber, and 61.45 and 65.60% carbohydrates contents respectively.

Conclusion and Future Prospects

Chickpea and lentil breeding in the last decade have resulted in releases of varieties that are adopted, increased farm level productivity, economic benefits and impact. Use of modern breeding tools stimulated and enhanced development of several chickpea germplasm with desirable traits. This indicated that the traditional breeding that brought good level of success may not provide ending solutions to some of the complicated problems unless new breeding tools are applied. Longstanding biotic challenges including Ascochyta blight (*Ascochyta rabiei*)), Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*) and lentil rust (*Uromyces viciae-fabae*), chlorotic dwarf virus and abiotic stresses including heat and drought need further focus.

Diversified demands from the farming community and other users urge for modernization of the production, processing system, and the product concept approach. Recent initiatives like breeding program modernization (BMGF), wild gene source massive intrograssion, breeding management system, electronic data capturing, and value addition are hoped to provide ending solution to some of the problems.

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Progress of Common Bean Breeding and Genetics Research in Ethiopia

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Abstract

Common bean (Phaseolus vulgaris L.) contributes to food and nutrition security, and income generation for smallholder farmers and enhances foreign exchange earnings in Ethiopia. The crop is one of the major pulses that serve as a rotational crop in cereal based cropping systems in the lowland areas. However, the gap between the potential and national average productivity remains high due to several production constraints. Limited availability of improved multiple stress tolerant varieties like diseases, insect pests, moisture stress and soil fertility problems are the major problems. The national bean research program conducts research aimed to increase production and productivity through generation of consumer and market-preferred high yielding varieties tolerant to major biotic and abiotic stresses. Insitu population development by hybridization and introduction of advanced germplasm from International Center for Tropical Agriculture (CIAT), and introduction of commercially important bean varieties from both regional and intentional partners have been adopted. Major breeding efforts are put on the development of four major grain market classes, such as:(i) navy beans,(ii) speckled/sugar beans,(iii) red beans, and (iv) yellow beans. In the last ten years, the breeding program has released thirty varieties of these market types and several genetic information has been generated. Moreover, high advancement has been recorded in promoting bean varieties and package technologies through active involvement of common bean value chain actors from farmers to exporters. Other activities include identification of varieties for promotion, development and rolling out efficient and sustainable seed systems for faster and inclusive seed dissemination and stimulating market for bean products. The synergistic effect of demand driven variety development and promotion of common bean has doubled bean production and productivity and resulted in enhanced export earnings (>130million USD per annum) of the country and created employment for thousands of people through bean value chain development. Furthermore, the livelihood of bean producers and bean value chain actors has greatly improved from increased income from beans. Generally, the research program has played a significant role to enhance income, nutrition, and food security.

Keywords: Common bean, *Phaseolus vulgaris*, genetic variation, varietal development, convectional breeding

Introduction

Common bean (*Phaseolus vulgaris* L.), usually termed as haricot bean, dry bean or beans is believed to be introduced to Ethiopia during the 16th century (EIAR, 2000). Since then, it is under production all over the lowlands of the country. Common bean has different types of growth habits, of which bush beans (type I and type II) are widely produced as a sole or intercrop for the purpose of local and international market. The other types are the climbing beans (type III) mainly produced around homestead gardens and along the fences and sometimes intercropped with maize/pigeon peas. It can also be planted in the production fields by using stacks. Bush beans take the lion's share both in hectarage and production in the country and the research and development works have also mainly focused on these types (Amsalu *et al*., 2016).

The crop can be grown with a minimum amount of agricultural inputs like fertilizers and it is among the suitable grain legume crops for crop rotation in the maize/sorghum based cropping systems. Since it is the main pulse crop grown in the lowland areas of the country, common bean contributes to farming system sustainability, useful as a catch crop to parasitic *striga*, and as a low-risk and reliable crop for the farmers. Under rain-fed growing conditions, common beans also fit into various cropping systems (mono-cropping, sequential/ relay-cropping, double-cropping, mixed-cropping and inter-cropping).

Common bean is a short season annual crop, which is under production in both main and short (*belg*) growing seasons. It is produced by over 4 million smallholder farmers in Ethiopia. In 2015/16 (2008 E.C.) cropping season, the area covered by common bean was 357,299 and 306,335 hectares of land in main and *belg* seasons, respectively (CSA, 2016). Moreover, in the same year, private farmers (large scale) covered 10,212 hectares of land with common bean. Thus, totally 673,846ha of land was covered by beans with a total annual production of 845 thousand metric tons, mainly from three regions (Oromiya, SNNP and Amhara) of the country where Oromiya region alone covers 50% of the total production followed by Southern Nation Nationality and Peoples (27%) and Amahara Regional States (20.1%) (CSA, 2015).

Common bean is one of the most important food legume crops which has high starch, protein and dietary fiber and is an excellent source of minerals and vitamins including iron, zinc, calcium, thiamine, vitamin B6, and folic acid (Admassu and Kumar, 2004). It can be consumed both as a grain and vegetable in the drier regions where the diets tend to heavily rely on starchy foods such as millet, sorghum, maize, enset and cassava. Beans can be prepared and consumed in different types of recipes as *Nifro*, *Sambosa*, *shiro* and *kik.* Further, it can be mixed with different cereals or vegetables to prepare soup, and other local recipes like *kurkufa (*cabbage and boiled bean mashed mixture) and *fossese (*maize flour and boiled bean mashed mixture) (Teamir *et al*., 2003). Apart from its importance for human food, common bean straw is also highly nutritious for animal feed. Bean straw has found to have 7.7 MJ/kg dry matter "Metabolisable Energy" (ME) which is an estimate of the energy available to animals from digestion of a feed material. Further, it has higher crude protein (5.5%), natural digestible fiber (56.1%) digestibility, and lower fiber contents than cereal straws (Tolera, 2016).

Common bean also serves as a source of income for smallholder farmers especially those who grow exportable types of beans. In addition, production of common beans in the two seasons (main and *belg*) enabled the farming community to gain income throughout the year. Thus, farmers consider beans as a source of their income and as the main contributor for improvement of their livelihood. Common bean has been one of the leading exportable pulse crops in Ethiopia for the last four decade (Ferris and Kaganzi, 2008), Ethiopia being the leading exporter of common bean in Africa. The major bean market class for export is small white pea bean, but currently other bean market classes such as small red, sugar bean, pinto and cream beans are also exported to Europe, Middle East and Asia (Ministry of trade unpublished report). In recent years, the country's export earnings from common bean takes the first rank from pulses. According to Ethiopian Revenue and Costumes Authority (2015), common bean export earnings increased by three folds from 19 million USD in 2005 to 134 million USD in 2014, the quantity exported being 43 thousand MT in 2005 and 171 thousand MT in 2014. The main importers of Ethiopian common bean during the last ten years (2005-2014) include Yemen (10.7%), Belgium (8%), Greece (7.8%), and Russia (7.2%), Czech Republic and Italy (6.4%), Turkey (5.7%), Djibouti (5.4%) and others (Ministry of Trade, 2016).

Nationally coordinated bean breeding program was started at Melkassa Agricultural Research Center in the early 1970's, the objective being improvement of livelihood of smallholder farmers through generation and promotion of high yielder, disease tolerant/resistant bean and adaptable varieties suitable for export market and local consumption. This paper reviews progresses and achievements of past bean breeding efforts, a collaborative program with CGIAR centers like CIAT and other regional research programs like Pan Africa Bean Research Program (PABRA) and East and Central Africa Bear Research Network (ECABREN).

Breeding Common Bean in Ethiopia

Sources of genetic variation

The basic aim of any breeding program is broadening the genetic base of the crop and to exploit the variation created in different traits of interest. The national bean improvement program has been conducting research and variable germplasms have been developed through different breeding approaches. The primary source of breeding materials is mainly introduction of germplasm and advanced lines from CIAT/PABRA. The other sources are targeted hybridization with the aim of improving diseases and insect pest resistance, seed quality traits (preferred color and shape) and adaptability to moisture stress and collection and utilization of landraces from the local sources.

From among the introductions of segregating progenies and landraces, a series of selection and multi-location evaluation have been made during the past 50 years. Superior genotypes for agronomic, adaptive and quality characters have been selected and advanced to subsequent stages of variety trials, starting from breeding nursery to the final stage of yield evaluation and verification. Genotypes selected from nursery (16 to 25) have been promoted to preliminary variety trial (PVT) to be evaluated at 5 to 6 locations followed by national variety trial to be tested across multi-environment(at 8 to 10 locations for two years). Randomized Complete Block Design (RCBD) and balanced lattice designs with three replications have been used at PVT and NVT stages. At the advanced yield trials, genotypes have been evaluated for yield and yield components, disease resistance and all other relevant agronomic characteristics. From the multi-environment trials, varieties with outstanding performance have been identified based on yield and quality traits as compared to the standard checks. The candidate varieties are proposed and verified for release, after being assessed by the National Variety Release Committee (NVRC). The NVRC evaluate the varieties not only for their biological performance but also for legal requirements including uniformity, distinctness and stability. In a number of cases, however, when such established cultivars are not available, the bean breeding program also make an accelerated agronomic and adaptive evaluation from which better performing varieties are presented to the NVRC for registration of candidate cultivars.

In addition to variety development, basic information have also been generated in areas like genetic progress from breeding in released varieties (Bekele *et al.*, 2016), response to inoculation with Rhizobial strains (Assefa *et al.*, 2017), tolerance of bean varieties to soil acidity stress (Kassim *et al.*, 2016; Alemu *et al.*, 2016), tolerance of bean populations for drought and bruchid resistance (Assefa, 2010), resistance to bean buchids (*Zabrotes subfasciatus* Boheman) (Shiferaw *et al*., 2017), grouping of environments for testing navy beans (Negash *et al*., 2017), genotype by environment interaction studies (Ashango *et al*., 2016; Alemu *et al*., 2017; Ejara *et al*.,2017) and molecular and morphological characterization of Ethiopian landraces and breeding materials (Asfaw *et al*., 2009; Dagnew *et al*., 2014, Fisseha, 2016; Bareke *et al*, 2016; Shiferaw, 2017).

Varietal development

During the past one decade, the bean breeding program has developed several widely and specifically adapted, high yielding and disease resistant varieties meeting the requirements for local consumption and/or export markets (Tables 1 and 2).

Among 30 varieties released in the past ten years, two varieties each form food type (Adda/ KAT B1 and Dursetu/KAT B9) and export type (Acos-red or DRK and Cranscope), were legally registered through importation of 'finished' technologies from abroad. These four varieties have been imported and registered in the interest of the production sector due to their high market demand by the exporters and also for extra early maturity of the two food types. The remaining 26 varieties (87%) of the released varieties were developed and release through the regular procedures.

Breeding efforts during the past decade resulted in releases of a number of small and large red and red mottled beans as the major bean market classes (Table 1). Likewise, small white pea bean with a well-established export market, large specked bean with emerging market and large white beans for future market were also released for commercial production/export market (Table 2). The release and promotion of commercial bean types of different seed color and size is considered as a shining success of the national bean improvement program. The recent release of the large white beans has been the first of its kind in bean variety development history of Ethiopia. The release of food types for local consumption was also a great achievement not only because of their magnificent role in food and nutrition security but also because of their earliness and adaptation in areas with terminal drought/short production season (*belg*) and fitness in double cropping system. For example, two of these varieties, namely Adda and Dursitu, need only two months for maturity and they have a regional market demands mainly in Kenya and Uganda.

Table 1. Food type common bean varieties released mainly for local consumption between 2006 and 2014

Name of Variety	Altitude (m)	Seed color	Productivity (q/ha)		Year of release	Seed maintaining center*
			Research field	Famers field		
SER-119	1450-2000	Red	33	25	2014	Melkassa
SER-125	1450-2000	Red	35	22	2014	Melkassa
Dendesu	1300-1650	Red	22-30	19-23	2013	Melkassa
Adda	1300-1650	Yellow	19-33	17-25	2013	Melkassa
Tinike	1600-2200	Red Kidney	30	25	2012	HU
Hundene	1600-2200	Red mottled	30	25	2012	HU
Fedis	1600-2200	Red mottled	30	20	2012	HU
Babile	1600-2200	Red	36	30	2012	HU
Hirna	1600-2200	Red	30	27	2012	HU
Morka(ECAB-0056)	1400-2200	Red mottled	25	20	2012	Melkassa
SARI-1	1800-2200		25	20	2011	Hwassa
GLP-2	1400-2200m	Red mottled	30	22	2011	Melkassa
Lehode	1200-1900	Cream	24	18	2010	Sirinka
Lokku	1300-1900	Cream	14-20	13-18	2009	Bako
Kufanziq	1600-2200	Pinto	40	32	2008	HU
HawassaDume	1800-2200	Red	28	22	2008	Hawassa
Dursetu	1600-2200	Red	24-40	18-30	2008	HU
Gabisa	1200-1900	Light yellow	17-35	16-30	2007	Bako
Haremaya	1650-2200	Cream	20-32	15-30	2006	HU
Mekadima	1300-1800	Red	28	18	2006	Melkassa
Dinknesh	1400-1850	Red	25-30	20-23.5	2006	Melkassa

* HU= Haremaya University

Table 2. Commercial type of common bean varieties released between 2006 and 2014

Name of Variety	Date of maturity	Seed color	Productivity (q/ha)		Year of release	Seed maintaining centre*
			Research field	Famers field		
Ado (SAB736)	85-90	Large White	20-25	18-22	2014	Melkassa
Tafach (SAB- 632)	85-90	Speckled	22-26	19-24	2014	Melkassa
Awash-2	85-90	White	28-31	18-22	2013	Melkassa
Deme	85-90	Red Speckled	19-20	18-22	2008	Melkassa
Batu	75-85	Large White	18-25	16-20	2008	Melkassa
Acos-red (DRK)	75-82	Dark red	19- 22	16	2007	Melkassa
Cranscope	90-98	Red Speckled	19-27	16	2007	Melkassa
Chorie	87-109	White	23	19	2006	Melkassa
Chercher	95-105	White	22-28	21-27	2006	HU

*HU= Haremaya University

Generation of basic genetic information

Apart from variety development, basic studies have been conducted on genetic progresses from past breeding. Accordingly, a study in western Ethiopia revealed existence of 22.3 kg ha^{-1} (0.31%) and 10.56 kg ha^{-}

[1](0.19%) genetic gain for grain yield in medium and small seeded common bean varieties (Bekele *et al*., 2016). Yield gain in large-seeded beans was very minimal
as compared to medium and small seeded beans, as more focus was given to seed size in large-seeded beans in order to fulfill market requirements.

A study on response of six food and commercial type common bean varieties (Batu, DRK, Awash Melka, Awash-1, Nassir and Dinkinesh) to *Rhizobium* inoculation resulted in yield increments ranging from 7-35% as compared to the control. The variety Nassir was found to be the best for nodulation and biological nitrogen fixation (Assefa *et al*., 2017). The significant differential response of these varieties for nitrogen fixation gave an insight that further investigation may be needed for improvement of N-fixing ability in common bean.

An evaluation of common bean lines for adaptation on acidic soils in western Ethiopia resulted in significant differences among the genotypes for a number of traits including phenological characters, root morphology, yield and yield components. Three of the genotypes, namely ALB 204, ALB 17 and ALB 209,gave a high mean grain yield of 2 t/ha on both lime treated and untreated soils (Kassim *et al*., 2016), indicating the potential of common bean in soil acidity prone areas .

Results from characterization of local and exotic germplasm collections from different eco-geographical locations showed existence of high genetic diversity for a number of traits including seed color, shape, and size, particularly in southern Ethiopia than in northern Ethiopia (Bareke *et al*, 2016; Berhane *et al*., 2017). The genetic diversity and population structure of common bean landraces were done by using different markers including, Inter Simple Sequence Repeat (ISSR) (Dagnew *et al*., 2014), Simple Sequence Repeats (SSR) (Fisseha *et al*., 2016 and Asfaw *et al*., 2009) and Single-Nucleotide Polymorphism (SNP) (Shiferaw, 2017). The studies revealed existence of considerable variation among the Ethiopian common bean genotypes, the two known genepools (Andean and Middle American) and the Middle American genepool which are predominant in Ethiopia. Therefore, the common bean breeding program must focus on broadening of the genetic base through continuous collection and conservation of landraces, introduction from exotic sources and hybridization of broader parents.

Genotype by environment interaction and the association of yield and yield related traits were studied in different types of beans in different areas (Alemu *et al*., 2016; Ashango *et al*., 2016; Ejara *et al*., 2017). Alemu (2016) ascertained the existence of significant differences among the locations, genotypes, and genotype by environment interaction effects for phenological traits, yield and other yield related traits (number of pod per plant and seed per pod). Moreover, genotypes with specific and wide adaptability were identified (ALB 179, ALB 209 and BFS 39). Ashango (2016) also identified the most stable genotype (KG-71-1, KG-71-23, and KG-71-44) based on AMMI and GGE ranking and GGE comparison bi-plots. Another study grouped some testing sites of common bean as high-yielding (Melkassa, Alemtena and Haramaya) and other sites (Jimma, Bako, Pawe, Areka, Assosa and Sirinka) as low to medium yielding (Negash *et al*., 2017). Ejara *et al*. (2017) found that thousand seeds weight, seed number per plant, seed number per pod and number of primary branches per plant had high positive correlations with grain yield in beans.

Technology promotion

The bean research program has been engaged not only in variety development, but also in multiplication of early generation seed to catalyze common bean seed system and promotion of bean varieties to the end users in collaboration with multi-stakeholders following different innovative approaches including the following:

Identification of potential partners to implement de-centralized bean seed system: The national bean research program has taken the leadership role and initiatives in identification of potential partners and organization of forums that helped in establishing functional bean seed system and technology promotion. The different forums organized at different levels (e.g. annual planning and review meetings and regional extension-farmer linkage forums) enhanced the engagement and commitment of partners in the implementation process. Funds obtained from CIAT/PABRA and Tropical Legume projects (TL-II and TL-III) specifically helped in designing the seed system. Forums are mainly meant for mapping the seed demand, sharing information on seed production, discussing challenges and possible solutions during seed production-to-marketing. Multiple stakeholders also share responsibilities willingly in a win-win bases. As a core partner, the national bean research program has been serving in capacity building to enhance the knowledge of development actors mainly personnel from the Ministry of Agriculture and Natural Resource based at village and higher levels, partner NGO community facilitators, and seed producing farmers. Development and production of training manuals, posters, leaflets and calendars and their distribution to trainers, trainees and to the community at large have been the other important tools in facilitating the capacity building for not only seed but also grain producers (Amsalu *et al*., 2016).

Enhancing seed production: One of the responsibilities of the national bean research program has been facilitation of seed production through formal and informal seed systems in addition to producing early generation seeds. In the formal seed system, research centers, public seed producers, private seed producers and farmer's cooperative unions have been engaged. In the informal seed sector, mostly progressive individual farmers, seed producer groups, and private seed producer entrepreneurs produce quality declared seed (QDS) with some technical and material assistance. Optional distribution of initial seeds in 'small packs'(0.5-10 kg) and 'commercial packs' (25-50 kg) has been used as an innovative approach to reach both the poor-of-poor and well-to-do farmers, thereby facilitating the promotion of improved technologies. Labels on the bags/sacks provide the necessary biological and legal information based on the national seed standards. Generally, substantial amount of seed have been produced and distributed during the last ten years. For instance, during the period of 2004/5 to 2013/14, the amount of seed produced by research centers and other actors have covered about 30% of the bean seed demand in the country with a significant spillover effects on bean production (Amsalu *et al.*, 2016). The recent aggressive move in both technology generation and promotion in partnership with multi-stakeholders has tremendously boosted yield and transformed bean production as could be witnessed from the increased productivity from lower than 1t/ha to 1.5 t/ha in the last ten years (Figure 1) (CSA, 2016). Expansion of bean production all over the production areas and increment in total production were among the measured impacts obtained from the intervention work (Figure 2). Likewise, the foreign currency earnings of the country from the export of bean grain is also periodically increasing (Figure 3) (Ministry of Trade, 2016 unpublished report).

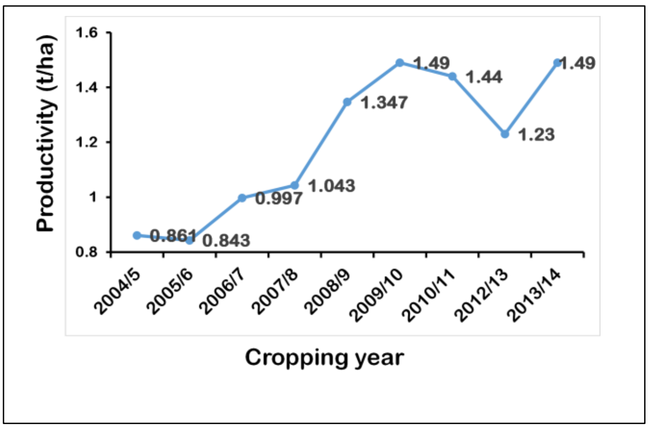

Figure 1: Common bean productivity per hectare for the period 2004/5 to 2013/14 (Source: modified from CSA, 2004 to 2015)

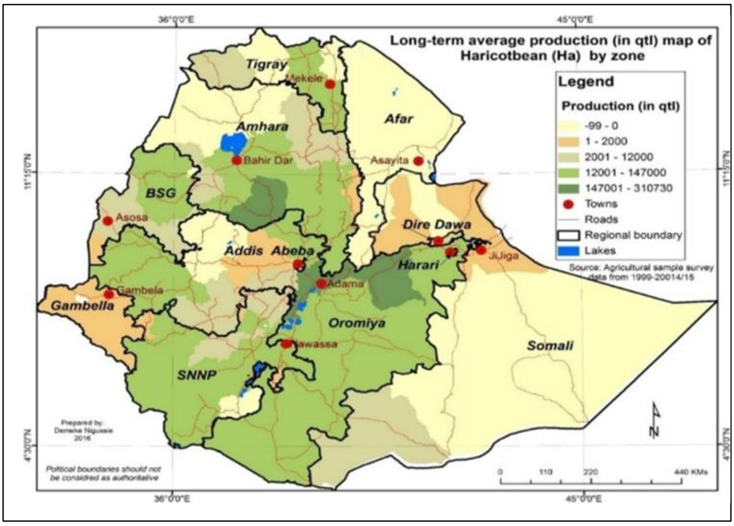

Figure 2: Geographic distribution of common bean production in Ethiopia (Source: Nigusse, 2016)

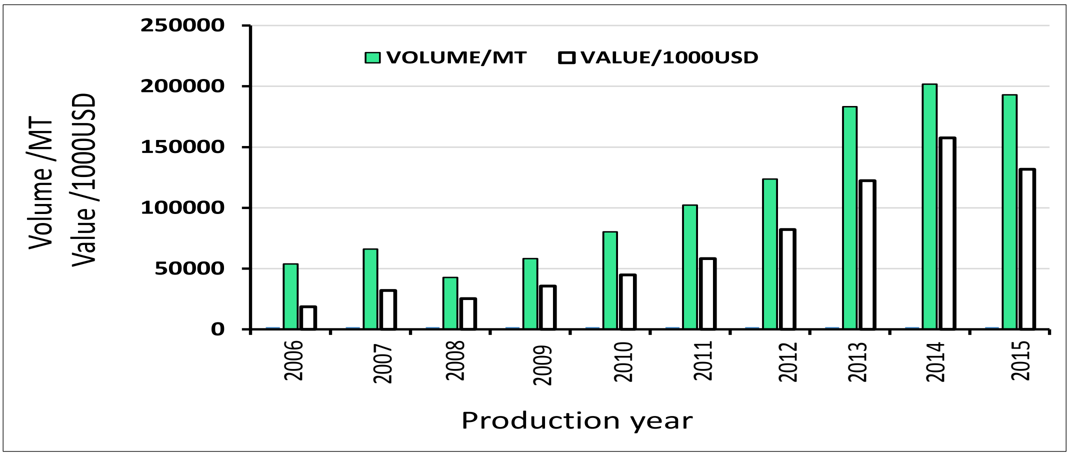

Figure 3.Common bean export for the period 2006 to 2015 (Source: Ministry of Trade, 2016).

Challenges and opportunities

Although common bean research program has been contributing a lot to the national agricultural development in technology generation and promotion, there are still challenges, which need to be tackled in the future to enhance the benefits from this sub-sector. Some of the challenges include: narrow genetic base in navy bean germplasm, limited source materials with multiple-stress tolerance, lack of varieties adaptable to new production niches (heat, cold, acid soil), limited number of varieties tolerant/resistant to bruchids and bean stem maggot, limited number of nutrient dense bean varieties and lack of varieties which suit to mechanization. There are also several other challenges including limited crop management (agronomic and pest management) and mechanization technologies which need more attention in the future.

Moreover, there are also general challenges which hinders the technology promotion and dissemination in the country. These include limited engagement of the private sector in common bean seed production and delivery, limited focus of the extension system on pulse technology promotion, common bean seed and grain market fluctuation and too many market actors in bean value chain which reduces the benefit of producers, recurrent drought, decline in soil fertility and expansion of soil acidity with time.

To unlock these challenges, there are several opportunities, which need to be harnessed. These include the existence of several new common bean varieties, which might bring immense changes. There are also enormous experiences in common bean technology promotion and well linked established value chain actors, willingness of different partners to collaborate with bean program, expansion of common bean into different agro-ecologies, conducive policy environment for research and development, availability of several exporters and structured market platform (ECX) for beans and high international and regional market demand for bean products. These opportunities should be utilized by the bean value chain actors to solve the research-development-market challenges of this crop.

Summary and Conclusions

In the past ten year, the common bean improvement program has generated substantial number of common bean varieties which are targeted for export and local market. Moreover, several genetic information on genetic gain from breeding, assessment of genetic variation, G × E interaction and other relevant information have been developed as backgroundconcepts and principles of bean breeding. Apart from technology generation, promotion of bean technologies has also been conducted using the support of CIAT-TL-III projects and significantly contributed to the enhanced recent bean production and bean export in the country.

In the future, there is a dire need to bring about better genetic gains from breeding. Conducting strategic research and building the information base, broadening the genetic base through further introduction, collection, and hybridization followed by selection and evaluation of germplasm with broad genetic base using multidisciplinary and participatory approaches to come up with adaptable, high yielding, multiple stress tolerant and nutrient dense varieties with good market demand and better fitness for mechanization. The conventional breeding techniques should be complemented with modern biotechnological tools and modernize breeding data management system in order to accelerate gains from breeding and improve the technical relevance of the varieties to different recommendation domains. A more innovative seed system and promotion strategies should also be implemented for effective and efficient seed multiplication and technology promotion.

Acknowledgments

We are grateful for the technical and financial support of Tropical legume III (TL III) through International Centre of Tropical Agricultural (CIAT) Cali, Colombia and Pan Africa Bean Research Alliance (PABRA), Uganda.

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Progresses in Breeding and Genetic Improvement of Soybean in Ethiopia: A Review

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Abstract

Soybean is a strategic crop for developing countries, like Ethiopia, because of its importance in fighting malnutrition, in integrated and sustainable soil fertility management, and as a raw material for rapidly growing oil, food and feed processing industries. Despite the recent history of introduction, soybean has attained greater importance in production and productivity in Ethiopia on smallholder farming system. However, both the production and productivity are still very low compared to the yieldpotential and suitable agro-ecologies for its production in the country. Weak extension system, low availability of market for the produce, low productive potential of the improved varieties and inefficient seed system are among the most important production constraints identified responsible for the low productivity of the crop. Breeding efforts have been underway,since 1970's to improve the low productive potential of the improved varieties. Introduction of germplasm from external sources and hybridization of selected parental lines have been considered, as the priority approaches to enhance soybean germplasmin the country. The introduced germplasm has been utilized directly in variety trials, and as parental lines for hybridization. Modified single seed descent method was identified as the best procedure to evaluate segregating populations and develop superior Recombinant Inbred Lines (RILs). About 26 soybean varieties have been released in the country with various merits by the different research centers of the country. Generally, strategies that improve the productive potential of the crop and farm gate price that makes the crop attractive choice of smallholder farmers need to be designed to help smallholder farmers and the country exploits the multiple benefits of the crop.This paper is aimed at reviewing the soybean breeding progresses made over the last decade.

Keywords: Soybean production and productivity, modified single seed descent method, germplasm enhancement, released varieties

Introduction

Soybean belongs to the family Leguminosae, subfamily Papilionoideae, and the genus *Glycine* (USDA, NRCS, 2016). Historical and geographical evidences suggest that soybean is originated in China and has been cultivated for greater than 500 years (Qiuand Chang, 2010). According to Orf (2010), *Glycine soja* is the progenitor of the cultivated soybean (*Glycine max* (L.) Merrill) and the chromosome number of both the cultivated and the wild soybean is 2n=4x=40 and are derived from GG genome (chromosome set). The cultivated and wild soybeans are crossable and the resulting F1s from their crosses are fertile.

Sub-Saharan African countries are experiencing the highest mal-nutrition problem, which is more acute on underage children, mainly manifested in the form of stunted growth relative to children of their age (Thoenes, 2004). Ethiopia is also among countries that have the highest level of malnutrition, which is manifested, according to Lemma (2014), in the form of stunting (40%), wasting (9%) and underweight (25%) in children of the age of below five. Chronic energy deficiency is reported in 27% of all child bearing age women (FMOH, 2008). The same report also indicated that the micronutrient deficiency in Ethiopia is very high and described as ‘hidden hunger’ and resulted from insufficient intake of micro-nutrients, such as vitamin A, iodine and iron, and it is the main cause of weak resistance to infections, chronic fatigue, poor mental and physical development, blindness, complications in pregnancy, delivery and low birth weight.

Improving the dietary intake, especially protein, is the appropriate strategy to alleviate the malnutrition problem. However, subsistence farmers have very rare access to livestock-based protein sources, such as milk and meat, because of their low purchasing capacity that makes these protein sources unaffordable. However, crops, such as soybean, which contains 40 to 42% protein, and 20 to 22% oil on dry grain basis (FAO, 1994), are rich and affordable sources of protein that can be easily produced and accessed by smallholderfarmers.Soybean contains 2.5 times the proteincontents of wheat and four times the protein contentof m aize. Soybean is highly digestible, high in unsaturated fatty acids and contains no cholesterol (Singh *et al.,* 1987). According to Duvenage *et al.* (2016), soybean, not only provides all the essential amino acids that children need to grow, but also serves as a good source of some of the essential micronutrients, such as folic acid; vitamins B1, B2 and E; zinc; iron; magnesium and calcium to the diet.

It is also a very important crop for rotation with maize and other cereals, improving the fertility of the soil, because of its high nitrogen fixing capacity. The sole cropping of maize and other cereals is a very common practice in most parts of Ethiopia for several years resulting in the depletion of the fertility of the soil and a diet that is predominantly carbohydrate based, which in-turn caused malnutrition/unbalanced diets in the community. The integration of soybean in the cropping system could play an important role in introducing crop rotation in the cropping system, which is also helpful in the improvement of the fertility of the soil, reducing the buildup of diseases and pests that resulted from the sole cropping of cereals.

Among the important challenges that has been commonly raised by farmers in the effort to integrate soybean into the cropping system has been lower productivity of the crop relative to other competitive crops. Hence, the key issue in increasing the productivity of soybean is to develop improved varieties that are high yielding, disease resistant and acceptable quality for processors. For this to occur, there is a need to design an effective soybean breeding program that employs all the important breeding tools i.e., evaluation and selection of superior varieties from introduced and locally collected germplasm, crossing and selecting superior lines from segregating populations, breeding for disease resistance and adaptation to specific soil fertility constraints (eg., soil acidity).

Hence, concerted efforts have been made by the different research centers; mainly, Jimma, Pawe and Assosa Agricultural Research Centers of the country to address some of the major production constraints through plant breeding solutions, which includes development of soybean varieties that are high yielding and well adapted to the major soybean production agro-ecologies of the country, and tolerant/resistant to the major biotic and abiotic constraints. The variety development effort considered three major maturity groups i.e., early, medium and late maturity groups, to help identify varieties that are well adapted to the different agro-ecological conditions of the country. Similarly, emphasis has been given to incorporate traits that help meet the end users i.e., processors (oil, food, and feed) and exporters requirements in the soybean varieties that have been developed and released for production.

Considering the number of improved varieties released so far, the effort made to improve the production and productivity of the crop, the milestone achieved in terms of volume of production and productivity, the volume of import substitution and export volume, the past decade might be judged as effective in terms of soybean research and development. Hence, this paper is aimed at reviewing the progress made so far in the breeding and genetic research of soybean, and the challenges facing the soybean value chain, and give direction for future soybean genetic improvement efforts.

Global and local importance of the crop

Soybean is the leading world imported crop of agricultural products based on value (FAO, 2017), indicating that it is one of the most traded and globally consumed agricultural products. According to the same report, global trade of soybean is estimated to worth $26 billion, and Africa's share of the soybean trade is estimated to be 0.8 %; while Sub Sahara Africa's and Ethiopia's share are 0.48%, and 0.003%, respectively, which is too low global share. Evidences are showing that Ethiopia's soybean export market is growing, and in 2016/17 a total of 47,837 ton soybean was exported (Harvest Insight, 2017), which was 60.9% of the total production with an estimated export value of 20,784 USD (Figure 1).

However, import substitution need to be prioritized relative to the grain export, mainly because of the large volume of oil the country is importing. For instance, in the year 2013, the country imported 4,819 tons of soybean and 346,450 tons of palm oil, costing the country an estimated 394.78 million USD (EIAR, 2017), which could have been possibly substituted by the local production and processing of soybean and other crops for oil. In addition, the local processing (oil, food and feed) industries have shown increase in the last decade, which has resulted in a very high increase in the local demand for soybean. This rising demand need to be met through increasing the supply of soybean through increased production and productivity. On the other hand, the adequate availability of local soybean demand will have a very important role in stimulating and sustaining the production of the crop, because of improved market price of the produce, there by, improving the income and benefit of smallholder farmers. However, government policy support, especially in encouraging the local soybean processing industries is very important in improving the value chain of the crop.

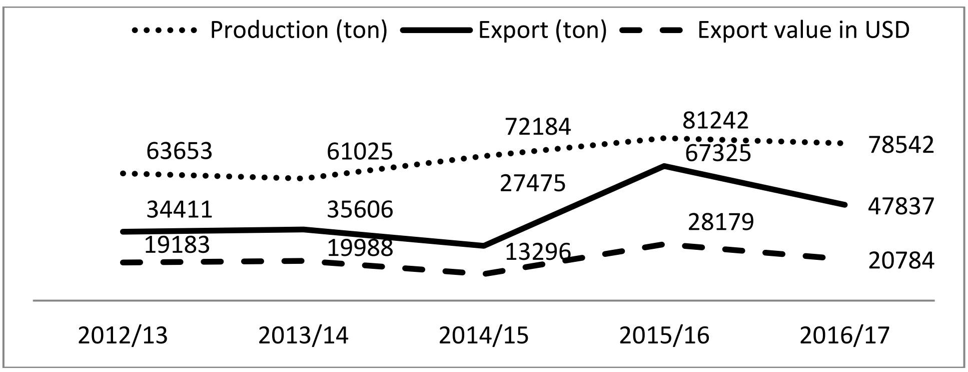

Figure 1. Soybean total production (tons), export volume (tons) and export value (USD) for the period 2012/13-2016/17 (Source: Harvest Insight, 2017)

Production and productivity of soybean in Ethiopia

Soybean production is the fastest growing in the world relative to other grain crops, such as wheat, maize, rice, barley and sorghum (FAO, 2017). The global production of soybean is estimated to be 306,519,256 ton in the 2014 cropping season (Table 1). The leading soybean producing countries in the world are USA, Brazil and Argentina with 34.9, 28.3 and 17.4% share of the global production, respectively. The major soybean producers in Africa are South Africa and Nigeria, each producing far higher than the collective production of the East African region (Table 1).

Soybean production believed to be started very recently in Africa i.e., during the second half of the 20th century (EIAR, 2017), and similarly it is believed introduced to Ethiopia in the 1950's (EIAR, 2017, Asfaw *et al.,* 2006). Extensive efforts have been made to introduce soybean into the cropping system of smallholder farmers, since its introduction to the country. However, little was achieved until 2002, for reasons the soybean market was not well developed, the processing industries were very few and lack of know-how on household utilization.

Ethiopia's soybean production has been showing rapid growth, since 2002. The total production of the crop on smallholder farmer's field, excluding the large-scale commercial production in the year 2016 was estimated to be 81,242 ton (CSA, 2017). The increase in soybean production might be attributed to the fast-growing demand for soybean oil, soybean-enriched human food and livestock feed. More importantly, research and development efforts have played a very important role in popularizing the crop, creating awareness on the nutritional and agricultural importance, and promoting household consumption with the aim of reducing malnutrition and improving the maize and other cereals-dominated cropping system; through integrating soybean as a rotation crop. In addition, the crop has strategic significance for developing countries, in general, and Ethiopia, in particular, to meet the rapidly growing demand of the processing, livestock and poultry feed industries, and the opportunities for import substitution of food, edible oil and livestock feeds; and the export market.

The productivity potential of soybean varies depending on the management practices followed to produce, and the management practices followed in producing the crop. The national average productivity of soybean on smallholder farmer fields in Ethiopia in the 2016 cropping season was 2217 kgha^{-1}(Figure2; CSA, 2017), which was low relative to the global average (Table 1). However, 75% improvement in the Ethiopian soybean yield was reported in two decades (1995-2015) (Fikre, 2016), and soybean yields on research plots at the Jimma Agricultural Research Center (JARC) may exceed 4000 kg/ha in favorable seasons (JARC, 2017). According to Irwin *et al.* (2017), the average productivity of irrigated soybean in the US was 3577.89 kg/ha; while the non-irrigated soybean productivity was 3264.04 kg/ha. Cooper *et al.* (1991) and Specht *et al.* (1999) forecasted the potential average soybean yields might reach5380.09 to 6052.6kg ha^{-1} in favorable Corn Belt production areas. World yield record of soybean is reported 11,499.93 kg ha^{-1}(BASF, 2016).This shows that the national average productivity in Ethiopia is far behind the potential productivity of the crop. This require understanding the major production constraints affecting the productivity of the crop and addressing these constraints with well adapted varieties combined with the best bet crop production practices.

The factors that are limiting soybean productivity in Ethiopia includes: low productive potential of the existing released varieties; very weak seed system, which limited the availability of good quality seeds of the released varieties; poor soil fertility; inadequate moisture during the growing period (especially during pod development and grain filling period); water logging; erratic distribution of rainfall. In addition, biological factors i.e., diseases, such as Asian soybean rust, brown spot, and frog eye leaf spot; and insect pests, such as web worm, fall army worm, and aphids are also major soybean production constraints. The very low market price and weak access to market were also identified as the major problems discouraging smallholder farmers not to produce the crop widely (Achamyeleh, 2018). Despite reasonably good price in the central market, farmers get low price at farm gate, because of absence of marketing system that reduce the market chain between the producers and the major buyers (processors and buyers). Mainly, price is determined by the local traders without competitions, which makes the price of the crop very low at farm gate. This might require reducing the chain between the producers, and the major buyers of the crop i.e., processors and exporters.

Table 1.Area harvested, total production, percent share to the global production, and productivity of soybean in different regions/countries of the world (FAO, 2017)

Producing country/region	Year	Area harvested	Total production (ton)	% share to the global production	Productivity kg/ha
Global	2012	105477217	241732260		2.29
	2013	111161196	277679429		2.5
	2014	117549053	306519256		2.61
East Africa	2012	473313	653945	0.271	1.38
	2013	527599	560505	0.202	1.06
	2014	441116	535779	0.175	1.21
Ethiopia	2012	31855	63653	0.026	2.00
	2013	30517	61025	0.022	2.00
	2014	35260	72184	0.024	2.05
Nigeria	2012	668300	650000	0.269	0.97
	2013	680000	517960	0.187	0.76
	2014	719300	679000	0.222	0.94
South Africa	2012	472000	650000	0.269	1.38
	2013	516500	785000	0.283	1.52
	2014	502900	948000	0.309	1.88
USA	2012	30814720	82790870	34.249	2.69
	2013	30858830	91389350	32.912	2.96
	2014	33423750	106877870	34.868	3.2
Brazil	2012	24975258	65848857	27.240	2.64
	2013	27906675	81724477	29.431	2.93
	2014	30273763	86760520	28.305	2.87
Argentina	2012	17577320	40100196	16.589	2.28
	2013	19418824	49306200	17.757	2.54
	2014	19252552	53397715	17.421	2.77

(Source: FAO, 2017)

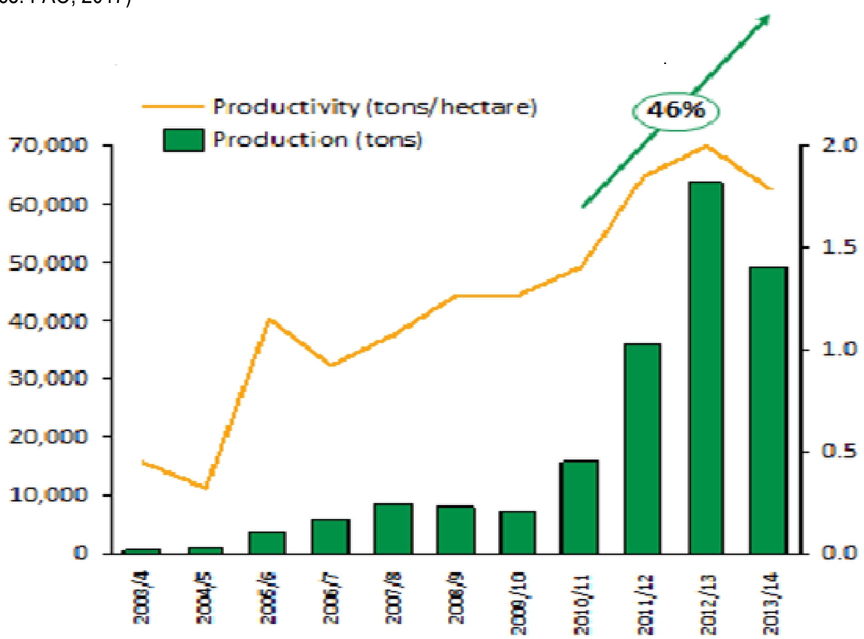

Figure 2. Soybean production and Productivity in Ethiopia (Source: USAID, ATA, 2016)

Soybean production areas and agro-ecological suitability in Ethiopia

With its diverse agro-ecological and climatic conditions, Ethiopia is endowed with a very large area of land, where soybean can be suitably produced, especially in rotation with maize. According to EIAR (2017), soybean can be grown in altitudes ranging from 1250 to 2200 meters above sea level (m.a.s.l.); however, it performs well between 1300 and 1700 m.a.s.l. It can also be grown in an area receiving 450 to 1500 mm annual rainfall; however, to grow very well, and for optimum yields, soybean requires a minimum of 500 mm annual rainfall. Temperature ranging from 23-25^{o}C is reported to be optimum for soybean production; however, it performs well at warm temperature and medium relative humidity. Very high temperature adversely affects pod production and grain filling. Though, soybean performs on a wide range of soil types, it grows best on fertile, drained and light clay-loam or alluvial soils. It grows best in soils with pH ranging between 6.5 and 7.0, or in neutral soils. Hence, acidic soils should be amended with lime to enhance soybean productivity. Generally, soybean can be produced very well in low to mid-altitude environments that are suitable for maize production, which makes it an ideal rotation crop with maize.

Soybean is widely produced in different parts of the country, and well adapted to low to mid altitude agro-ecologies of Ethiopia, where most of the potential arable land is found (EIAR, 2017). Currently, the major soybean production areas in the country includes: Benishangul Gumuz (Metekel, Assosa, Kamashi and Mao-Komo zones); Oromia (Jimma, Buno Bedele, West and East Wellega, Illubabor, and Kelem Wellega zones); and Amhara (East Gojam, and Awi special zones). In 2012/13 cropping seasons, 89% of the soybean area coverage and 92% of the soybean production in Ethiopia came from the two regions i.e., Benishangul Gumuz and Oromia, of which Benishangul Gumuz contributed to about 45% of the total area and 52% of the total production; while Oromia region covered 44% the total area and 40% of the soybean production in the country (EIAR, 2017).

In addition to the areas where soybean is already introduced and production started, there are large areas of potential production in the country (Figure 3). According to EIAR (2017), an estimated more than two million hectares of land is covered by maize production, and of which more than 70% is believed to be suitable for soybean production. Similarly, the major sesame production areas of the country in the North i.e., Metema and Humera, and the low altitude sorghum production environments of Amhara region, i.e., Kobo, Showa Robit, and Sirinka might also have high potential for soybean production, especially in rotation with the dominant crops of the areas i.e., sesame and sorghum, respectively. However, this requires identification of the right soybean varieties for the areas, wider scaling up of soybean varieties with their best production practices and improving the value chain of the crop through ensuring better farm gate price through improving the marketing system of the crop. It also requires improving the seed system, since the soybean seed system is not well developed in Ethiopia, as soybean is not in the priority list of crops of the formal seed system.

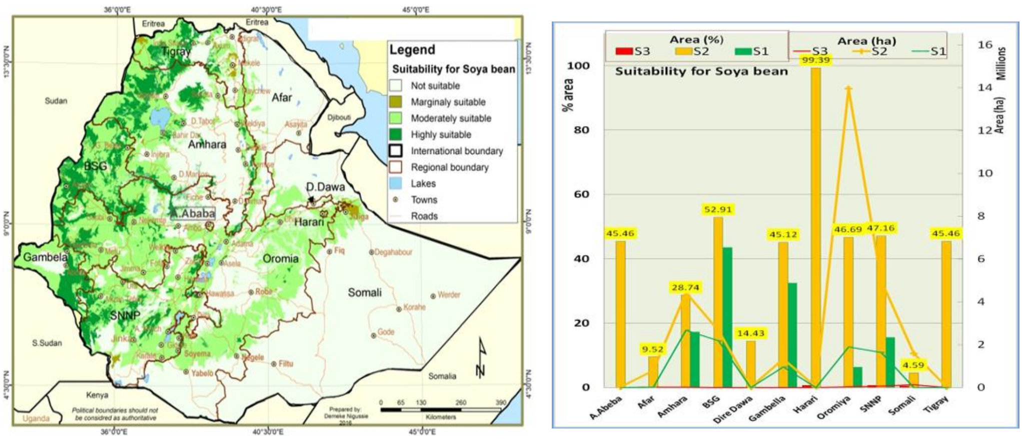

Figure 3:Suitability map of soybean in Ethiopia (Source: Nigussie, 2018)

Decadal soybean breeding and genetics efforts and achievements in Ethiopia

The soybean breeding program in the country is organized under the National Lowland Oil Crops research program, along with ground nut and sesame, coordinated by the Jimma Agricultural Research Center. The major soybean breeding centers are Jimma and Pawe; while several others i.e., Bako, Assosa, Hawassa, Sirinika, Mytsebri, Gonder, and Tepi are among the research centers, where soybean variety testing have been underway. The major soybean breeding objectives are:

- Development of soybean varieties that are high yielding with wider adaptability; resistance to the major diseases i.e., Asian soybean rust, brown spot, frog eye leaf spot, leaf blotch and bacterial pustule; and resistance to insect pests, tolerance to abiotic stresses i.e., tolerance to acidic and low phosphorus soils.
- Development of early maturing soybean varieties for production in areas of short growing period
- Developing technologies that help respond to agro-processing requirements i.e., high oil content, larger seed size and better nutritional value.

The protein enriched foods, and animal and poultry feed processors, demand soybean varieties with high protein content. However, protein and oil content in soybean are reported to be negatively correlated with grain yield (Filho *et al.*, 2001). Consequently, breeders need to compromise between the two traits in the varieties they are developing.

Germplasm enhancement

The identification of high yielding, disease resistant and well adapted varieties of soybean relies on the existence of wider genetic variability of the crop. However, Ethiopia is not both the center of origin and diversity of the crop; and hence, the breeding programs depends on the germplasm resource introduction. Consequently, the genetic variability of the crop is narrow and working materials are limited. Hence, further enhancement on the genetic variability of the crop through introduction of diverse germplasm resources from external sources and developing soybean population through hybridization of selected parental lines to develop transgressive segregants is among the primary strategies of the breeding program.

Hence, obtaining germplasm from other National and International Research Organizations that have rich soybean germplasm reserve was given high priority. Establishing soybean research partnerships with such soybean research programs, which include: International Institute of Tropical Agriculture (IITA), and The National Soybean Genetic Resource Center of University of Illinois, soybean breeding program of University of Missouri have been paramount importance to acquire working germplasm lines. Currently, the soybean breeding program of Jimma Agricultural Research Center is undertaking a collaborative research and genetic resource exchange that intends to develop improved varieties of soybean and enhance the genetic variability of the crop in the country. In this effort, the program previously received more than 500 germplasm that includes released varieties and accessions from the breeding program of University of Illinois and University of Missouri, and also from the National Soybean Genetic Resource Center of United States. Similarly, both Pawe and Jimma Agricultural Research Centers have been receiving soybean germplasm from the International Institute of Tropical Agriculture (IITA),and more than 100 soybean germplasm was received so far. The germplasm inflow is presented in the Table 2 below. The program will continue receiving and exchanging, such materials as means of variety delivery, based on direct evaluation or interbred population development.

Table 2.Germplasm and breeding populations introduced from various sources

No.	Type of germplasm	Source of germplasm	Year			Total
			2014	2015	2016	
1.	Lines /varieties	USA	62		196	258
2.	Lines/varieties	IITA	32	40	40	112
3.	F_2 and F3 populations	USA		77	11	88
4.	Brazilian origin lines	USA		16		16
5.	Rust resistant lines	USA			118	118
6.	Low P tolerant lines	IIAM, Mozambique			40	40
	Total		94	133	405	632

Genetic variability studies on soybean

Enideg (2011) studied the genetic variability of forty-nine soybean (*Glycine max*(L.) Merrill) genotypes in two locations i.e., Jimma and Assosa, and reported significant differences for all of the studied traits, except root volume and root dry weight at Jimma. The author also reported high phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for grain yield, biomass yield, pod number per plant, plant height, total nodules per plant, effective nodules per plant, and harvest index at both locations. The highest heritability value was recorded for grain yield at both locations (Enideg, 2011). High heritability value, coupled with high expected genetic advance as percent of mean, was found for grain yield, harvest index, biomass yield, total nodules per plant, effective nodules per plant and pod number per plant across both locations, which indicates the presence of considerable additive genetic variance in the germplasm, which can be improved through selection.

The genetic variability of 64 early maturing soybean genotypes was also studied by Ali (2018), as part of his MSc thesis research, and reported highly significant differences among genotypes for traits, such as, plant height, number of primary branches, grain yield, days to maturity and harvest index, which shows the presence of sufficient amount of variability among the genotypes. The author also reported that high phenotypic and genotypic coefficient of variance, heritability and genetic advance estimates for plant height, number of primary branches, and grain yield, which indicates that the additive genetic variance is high in the germplasm, and hence, these traits might be improved through selection.

Hybridization based germplasm enhancement

Genetic recombination based on crossing of selected parental lines is one of the most important plant breeding approaches that helps enhance the genetic variability of crops, including soybean. Hybridization on soybean was started in 2010 at Jimma Agricultural

Research Centre by crossing parental lines screened for high yield, low P tolerance, and disease resistance in a 9X9 half diallel mating design. In total, 72 segregating populations were developed, of which 200 plant to row selections or recombinant inbred lines (RILS) were developed. Some of these RILs are found to be superior in performance, and currently are in advanced multi-location yield trials showing good performance for low soil phosphorus tolerance, disease resistance, and high yield. The population gave rise to competing lines against preceding cultivars, and ultimately might be released for production or used as parental lines for crossing to improve some of the important traits in soybean i.e., high yield, disease resistance, tolerance to low pH soil.

Single Seed Descent method is one of the commonly used breeding procedures of self-pollinated crops, which involves selection of single seeds from each plant in the segregation population starting from the F2 and selection of plant to rows starts at the F5 generation (Chahal and Gosal, 2006). Jimma Agricultural Research Center adopted Modified Single Seed Decent (MSSD) method to select the superior recombinant inbred lines from the segregating population (Figure 4). The modification to the single seed descent method includes: single pods harvested from each plants, instead of single seeds as in the case of Single Seed Descent Method, which is intended to avoid the risk of losing single seeds, due to reasons, such as germination failure. In addition, plant to row selection starts early at F4, instead of F5, as in the case of Single Seed Descent Method with the inspection and rouge out of off-types at the F5 stage. In addition, off-season nursery was used to increase the breeding cycle by one season per year, which has been an important factor for rapid breeding progress. The first 200 RILs were developed at Jimma Agricultural Research Center and evaluated at different stages of variety trials and some of these materials are in the National and Pre-National variety trials. So far, over 2000 RILs have been developed from segregating populations and nearly 300 F2-F4 segregating populations have been under evaluation at JARC and Pawe Agricultural Research Center (PARC). Some of the selected inbred lines are at different stages of variety trials, including Preliminary Variety Trial (PVT) and National Variety Trials (NVT).

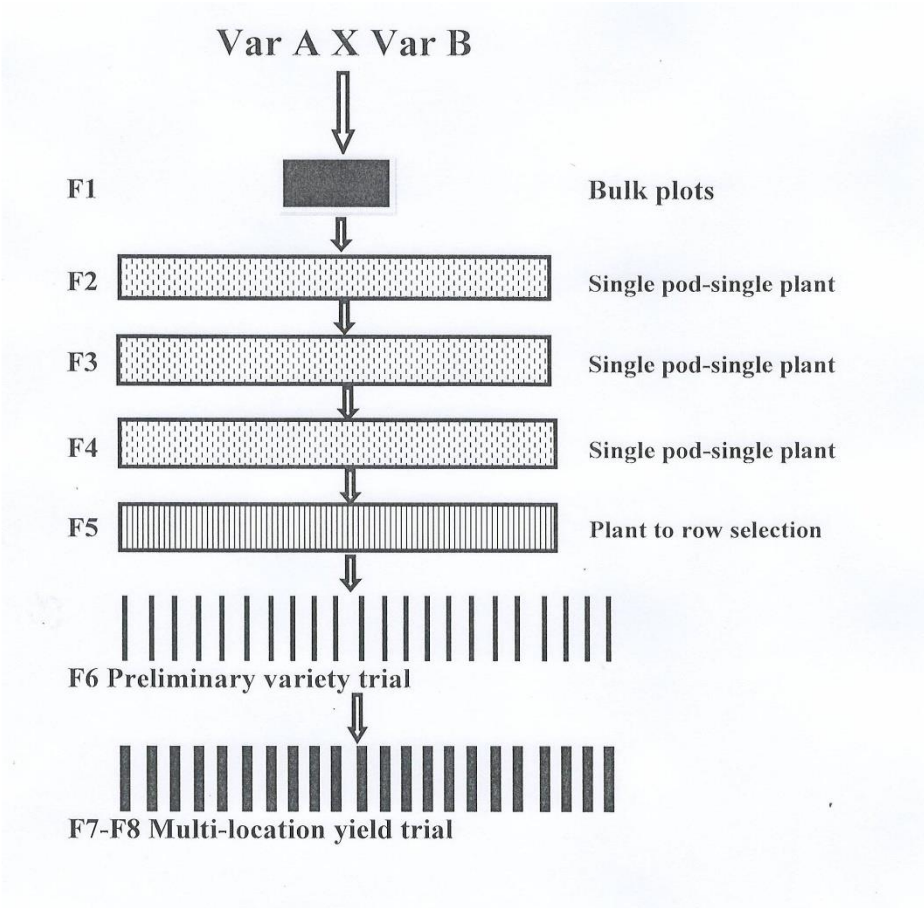

Figure4.Modified Single Seed Descent method used for developing pure lines from segregating populations in soybean at Jimma Agricultural Research Center, Ethiopia

Multi-location testing and variety release

Coordinated soybean variety trials for adaptability and release was started in the 1970's (EIAR, 2017; Asfaw *et al.*, 2006),and initially it was supported by the International Soybean (Intsoy). To date, nearly 26 soybean varieties were released in the country, including the five varieties i.e., Davis, Clark 63 k, Coker-240, Williams, and Crowfordthat were recommended (at that time there was no release, rather it was recommendation) for production in 1981. Almost all of the released varieties are identified from introduced germplasm through simple selection breeding. Among these varieties, clarck 63 K is still in production and among few of the high performing varieties in Southwestern Ethiopia, particularly, around Jimma and Illubabor. The majority of the released varieties (42.3%) fall under medium maturity group; while 23.07% were early maturity; and 11.54% of the varieties fall in the range of medium to late maturity group; while23.07%of the varieties were late maturing(Table 4). The highest proportion (46%) of the varieties were released by Hawassa Agricultural Research Center; while Bako, Pawe, and Sirinka Research Centers released seven, six and one varieties, respectively. High oil contents percentage i.e., 33.5, 30.6, 29.1 and 28.3 were found in varieties Crowford, Williams, Coker 240 and Davis, respectively. The recently released variety Pawe 03 was reported had high protein (42%) and oil (23%) content. Considering the negative correlation between protein and oil content in soybean (Filho *et al.*, 2001), Pawe 03 has a very good compromise for both protein and oil contents. Generally, the oil content of the released varieties showed declining trend and protein content showed increasing trend, while the yield levels of the recently released varieties did not show much difference from those released in the 1981 (MoANR, 2016). This finding is in-line with the report of Filho *et al*. (2001), who reported significant negative correlation between oil and protein content, while weight of hundred seeds showed low correlation with oil and protein content.

Response of soybean varieties to Rhizobium inoculation

As part of his MSc thesis research, Yesuf (2017) studied the interaction of soybean varieties i.e., G9945, SCS-1, Clark-63k, Afgat, Hardee-1 and Hawassa-04 with five different strains of Rhizobia bacteria i.e., SB-MAR-1495, SB-MOROK, SB-6.1A2, SB-6.1B2, and SB-12. The analysis of variance revealed that the interaction of *B. japonicum* bacteria strains with soybean varieties showed highly significant ($P<0.01$) difference for total nodule number, effective nodule number and dry effective nodule weight, and showed significant ($P<0.05$) difference for tap root length, number of pods per plant, hundred seed weight and grain yield. Yesuf (2016) also reported that Rhizobium strain SB-MAR-1945 with soybean variety SCS-1 combinations showed the best performance for nodulation, yield and yield component parameters.

Table 4.Name of varieties, maturity type, altitude, year of release and ecology of adaptation soybean varieties in Ethiopia

Variety	Maturity Type	Altitude (m.a.s.l.)	Breeder/ Maintainer	Year of release	Oil Content	Protein Content	Yield t ha^{-1}	Resistance	Ecology/Region (where grown
Davis	Medium	1300-1800	AwARC/SARI	1981	28.30		2.5-3.0		
Clark 63k	Medium	1300-1800	AwARC/SARI	1981	27.90		2.5-3.0		
Coker-240	Medium	1300-1800	AwARC/SARI	1981	29.10		2.5-3.0	Bacterial purple, blight and viral diseases	
Williams	Early	1000-1700	AwARC/SARI	1981	30.60		2.5-3.0		Short rainfall areas of western and south western part of the country
Crowford	Early	1300-1700	AwARC//SRARI	1981	33.50		2.5-3.0		
Cheri (IPB-81-EP7)	Early	1300-1850	BARC/OARI	2003	21.30	35.90	2.2	Bacterial purple, blight	Intermediate & long rainfall areas
Belessa-95 (PR-149)	Late	520-1800	AwARC//SARI	2003	20.00		1.74-2.98	Bacterial purple, blight	Long rainfall areas of western and south western part of the country
Jalale (AGS-2017)	Early	1300-1850	BARC/OARI	2003	21.10	31.50	2.2	Bacterial purple, blight	Intermediate & long rainfall areas
Awassa-95 (G 2261)	Late	520-1800	AwARC/SARI	2005			1.8-2.6	Bacterial purple, blight and viral diseases	
AFGAT (TGX-1892-10F)	Medium	750-1800	AwARC/SARI	2007			1.48	Anthracnose	
ETHIO-YUGOSLAVIA	Late	1200-1900	BARC/OARI	2007	23.40	36.00	1.7-3.5		
BOSHE(IAC-13-1)	Medium	1200-1900	BARC/OARI	2008	19.86	35.95	1.6-3.0	Bacterial purple, blight and viral diseases	Intermediate & long rainfall areas
Dhidhessa (PR-143-81-EP-7-2)	Medium	1200-1900	BARC/OARI	2008	20.35	34.97	2.0-3.3	Bacterial purple, blight and viral diseases	Intermediate & long rainfall areas
Gizo (TGX-1885-33F)	Medium	520-1800	PARC/EIAR	2010	19.71	31.39	2.01	Bacterial purple, blight and Viral diseases	Long rainfall areas of western and south western part of the country
Gishama (PR-143-(26))	Medium	520-1800	PARC/EIAR	2010	20.06	31.37	1.80	Bacterial purple, blight and viral diseases	>>
Wegayen (TGX-1998-29F)	Late	520-1800	PARC/EIAR	2010	18.29	30.69	1.84	Bacterial purple, blight and viral diseases	

Table 4. Continued

Variety	Maturity Type	Altitude (m.a.s.l.)	Breeder/ Maintainer	Year of release	Oil Content	Protein Content	Yield t ha^{-1}	Resistance	Ecology/Region (where grown
Korme (AGS-129-2)	Late	1200-1900	BARC/OARI	2011	20.53	39.33	1.2-3.8		
Katta (PR-145-2)	Late	1200-1900	BARC/OARI	2011	18.82	38.73	1.4-3.2		
NOVA	Early	1200-1700	HWARC/SARI	2012	20.05	33.13	2.25		
Wello (TGX-1895-33F)	Medium	520-1800	SARC/ARARI	2012	17.9	30.40	1.9-3.2		
Hawasa-04 (AGS-7-1)	Medium	1200-1700	HWARC/SARI	2012	19.52	37.29	2.63		
Nyala	Medium	800-1700	AwARC and ARC	2014			2.5-3.5		
Gozela	Early	800-1700	AwARC/PARC	2015	22.78	30.10	1.8-2.22	Moderately resistant to major soybean diseases	
Pawe 01 (PARC-2013-2)	Medium to late	520-1800	PARC/EIAR	2015	21.00		2.44	Resistance to SMV, moderately resistance to leaf blotch	
Pawe 02 (PARC-2013-3)	Medium to late	460-1600	PARC/EIAR	2015	22.00		2.56	Resistance to SMV, moderately resistance to LB	
Pawe 03	Medium to late	520-1800	PARC/EIAR	2016	23.60	42.00	2.34		

NB: HwARC, PARC, BARC, SARC =Hawassa, Pawe, Bako and Sirinka Agricultural Research Centers, respectively.EIAR= Ethiopian Institute of Agricultural Researc, SARI, OARI and ARARI = South, Oromiya, and Amahara Agricultural Research Institutes, respectively. SMV, Soybean-Mosaic Virus, Source: (MOANR, 2016)

Performance re-validation of released soybean varieties

The soybean varieties that were recommended in the 1980's and also those released during the period 2000-2014 were evaluated in a very few testing locations, and also it was very long, since these varieties were released, and hence some of the potential production environments for these varieties might have been bypassed. In addition, in the face of rapidly changing environment, as a result of changes in climate and edaphic factors, it was decided to re-validate the performance of the released varieties in all the major agro-ecologies of the country. Hence, it is important to revise the recommendation domains of the varieties and also helps to delineate the soybean testing environments, based on similarity in the pattern of performance of the released varieties in the major soybean testing environments.

The performance of 19 released soybean varieties were evaluated across eight major soybean growing environments of the country with the aim of identifying the best performing released variety/varieties for the respective test locations, either for wider or specific adaptation, for the major soybean growing environments. Accordingly, variety clarck 63 k produced the highest across locations overall mean of 2102.6 kg ha^{-1}, with relatively better performance in locations Pawe (3690.1 kg ha^{-1}), Tepi (2722.4 kg ha^{-1}), Sirinka (2513.3 kg ha^{-1}), Jimma (2507.5 kg ha^{-1}) and Assosa (2200.5 kg ha^{-1}) (Table 5). Similarly, cocker 240 produced the next highest across locations mean yield of 1990 kg ha^{-1}, with better performance at three locations i.e., Tepi, Jima, and Pawe with respective mean yields of 3460.5, 3196.7 and 3125.5 kg ha^{-1}, respectively. Afgat showed better wider adaption across locations i.e., Tepi, Assosa, Sirinka, and Jima, with respective mean yields of 3698.6, 3018, 2743.1, 2514.5, and 2480.2 kg ha^{-1}. In general, the performance of all the varieties was low at Humera, and Abobo, which might be due to the moisture and heat stress prevalent in these locations, as these locations are known for high temperature and low elevation. Gihsama and Williams produced the highest yield of 846 and 841kg ha^{-1}, respectively at Humera; while Gishama and Davis produced the highest yields of 1289 and 1207.9 kg ha^{-1}, respectively at Abobo. It is important to note the unique and specific location performance of some of the varieties i.e., Afgat and cocker 240 produced the highest mean yields of 3698.6 and 3460.5 kg ha^{-1}, respectively at Tepi; and Gishama produced the highest 3696.4 kg ha^{-1} yield at Sirinka. Clark 63 K produced the highest yield of 3690.1 kg ha^{-1} at Pawe, and Nyala produced the highest mean grain yield of 3329 kg ha^{-1} at Jimma.

Genetic progress study in soybean breeding

According to de Felipe *et al.* (2016), genetic progress is estimated by comparing the performance of cultivars released over a given number of years, when grown in the same environmental conditions and under uniform management practices. It is important to estimate the extent of genetic improvement made by the recently released varieties over previously released varieties. A total of 25 released/registered soybean varieties, during the period 1974 to 2015 were evaluated in Ethiopia in three maturity groups i.e., early (7), medium (7) and late (11) at Bako Agricultural Research Center to determine the genetic gain in grain yield in the last 38, 31 and 12 years of breeding periods, respectively. In early set varieties, grain yield was found to decrease from 1418.73 kg/ha to 997.6 kg ha^{-1}; while in the medium set groups increased from 2314.5 kg ha^{-1} to 3075.5 kg ha^{-1} and the late set increased from 2558.7 kg ha^{-1} to 3253.9 kg ha^{-1} over the last 38, 31 and 12 years of soybean genetic improvement period, respectively. As estimated from coefficient of linear regression of variety means for each trait on year of release in the early, medium and late set soybean varieties, the average annual increase was 4.7, 21.7 and 91.55 kg ha^{-1} for grain yield; 6.4, 39.6 and 124.1 kg ha^{-1} for biomass yield and 0.048, 0.14 and 0.53% for harvest index, respectively. Generally, it can be seen from this study that encouraging genetic progress have been made in the last three decades, which might pose a challenge to the existing soybean breeders in developing and identifying varieties that have better performance than the already existing varieties.

The latest release of soybean varieties (Nyala and Gozela) was made by PARC, and large seed size, which is one of the preferred traits by the processing industries, was among the desirable features of these varieties. Nyala and Gozella showed 20.2 and 5.6% weight of 100 seeds increase over the standard check (Awassa-95), respectively. In addition, Nyala produced 5.73% grain yield advantage over the standard check, while the second candidate, Gozela gave almost similar yield with the check. Commonly, the soybean breeding programs aims to develop dwarf and compact plant types to minimize the problem of lodging and make harvesting operation easier. Both candidates i.e., Nyala and Gozella produced shorter plant height than the standard check variety with reduced height of 15.24 and 4.25% over Nyala and Gozella, respectively.

Oil content of the 19 released soybean varieties produced in two locations Mankush and Pawe was analyzed by Pawe Agricultural Research Center at the Ethiopian Institute of Agricultural Research Quality and Nutrition Research Laboratory, and it was revealed that Coker 240, Bellessa-95, Hawassa 04, and Jalele produced high across locations mean oil content of 23.6, 23.4, 23.2 and 23%, respectively (Table 6), indicating that these varieties are good for oil processing industries.

Table 5. Yield performance of 19 released soybean varieties across diverse agro-ecologies of eight divergent environments

S.N.	Varieties	Grain yield (kg/ha) of the soybean varieties in each location								Mean
		Assosa	Jima	Pawe	Mankush	Tepi	Sirinka	Humera	Abobo	
1	Belesa-95	2195.3^{f-i}	1420.9^{hg}	1996.0^{b-f}	2142.3^{abc}	1786.0^{a-d}	2636.8^{a-d}	405.3^{b}	837.4^{abc}	1677.5
2	TGX-1332644	2119.2^{hi}	826.6^{h}	1330.9^{ef}	2755.3^{a}	1642.1^{a-d}	2311.4^{b-e}	585.0^{ab}	1086.3^{abc}	1582.1
3	Wegayen	2315.8^{e-i}	1448.4^{hg}	2018.3^{b-f}	1977.6^{abc}	690.5^{b-d}	1267.7^{e}	479.0^{ab}	1091.5^{abc}	1411.1
4	AFGAT	3018.0^{a}	2514.5^{ede}	1833.6^{c-f}	2480.2^{ab}	3698.6^{a}	2743.1^{abc}	505.1^{ab}	817.5^{c}	1893.1
5	Gizo	2734.1^{fg}	1834.6^{fg}	2990.8^{ab}	2210.8^{abc}	1480.3^{b-d}		687.3^{ab}	1148.2^{abc}	1869.4
6	Gishama	2325.8^{e-g}	1027.5^{h}	2026.3^{b-f}	2115.8^{abc}	2896.7^{abc}	3696.4^{a}	680.2^{ab}	1289.6^{a}	1765.9
7	Awassa-95	2804.4^{a-c}	2211.8^{d-f}	2055.7^{b-f}	1359.1^{abc}	1902.5^{cd}		539.8^{ab}	944.2^{abc}	1688.2
8	Davis	2557.5^{b-f}	2645.8^{b-d}	2559.2	2176.5^{abc}	2126.5^{b-d}	1877.1^{c-e}	489.1^{ab}	1207.9^{ab}	1955.0
9	Williams	2663.2^{a-e}	2883.1^{a-c}	1547.2^{d-f}	1839.6^{abc}	1278.6^{cd}	1392.6^{e}	841.5^{a}	1167.4^{abc}	1701.6
10	Nova	1935.4^{i}	1014.9^{h}	949.0^{f}	733.4^{c}	657.9^{cd}				1058.1
11	Crawford	2899.3^{ab}	2575.9^{b-e}	2033.1^{b-f}	1362.9^{abc}	2310.6^{a-d}	1254.4^{e}	570.6^{ab}	1054.7^{abc}	1757.7
12	Boshe	2139.4^{ghi}	1939.2^{e-g}	2869.4^{abc}	2536.2^{ab}	2483.8^{a-d}	1659.5^{de}	739.8^{ab}	1090.8^{abc}	1932.3
13	Jalale	2289.2^{e-i}	2337.8^{e-f}	2117.8^{b-e}	1798.8^{abc}	945.4^{d}	1425.7^{e}	542.9^{ab}	1094.5^{abc}	1569.0
14	Cocker-240	2406.0^{d-g}	3196.7^{ab}	3125.5^{ab}	1287.8^{abc}	3460.5^{ab}	2053.5^{c-e}	509.7^{ab}	1037.0^{abc}	1990.4
15	Hawassa 04	2962.6^{a}	1981.1^{e-f}	3041.6^{ab}	1827.7^{abc}	1344.3^{b-d}	2111.5^{b-e}	357.6^{b}	989.9^{abc}	1827.0
16	Clark 63k	2200.5^{f-i}	2507.5^{c-e}	3690.1^{a}	1461.8^{abc}	2722.4^{a-d}	2513.3^{b-e}	711.7^{ab}	1013.4^{abc}	2102.6
17	Wello	1521.7^{j}	902.3^{h}	1672.2^{d-f}	1845.3^{abc}					1485.4
18	Nyala	2515.2^{c-g}	3329.0^{a}	2804.2^{abc}	1153.5^{bc}	1178.7^{cd}	1358.5^{e}	352.8^{b}	1047.3^{abc}	1717.4
19	Gozela	2413.5^{d-g}	1012.2^{h}	2329.0^{b-e}	2012.6^{abc}	658.7^{cd}	3154.1^{ab}	846.7^{a}	1017.9^{abc}	1680.6
	Mean	2421.90	1979.47	2262.61	1846.17	1539.66	2097.04	579.05	1055.03	1719.2
	CV (%)	9.5	19.5	30.2	50.14	27.6	29.5	43	21.8	29.1
	LSD (0.05)	383.6	639.6	1131	1533	1468	1072	415.6	383.3	615.2

Table 6.Oil content of some of the released varieties at two locations

No.	Varieties	Mankush (%)	Pawe (%)	Mean (%)
1.	Cocker-240	24.2	22.9	23.6
2.	Bellessa-95	22.8	24	23.4
3.	Wogayen	22.6	21.9	22.2
4.	Boshe	23.03	22.5	22.8
5.	Williams	22.8	21.3	22.1
6.	Clarck 63k	23.8	21.5	22.7
7.	AFGAT	23.77	19.6	21.7
8.	Wollo	22.03	21.6	21.8
9.	Gizo	20.4	19.5	20
10.	Awassa-95	20.37	20.8	20.6
11.	Nyala	21.03	21.4	21.2
12.	Gishama	22.5	21.8	22.1
13.	TGX-1332644	22.2	21.6	21.9
14.	Hawassa-04	23.57	22.8	23.2
15.	Jalale	24.8	21.3	23
16.	Nova	21.87	21.6	21.7
17.	Crawford	22.37	21.3	21.8
18.	Gozella	22.6	21.4	22
19.	Davis	22	21.9	21.9

Summary and Conclusion

Soybean (*Glycine max* L Merill) is a leguminous, high oil and protein, and nitrogen fixing crop. Its importance is showing rapid growth, both globally and locally. It is one of the most traded crops globally, as a dry grain and processed products. However, the multiple importance of the crop is not well recognized and exploited in Sub-Saharan African countries, in general, and Ethiopia in particular. Some of the well-recognized importance of soybean includes, its role in fighting mal-nutrition, mainly because of its high protein content; its role in improving the fertility of the soil, due to its nitrogen fixing capacity; its significance in sustainable cropping system management, because of its role as a rotation crop with maize, sorghum and other cereals, and as raw material for agro-processing industries in the country. In addition, its importance for import substitution is paramount important, as the country is importing large volume of soybean and palm oil, which is supposed to be substituted with locally processed soybean oil and oil from other oil crops.

Despite its importance, the national average yield of soybean is still low relative to the productivity of the crop in the research plots and in other countries that have rich experience in its production. The major production constraints include: weak emphasis by the extension system relative to the other crops; insufficient availability of high yielding varieties, disease resistant and well adapted released varieties, weak seed system, emerging diseases and insect pests; and weak marketing and supply chain system. Limited genetic variability of the crop is one of the major limitations of breeding soybean in Ethiopia, as soybean is a recently introduced crop to the country. Two approaches i.e., introduction of germplasm from external sources and genetic recombination of the crop through hybridization were considered for the genetic enhancement of the crop. Modified single seed descent method in which two modifications i.e., harvesting of single pod instead of single seed, and the start of plant to rows selection at F4 instead of F5, as used in the case of single seed descent method, was employed to develop RILs from segregating generations at Jimma Agricultural Research Center. The breeding effort in the country targets three maturity groups i.e., early, medium and late. Overall, more than 26 soybean varieties were released for production, which fall into either of the three maturity groups.

The breeding programs continue their effort to develop new varieties emphasizing producers, processors and end users preferred traits, such as high yield, disease resistance, high oil, high protein and larger seed size. The breeding programs need also to focus developing and identifying varieties resistant to major soybean diseases, such as soybean rust, leaf blotch, brown spot, and frog eye leaf spot. Developing varieties with early maturity that adapts to areas with short growing season should also be among the priority breeding objectives. As the commercial production of the crop is growing in the country, the importance of irrigated soybean production is expected to grow, and hence developing varieties that fits into irrigated production system need to be in the priority. Similarly, emphasis should also be given in improving the value chain of the crop, so that farmers get better benefit from their soybean harvest. This requires concerted effort of all the relevant stakeholders along the value chain i.e., policy makers; producers; processors; farmer marketing organizations; i.e., Ethiopian Commodity Exchange (ECX), primary cooperatives and unions, financial institutions, banks and micro-finances, Research and Development organizations i.e., Ministry of Agriculture, Agricultural Research Institutions and Non-Governmental organizations.

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Progress of Forage Legumes Breeding and Genetics Research in Ethiopia: A review

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Abstract

Ethiopia has the highest livestock population in Africa. However, the productivity is very low, which is attributed to poor quality feed and feeding practice. Use of forage legume crops can play a very important role in improving the nutrition of livestock, due to their high nutritional value. Realizing this, the forage legumes genetic improvement research efforts in Ethiopia has largely focused on acquisition of germplasm from both local and external sources, on which selection efforts have been underway to identify new varieties for production. The traits that have been emphasized in the forage legume variety improvement program includes: high yield of better quality forage; efficiency in biological nitrogen fixation (BNF), and high adaptation to agro-climatic variations and climate changes. So far, the genetic improvement and selection of forage legumes has been limited to a few temperate annual legume species, because of the need to develop fodder crops that could be integrated into the highland mixed crop/livestock production systems. For such integrated production systems, the major forage legume species on which research emphasis was placed were in the genera: Vicia, Trifolium, Medicago, Vigna and Cajanus. In response to the recent increasing demand for animal feed technologies for commercial-oriented livestock production systems, selection of legume varieties suited to conventional pasture production systems were considered as a major research strategy option. Under this strategy, the various annual, perennial herbaceous and tree legume species in both temperate and tropical categories were gathered and subjected to the screening and variety selection program. Overall, twenty forage legume varieties that belong to ten species in seven genera, were selected and released/registered for production. Future research direction of the breeding and genetics effort should largely invest on gathering a wide genetic base of forage legumes, both from external and local sources, with special emphasis on collection of the untapped native forage legume germplasm. To exploit the full potential of forage legumes, the forage breeding program need to be strengthened through capacity building, in terms of germplasm handling and conservation facilities; modern breeding facilities that enable to make use of biotechnological tools; training of specialists in conventional and molecular breeding.

Keywords: Biological N_2 fixation; climate change; food and forage legume integration; forage genetic resources

Introduction

Legumes provide multiple uses for smallholder farmers, such as food and feed, soil fertility management through the traditional crop rotations with cereals that is also very important to break the disease cycle in mono-crop conditions. Their ability to biologically fix atmospheric nitrogen (N_2) to ammonia through symbiotic relationship with *Rhizobial* bacteria, which provides free nitrogen to the agricultural systems, represents an important contribution of legumes to the global crop production system.

Forage legumes, in particular, play pivotal roles in mixed pastures. They improve the quality and herbage yield; fasten establishment and consolidation of the sward; ensure better seasonal distribution of pasture growth through inclusion of both early and late-maturing legume species, allowing extended grazing period. Grass-legume pastures are also known for the supply of high protein and greater herbage yields with greater palatability and digestibility, and help enhance the nutritive value of the sward, as they are rich in vitamins, minerals: calcium, sulphur and phosphorus, thus providing stocks with more balanced diets. Fodder legumes improve the palatability of a mixed grass-legume pasture by keeping the crude protein level above the critical level (7.0 % tropical species; 8.5% temperate species) below which voluntary intake declines (Whiteman, 1983). Dry matter digestibility and voluntary intake of legumes is generally higher than the grasses. The fibre content increases at a later stage of maturity, as compared to grasses, thus ensuring quality feed supply during the dry season.

Realizing the multiple benefits of legumes, research efforts in Ethiopia initially gave the highest emphasis on screening and selection of annual forage legume species that could be easily integrated into the cereal and cash cropping systems under the various strategies in the smallholder mixed crop/livestock production system. The major forage legume species evaluated for their fitness in such food-fodder legume crop integration strategy were clover species (*Trifolium*), mostly the native species including *Trifolium quartinianum*, T. *steudneri* and *T. tembense*, vetches (*Vicia*), medics (*Medicago*), cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*). Selected varieties from these species were successfully integrated with food crops in the form of crop rotations (Tedla and Jutzi, 1985; Mengistu, 2006; Mengistu, *et al.*, 2010), intercrops, over-sowing/under-sowing, alley crops (Tadesse, *et al.*, 1987; Gebrehiwot, *et al.*, 1987; Mengistu and Robertson, 1989). In the face of increasing trend of specialized and market-oriented livestock production systems, research focus shifted more towards selection of species that fit into conventional pasture production systems. In line with this, variety development efforts considered more of the perennial legumes rather than the annuals as in the past. Perennial herbaceous species that were recommended or formally registered/ released for wider use includes: lucerne (*Medicago sativa*), *Desmodium* spp., siratro (*Macroptilium atropurpureum*), glycine (*Neonotonia wightii*), stylo (*Stylosanthes*) and axillaris (*Macrotyloma axillare*). Among the tree legume species, tree lucerne (*Chaemacytisus palmensis*), sesbania (*Sesbania spp.*) and leucaena (*Leucaena spp.*) were the major ones.

Overall, the research system has attempted to develop increasing number of new improved forage legume varieties together with their production and utilization techniques, both for the smallholder farmer, as well as, for the specialized market-oriented enterprises, such as the urban and peri-urban dairy and beef enterprises. Although, the number of new varieties released or registered has increased from year to year, the progress made thus far has been severely limited by lack of trained manpower specialized in forage breeding and genetics, including the use of modern breeding tools, such as molecular breeding and microbiology, and lack of essential field and laboratory facilities. At present, the forage improvement program in the national research system has given prime emphasis to germplasm assembly, selection and development of well-adapted, high yielding and nutritionally rich forage legume varieties, together with their production, conservation and utilization technologies that can be combined as packages of improved animal feed and feeding practices for dissemination to the producers. This paper aims to review the research efforts, achievements, opportunities and challenges of the decadal forage legume research in the country.

Forage Legume Genetic Resources

Ethiopia is known for its enormous diversity of flora and fauna, which is related to its diverse edaphic, physiographic and climatic features. There is immense wealth of forage genetic resources in both temperate (tropical highland) and tropical categories. Ethiopia shares three of the eighteen major floristic regions of Africa (White, 1983) that are known to be important centers of forage genetic diversity, namely, 1) the Afromontane and Afroalpine 2) the Sudanian, and 3) the Somali-Masai floristic regions.

The Afromontane and Afroalpine floristic region is home to the various temperate (tropical highland) forage legume species, especially those in the herbaceous genera *Trifolium*, *Medicago*, *Lotus*, and *Biserulla* that occur in great diversity and high endemism (Williams, 1983). The various endemic and near-endemic legume species with high potential for development as forage crop have not been fully collected and utilized to any significance in forage breeding and variety development programs. The Sudanian floristic region, extends westwards into Ethiopia along its Western and South-western frontiers with the Sudan and Kenya, respectively. The Sudanian woodland vegetation is home to the various tropical perennial grass species, such as *Brachiaria, Panicum, Sorghum* and *Andropogon*, most of which are cultivated as commercial varieties throughout the world. Among the legumes, *Lablab, Macrotyloma, Neonotonia* and the various *Acacia* species occur in high diversity. The Somali-Masai floristic region is rich in the tree legume genera, especially those in the sub-family Caesalpinio-ideae. *Cordeauxia edulis* is one of the rarest and endemic valuable species that need immediate attention for collection, conservation and utilization.

Afromontane and Afroalpine Grasslands-source of Temperate Forage Genetic resources

The bulk of the Afromontane and Afroalpine floristic region is found in the vast Ethiopian highlands that cover an area totaling 490,000 km^2 or 43% of the total highland area of Africa (Amare Getahun, 1978). This highland mass is separated by the Great East African Rift Valley into the North-western and the South-eastern highlands. The main vegetation types under this floristic region includes: 1) Afromontane forest, 2) Afromontane bamboo, 3) Afromontane bushland and thicket, and 4) Afromontane and Afroalpine grassland (White, 1983). The latter vegetation type, Afromontane and Afroalpine grassland is of interest as a source of temperate forage genetic resources.

The Afroalpine and Afromontane grasslands are climax and biotic types, respectively, maintained by two factors, i.e., cold temperature in the alpine meadow; biotic factors (man's destructive activity) in the montane grasslands. The Afroalpine grassland is mostly climax, but it also contains secondary grassland in and above the *Ericaceous* and Afroalpine belts dominated by temperate grass tribes i.e., Festuceae, Aveneae, and Agrosteae, which are Afromontane/ Afroalpine endemics (White, 1983). While the Afromontane grassland in the lower altitude forest belt, which is typically a biotic secondary grassland maintains a balance of plant composition in favor of herbaceous communities with a dominance of important forage plant species, including the two grass tribes Andropogoneae and Paniceae, and among the legume herb tribes, the Trifoleae. The Afromontane sub-region in Ethiopia is very diverse in soil and physiography. It is home to many endemic and near-endemic forage legume species and varieties in the genera: *Trifolium, Medicago, Biserula*, *Lotus* and *Erythrina* spp. (Kahurananga and Mengistu, 1983; 1984) (Table 1).

Table 1. List of the more important forage legume species in the Afromontane and Afroalpine floristic region in Ethiopia

Species	Characteristics
*Trifolium spp**	Herbaceous legume
Medicago polymorpha	Herbaceous legume
Medicago lupulina	Herbaceous legume
Medicago minima	Herbaceous legume
Lotus schoeleri	Herbaceous legume
Biserula spp	Herbaceous legume
Scorpurus muricatus	Herbaceous legume
Argyrolobium rupestri	Herbaceous legume
Sesbania sesban	Tree/shrub legume
Aeschynomene abyssinica	Tree/shrub legume
Erythrina brucei	Tree legume

*includes 28 native annual and perennial species of the genus *Trifolium*, nine of which are endemic.

The Ethiopian highlands as the secondary center of diversity of *Trifolium*

The Ethiopian highlands, together with the rest of the Eastern and Central African highlands, are considered as the secondary center of diversity of the genus *Trifolium* (Bogdan, 1977; Williams, 1983; Zohary, 1972). The huge highland masses of Ethiopia in particular are home to 28 *Trifolium* species, nine of which are endemic (Akundabweni, 1986; Hansen and Mengistu, 1991; Kahurananga and Mengistu, 1983; 1984) (Table 2).

Initial agronomic evaluation of native clovers at ILRI, the then ILCA, including annual species (Akundabweni, 1986; Kahurananga and Tsehay, 1984; Kahurananga *et al*, 1984) and perennial species (Kahurananga, 1987) has showed exciting fodder yield potential that excels many of the introduced clover species, such as white clover (*T. repens*), and red clover (*T. pretense*) (Tables 3 and 4).

Table 2. Distribution of *Trifolium* species and varieties in Ethiopia

Distribution	Species
Gojjam: Agewmidir Dejen-Gozamin plateau Mount Choke	*T. quartinianum; T. steudneri, T. simense; T. decorum; T. billiniatum, T. rueppellianum, T. usambarense, T. pichisermole, T. semipilosum; T mattirolianum; T. polystachyum, T. schemperi*
N. Gondar: Debark, Gaynt highlands	*T. campestre, T. arvense, T. mattirolianum, T. decorum*
South Wollo: Kutaber/ Boru plain	*T. polystachyum,* var. *contractum*
North Shewa: DebreBerhan-DebreSina	*T. semipilosum,* vars.*brunellii* and var. *intermedium, T. acaule, T. cryptopodium, T. simense*
Arsi-Bale Highlands: Mount Chilalo (3500 m), Dinsho Massif (4000 m)	*T. burchellianum,* var.*Johnstonii* and *var oblongum; T. semipilosum* var. *semipilosum*, var.*brunellii* and var. *intermedium, T. usambarense, T. simense*
Sidama Highlands: Amaro Mountain massif (Mount Dello, 4,000 m.a.s.l)	*T. burchellianum,* var.*oblongum, T. usambarense*
Borie-Kibre Mengist plateau	*T. somalense, T. semipilosum*
Eastern Wollega Highlands: Arjo, Horo Gudru	*T. biliniatum, T. usambarense, T. burchellianum, T. rueppellianum*

Source: (Kahurananga and Mengistu, 1983; 1984)

Table 3. Top average dry matter (DM) yields, chemical composition, and in vitro DM digestibility of seven annual Ethiopian *Trifolium* species grown at Shola, ILCA, Addis Ababa*.

Species	DM yield (t/ha)	P input (kg P/ha)	% crude protein	%IVDMD
Trifolium decorum	5.8	40	19.8	76.0
Trifoliumquartinianum	6.2	35	19.1	
Trifoliumrueppellianum	5.2	Barn site	19.0	75.88
Trifoliumschemperi	2.9	40	19.1	-
Trifoliumsteudneri	5.3	40	21.3	73.56
Trifoliumtemebense	6.8	40	21.3	74.09
*Trifolium*sp.	1.5	40	-	-

*Source: Kahurananga and Tsehay, 1984

Table 4. Average and range of the important observations of perennial *Trifolium*at Shola, Addis Ababa in 1985 and 1986*.

Trifolium species & variety	No. of accessions	Dry season vigor (1-10)	DM weight (g/plant)	Days to first flowering	% plants in flower
T. africanum	3	4 (3-4)	69 (20-176)	192 (176-207)	60 (50-70)
T. burchellianum, var.*johnstonii*	23	6 (4-9)	192 (11-342)	185 (182-252)	23 (0-50)
T. burchellianum, var.*oblongum*	1	5 (5)	49 (31-71)	139 (139)	10 (10)
T. cryptoodium	13	6 (3-8)	224 (42-569)	212 (181-233)	49 (30-80)
T. repens	1	5 (5)	61 (21-160)	183 (183)	30 (30)
T. semipilosum, var.*brunelli*	1	1 (1)	68 (4-14)	221 (221)	50 (50)
T. semipilosum, var.*glabrescens*	12	3 (1-7)	111 (11-240)	156 (119-184)	98 (90-100)
T. semipilosum, var.*intermedium*	2	3 (2-3)	87 (55-120)	223 (217-228)	50 (50)
T. semipilosum, var.*semipilosum*	42	4 (1-7)	147 (41-222)	205 (166-231)	88 (40-100)
Total	98				

Source: Kahurananga (1987)

The Sudanian Floristic Region in Western and South-Western Ethiopia

This humid savannah in the Western and South-western Ethiopia is part of the Sudanian Floristic Region (White, 1983) that extends as a narrow strip of the lowland bordering Sudan in the west, and the North-western Ethiopian highlands in the East. The region extends narrowly into the sub-humid Sahelian Africa region up to Guinea (White, 1983). It has rich floristic endemism containing about 2,750 species, of which one-third are endemic. The vegetation is a woodland in which the more important tropical forage grass genera (*Andropogon, Sorghum, Panicum, Brachiaria*) and climbing herbaceous legume genera (*Macroptyloma, Lablab, Psophocarpus, Neonotonia* and *Rhynchosia*) are found in rich diversity and endemism. Among the tree legumes of browse potential, the rare species: *Aescynomene ruspoliana, Bauhinia farek, Sesbania dummerii* and *S. rostrata*, remain as the least explored and collected species for their forage potential, apart from botanical explorations carried out in the 1970s (Thulin, 1972; 1983) (Table 5).

Table 5. Forage legume species in the humid savannah of western and south-western Ethiopia

Species	Description
Herbaceous legumes	
Macrotyloma axillare	Perennial, climbing
Stylosanthes fruitcosa	Perennial semi-woody; tolerant to soil acidity
Clitoria ternatea	Perennial, climbing; adapted to waterlogged black clay soils (*Vertisols*)
Neonotonia wightii	Perennial, climbing
Vigna membranacea	Perennial, climbing
Teramnus labialis	Perennial, climbing
Zornia setosa	Perennial prostrate; tolerant to soil acidity
Zornia glochydiata	Annual herb; tolerant to soil acidity
Psophocarpus grandiflora	Climbing; wild relative of the high-protein pulse -winged bean (*P. tetragonolobus*)
Tree legumes	
Acacia albida	Tree legume with fleshy pods
Acacia sieberiana	Tree legume with fleshy pods
Acacia polycantha	Tree legume with fleshy pods
Albizia malacophylla	Perennial tall tree legume; highly palatable; endemic to W. Wolega woodlands
Aeschyomene ruspoliana	Perennial small tree legume; endemic to W. Ethiopia (Metekel)
Sesbania sesban	Small tree legume, leafy
Sesbania dummeri	Perennial small tree legume; endemic to S.W. Ethiopia (Gambella)
Sesbania rostrata	Annual legume; nodulates in both the phylosphere (aerial) & rhizosphere (root)
Sesbania macrantha	Annual/short-lived perennial small tree legume, fast growing and leafy

The Somali-Masai Floristic Region in the Eastern and South-eastern Ethiopia

The Eastern rangelands of Afar and Somali constitute the northern part of the vast 'Somali-Masai Floristic Region' of Eastern Africa (White, 1983). This region is an expanse of lowland that encompasses the eastern and southern lowland territory of Ethiopia, and the neighboring lowland territories of most of the rangelands of Kenya, and Central and Southern Tanzania. The Great East African Rift Valley is a common physiographic feature of this floristic region bisecting it on a North-South transect from the Afar Depression up to Malawi. Vast areas of the Rift System consist of soils of volcanic origin, (*Andepts*/ *Andosols*) that largely determine the composition and physiognomy of the vegetation (White, 1983).

The region is predominantly covered by *Acacia-Commiphora* deciduous bushland and thicket climax. As a result of biotic and abiotic factors, these climax components have been replaced by evergreen bush land and thicket on the lower slopes of the adjoining mountains. The region, together with the adjoining wetter East African Savannah regions, is the center of diversity of the legume subfamily Caesalpinioideae (Williams, 1983). In Ethiopia, the region is home to important endemic and near-endemic legume tree species, such as the dual-purpose food and forage legume Yehib (*Cordeuxia edulis*) that thrives under harshest environment in the Ogaden Desert of the Somali Region of Ethiopia. There are also other potential browse legume tree species in the genera: *Acacia,* *Aeschynomene, Erythrina, Parkinsonia* (Hanson and Mengistu, 1991; Mengistu, 1993; Williams, 1983). The more important potential forage legume species native to the Somali-Masai floristic region, are listed in Table 6.

Table 6. Forage legume species native to the Somali-Masai floristic region in Ethiopia

Species	Description
Herbaceous legumes	
Stylosanthes fruitcosa	Perennial sub-shrub; adapted to dry lands; tolerant to soil acidity
Clitoria ternatea	Perennial climbing herb; adapted to heavy clay soils (*Vertisols*)
Neonotonia wightii	Perennial climbing forage legume
Macrotyloma axillare	Perennial climbing forage legume
Teramnus labialis	Perennial climbing forage legume
Zornia setosa	Perennial herbaceous forage legume; tolerant to soil acidity
Zornia glochydiata	Perennial herbaceous forage legume; tolerant to soil acidity
Rhynchosia minima	Perennial climbing forage legume
Tree legumes	
Cordeuxia edulis	Small tree; dual uses: fruits edible, leaves palatable to stock
Dichrostachys cinerea	Tree legume with fleshy pods
Acacia albida	Tree legume with fleshy pods
Acacia nilotica	Tree legume, leafy
Acacia polycantha	Tree legume with fleshy pods
Acacia sieberiana	Tree legume with fleshy pods
Aeschyomene elaphroxylon	Tree legume; adapted to wetlands and saline-sodic soils
Sesbania sesban	Small tree legume, leafy
Sesbania quadrata	Small tree legume, leafy
Sesbania goetzei	Small tree legume; adapted to wetlands and saline-sodic soils
Erythrina burana	Tree legume, leafy; endemic to south-eastern Ethiopia
Erythrina melanacantha	Tree legume; endemic to south-eastern Ethiopia
Parkinsonia aculeata	Small tree legume, adapted to arid infertile soils

Research Achievements in Forage Legumes

The research efforts on forages, in general, and forage legumes, in particular, focused on the development of varieties that provide multiple benefits as feed, and in some cases for dual use i.e., as food and forage; efficient in N_2 fixation in the pasture system, as well as, in an integrated food/forage crop production systems. Under this perspective, forage technologies generated by the research system, thus far try to address the following two thematic areas, which are discussed in the foregoing sections.

1) Development of integrated forage legume and food crops production technologies with the goal of producing protein-rich forage legume crops, which can be used as supplementary ration to improve the intake and digestibility of crop residues and poor quality native hay.
2) Development of conventional pasture technologies for specialized animal producers.

Integrated forage legume and food crops production technologies

In the face of rapidly increasing demand for arable land in the highlands, allocation of cultivable land for pasture crops seems unlikely, now and in the near future, in the context of the smallholder farmers. The smallholder farmer is often reluctant to sacrifice arable land for sole pasture production. An alternative promising approach has been integrating forage legumes into the existing cropping system without significantly affecting the yield of food and cash crops.

The ultimate goal of employing the various crop livestock integration techniques is to solve the critical shortage of protein in the fibrous feedstuff (poor quality native hay and crop residues), the only available animal feed during the dry season, which is a common practice across the highlands of Ethiopia. Improving the palatability and digestibility through strategic supplementation with protein-rich fodder legumes, immensely, improves livestock productivity, and has positive effect on crop production because of feeding oxen with better quality feedstuff improves their tilling efficiency. In addition, introducing improved forage legumes into the cereal dominated cropping systems improves soil fertility, through symbiotic N_2 fixation, and nutrient recycling from animal waste deposited during grazing crop aftermath. Therefore, in the highlands mixed crop/livestock farming system, any attempt to promote agricultural productivity should consider a program of soil fertility maintenance, in addition to improving the supply of good quality forage that in turn contributes to crop yield through enhancing the tilling capacity of draught oxen (Tothill, 1987). Selection of forage legumes with desirable traits of high yield of good quality fodder and efficient in fixing atmospheric N and introducing them into the cropping systems are, therefore, cheaper and sustainable approaches of improving the overall agricultural productivity in the mixed crop/livestock farming system of the highlands. To that end, research has been underway to select legume crop varieties and develop efficient strategies of integrating them with food and cash crops production.

Promising strategies developed for integrating forages with food and cash crops includes: forage/crop rotation, sequential cropping, relay cropping, under-sowing/over-sowing forage legumes, alley cropping, and inter-sod transplanting. These strategies have been observed to be better routes towards introducing improved forage crops to the smallholder, as compared to the more expensive conventional pasture systems. This is because, in the above-mentioned integrated cropping strategies, primary tillage is carried out for the sake of the food crop, and hence, there is little special input for pasture establishment, which might result in farmers acceptance of technologies that combine food and forage crops production. The more promising food/forage crop integration strategies and suited best bet crop varieties are discussed in the following sections.

Cereal/forage legume crop rotation

This system involves introducing annual forage legumes into the traditional cropping pattern. In the central highlands, where the system is more applicable, the commonest cropping sequence is cereal-cereal-pulse. After the two cycles of cereal crop, the third cycle necessitates introducing a legume crop to replenish depleted nitrogen in the soil. This legume phase could be used to grow selected annual forage legume species that combine characteristics of high herbage yield and efficiency in symbiotic nitrogen fixation. Promising legumes species have been identified based on these desirable traits from both the native and exotic genera, which includes: *Vicia* (vetches), *Trifolium* (native clover spp), *Medicago* (medics) and *Lablab* (lablab) (Mengistu, 2006). These annual fodder legume crops can be sown as full season crop, harvested and conserved as hay for strategic feeding, during the dry season (Fig 1).

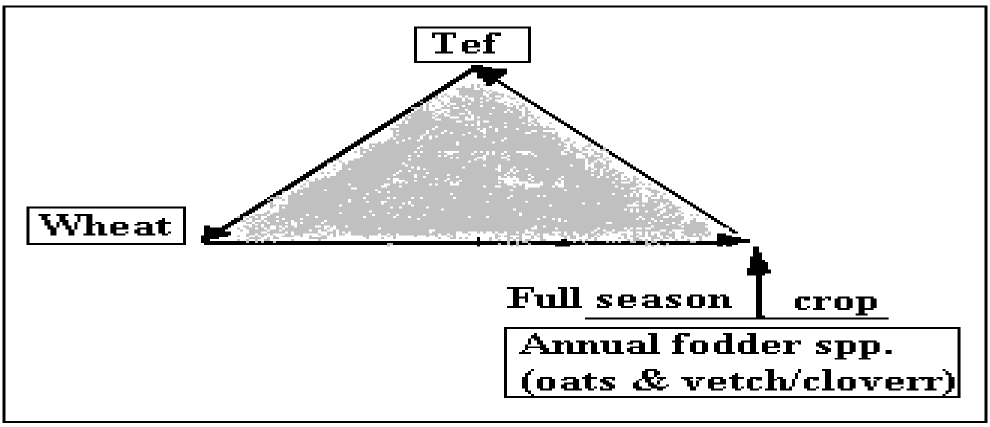

Figure 1. Modified cropping cycle with a replacement of the pulse phase with annual fodder legumes grown as full-season crop in the Ethiopian highland cereal-based farming system.

The advantage of this system is primarily to provide high quality fodder and to maintain soil fertility, so as to extend the period in which a given land is cropped, which otherwise would have been left as fallow for some years until the soil fertility is replenished, or alternatively chemical fertilizers might be used, that incurs high cost to the smallholder farmer. Long-term experiments conducted at Debre Zeit Research Center enabled to identify a number of forage legumes with high dry matter yields that could be grown as pure stand or in mixture with oats, in rotation with cereal crops (Mengistu, 2006). Table 7 shows the selected species and their average dry matter yield; while Table 8 shows the effect of these fodder crops on durum wheat grain yield grown at four levels of N fertilizer i.e., optimum (64 kg N/ha), sub-optimum (32 kg N/ha), low level (18 kg N/ha), and zero (without N fertilizer) subsequent to fodder crops.

Table 7. Herbage yield of different annual forage legumes grown in mixture with an oats variety on *Vertisols* at two locations: Debre Zeit and Akaki

Oats-legume mixture (treatments)	Herbage yield (DM t/ha)*	
	Debre Zeit	Akaki
Oats (pure stand)	6.10 a	6.46 a
Oats + *Vicia dasycarpa*	6.03 a	5.23 b
Oats + *Trifolium quartinianum*	6.22 a	5.98 ab
Oats + *T. steudneri*	5.52 ab	6.26 a
Oats + *T. rueppellianum*	5.86 a	5.83 ab
Oats + *T. decorum*	4.86 b	5.20 b
LSD (0.05)	0.87	0.79
CV (%)	12.68	11.41

*Means followed by similar letters are not significantly different at $P \leq 0.05$. Source: Mengistu (2006)

Table 8. Grain yield of durum wheat grown under four different fertilizer levels, subsequent to grass-legume mixed fodder crops of oats with annual legume species on *Vertisol* at Debre Zeit

Precursor crop ofOats-legume Mixture	Nitrogen fertilizer level on wheat crop*				
	Optimum	Sub-optimum	Low	None	Mean
Oats + *Vicia dasycarpa*	1744.0	1643.3	1263.0	1135.3	1446.4 a*
Oats + *T. quartinianum*	1777.0	1604.3	1319.7	1098.3	1449.9 a
Fallow	1552.0	1520.0	755.0	906.0	1283.4 bc
Oats + *T. steudneri*	1745.3	1659.7	1264.3	1235.3	1476.2 a
Oats + *T. rueppellianum*	1683.3	1519.0	1419.7	1218.3	1460.1 a
Oats (pure)	1522.7	1429.7	1058.7	1011.3	1255.6 c
Oats + *T. decorum*	1733.7	1595.7	1211.3	1057.3	1399.5 ab
LSD (0.01)	NS				122.00
SEM	64.32				32.16
Mean (Fertilizer)	1679.8 a	1567.4 a	1241.8 b	1094.6 b	
LSD (0.01)	207.60				
SEM	39.59				
CV (%)	7.98				

*Means followed by similar letters are not significantly different at $P \leq 0.01$. NS = none significant
Source: Mengistu *et al.* (2010)

Sequential cropping

Sequential or double cropping is a shorter version of cereal-fodder legume rotational cropping in which two crops (forage and pulse) are grown during the main growing season, one after the other. The essential feature of this system is that the two crops do not overlap i.e., the second crop being planted only after the harvest of the first within the same growing season. As in the conventional full season crop rotation, the double cropping phase is incorporated after two cycles of cereal crop, thus without affecting the usual traditional cropping cycle (Fig 2). For example, at Debre Zeit Agricultural Research Center (DZARC), short duration native clovers (*Trifolium quartinianum* and *T. steudneri*) were successfully grown in sequence with chickpea on black clay soils (*Vertisols*) that retain residual moisture, to exploit the advantages of: 1) producing a double crop of food legume and fodder legume of high feed value, and 2) improving the nitrogen content of the soil through biological nitrogen fixation of both legume crops.

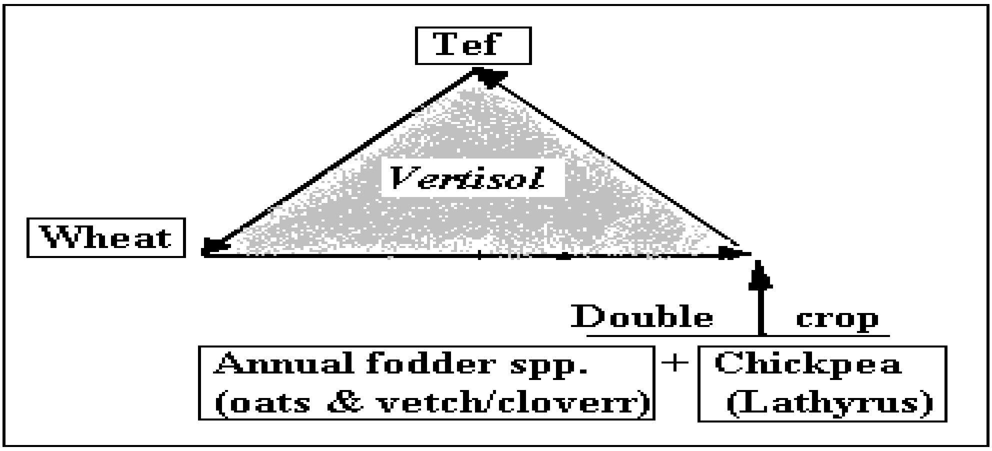

Figure 2. Modified cropping cycle without affecting the traditional crop rotation practice on the Ethiopian highland *Vertisols* through sequentially growing of fast-maturing legume fodder crops with off-season pulses (chickpea or grass pea).

Employing this technique, long-term experiments conducted at Debre Zeit on a *Vertisol* enabled to identify a number of short-duration and fast-growing forage legumes with attributes of fast growth and high dry matter (DM) accumulation, and that could be grown as pure stand or in mixture with oats, as double crop with either chickpea or grass pea in one cropping season. A special feature of this technique is that the traditional cropping cycle has not been altered (Mengistu, 2006; Mengistu *et al.*, 2010).The field trial involving annual medics, native clovers and vetches revealed that *Medicago scutellata* produced the highest dry matter yield of 4925 kg ha^{-1} and the highest double crop yield of chick pea 2650kg ha^{-1}, followed by *Vicia dasycarpa* which gave a dry matter yield of 3585 kg ha^{-1} and double crop chick pea grain yield of 2530 kg ha^{-1} (Table 9). The effect of the fodder crops on durum wheat yield grown at four fertilizer N levels: optimum (64 kg N/ha), sub-optimum (32 kg N/ha), low level (18 kg N/ha), and zero (without N fertilizer) subsequent to fodder crops was assessed, and the result revealed that the highest wheat yield of 3476 kg ha^{-1} was obtained at optimum N level, when wheat was produced in phase III, following *Trifolium quartinianum* and chick pea in phase I and II, respectively. The next highest yield of 2603 kg ha^{-1} was obtained when wheat was produced at optimum level of P in phase III, following *Trifolium steudneri* and chick pea at phase I and II, respectively (Table 10).

Table 9. Dry herbage yield of forages legumes and grain yield of a sequentially grown chickpea on a *Vertisol* at Debre Zeit

Phase I	**Phase II**	
Annual forage legumes (June-Mid-Sept. 1998)	**DM yield (kg/ha) (June-mid-Sept.)**	**Chickpea grain yield (kg/ha) mid-Sept.- Dec**
Medicago scutellata	4925	2649
Fallow (partial) + Chickpea	-	2553
Trifolium steudneri	2645	2468
Fallow (full season)	-	-
Vicia dasycarpa	2549	2384
Trifolium quartinianum	3585	2530
C.V. %	12.69	9.18

Table 10.Grain yield of durum wheat grown under four nitrogen fertilizer levels, subsequent to sequentially grown forage legume species and chickpea on *Vertisol* at Debre Zeit

Phase I	Phase II	Phase III. Wheat yield (kg/ha) at four N levels*				
Annual forage legumes (June-Mid-Sept.)	(June-Sept.)	Optimum level	sub-optimum level	Low level	None	Mean
Medicago scutellata	Chickpea	1911	1765	1569	1230	*1619*
Fallow + Chickpea	Chickpea	2065	1215	1119	631	*1258*
Trifolium steudneri	Chickpea	2603	2451	1617	1550	*2055*
Fallow (full season)	Fallow	2116	1023	769	653	*1140*
Vicia dasycarpa	Chickpea	2267	1720	1360	1158	*1626*
Trifolium quartinianum	Chickpea	3476	2258	1599	1498	*2208*
Fertilizer means		*2406*	*1738*	*1339*	*1120*	
C.V. %		12.72				

*Optimum N_2 level (64 kg N/ha), sub-optimum (32 kg N/ha), low level (18 kg N/ha), and zero (without N fertilizer). Source: Mengistu *et al.* (2010)

Table 11. Herbage yield of fodder crops grown on-farm at Akaki and Lumme, Ada'a District

Woreda	**Fodder crop type**	**Fodder yield (DM t/ha)***	**% composition of mixture**		
			Grass	**Legume**	**Weed**
Lome	Oats/*T. quartinianum*	3.224	90.08	5.58	4.35
Akaki	Oats/*T. quartinianum*	1.137	44.79	31.04	24.18
	Mean	*2.180*	*67.43*	*18.31*	*14.26*
Lome	Oats/Vetch	4.590	68.99	31.01	0.00
Akaki	Oats/Vetch	1.823	76.51	20.83	2.67
	Mean	*3.207*	*72.75*	*25.92*	*1.33*
Lome	Oats, pure	4.103	99.40	0.00	0.60
Akaki	Oats, pure	1.515	89.94	0.00	10.06
	Mean	*2.809*	*94.67*	*0.00*	*5.33*

* Oven dry weight with approximately 5% moisture. Source: Mengistu *et al.* (2010)

On-farm piloting of this practice on smallholder farmer's fields around Debre Zeit showed interesting result, in which farmers enjoyed the double crop of: 1) fodder legume with an average DM yields in the range of 2100 to 3200kg ha^{-1} and 2) food legume, i.e., chick pea with an average 1000kg ha^{-1}grain yield, which was within the range of the normal yield, as full season crop (Table 11).

Intercropping

Intercropping is a practice in which two fairly compatible crops, often a leguminous forage species and a cereal crop, are grown together at a given planting pattern in a season. Competition between the cereal and the intercrop is minimized through selection of lines with different growth rate, rooting pattern and adaptation to light intensity (Tedila and Jutzi, 1985; Tothill, 1987). The intercrop, being leguminous, fixes nitrogen, and thus, reduces competition with the cereal for nitrogen, which is often scarce in tropical soils. Different forage legumes have different intensity of reaction with cereal crops. Relay cropping is another form of intercropping practice, where a cereal crop is grown within or between the rows of forage, by offsetting the planting time of the cereal crop and the intercrop by two to three weeks to reduce competition.

The advantages of legume-cereal intercropping system include: the possibility of nitrogen accretion from the legume to the cereal; maintenance of continuity of feed supply, during the dry season; more efficient utilization of low-quality cereals, through the addition of high-protein forages; possibility of returning manure from livestock to the field; and increasing crop productivity. Annual dual-purpose legumes including cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*) are suited for intercropping with cereals (Tedila and Jutzi, 1985) and tall cereal crops, maize and sorghum (Tadesse *et al.*, 1987). Cow pea in particular is valued for its suitability for intercropping. It is a warm season crop well adapted to medium to low altitude areas, where it avails itself for intercropping with tall cereal crops, like maize and sorghum, which are dominant crops in warm to hot areas. Two cowpea varieties i.e., Sewunet and Temesgen were released in 2009 and 2014, respectively (MoANR-NVRC, 2016). Pigeon pea (*Cajanus cajan*) is an annual or short-lived perennial shrub legume, grown for dual use as pulse/fodder. Similar to cowpea, it is well adapted to medium to low altitude areas, which makes it suitable for intercropping with tall cereal crops, like maize and sorghum. Pigeon pea is tolerant to moisture stress and soil acidity (Mathews and Saxena, 2001; Singh *et al*, 2011).

Fodder bank/lay pastures

A fodder bank is a concentrated unit of forage legumes; established and managed by smallholder farmers near their homesteads for the dry season supplementation of selected animals (Tothill, 1987). Fodder bank, as with the various crop-livestock integration techniques, is devised to solve the critical shortage of protein in grazed native pastures and crop residues during the dry season, which is common across the highlands of Ethiopia. At the same time, the complex linkage of livestock and crop production necessitates cheap and sustainable soil fertility management practices. To that end, research has been underway to identify high biomass yielding and high protein source forage legumes that can be raised as fodder banks. Forage legumes selected for fodder bank system must be high yielding perennial or self-seeding annual legume species (Table 12) and able to fix soil nitrogen. Legumes established as fodder banks retain the protein content above 8% for a greater part of the dry season (Tothill, 1987). The high quality fodder produced is used as supplement to poor quality roughage basal diets (crop residues, native hay and natural pasture grazing), so as to keep the protein content of the total ration beyond the critical level of 8%, below which intake and digestibility of feedstuffs declines (Whiteman, 1983). The overall benefits of establishing forage legumes fodder bank includes: 1) improved health and body condition of draught animals (oxen), and hence enhanced capacity to till the soil 2) increased milk and meat production 3) improve the nitrogen content of soils (the most limiting soil nutrient in arable soils),through symbiotic N_2 fixation by the legumes. Some of the most common fodder legumes species that are suited for fodder bank includes: lablab (*Lablab purpureus*), cowpea (*Vigna unguiculata),* lucerne (*Medicago sativa),* green leaf desmodium (*Desmodium intortum*), silver leaf desmodium (*Desmodium uncinatum)*, common stylo (*Stylo santhesguianensis*), and siratro (*Macroptilium atropurpureum*).

Backyard forage legume crops

Backyard forage/fodder legume crops include highly productive species grown around farmer's homestead under intensive management conditions. The objective is to produce high quality fodder, as supplementary feed, to highly productive dairy cows and young animals. One form of backyard fodder is ‘live fencing’; whereby woody plants are planted in and around the housing compounds and farm yards. Live fences can be permanent or semi-permanent structures and different species of plants can suit to this purpose. The system has gained popularity among smallholder farmers, since it does not compete with food crops for arable land (Mengistu, 2004; Mengistu and Robertson, 1989).

Recent forage innovation surveys undertaken nationwide (Kigundu and Mengistu, 2009) indicates that most forage technologies successfully introduced to the farming community are based on backyard forage production strategy. The volume of fodder produced can be increased through the use of irrigation (from wells or surface water ponds), making multiple harvests possible. For instance, where water is abundant for irrigation, multiple harvests of high quality fodder has been possible every three to four weeks interval (about 10-12 cuts per year) from alfalfa (DZARC, 2011). Highly productive and intensive herbaceous fodder species recommended for this system includes: lucerne (*Medicago sativa)*, green leaf desmodium (*Desmodium intortum),* silver leaf desmodium (*Desmodium uncinatum),* common stylo (*Stylosanthes guianensis*) and siratro (*Macroptilium atropurpureum*), lablab (*Lablab purpureus*). Among the woody tree and shrub species suited for this purpose are: tree lucerne (*Chaemacytisus palmensis*), leucaena (*Leucaena pallida*), sesbania (*Sesbania sesban),* calliandra (*Calliandra calothyrsus*), desmanthus (*Desmanthus virgatus*), *and* pigeon pea (*Cajanus cajan*).

Development of Conventional Forage Legume Crops

Registered/Released Varieties of Forage Legumes

The ultimate objective of forage species introduction, breeding and selection is to release superior species/varieties for wider utilization; mainly as source of feed and for natural resource conservation in the farming systems and suited agro-ecologies. However, forage research activities have been going on without a formal variety release mechanism for quite a long period of time (IAR, 1976). Despite this, various promising forage species/varieties have been informally recommended and promoted to users via different livestock development projects like the Fourth Livestock Development Project (FLDP) and ARDP (Mengistu and Robertson, 1989; Mengistu, 2002), and utilized under varying scales in different parts of the country. Towards 1991, the forage crop variety release guideline started to be implemented in the country and by the end of the year 2016, the officially released/registered forage varieties increased to a total of 33, of which 20 were legumes (MoANR-PVRPSQCD, 2016) (Table 12).

It has been noticed that the number of officially registered varieties are still inadequate for a country with a highly diverse agro-ecological conditions. For instance, some forage species in the genera *Stylosanthes*, *Desmodium*, *Leaucanea* and *Bracharia* that have been found promising in the mid and lowland areas, did not pass through the formal variety improvement process, as per the new guideline of forage variety evaluation and registration. There are also various promising species that have not yet received due attention, such as the dual-purpose legumes pigeon pea (*Cajanus cajan*), cow pea (*Vigna unguiculata*); the various indigenous species of clovers (*Trifolium*) and medics (*Medicago*), which need to be subjected to the variety evaluation and registration procedures. Indigenous collection efforts must be intensified to acquire sufficiently diverse germplasm of the untapped forage genetic resources. For example, the recently identified indigenous perennial forage grass, locally named as 'Desho' (*Pennisetum glaucifolium* Hochst. Ex. Rich.), has become popular in most of the highland areas of Ethiopia, where government organizations (GOs) and non-government organizations (NGOs) have been promoting it both as fodder and soil conservation material, long before it passed through the formal research and variety release process. Similarly, collection and evaluation of potential indigenous legume species have been a priority area in forage research endeavors of EIAR. At present, a survey and collection expeditions for perennial clover species is underway in areas known to be centers of diversity.

Summary and Way Forward

Assemblage of genetic material from native collections and exotic sources

Introduction of new species offers a valuable opportunity to enhance the germplasm of forage crops to undertake selection, which might help identify forage species and varieties with high productivity and nutritional quality with stable long-term performance, buffered against greater variation in growing season, timing and intensity of rainfall, soil fertility, pests, diseases and management decisions associated with climate change and other emerging environmental threats. As outlined in Section 2, there is rich wealth of forage plant genetic resources with high potential for forage production; source of novel genes for breeding food and forage crops; soil fertility maintenance and erosion control, and environmental protection. These resources are exposed to extreme habitat destruction and threats of extinction before a single population has been collected, evaluated and conserved. Hence, resources must be allocated and rescue collection efforts need to be intensified without any further delay.

Acquisition of forage germplasm and establishment of facilities for conservation and utilization

A survey on the diversity of species, varieties and accessions undertaken by some of the federal research centers has revealed ridiculously narrow genetic material available for screening, selection and development of varieties required for different environments and production systems. Most centers work on just a few species and the accessions under each species are below five.

Table 12. List and herbage productivity of officially registered/released forage legume species and varieties (MoANR-PVRPSQCD, 2016)

No.	Species	Variety	Common Name	Adapted to altitude (m)	Forage (DM t/ha)/ grain (q/ha)	Year released	Breeder
	Herbaceous Legumes						
1	*Lablab purpureus*	-	Lablab	1000-2004	3.0-5.0	1984	HARC
2	*Lablab purpureus*	ILRI 14417	Lablab	800-2000	Forage 8.43; grain 17.33	2015	BARC-OARI
3	*Lablab purpureus*	ILRI 14455	Lablab	800-2000	Forage 8.37; grain 17.96	2015	BARC-OARI
4	*Lupinus angustifolius*	Sanabor	Sweet lupine	1935-2610	grain, 31 q/ha	2014	ARARI
5	*Lupinus angustifolius*	Vitabor	Sweet lupine	1935-2610	grain, 28 q/ha	2014	ARARI
6	*Medicago sativa*	DZF-552	Alfalfa	500-2400	3.0-4.0	2014	DZARC
7	*Sesbania macrantha*	DZF-092	Macrantha	500-2200	Leaf hay 3, wood 6	2012	DZARC
8	*Trifolium quartinianum*	-	Clover	1500-3000	3.0-6.0	1976	HARC
9	*Vicia dasycarpa*	Lana	Vetch	1500-3000	5.0-7.0	1976	HARC
10	*Vicia narbonensis*	Abdeta	Narbon vetch	2300-3000	3.1-3.4	2011	SARC
11	*Vicia sativa*	ICARDA-61509	Vetch	2200-2004	5.0-6.0	2012	HARC
12	*Vicia sativa*	Gebisa	Vetch	2300-3000	4.3-5.1	2011	SARC
13	*Vicia villosa*	Lalisa	Vetch	2300-3000	6.6-8.4	2011	SARC
14	*Vigna unguiculata*	Sewinet	Cowpea			2009	PARC
15	*Vigna unguiculata*	Temesgen	Cowpea			2014	HARC-TARI
	Browse Trees and Shrub Legumes						
16	*Cajanus cajan*	Dursa	Pigeon pea			2009	MARC
17	*Cajanus cajan*	Tsigab	Pigeon pea	590-1000	Forage 14-29 grain, 53q/ha	2009	HARC-TARI
18	*Cajanus cajan*	Kibret	Pigeon pea	967-1200	Forage 15-62 grain, 48q/ha	2009	HARC-TARI
19	*Chamaecytisus palmensis*	-	Tagasaste	2000-3000		1992	HARC
20	*Sesbania macrantha*	DZF-092	Sesbania	400-2000	3.0-4.0	2012	DZARC

In most centers, seeds are kept in rooms meant for office, without any modifications to control temperature and humidity. Again, almost in all centers, irrigated nurseries, lath houses and greenhouse facilities are lacking to maintain sterile or shy seeder species. As a kick-off towards improving the availability and maintenance of forage legume genetic resources, at least some of the research centers need to undertake rejuvenation of old collections, the viability of which might be so poor as to entail the risk of being lost. There is also a need to establish new working collections; while at the same time a base collection can be established at a strategic location for long-term conservation that may serve as the source of breeding material. This task will have paramount importance to the research system, because, so far, forage germplasms have not been collected, conserved and provided to the forage researchers from local institutions, such as the national Biodiversity Institute. Researchers have totally relied on Consultative Group on International Agricultural Research (CGIAR) centers, like International Livestock Research Institute (ILRI) and International Center for Agricultural Research in the Dry Areas (ICARDA), which are globally mandated for supply of germplasm for research purposes.

The use of biotechnology tools for forage breeding

So far, the country's forage breeding efforts focused on variety selection that helps meet certain agronomic and nutritional requirements through the conventional techniques. In the future, the breeding program need to make use of hybridization based genetic improvement of forage legumes and modern biotechnological tools with the aim of developing genetic solutions for the most critical biotic and abiotic constraints of forage production and productivity. In addition, genomic selections in forage grasses and legumes has to be employed in the variety improvement program of the country, so as to increase selection efficiency, accuracy, and reduce screening cycle, time, and evaluation costs per genotype.

Microbiology studies

Rhizobium inocula development

Many of the elite forage legume varieties, such as clovers, medics and lucerne fail to perform as good as in their native habitat or in the compound of the research centers. This has been a challenge for researchers who have been confronted with disappointing results in promoting the improved feed varieties to users. One of the possible reasons identified for the lack of success has been the inability of the legume species and varieties to take up the right strain of *Rhizobium* bacteria responsible for nitrogen fixation in soils away from their natural area of distribution. Such *Rhizobium* strain-specific legume species and varieties need inoculum of compatible strains that must be identified through isolation, characterization and culturing of *Rhizobium* bacteria collected from their native area of distribution. Consequently, researchers have been collecting nodules from targeted legume's native area of distribution for subsequent isolation and culturing of bacterial strains and develop inocula. However, such efforts need to be strengthened through capacity building, including training of manpower and establishing microbiology laboratory facilities.

Pathology

Several forage varieties have been registered or released in the past decade, some of which are scaled out to users, regardless of the limited acreage established per household. However, there has been little emphasis on the management of some of the most important diseases and pest outbreaks. Understandably, alongside variety development efforts, capacity building, in terms of trained manpower and laboratory facilities, are required that might help undertake crop protection research, diagnosis of common diseases and pests; and design control measures, including selection of resistant varieties and introgression of the resistance genes into the existing adapted varieties.

Breeding for reducing impact of climate change and enhancing adaptive capacity

Global climate change is likely to affect the adaptive capacity of most forage species in the long term. Hence, there is a need to identify and incorporate the relevant adaptive traits into existing and new forage species and varieties, so as to maintain and enhance the productivity of both native grasslands and improved pastures in the face of rapidly changing environmental constraints (Abberton *et al.,* 2008).

Realizing the potential contributions of managed pastures and grasslands to food security and reducing the environmental impact of livestock agriculture, the targets and approaches of forage plant breeding programs need to consider animal production systems that adapts to climate change focusing on: (i) developing forage varieties with high plasticity of adaptation to varied environmental conditions (ii) developing forages with improved drought tolerance, enhanced water use efficiency and tolerance to salinity (iii) select forage species and varieties that are tolerant to floods and related consequences of changes in rainfall patterns (iv) select forage species and varieties efficient in maintaining nutrient use efficiency (v) select forage species and varieties with high forage quality, and (vi) introduction of new species or ecotypes, as source of novel genes to breed for drought tolerance and other desirable traits.

Breeding and selection for improved crop adaptation, yield and quality

Forage species are generally adapted to specific climatic regions, and at the center of their adaptive zone may regularly survive extremes of temperature and moisture, as well as, stress of lax management (Nelson and Moser, 1994). Both genotypic and phenotypic plasticity influence adaptation (Nelson, 2000); the former depends upon survival of genotypes making up the population, and the latter results from interaction between the genotype and environment. Alfalfa (*Medicago sativa*) is an example of a forage species with high genotypic and phenotypic plasticity enabling its adaptation to many eco-regions (Baron and Bélanger, 2007). Species with high adaptive plasticity must be assembled from native and exotic sources, as source of novel genes that can be incorporated into successful crops under production.

Breeding and selection for drought tolerance

Drought is an important environmental factor limiting the productivity of crops worldwide. Climate change models predict greater variability in rainfall patterns and increased periods of drought will affect many regions, including grassland systems. Predicted population growth also requires the available water is used for domestic and industrial use, rather than irrigation (Condon *et al*., 2004). Nowadays, there is an increasing global emphasis in forage plant breeding programs that target selection of varieties with better tolerance to prolonged periods of water deficit. Molecular marker technologies and their use in quantitative trait loci (QTL) analysis have provided effective new opportunities for the study of plant responses to environments, including traits for tolerance to drought (Courtois *et al*., 2000; Yadav *et al*., 2002, 2004). Molecular marker technology provides opportunities not only to identify QTL that determine complex phenotypes such as drought tolerance (Tuberosa and Salvi, 2006), but also to greatly improve the efficiency of genetic improvement by facilitating introgression of desirable traits through the use of linked markers (Tanksley, 1993, Mohan *et al*., 1997).

Breeding for forage quality

Breeding for forage quality involves selection for the three main components of forage quality i.e., digestibility, intake potential and energetic efficiency (Raymond, 1969). These require evaluation as proxy traits like in vitro dry matter digestibility (IVDMD), acid detergent lignin (ADL) and neutral detergent fibre (NDF). Breeding for quality considers compositional traits, such as digestibility of a species/variety, which is identified the most achievable target, as it is a repeatable and heritable trait, measured in terms of genetic variation in IVDMD (Casler, 2001; 2006), and its improvement is highly geared towards changes in profitability of livestock enterprises (Vogel and Sleper, 1994). Selection criteria including stability in ratios of soluble carbohydrate: structural carbohydrate concentrations; leaf-to-stem ratio, and lignin contents under fluctuating environmental conditions, are worth evaluating in the context of maintaining overall digestibility. Studies have showed that lignin, measured as acid detergent lignin (ADL), accounted for up to 80% of variation in IVDMD (Casler, 2001). However, Clark and Wilson (1993) have reported that breeding explicitly for lower lignin contents, as an adaptive measure can have a possible knock-on effect on traits, such as yield and drought tolerance, particularly, if realized through increase in leaf-to-stem ratio.

In conclusion, legumes play pivotal role in food security of societies and stabilizing agro-ecosystems. They provide high quality animal feed; while maintaining the fertility of arable land, grassland and forest soils via their unique ability to fix atmospheric N_2 in symbiotic relationship with *Rhizobia* bacteria. Legumes also stabilize agricultural production systems and the environment by increasing soil carbon content and stimulating the productivity of subsequent crops in rotational cropping systems. They contribute to climate change mitigation through reduction of greenhouse gas emissions, lower the use of fossil energy, and accelerate the rates of carbon sequestration. Therefore, legumes should receive the highest emphasis in future forage breeding and variety development programs.

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Part III. Natural Resources and Crop Management Research in Food and Forage Legumes of Ethiopia

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GIS-Based Land Suitability Mapping for Legume Crops Technology Targeting and Scaling-Up

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Abstract

It is essential to utilize the scarce land resource optimally and sustainably based on its suitability for a particular use. Suitability is a function of land characteristics and crops requirements; and it involves evaluation and matching of the land characteristics with a particular crop requirement. The main aim of this study was to identify lands suitable for selected legume crops using a GIS-based analysis for rainfed production at the national level. The crops considered includes: faba bean, field pea, lentil, chickpea, haricot bean, soybean and cowpea. The lands were categorized into four suitability classes, namely: not suitable (N), marginally suitable (S3), moderately suitable (S2) and highly suitable (S1). Accordingly, taking into account the total area of the country, the suitability analysis shows that 25,650,924 (22.66%), 23,100,500 (20.4%), 18,207,028 (16.1%), 23,567,012 (20.1%), 32,786,580 (29.0%), 42,067,700 (37.2%) and 48,904,652 (43.2%) hectare of land in the country are moderately to highly suitable for faba bean, field pea, lentil, chickpea, haricot bean, soybean and cowpea, respectively. Lands occupied by forests, woodlands and towns, except Addis Ababa, Dire Dawa and Harari, were not excluded in this analysis. These crops are not mutually exclusive, since they overlap in locations where they share similar adaptation areas. Hence, it should be noted that the actual available land would be lower than what is reported in this paper. The moderately to highly suitable areas for faba bean, field pea, lentils and chickpea are situated in the mid to high altitude areas of the country; while haricot bean, soybean and cowpea are mainly suitable in the low to mid altitude areas of the country. These legume crops are widely suitable in different regions of the country that shows the potential for expanding their production.

Keywords: *GIS, legumes, land suitability, mapping, environmental requirements*

Introduction

Ethiopia is a vast country with diverse agro-ecologies, which is mainly attributed to the wide altitudinal ranges of the country (ranging from about 116 to 4550 masl) (Nigussie, 2014). The existences of diverse farming systems, agro-ecologies, socio-economic and cultures have also greatly contributed to the country's biological wealth of species diversity, especially crops (IBC, 2007).

The major food crops produced in almost all regions of the country varies in volume of production, which might be attributed to the size of area allocated to each crop; difference in the crop management practices, weather conditions and shifts in preference to the crops grown (CSA, 2015). Crop yields are inevitably affected by many factors, such as farming practices, weather conditions, input price, low use of inputs, such as fertilizers and pesticides, lack of use of good quality seeds of the improved varieties, and very low use of irrigation facilities(CSA, 2015). Such and other constraints led to the low productivity of various crops; as a result, the country remained food insecure for several years. This is also partly due to lack of appropriate land use planning and decision-making for efficient use of available farming land.

The overall productivity of most crops is still not adequate in the country. To improve the production and productivity, appropriate land use planning should be considered among the decisive actions, which helps to allocate land systematically to the best uses considering the biophysical potentials, socio-cultural and economic factors. Different crops require different land quality and growing conditions, and different areas have different potentials and constraints for a particular use. Sufficient information about land resources and their potential for various uses is thus essential for land use planning and in making decisions what to grow where (FAO, 1993; Mustafa *et al.*, 2011).Geographic Information System (GIS) is a useful tool and application that can provide the capacity to combine and analyze the different geospatial layers for suitability analysis of land use.

In Ethiopia, the land use practices have been in most cases not planned. Consequently, some of the agricultural land uses may not match to the actual potential of the land. Cropland suitability analysis is an important prerequisite to achieve optimum utilization of the land resources for sustainable agricultural production (Perveen *et al.*, 2007). FAO (1976) defined land suitability as ‘the fitness of a given type of land for a specified kind of land use’. Appropriate decision on crop technology targeting crop production and productivity avoids various risks associated to it. If potentials and constraints of the land are properly identified, it will be easy to choose or develop appropriate technologies and extend them to appropriate locations.

This study is a qualitative, nationwide land suitability analysis; i.e., the results are qualitative without indicating socio-economic returns. Hence, the assessment is limited to the evaluation of physical factors, such as climate, topography, soils and land use/cover. Moreover, this study focused only on rain-fed agriculture. This national level suitability study is constrained by scarcity of reliable and accurate geospatial data in the required scale having a national-coverage. Hence, the scope of this suitability analysis is limited to the available data and analysis components outlined in the approaches and procedures section.

The main aim of this study was to conduct land suitability analysis using a GIS-based tool for selected major legume crops grown in the country. The crops include: faba bean, field pea, chickpea, lentil, common bean and soybean, which according to CSA (2016) report covers 3.56% (443,966 ha), 1.77% (221,415.67 ha), 0.81% (100,693 ha), 2.07% (258,486 ha), 1.95% (357300 ha) and 0.31% (38,166 ha) of the total grain crop area of the country, respectively.

Approaches and Procedures

The GIS-based land suitability analysis was undertaken for selected legume crops grown in the country, considering the total land area of the country (Table 1). The estimated total land area of the country, i.e. 113,216,009 ha, was used as the basis, where Oromia ranked first (28.66%), and followed by Somali (27.88%), Amhara (13.75%), SNNP (9.97%), Afar (8.45%), Tigray (4.43%), Benishangul Gumuz (BSG) (4.5%), and Gambella (2.27%) regions. Parks and lakes were excluded in the land suitability analysis. Furthermore, lands occupied by forests, woodlands and towns, except Addis Ababa, Dire Dawa and Harari, were not excluded in the suitability analysis. Hence, it should be noted that the actual available suitable land would be lower than what is presented in this study. The total land area and proportion of the different suitability classes were calculated in reference to the total area of the respective regions.

Table 1. Area (ha) of regional and city administrative states

Region Name	Area (ha)	%
Tigray	5,020,658	4.43
Afar	9,562,336	8.45
Amhara	15,563,369	13.75
Benishangul Gumuz(BSG)	5,000,357	4.42
Oromia	32,449,413	28.66
Somali	31,561,965	27.88
Dire Dawa	105,556	0.09
Harari	37,165	0.03
Addis Ababa	55,069	0.05
Southern Nations and Nationalities (SNNP)	11,289,986	9.97
Gambella	2,570,136	2.27
Total Area	113,216,010	

Geospatial data

Large amount of data is required to undertake land suitability analysis for crops. Due to the large number of attributes and various criteria involved in decision-making, agricultural land suitability evaluation has been identified as a multi-criteria evaluation problem (Abd El-Kawy*et al.*, 2010). Soil properties, temperature, rainfall and other environmental factors influence the development, growth and yield of crops.

Most factors, mainly those related or controlled by climate, vary in time (temporal variability) and vary across the landscape (spatial variability) (AIWG, 1995). The main factors considered in this analysis related to plant growth include: climate layers (rainfall and temperature during the growing period, and length of growing period-LGP); topography (digital elevation models-altitude data and slope); soil types, soil chemical (pH) and physical (effective soil depth, soil texture, and drainage) properties; administrative boundaries and infrastructure (roads, towns, and other facilities); and land use/land cover map.

Since climate plays a major role in crop production, more weight was given in this analysis. The climate data used were rainfall and temperature surface maps (during the growing period) interpolated at a resolution of about 300 m, which again resampled to 200 m to match the 200 m analysis resolution, and LGP of Ministry of Agriculture and Rural Development (MoARD) was used with a slight modification. Climatic conditions can vary widely from year to year, and this was addressed using long-term means and the approach is valid as long as the aim is to assess overall suitability or potential, and not to model crop growth in any one year (AIWG, 1995).

The soil data used were soil type and soil properties, which include effective soil depth, soil texture, and drainage; and the data were acquired from two sources. The soil properties were extracted from Soil and Terrain Database of East Africa (SEA); while the soil type used was from MoARD modified by Woody Biomass Inventory and Strategic Planning Project (WBISPP). For the altitude information, Shuttle Radar Topography Mission (SRTM) 90 m (Jarvis *et al*., 2008) Digital Elevation Model (DEM) database was used. This data was resampled to a resolution of 200m to fit the analysis resolution, which is 200m. Slope map was derived from this SRTM database.

Methods

In a suitability analysis, some value ranges in a particular criteria layer may be more suitable for the purposes; while others may be moderate, marginal, and still others unsuitable (ESRI, 2016). Since the input criteria layers were in different numbering systems with different ranges, each cell for each criterion must be reclassified into a common preference scale, such as 1 to 10, with 10 being the most favorable to combine them in a single analysis, (ESRI, 2016).In this work, each layer was reclassified to have a common scale with the higher value being more favorable. After the important crops' environmental requirement and geospatial data were identified, each criteria layer was reclassified according the suitability value ranges limits (boundaries) and assigned a scale value. Based on the common scale values assigned to each pixel and weight assigned to each criteria layer, the land suitability maps were generated using weighted overlay approach built on ModelBuilder of ArcGIS software. Finally, tabular data showing the area and proportion of the potential growing areas of the legume crops in the country is prepared for each crop.

Defining the limits of crop's environmental requirements

In order to define the suitability classes, based on the land use types, several literatures, such as research result reports of EIAR and several series of variety register books were reviewed and discussed with researchers. The performance suitability and ranges/limits were defined based on the information collected on the environmental requirements of the various crops indifferent locations. For classification of the data layers according to the degree of favorability for each crop, the existing maps, reports and other relevant information were reviewed and used in defining the limits of the suitability ranges of the crops. The land evaluations study conducted by the FAO (1984), Sys *et al*. (1993) and EIAR (2007) were used as the main basis. The environmental requirements of the selected legumes were collected from the abovementioned references. Then, the crop environmental requirements were defined by means of a set of critical values that determine the limits between the land suitability levels (classes). The suitability classes considered were S1 (very suitable), S2 (moderate suitable), and S3 (marginally suitable) and N (not suitable).

Since the analysis was a raster based, some of the data, which were in vector format, were converted to raster format. The reclassification of each layer into suitability levels was done using Reclassify by Table tool of the spatial analyst tool. This was implemented in the model by preparing separate tables for each factor and crop.

Calculation of weight for criteria layers and overall suitability analysis

The overall suitability map is the combined results of altitude, soil types and properties, and the climate layers. Each of the criteria layer in the weighted overlay suitability analysis may not be equal in importance. The purpose of weighting is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate (Perveen *et al.,* 2007). The weighted overlay approach built on ModelBuilder was used for the weighted overlay analysis to solve, such multi-criteria problems of suitability. Therefore, each criteria layer was assigned weights that accounts for their relative importance/influence in the growth of the crops, and combined (overlaid) using weighted overlay to produce the overall land suitability map.

The field check

The fieldwork was mainly important to observe and extract additional environmental information to help adjust the rating and limits of each factor. It is also necessary to confirm whether the suitability classes obtained from the preliminary analysis are in agreement with what is expected by expert judgment. In view of this, several *woredas* (districts) anticipated to have potentials to at least two crops under consideration were surveyed and relevant data were collected to improve the final suitability analysis. While surveying the selected *woredas*, information related to growing location, potentials and constraints were collected from each *woreda* in consultation with the crop specialists and two farmers from each *woreda*. For this, a simple *woreda* level and farmer level questionnaires were filled-up during the field survey. Moreover, maps showing *kebele* (lowest administration level) boundaries of each visited *woreda* was prepared and tried to group each of the *kebeles* into different suitability for crops under consideration and grown in the *woreda*. The overall methodological approach flowchart of suitability analysis is shown in Figure 1 below.

Results and Discussion

This land suitability analysis includes faba bean, field pea, chickpea, lentil, common bean, soybean and cowpea. The results are presented below in the form of maps, tabular data and graphs.

The land suitability was categorized into four suitability classes, namely: not suitable (N), marginally suitable (S3), moderately suitable (S2) and highly suitable (S1) for the crops considered in this study. Accordingly, the combined estimate of moderately and highly suitable lands is 25,650,924 (22.66%) for faba bean, 23,100,500 (20.4%) for field pea, 18,207,028 (16.1%) for lentil, 23,567,012 (20.1%) for chickpea, 32,786,580 (29.0%) for common bean, 42,067,700 (37.2%) for soybean and 48,904,652 (43.2%) for cowpea in the country (Figure 2). For example, for faba bean, 1,884,700 ha (1.66%) is highly suitable, 23,766,224 ha (21.0%) is moderately suitable, 2,251,192 ha (2.02%) marginally suitable and 85,116,104 ha (75.26%)) not suitable across the country.

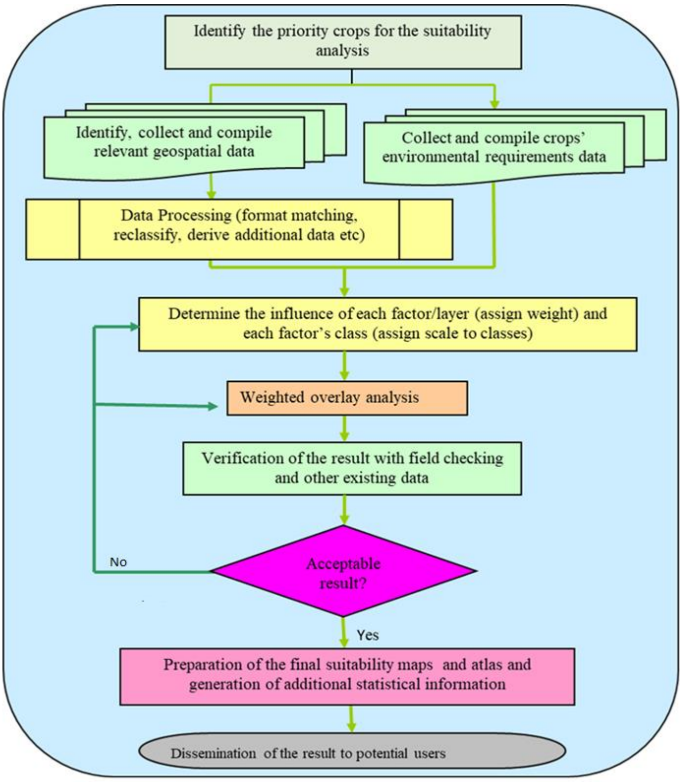

Figure 1. Methodological flowchart of suitability analysis process

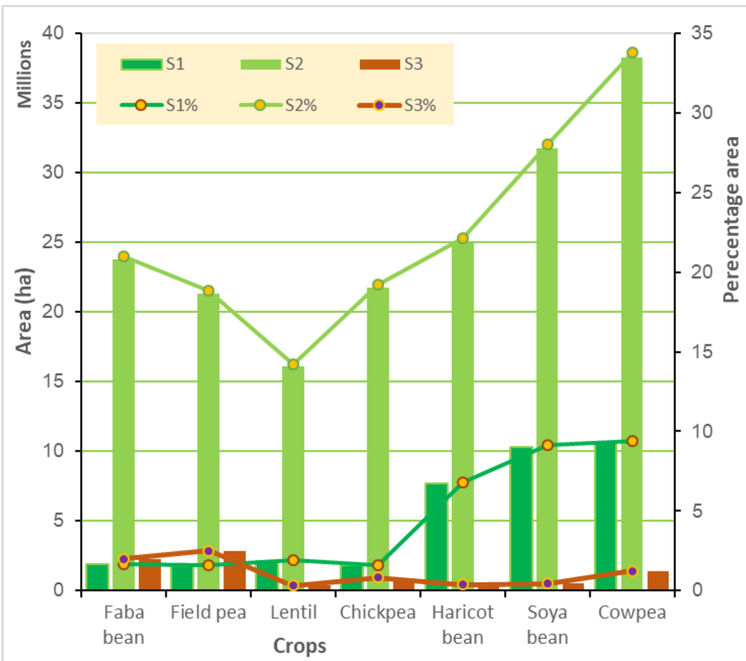

Figure 2. Area (in ha) and percentage area under different suitability classes of selected legume crops in Ethiopia

Land suitability for faba bean (*Vicia faba*)

Land suitability analysis for faba bean is presented in Figure 3 and Table 2. Accordingly, about 25,650,924 ha (22.66%) of the country is moderately and highly suitable for faba bean production, where 11.3(10%), 8.1(7.1%), 3.8(3.4%) and 1.6(1.4%) million ha of the areas are in Oromia, Amhara, SNNP and Tigray regions, respectively. Oromia region stands first in terms of total area of moderately suitable and highly suitable land for faba bean production, and estimated at 10.2 and 1.1 million ha, respectively; followed by Amhara region which stood second with 8.1 and 0.63 million ha in the same order. Southern Nations and Nationalities Peoples Region (SNNPR) is the third with 3.7 and 0.16 million ha of moderately and highly suitable land for faba bean, respectively. Tigray ranks fourth with 1.6 million ha of moderately suitable and 1,908 ha of highly suitable land area in terms of faba bean production.

In terms of percentage area of suitability, the results of suitability analysis of this study show that faba bean has large proportion of highly suitable and moderately suitable land in Amhara, which accounts for 4.06% and 51.91% of the total area respectively. Oromia region has the next largest proportion of highly suitable (3.36%), followed by SNNP (1.44%). Whereas, for moderately suitable land SNNP (32.39%) comes second followed by Oromia (31.47%).

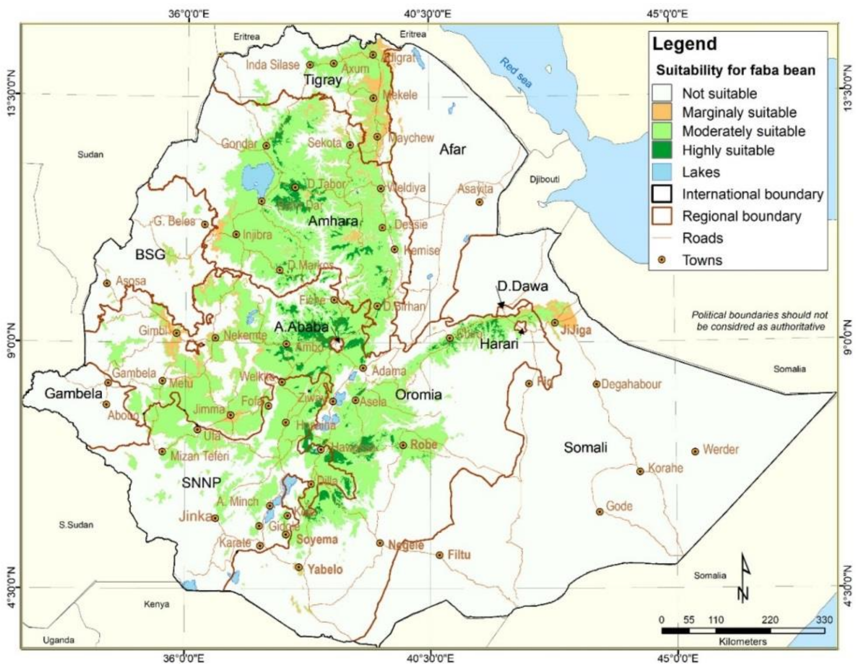

Figure 3. Land suitability map for faba bean (Nigussie, 2014)

Table 2. Area of land under different suitability classes for faba bean (Nigussie, 2014)

Regions	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Tigray	2,931,138	58.38	528,192	10.52	1,559,420	31.06	1,908	0.04
Afar	9,469,192	99.03	81,020	0.85	12,124	0.13	0	0.00
Amhara	6,405,789	41.16	448,156	2.88	8,078,204	51.91	631,220	4.06
BSG	4,841,309	96.82	61,076	1.22	97,972	1.96	0	0.00
Oromia	20,318,485	62.62	829,868	2.56	10,212,376	31.47	1,088,684	3.36
Somali	31,198,677	98.85	221,336	0.70	141,776	0.45	176	0.00
SNNP	7,388,366	65.44	81,544	0.72	3,657,364	32.39	162,712	1.44
Gambella	2,563,148	99.73	0	0.00	6,988	0.27	0	0.00

Land suitability for field pea (*Pisum sativum*)

Moderately and highly suitable lands in combination are estimated to cover about 23,100,500 ha of land, which is 20.4%, where 9.3, 6.78, 3.3 and 1% of the areas are found in Oromia, Amhara, SNNP and Tigray regions, respectively (Figure 4 and Table 3). Oromia region stands first in terms of total area of moderately suitable and highly suitable land for field pea production estimated at 9.5 and 1.1 million ha, respectively; followed by Amhara which stood second with 7.2 and 0.41 million ha in the same order. Southern Nations and Nationalities Peoples Region (SNNPR) is third with total area of moderately suitable and highly suitable land for field pea production with 3.64 and 0.23 million ha, respectively. Tigray ranks fourth with 1.1 million ha of moderately suitable and 31,708 ha of highly suitable land area for field pea production.

Field pea occupied large proportion of moderately and highly suitable land in the Amhara region, which accounts for about 46.20% and 2.60% of the total area of the region, respectively. The proportion of moderately and highly suitable land in SNNP region is estimated at 30.3% and 2.3%, respectively. Similarly, Oromia region has 29.31% and 3.3% of moderately and highly suitable land of the total area of the region, respectively.

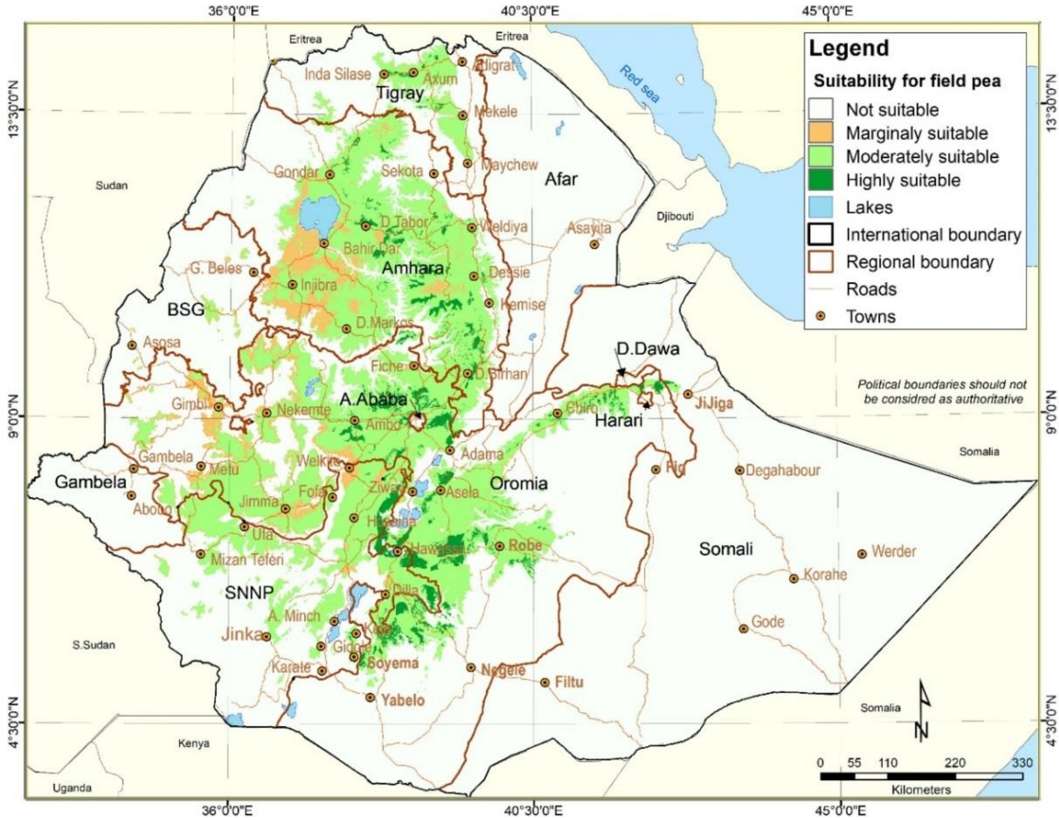

Figure 4. Land suitability map for field pea (Nigussie, 2014)

Table 3 Area of land under different suitability classes for field pea (Nigussie, 2014)

Region	Land suitability class							
	N		**S3**		**S2**		**S1**	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Tigray	3,888,530	77.45	27,940	0.56	1,072,480	21.36	31,708	0.63
Afar	9,561,848	99.99	0	0.00	488	0.01	0	0.00
Amhara	6,639,161	42.66	1,322,024	8.49	7,196,688	46.24	405,496	2.61
BSG	4,841,237	96.82	54,052	1.08	105,068	2.10	0	0.00
Oromia	20,690,897	63.76	1,189,772	3.67	9,495,908	29.26	1,072,836	3.31
Somali	31,526,729	99.89	1,468	0.00	26,516	0.08	7,252	0.02
SNNP	7,372,670	65.30	236,728	2.10	3,425,500	30.34	255,088	2.26
Gambella	2,563,144	99.73	1,520	0.06	5,472	0.21	0	0.00

Land suitability for lentil (*Lens culinaris*)

The suitability analysis depicted that lentil production covers about 18,207,028 (16.1%) ha of the country is moderately and highly suitable, where 8.0, 4.5 and 3.2% of the areas are in Oromia, Amhara and SNNP regions, respectively (Table 4 and Figure 5). Table 4Oromia region stands first in terms of total area of moderately suitable and highly suitable land for lentil production with an estimated 7.8 and 1.3 million ha, respectively; followed by Amhara which stood second with 4.8 and 0.27 million ha in the same order (Table 4). Southern Nations and Nationalities Peoples Region (SNNPR) is third in terms of moderately suitable and highly suitable land for lentil production with respective land size of 3.0 and 0.59 million ha.

The proportion of suitability area by region shows that lentil has largest proportion of moderately suitable land in Amhara region, which accounts for 31.0%, while the largest proportion of highly suitable land is found in the SNNP region with 5.2% of the total area of the region. Similarly, Oromia and Amhara regions have the next largest proportion of highly suitable land of 3.9 and 1.7% of the total area of the regions, respectively. The moderately suitable land in Amhara, SNNP, Oromia, and Tigray was estimated to be 32.0, 26.8, 24.0 and 7.5% of the land of the regions, respectively.

Table 4. Area of land under different suitability classes for lentils by region

Region	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Tigray	4,581,470	91.25	54,580	1.09	374,764	7.46	9,844	0.20
Afar	9,561,156	99.99	0	0.00	1,180	0.01	0	0.00
Amhara	10,343,801	66.46	125,180	0.80	4,828,196	31.02	266,192	1.71
BSG	4,977,385	99.54	0	0.00	22,972	0.46	0	0.00
Oromia	23,242,649	71.63	144,936	0.45	7,783,036	23.99	1,278,792	3.94
Somali	31,523,757	99.88	4,420	0.01	32,540	0.10	1,248	0.00
SNNP	7,649,998	67.76	31,724	0.28	3,023,240	26.78	585,024	5.18
Gambella	2,570,136	100.00	0	0.00	0	0.00	0	0.00

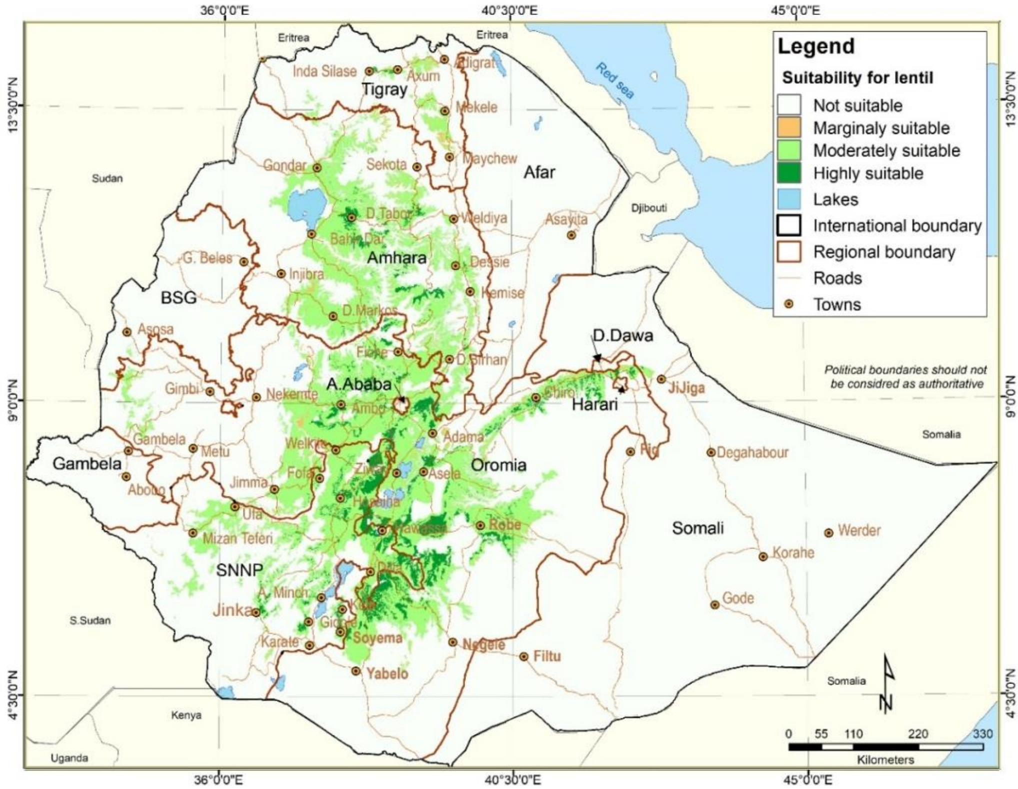

Figure 5. Land suitability map for lentils

Land suitability for chickpea (*Cicer arietinum*)

Chickpea has the second largest proportion of highly and moderately suitable land of 23,567,012 (20.1%) ha in the country, although the highly suitable area is relatively low (Figure 6 and Table 5) in Oromia, Amhara, SNNP and Tigray with an estimated 10.9, 7.0, 4.0 and 1.5 million ha of land, respectively. Oromia region stands first in terms of total area of moderately and highly suitable land for chickpea production with an estimated area of 9.7 and 1.2 million ha, respectively; followed by Amhara region which stood second with 6.8 and 0.21 million ha of land in the same order (Table 5). Southern Nations and Nationalities Peoples Region is the third in total area of moderately and highly suitable land for lentil with 3.6 and 0.42 million ha, respectively; whereas Tigray region is fourth with an estimated 1.5 and 0.027 million ha of that is moderately and highly suitable land area in the same order.

Amhara (43.5%), SNNP (32.3%), Oromia (30.1%) and Tigray (29.0%) stood first to fourth in the proportion of moderately suitable chickpea production area. Whereas, 3.7, 3.6, 1.3 and 0.5% of the total area of SNNP, Oromia, Amhara and Tigray regions, respectively, are considered highly suitable for chickpea production.

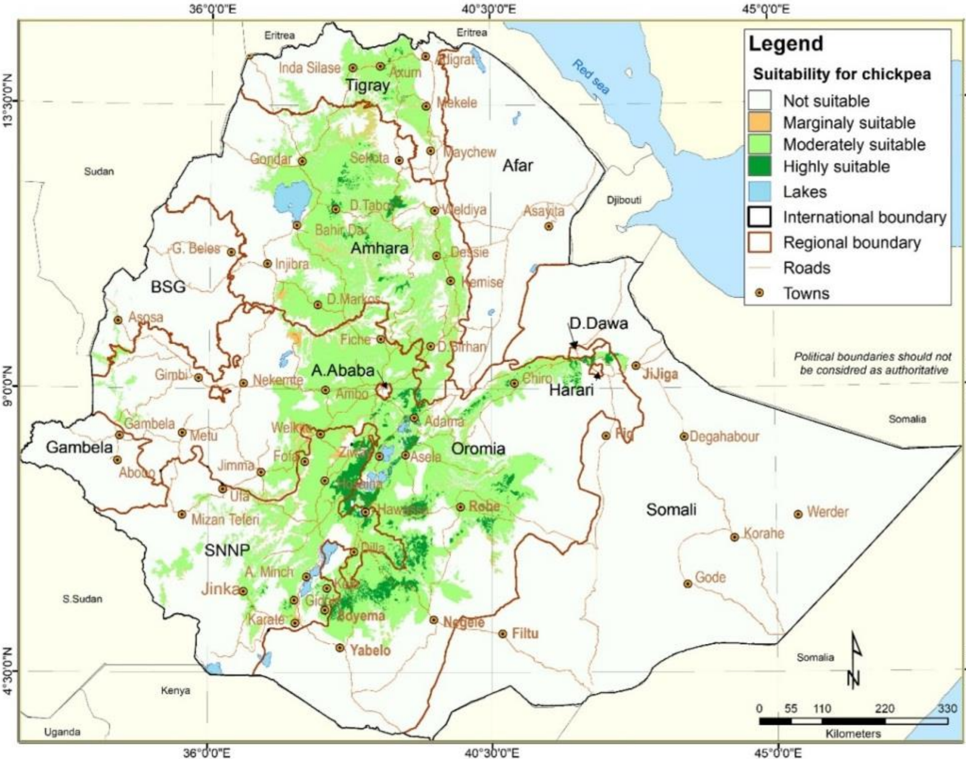

Figure 6. Land suitability map for Chickpea

Table 5. Area of land under different suitability classes for chickpea by region

Region	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Tigray	3,472,002	69.15	63,416	1.26	1,457,972	29.04	27,268	0.54
Afar	9,546,764	99.84	156	0.00	15,416	0.16	0	0.00
Amhara	8,198,209	52.68	395,096	2.54	6,765,112	43.47	204,952	1.32
BSG	4,931,629	98.63	8,548	0.17	60,180	1.20	0	0.00
Oromia	21,289,441	65.61	249,808	0.77	9,751,300	30.05	1,158,864	3.57
Somali	31,493,881	99.78	7,240	0.02	57,168	0.18	3,676	0.01
SNNP	7,039,930	62.36	185,812	1.65	3,646,948	32.30	417,296	3.70
Gambella	2,569,248	99.97	28	0.00	860	0.03	0	0.00

Land suitability for common bean (*Phaseolus vulgare*)

The suitability analysis showed that common bean production occupied the third highest area of 32,786,580 (29.0%)ha of highly and moderately suitable land area in the country; where the contribution of Oromia, Amhara, SNNP, Benishangul Gumuz (BSG) and Tigray was 12.9, 6.1, 5.3, 2.3 and 2%, respectively (Figure 7, and Table 6). Oromia, Amhara, SNNP, BSG and Tigray regions, in decreasing order, contributed to the largest proportions of highly and moderately suitable land of 14.4, 6.8, 6.0, 2.7 and 2.3 million ha, respectively.

The regional coverage of common bean showed that the proportion of highly suitable land in SNNP, Oromia, Tigray and Amhara regions accounted for 14.7, 13.9, 7.3 and 7.2% of the country's total common bean potential area, respectively. Regions that have the largest proportion of moderately suitable land are BSG (53.0%), SNNP (38.8%), Tigray (38.0%), Amhara (36.8%) and Oromia (31.3%).

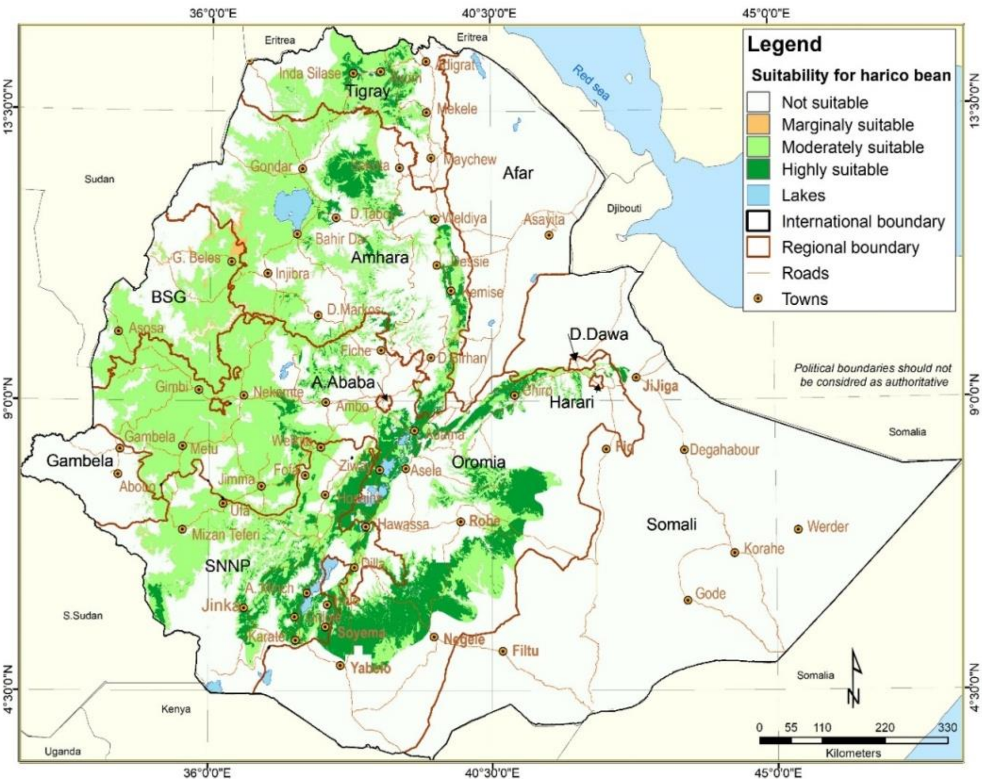

Figure 7. Land suitability map for haricot bean

Table 6. Area of land under different suitability classes for haricot bean by region

Region	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Tigray	2,725,810	54.29	17,204	0.34	1,909,844	38.04	367,800	7.33
Afar	9,511,832	99.47	0	0.00	48,280	0.50	2,224	0.02
Amhara	8,587,677	55.18	125,836	0.81	5,731,976	36.83	1,117,880	7.18
BSG	2,156,253	43.12	193,552	3.87	2,650,552	53.01	0	0.00
Oromia	17,729,661	54.64	34,984	0.11	10,160,384	31.31	4,524,384	13.94
Somali	31,465,089	99.69	264	0.00	63,732	0.20	32,880	0.10
SNNP	5,216,982	46.21	40,204	0.36	4,377,832	38.78	1,654,968	14.66
Gambella	2,426,276	94.40	16	0.00	143,844	5.60	0	0.00

Land suitability for soybean (*Glycine max*)

The land suitability analysis shows that soybean is the second among legumes in terms of land area that is moderately and highly suitable for its production in the country, with an estimated 42,067,700 (37.2%) ha of land(Figure 8 and Table 7), of which Oromia (14.6%), Amhara (6.3%), SNNP (6.2%), BSG (4.2%), Tigray (2.5%), Gambella (1.7%) and Somali (0.87%) regions that contributed about 16.5, 7.2, 7.0, 4.8, 2.8, 1.9 and 1.0 million ha of land, respectively.

Oromia has the largest moderately suitable land area of 14,502,728 ha followed by SNNP (5,151,564 ha), Amhara (4,472,544 ha), BSG (2,642,224 ha) and Tigray (1,894,756 ha). Amhara, BSG, Oromia, SNNP, and Tigray have 2.7, 2.1, 2.0, 1.9 and 0.9 million ha of highly suitable land respectively; with percentage contributions of 17.3, 42.6, 6.2, 16.6 and 18.3% in that order.

Table 7. Area of land under different suitability classes for soya bean by region

Region	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Tigray	1,978,182	39.40	227,876	4.54	1,894,756	37.74	919,844	18.32
Afar	8,649,804	90.46	15,028	0.16	892,696	9.34	4,808	0.05
Amhara	8,379,001	53.84	15,612	0.10	4,472,544	28.74	2,696,212	17.32
BSG	226,441	4.53	16	0.00	2,642,224	52.84	2,131,676	42.63
Oromia	15,930,669	49.09	17,148	0.05	14,502,728	44.69	1,998,868	6.16
Somali	30,425,065	96.40	148,092	0.47	988,708	3.13	100	0.00
SNNP	4,193,974	37.15	65,708	0.58	5,151,564	45.63	1,878,740	16.64
Gambella	677,904	26.38	0	0.00	1,191,524	46.36	700,708	27.26

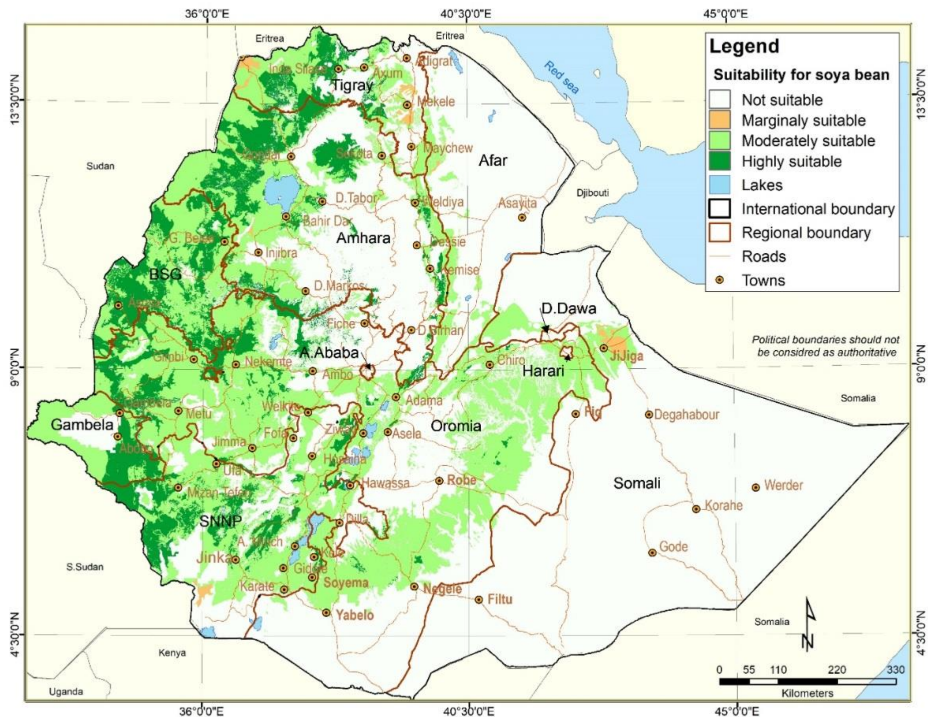

Figure 8. Land suitability map for Soybean

Land suitability for cowpea (*Vigna ungulculata*)

The GIS-based land suitability analysis showed that cowpea ranks first with an estimated 48,904,652ha (43.2%) of moderately and highly suitable land area in the country (Figure 9and

Table 8). The distribution of highly and moderately suitable land for cowpea production in the country are 9.4 and 33.8%, respectively. Oromia region stands first in terms of total area of moderately and highly suitable land for cowpea production with an estimated 15.1 and 3.0 million ha, respectively; followed by Amhara region which stood second with 4.8 and 3.1 million ha in the same order. Southern Nations and Nationalities Peoples Region is third in the total area of moderately and highly suitable land for cowpea production with 6.3and 1.2 million ha, respectively. Benishangul Gumuz with an estimated 4.5 million ha of moderately suitable and 0.3 million ha of highly suitable land area ranks fourth and closely followed by Tigray and Somali regions.

Oromia (3,062,452 ha), Amhara (3,073,232ha), Tigray (2,070,744 ha) and SNNP (1,193,372 ha) are the regions with the largest and highly suitable land area for cowpea production across the regions with percentage contributions of 9.4, 19.8, 41.2, and 10.6%, respectively of the total area of the respective regions.

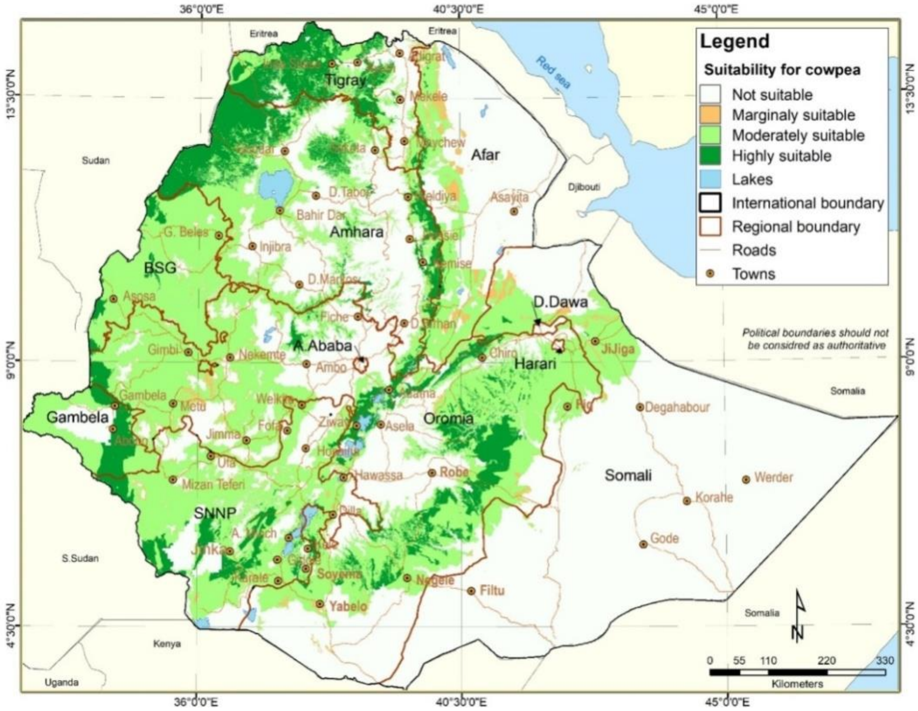

Figure 9. Land suitability maps for cowpea

Table 8. Area of land under different suitability classes for cowpea by region

Region	Land suitability class							
	N		S3		S2		S1	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Tigray	1,504,766	29.97	26,572	0.53	1,418,576	28.25	2,070,744	41.24
Afar	6,635,908	69.40	438,152	4.58	2,313,592	24.19	174,684	1.83
Amhara	7,658,305	49.21	71,316	0.46	4,760,516	30.59	3,073,232	19.75
BSG	189,033	3.78	18,904	0.38	4,480,372	89.60	312,048	6.24
Oromia	13,806,065	42.55	477,228	1.47	15,103,668	46.55	3,062,452	9.44
Somali	28,576,261	90.54	255,072	0.81	2,675,424	8.48	55,208	0.17
SNNP	3,663,654	32.45	111,596	0.99	6,321,364	55.99	1,193,372	10.57
Gambella	680,736	26.49	0	0.00	1,207,872	47.00	681,528	26.52

Salient features of the land suitability analysis

Despite all its limitations, the following are some of the salient features of land suitability analysis of legume crops in Ethiopia.

1. Oromia, Amhara and SNNP are among the regions with the highest proportion of moderately and highly suitable areas for all crops showing their potential for legume production in the country. However, the importance of BSG, Gambella and Somali regions for

lowland legumes such as common bean, soybean and cowpea production is apparent as the case with showing the potential area for expansion.

2. The potential highly suitable areas for legumes production ranging between 10.6 million ha for cowpea and 1.8 million ha for field pea are by far less than the moderately suitable areas that range between 38.3 million ha for cowpea and 16.1 million ha for lentil across the country.
3. The lowland legume crops i.e., cowpea, soybean and common bean have the highest moderately and highly favorable potential production areas, compared to cool season food legumes, such as faba bean, field pea, chickpea and lentil, which are adapted to the highlands, which implies the potential for the expansion of lowland legumes is higher than highland legumes.
4. The moderately to highly suitable areas for faba bean, field pea, lentils and chickpea are situated in the mid to high altitude areas of the country; while the low to mid altitude areas of the country are suitable for common bean, soybean and cowpea production. These crops are not mutually exclusive, since they share similar adaptation areas. However, this study does not provide the final evidence in making the decisions to choose the best agroecology for the legume crops, since socioeconomic issues are not considered in the findings of this study. Hence, it should be noted that the actual available land would be lower than what is reported in this study. In general, the finding of this study confirms the suitability of legumes to the different regions of the country, which in turn implies the possibility of integrating and expanding the production of legume crops into the cropping system of different parts of the country.

Conclusions and Recommendation

Although this work is a qualitative, nationwide suitability analysis, which is only based on biophysical factors, it is believed to serve as a guide for agricultural research, and development efforts in the country. One of the constraints that limit the quality of suitability maps is the scarcity of reliable and fine-resolution geospatial data on biophysical and socio-economic factors. The quality and scale of such work is inherited from quality of the available geo-spatial data. Hence, the outputs may not directly be used for applications that demand finer resolutions. Generally, the result of this multiple criteria land suitability analysis for crops can be used to help design policy on land use planning and decision making that ensures land resources are utilized in the most productive and sustainable ways, and to solve mismatches between current land use and land suitability of the legume crops.

In the crop suitability analysis, scale of geospatial data such as soil and climatic information are the major constraints. Institutes that are involved in improving soil and climate information at national level need to produce high-resolution and consistent information that could be used for spatial and simulation modelling.

Researchers working in the areas of crop improvement might use the findings of this study as a general guide for making decisions, and also provide important feedbacks on performance of the respective crops for the respective agro-ecologies that might help to further refine the suitability analysis. It is also important to develop updated and detailed documents elaborating environmental requirements of the different crops and varieties considered in the suitability classes based on recent research findings, particularly when new varieties are released. It is also recommended that the future suitability analysis might be directed to a variety and site-specific analysis, which might help understand and define the domain a released variety may perform well and the agro-ecologies where the variety might be scaled up and also the scope of scaling-up of the specific crop technology; using site and crop/variety specific data.

Acknowledgments

I would like to acknowledge Ethiopian Institute of Agricultural Research (EIAR) for financing the study and McKnight Foundation for partially supporting this work. I would like to express my special gratitude in particular to Dr. Berhanu Amsalu, Diriba Tadesse, Girma Kassa, and Minilik Tsega of EIAR for providing data and technical advises. I also thank reviewer(s) for their thoughtful comments and suggestions in improving the manuscript.

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Progresses of Acid Soil Management Research in Legumes of Ethiopia: A Review

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Abstract

Low soil pH and associated soil fertility decline are considered to be among the major challenges to crop production in the highlands of Ethiopia. Currently, land area affected by soil acidity is estimated to be about 43% of the total arable land in the country. Legume crops are among the most sensitive plant species to soil acidity, and total crop failures have been occurred in strongly acidic soils of South and South-western Ethiopia. Acid affected soils are usually made more suitable for agricultural use by liming and/or breeding crops for low pH tolerance. The purpose of this review is, therefore, to bring together past and present research achievements in soil acidity management on legumes in Ethiopia. An experiment conducted at Bedi in the central highlands of Ethiopia from 2009 -2012 cropping season on faba bean revealed that application of lime along with phosphorus fertilizer brought up to 200% yield advantage over the control. Similarly, on Nitisols of Welemera, the application of lime, as $CaCO_3$, at the rate of 1, 3, 5 t ha^{-1} increased mean seed yield of faba bean by 45, 77 and 81%, respectively. On contrary, no significant yield advantage has been obtained by application of different rates of lime to Soybean around Jimma area. A study carried out at Bako, however, indicated that application of lime enhanced seed yield and nodulation potential of soybean. Despite tangible benefits of liming on acid soils in the highlands of Ethiopia, the correction of soil acidity to neutralize the toxic effects of Al^{3+} in layers 20 cm below the surface are costly and difficult to operationalize. Thus, recently, selection and/or breeding for tolerance to soil acidity has been started and four crop varieties (sweet lupin, food oats, triticale and bread wheat), have been tested over several locations and nationally released for wider use where soil acidity is a major constraint for crops production in the highlands of Ethiopia.

Keywords: Aluminum toxicity, calcium carbonate, lime, soil acidity tolerance

Introduction

Soil acidity is one of the major constraints to increase crop productivity worldwide. It is a problem manifested by stunted growth of roots, which is considered to be a complex of nutritional disorders of many crops grown on acid soils. Although the poor growth of crop plants is due to a combination of mineral toxicities and deficiencies, Al toxicity is the single most important factor being a major constraint for crop production in tropical and sub-tropical countries (Eswaran *et al.*, 1997). Numerous authors (Bolan *et al.*, 2003; Fageria and Baligar, 2008) reported that plant growth in acidic soils is limited by a set of conditions, including the excess of protons (H^+), aluminum (Al^{3+}) and manganese (Mn) phytotoxicities, and deficiencies of essential nutrients, such as phosphorus (P), calcium (Ca), magnesium (Mg) and molybdenum (Mo). Other authors, viz., Fageria and Baligar (2003); Dahlgren *et al.* (2004), experimentally demonstrated the limited agricultural productivity of acidic soils is due to diminished microbial activity, as a consequence of the presence of high concentrations of Al around the root zone.

Currently, about 43 % of the total arable land is affected by soil acidity and 33% of this area has Al-toxicity in Ethiopia (ATA unpublished; Schlede, 1989). The highlands of Ethiopia are the major breadbaskets of the country. However, low soil pH and associated soil fertility depletions are amongst the major challenges to crop production. Legumes crops are the most sensitive plant species to soil acidity, and total crop failures have been frequently observed in strongly acidic soils of South and South-Western Ethiopia. The cause of soil acidity in these regions is high amount of precipitation that exceeds evapo-transpiration, thereby, leaching appreciable amounts of exchangeable bases from the soil surface.

Nowadays, the problem of soil acidity has grown in magnitude and scope in the highlands, where areas which were not previously acidic has come to this category, and negatively affecting household food security in the region. However, numerous research and development efforts have been underway to curb this critical problem in the country. Many research outputs have been generated by different institutions and have been demonstrated promising in different parts of the country. However, these research outputs in the management of soil acidity for food legumes are scattered here and there, and have been inaccessible for wider use. The purpose of this review is, therefore, to bring together scattered research achievements and state of the art knowledge in soil acidity management for food legumes in Ethiopia.

Approaches

- Review collection of published soil acidity research works on food legumes in EIAR, RARIs and HLIs
- Relevant unpublished research results have also been included
- Online literature search for published documents on similar line has been done

Soil acidity management for legumes production using lime amendments

Several agricultural practices have been recommended to overcome the problem of tropical acid soil infertility. Among them, the most common and widely used method is liming, which is defined as the application of ground calcium and/or magnesium carbonates, hydroxides, and oxides aiming at increasing the soil pH, modifying its physical, chemical and biological properties (Edmeades and Ridley, 2003).

The success stories of liming in ameliorating soil acidity problem have been well documented (Scott *et al.*, 2001, Desalegn *et al.*, 2016). Lime application at an appropriate rate brings several chemical and biological changes in the soil, which are beneficial in improving crop yields on acid soils, through eliminating toxicity of Al, Mn, and H; improving availabilities of Ca, P, Mo, and Mg and by enhancing N_2 fixation in legumes. The practice of liming had not been in use among Ethiopian smallholder farmers in the past, owing to technological, institutional and socio-economic related constraints. However, in the recent past, the problem of soil acidity has been given utmost priority by various governmental and non-governmental institutions for research and development. Accordingly, many promising soil acidity management technologies have been developed and demonstrated to enhance legumes production and productivity in Ethiopia.

An experiment aimed at investigating the effect of different levels of lime and phosphorus fertilizer on seed yield of Faba bean at Bedi in the central highlands of Ethiopia is presented in Table 1. Results indicated that significant ($p \leq 0.05$) seed yield of faba bean was recorded from the application of 2.2 t ha^{-1} lime along with 30 kg phosphorus fertilizer per hectare. However, this treatment was statistically not different from the application of 1.65 t ha^{-1} lime and 20 kg/ha of phosphorus fertilizer.

As evidenced from Table 2, the increase in faba bean seed yield was due to drastic reduction in the concentration of exchangeable acidity and significant increase in soil pH, thereby, creating conducive environment for faba bean production. Upon liming, numerous authors have reported the decreases of Al^{3+} in the soil solution, as well as, in the exchange complex (Delhaize *et al*., 2007; Prado *et al*., 2007; Álvarez *et al*., 2009), improved soil structure (Crawford *et al*., 2008), significant yield increases (Buri *et al*., 2005), increases in P uptake by plants (Fageria and Santos, 2008), higher abundance and diversity of earthworms (Bishop, 2003); and improved organic matter decomposition and nutrient mineralization (Bradford *et al*., 2002).

Table 1. The interaction effect of lime and Phosphorus fertilizer rates on seed yield of Faba bean (kg ha^{-1}) at Bed, central highlands of Ethiopia

	Phosphorus rates (kg ha^{-1})				
Lime rate (t/ha)	0	10	20	30	Mean
0	1338.5	2071.2	2332.8	2355.8	2024.6
0.55	2275.6	2817.4	3242.2	3310	2911.3
1.1	2804.2	3886.2	4081.9	4330.6	3775.7
1.65	3119.9	3769.9	4924.2	5007.4	4205.4
2.2	3466.3	4489.7	4647.7	4997.6	4400.3
Mean	2600.9	3406.8	3845.8	4000.3	
Lime x P= LSD (0.05)= 720.2					

Source: Desalegn *et al.* (2016)

Table 2. Effect of different lime rates on soil pH and exchangeable acidity of soil after crop harvest at Bedi, during 2009/10 cropping season

Lime rate (t ha^{-1})	pH	Exchangeable acidity (Cmol+/kg)
0	5.10 c	1.32 a
0.55	5.30 bc	0.44 b
1.1	5.53 ab	0.21 b
1.65	5.67 ab	0.12 b
2.2	5.91 a	0.13 b
LSD (0.05)	039	0.36
CV (%)	4.31	4.9

Source: Desalegn *et al*. (2016)

Faba bean without lime and P Faba bean with lime and P

Figure 1. Pictorial presentation of the effect of lime on faba bean at flowering stage.

Soil pH increased, linearly, with increase in lime rate (Table 2). The increase was highest with the applications of the maximum rate (2.2 t ha^{-1}) of lime. Generally, when lime is added to acid soils that contain high aluminum and H^{+} concentrations, it dissociates into Ca^{+2} and OH^{-} ions. The hydroxyl ions will react with the hydrogen and aluminum ions forming aluminum hydroxide and water, thereby, increasing soil pH in the soil solution. Meanwhile, the application of the highest rate of lime appreciably reduced soil exchangeable aluminum, which was 1.32 Cmol kg^{-1} at the start of the experiment to a negligible level of 0.12 Cmol kg^{-1} after two years of soil analysis. Likewise, Fageria and Stone (2004); Fageria and Baligar (2008); Álvarez and Fernández (2009) have also reported that liming raises soil pH, base saturation, and Ca and Mg contents, and reduces aluminum concentration.

As some released crop varieties may develop inherent mechanisms to overcome the toxic effects of Al in the soil, a study was made to evaluate the tolerance of 10 released faba bean varieties under limed and un-limed conditions in the central highlands of Ethiopia (Table 3). Results revealed that none of the tested previously released faba bean varieties had inherent capacity to withstand the negative effects of soil acidity. However, these varieties performed very well under limed conditions. It can be inferred that the released crop varieties might not have inherent capacity to tolerate soil acidity. Therefore, breeding/selection for soil acidity tolerance need to be emphasized in the future faba bean breeding programs.

Table 3. Performances of ten released faba bean varieties under limed and unlimed conditions at Bedi

	Seed yield (kg ha^{-1})	
Variety	Unlimed	Limed
Mesay	249.9	3659.0
Bulga	647.5	1395.1
Degaga	200.6	2144.9
Moti	190.8	1801.7
Gebelicho	435.9	2634.3
Obse	208.1	1984.9
Wolki	204.6	1829.8
Dosha	241.6	2199.3
CS-20-DK	118.0	2704.8
Wayu	140.8	1646.3
LSD (0.05)	1570.3	

Source: HARC progress report (2010)

The mean seed yield of faba bean was significantly (P < 0.001) affected by lime application on Nitisols at Holetta. The application of lime at the rates of 1, 3 and 5 t ha^{-1} resulted in significantly linear response with mean grain yield advantages of about 45, 77 and 81% over the control, respectively (Fig. 2). Similarly, Mahler *et al.* (1988) found that grain yields of legumes were optimal between soil pH values of 5.7 and 7.2, and yields of pea could be increased by 30%, due to the application of lime to soils with pH values less than 5.4.

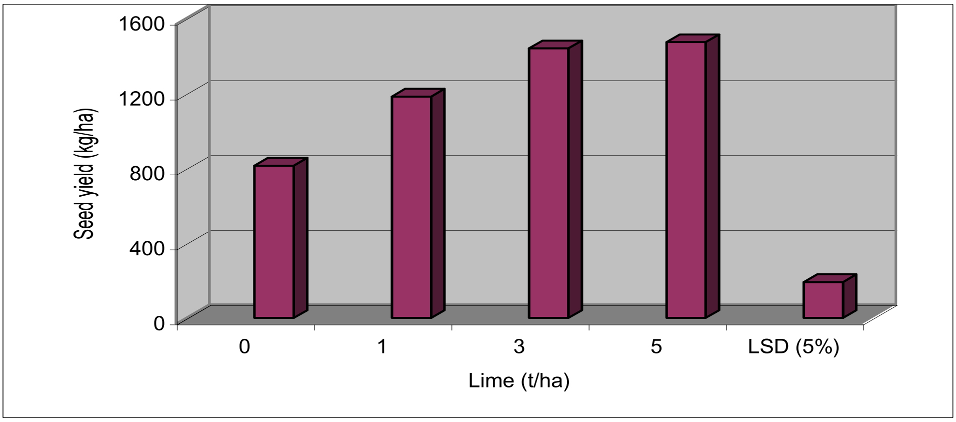

Figure 2. Faba bean mean seed yield as influenced by the application of lime at Holetta during 1998-2000 cropping season. Source: Agegnehu *et al*. (2007)

Table 4. Effects of split applications of lime on the grain yields (kg ha^{-1}) of Faba bean at Bedi, central highlands of Ethiopia

Treatment	Seed Yield (kg ha^{-1})
Control	2114d
25% recommended lime every year	3410c
33% recommended lime every year	3780bc
50% recommended lime every year	4208b
Full dose of lime once	5291a
CV (%)	10.4
LSD (0.05)	736

Source: HARC progress report (2010)

The cost of lime is unaffordable, due to large amounts required per hectare of land, and over liming may reduce crop yields by inducing phosphorus and micronutrient deficiencies (Fageria, 1984). In an attempt to reduce the large amounts of lime applied at once, an experiment was conducted at Bedi by splitting the full recommended dose of lime over years (Table 4). Results showed that the three splits (25%, 33% and 50% of recommended) gave significantly superior grain yield of faba bean, as compared to the control. Fifty percent of recommended dose of lime every year gave significantly higher seed yield of faba bean as compared to 25% and 33% of lime every year. However, significantly ($p \leq 0.05$) higher grain yield of faba bean was obtained from the application of the full dose of lime at once. Therefore, for amelioration of soil acidity and remunerative faba bean production in the central highlands of Ethiopia, application of full dose of recommended lime at once is indeed required.

In extremely acidic soils of Emdbir, seed yield of faba bean variety, Degaga, was extremely very low even by the application of the maximum lime and phosphorus rate (Table 5, Fig 3). This indicates that faba bean does not give economical yield by application of whatever dose of lime under highly acidic soils of Ethiopia such as like Emdbir and Nedjo.

Table 5. Interaction effect of lime and phosphorus fertilizer rates on seed yield of Faba bean (kg ha^{-1}) at Emdibir, during 2009/10 cropping season

	Phosphorus rate (kg ha^{-1})				Mean
Lime rate t ha^{-1}	0	10	20	30	
0	64.8	93.0	92.2	51.1	75.3
2.05	190.	193.4	256.0	324.1	240.9
4.1	236.6	260.7	374.5	383.5	313.8
6.15	241.8	318.5	381.3	420.1	340.4
8.2	281.1	278.6	426.6	378.9	341.3
Mean	202.9	228.8	306.1	311.5	

Source: HARC progress report (2011)

Figure 3. Faba bean applied with maximum dose of lime under highly acidic soils.

In Gedo and Horro highlands, hundred seed weight was not affected by the application of different levels of lime (Table 6). Application of different levels of lime significantly ($p \leq 0.05$) affected grain yield of faba bean (Table 6). The maximum rate of lime (6 t ha^{-1}) produced significantly the highest grain yield of faba bean at both locations. However, before reco-mmending this result to users, partial budget analysis need be done to reach at economically feasible lime rate for faba bean production at both locations.

Table 6. Effects lime rate on 1000 seed weight and seed yield of faba bean at Horro and Gedo highlands, Ethiopia

Lime rate (t ha^{-1})	1000 seed weight (g)		Seed yield (kg ha^{-1})	
	Horro	Gedo	Horro	Gedo
0	531	632	844	2192
2	533	639	952	2501
4	542	623	1207	2520
6	554	623	1451	2758
LSD (5%)	Ns	Ns	88.9	92.9
CV (%)	13.04	6.3	17.1	8.0

Source: Abera and Abebe (2014)

Similar to faba bean, higher grain yield of field pea at Horro was obtained in response to the application of maximum dose of lime (6 t ha^{-1}). The application of different rates of lime to field pea did not show significant yield difference at Gedo (Table 7), which might be due to the non-acidic condition of the sites, where the experiment was conducted, as evidenced by the soil analysis result presented in Table 8.

Table 7. Effects of rate of lime application on grain yield of field pea for two years (2007-2008) at Horro and Gedo highlands, Ethiopia

Lime rate (t ha^{-1})	Horro			Gedo		
	2007	2008	Mean	2007	2008	Mean
0	2013	1017	1515	2093	3138	2616
2	2153	1119	1636	2100	3227	2664
4	2319	1222	1771	2115	2998	2557
6	2383	1321	1852	2192	3031	2611
LSD (5%)	86.3	66.8	83.0	95.1	112.9	NS
CV (%)	5.80	8.5	10.5	6.7	5.4	8.9

Table 8. Soil pH and available phosphorus at Horro and Gedo before sowing

Soil pH and Av. P	Horro	Gedo
pH (H_2O)	5.2	5.7
Available P (ppm)	5	14.8

Source: Abera and Abebe (2014)

Table 9. Growth pattern of faba bean rhizobial strains in growth media at different pH levels

pH	AUFR 7 Log 10 CFU ml^{-1}	AUFR 46 Log 10 CFU ml^{-1}	AUFR 58 Log 10 CFU ml^{-1}	AUFR 100 Log 10 CFU ml^{-1}
4.5	NG*	7.62 $\pm$ 0.03c	NG	8.41 $\pm$ 0.10b
5.0	8.77 $\pm$ 0.02a	7.88 $\pm$ 0.1c	NG	8.42 $\pm$0.20b
5.5	8.91 $\pm$ 0.01a	8.41 $\pm$ 0.12b	8.98 $\pm$ 0.02a	8.45 $\pm$ 0.02b
6.0	8.95 $\pm$ 0.02a	7.88 $\pm$ 0.03a	9.00 $\pm$ 0.03a	8.95 $\pm$ 0.03a
6.5	8.97 $\pm$ 0.15a	7.88 $\pm$ 0.10a	9.00 $\pm$ 0.40a	8.99 $\pm$ 0.10a

*NG= No growth, Source: Jida and Assefa (2014)

A study that was conducted to evaluate the acidity tolerance of *Rhizobium leguminosarum* bv. *viciae* strains isolated from faba bean growing regions of Ethiopia (Table 9) indicated that only two of the tested strains were able to tolerate acidic soils (pH of 4.5). Only one isolate (AUFR 58) was sensitive, when tested at pH 5. It was concluded that *Rhizobium leguminosarum* bv. *viciae* collected from highly acidic soils were found to be tolerant; while those collected from mild acidic soils were moderately soil acidity tolerant. However, isolates that were collected from near neutral soil pH, were less tolerant to soil acidity.

The response of soybean to applications of different rates of lime and phosphorus fertilizer at Metu, during 2009/10 cropping season is presented in Table 10. Results showed that applications of different rates of lime could not bring any significant yield advantage of soybean at Hurumu in South-western Ethiopia (Table 10).

Table 10. Effect of lime and phosphorus fertilizer rates on seed yield of soybean at Metu (Hurumu) during 2009/2010 cropping season.

Lime rate (kg ha^{-1})	Phosphorus rate (kg ha^{-1})				
	0	**10**	**20**	**30**	Mean
0	1300	1728	1374	1400	1451
1410	1420	1834	1574	1566	1599
2820	1434	1887	1683	1720	1681
4230	1450	1549	1747	1785	1633
5640	1460	1480	1551	1717	1556
Mean	1413	1696	1586	1638	1583

LSD (0.05) = NS, Source: JARC progress report (2011)

Similarly, at Tiro Afeta (Jimma zone), there was no response of soybean yield to different rates of lime (Table 11). However, the response of soybean to rates of phosphorus fertilizer application was significant. The application of 20 and 30 kg ha^{-1} rates of phosphorus fertilizer, produced significantly higher grain yield of soybean than the other P rates, including the control. The grain yield obtained from the application of 10 and 20 kg ha^{-1} P were also statistically at par. Therefore, it could be inferred that application of 20 kg P ha^{-1} is sufficient to curb the problem of soil acidity in the study area. However, it has to be verified under multi-location trails to arrive at a conclusive result. The result confirms the general truth that soybean responds better to phosphorus fertilizer than lime on many acid soils in Ethiopia. The combined effect of lime and *Bradyrhizobium* inoculation to soybean was studied at Melko (Table 12). Results showed that the application of lime and *Bradyrhizobium* inoculation significantly ($p \leq 0.05$) increased nodule number, nodule volume and nodule dry weight, as compared to un-limed and non-inoculated treatments. Hence, in acid soils with low soil pH, co-treatment of rhizobia inoculation and lime could complement for better nodulation and growth of legumes.

Table 11. Effect of Lime and phosphorus fertilizer rates on grain yield of Soybean at Jimma (Tiro Afeta), during the 2009/10 cropping season

Lime rate (kg ha^{-1})	Seed Yield (kg ha^{-1})
0	1513
1410	1644
2820	1751
4230	1607
5640	1745
LSD (0.05)	NS
P rate (kg ha^{-1})	
0	1210
10	1542
20	1849
30	2011
LSD (0.01)	325
CV (%)	19.85

Source: JARC progress report (2011)

Table 12. Effect of lime and rhizobia inoculation on nodules of soybean at Melko, Jimma

Parameter	Lime (kg ha^{-1})	No inoculation	With inoculation
Nodule No. per plant	0	10.4^{d}	52.6^{b}
LSD $_{0.05}$ = 10	2.6	22.5^{c}	79.8^{a}
Nodule volume (ml plant $^{-1}$)	0	1.0^{c}	4.1^{b}
LSD 0.05 = 0.06	2.6	1.5^{c}	5.9^{a}
Nodule dry weight (g plant^{-1})	0		1.5^{b}
LSD 0.05 = 0.4	2.6	0.1^{c}	3.0^{a}

Source: Bekere *et al.* (2013)

Acidity has a deleterious effect on the symbiotic relationship between rhizobia and legumes, and generally, soils with pH below six results in poor nodulation and N fixation. According to Bolan *et al.* (2003), several physiological reasons have been attributed to this phenomenon including: (i) inhibition of infection of legume roots by nodule bacteria, decreasing nodule formation; (ii) inhibition of nitrogenase enzyme activity in the nodule, due to modification of the nitrogenase iron protein. The inhibitory effect of acidity on biological N fixation has also been attributed to the poor supply of Mo and Ca, which are essential for N fixation.

Table 13. Effect of split application of lime on soybean seed yield (kg ha^{-1}) at Jimma area during 2009-2013 growing seasons

Treatments	**2009**	**2010**	**2011**	**2012**	**2013**	**Mean†**
Control	1259	1185	1219b†	1705	2416	1557b
25% every year	1454	1541	1978a	1977	2441	1878a
33% every year	1674	1662	2270a	1739	2441	1957a
50% every year	1848	1694	2275a	1880	2108	1961a
Full dose	1944	1780	2286a	1850	2408	2054a
LSD (0.05)	NS	NS	638	NS	NS	294
CV (%)	22.86	20.77	16.91	8.92	7.91	11.62

†Means with in a column with the same letter(s) are not significantly different at 0.05 probability level. NS =Not significantly different, Source: JARC progress report (2011)

An experiment conducted around Bako area showed that lime application to soybean significantly increased plant height, number of nodules per plant, nodule dry weight per plant, biomass yield and seed yield (Table 14). The grain yield of soybean recorded from the application of 1.56, 2.34 and 3.91 t ha^{-1} lime did not show statistically significant difference, and gave significantly higher yield than the other lime rates, including the control. Therefore, around Bako area, modest application rate of 1.56 t ha^{-1} of lime could give better seed yield of soybean. Based on this experiment, further increase in the rate of lime seems to be uneconomical.

Table 14. Yield and yield related traits of soybean as influenced by lime rate around Bako area, Western Oromia.

Lime rate (t/ha)	SC/plot	Plant ht (cm)	Nodule Number/ plant	Nodule dry wt.(mg)/ plant	Biomass yield (t/ha)	Grain Yield (t/ha)
0	540	45.93c	65d	563.3d	6.46c	3.92c
1.56	604	50.93b	85c	633.3dc	7.3b	4.38ab
2.34	617	55.26b	97b	650.0bc	7.66ab	4.36ab
3.13	564	53.5b	93bc	713.3b	7.46b	4.2cb
3.91	593	51.66b	84c	653.3bc	8.27a	4.693a
4.69	605	60.23a	113a	963.3a	7.57ab	4.14cb
LSD (0.05)	NS	4.36	11.2	79.7	0.74	0.41

Source: Kifle (2014)

Soybean seed yield as affected by split application of full recommended dose of lime is presented in Table 15. Significantly superior grain yield of soybean obtained in response to the application of different splits of lime, as compared to the control. However, 50 % split application of lime consistently gave the highest significant grain yield of soybean, both in individual years and combined over three years analysis of variance. Therefore, modest application of lime could give better economic yield of soybean around Assosa area. However, to give recommendation for wider dissemination and use by smallholder farmers, prior economic analysis is very crucial.

Table 15. Individual years and combined analysis over three years (2013-2014) for number of seeds per pod and grain yield (kg ha^{-1}) of soybean as influenced by split application of lime at Doyo (Jimma)

Treatment	2013		2014		2015		Combined	
	NSPP	GY	NSPP	GY	NSPP	GY	NSPP	GY
Control	2.5^{a}	938.8^{b}	2.2^{b}	580.4^{b}	2.4^{a}	584.9^{b}	2.3^{b}	701.3^{c}
Full dose of lime	2.4^{a}	1075.0^{ab}	3.6^{a}	979.8^{a}	2.37^{a}	1040.0^{a}	2.8^{ab}	1031.6^{ab}
50% lime each year	3.1^{a}	1253.7^{a}	4.0^{a}	1251.8^{a}	2.4^{a}	1028.4^{a}	3.2^{a}	1178.0^{a}
33% lime each year	2.4^{a}	986.2^{b}	3.9^{a}	1006.9^{a}	2.37^{a}	785.3^{ab}	2.9^{a}	926.1^{b}
25% lime each year	2.2^{a}	906.8^{b}	4.0^{a}	1212.6^{a}	2.4^{a}	807.2^{ab}	2.9^{a}	975.5^{ab}
LSD (0.05)	Ns	197.7	0.77	340.2	Ns	428.5	0.54	216.7
CV (%)	20.6	10.2	11.7	17.9	5.5	26.8	20.2	23.5

* Ns= not significant, NSPP= number of Seeds per pod and GY= Grain yield (kg ha^{-1})

Table 16. Effect of lime and NP fertilizer rates on mean grain yield of soybean at Nedjo

Lime (t ha^{-1})	N/P_2O_5 (kg ha^{-1})			Mean (t ha^{-1})
	0 – 0	35 - 35	70 - 70	
0	2.17	2.09	2.02	2.09
1	2.36	2.64	2.01	2.34
2	1.74	2.46	2.17	2.12
Mean	2.09	2.40	2.07	

Source: BARC progress report (2009)

The effects of different levels of lime and N/P fertilizer rates on soybean and haricot bean yield at Nedjo are presented in Table 16 and 17. Results showed that there were no significant responses of soybeans to applications of different rates of lime and N/P fertilizers at Nedjo. However, a follow up study is required to arrive at a final conclusion through conducting a multi-location trial in the area on both crops.

Table 17. Effect of lime and NP fertilizer on haricot bean mean seed yield at Nedjo

Lime ($t\ ha^{-1}$)	N/P_2O_5 ($kg\ ha^{-1}$) 0 – 0	35 - 35	70 – 70	Mean ($t\ ha^{-1}$)
0	2.45	2.75	2.51	2.57
1	2.43	2.34	2.66	2.48
2	2.44	2.72	2.77	2.64
Mean	2.44	2.60	2.65	

Source: BARC progress report (2009)

The effect of lime on grain yield of haricot bean varieties (Omo-95 and Hawassa) was studied at two locations, during 2012/2013 cropping seasons in Wolyita zone (Table 18). Results indicated that the grain yield of haricot bean obtained in response to the application of 0.4 t ha^{-1} lime was significantly higher than the control treatment. However, as the response obtained from the application of 0.4 t ha^{-1} lime was minimal, a follow-up study is required by considering economic feasibility of lime application for the crop in the area.

Table 18. Effect of lime on seed yield of haricot bean varieties at two locations in Wolyita zone, during 2012-2013 cropping season

Lime ($t\ ha^{-1}$)	**Variety**	Testing sites **Gununo**	**Dolla**
0	Omo-95	826.3	875.2
	Hawassa dume	930.30	973.0
0.4	Omo-95	1079.4	1122.6
	Hawassa dume	1282.5	1417.0
CV (%)		34.27	46.0
LSD (0.05)		201.0	200.0

Source: Kassa *et al*. (2014)

Breeding/selection of legumes for soil acidity tolerance

Traditionally, liming is the most common practice used to overcome the impact of soil acidification. Liming, however, has some limitations, which includes: the effectiveness of surface application of lime to soils under sub-soil acidity conditions is uncertain, agricultural liming materials are relatively insoluble and lime effects may be restricted to the top few centimetres of soil for many years. Above all, large quantities of lime are, generally, required in improving plant growth, and for many subsistence farmers the high cost of lime restricts its use (Haynes and Mokolobate, 2001). However, crop species and genotypes within species greatly differ in their tolerance to acid soil stress. Therefore, the development of genotypes tolerant to soil Al has gained greater emphasis in the recent years.

In an attempt to identify acid tolerant high yielding and promising crop varieties, sweet lupin (*Lupinus angustifolius* L.) cultivar SWL-001 was introduced from Australia and was placed in the screening nursery along with hundred fifty local accessions at Holetta research center. The candidate variety (SWL-001) was purified using simple mass selection and promoted to national variety trial (NVR). The candidate varieties along with collected lupin accessions were planted on acid soils in multi-location trail under limed and un-limed conditions. Analysis of variance revealed that SWL-001 demonstrated the highest mean seed yield under un-limed conditions, as compared to other accessions (Table 19). The national variety release committee (NVRC) has evaluated the candidate variety and approved the release of the variety for use in soil acidity prone areas of Ethiopia.

Table 19. Grain yield (kg ha^{-1}) of different lupin genotypes at different acid soil testing sites, and across locations combined analysis

Genotype	Holeta	Jeldu	Bokoji	Jima	R/Gebya	Nedjo	Adet	Combined analysis
Probor (sweet)	2693.8	2235.4	1306.3	1822.9	1643.3	862.6	2767.1	1904.5
Acc.No 242249 (bitter)	3787.5	3489.6	2549	3958.4	3998.8	753.2	3634.9	3167.3
Acc.No 239003 (bitter)	4439.6	4659.4	4034.4	4791.7	3162.9	1209.4	3885.5	3740.4
SW-001(sweet)	3179.2	3198.0	2882.3	2343.8	2140.5	470.3*	3675.6	2555.7
Sanabor (sweet)	2554.2	3621.9	1654.2	2239.6	2157.3	1632.4	2806.3	2380.8
Acc. No 239056 (bitter)	3745.8	2636.5	3111.5	3750	2778.2	1078.3	3564.2	2952.1
Vitabor (sweet)	3130.2	3130.2	1745.8	1927.1	1741.6	891.1	4375.5	2420.2
Acc.No 239006 (bitter)	4811.5	3606.3	4409.4	3645.8	3067.3	1119.3	3387.8	3435.3
Bora	2852.1	2388.6	2017.7	1823	2023.9	1464.8	3806.5	2339.5
Mean	3465.9	3218.4	2634.5	2922.4	2523.7	1053.5	3544.8	2766.2
CV(%)	17.7	19.08	15.7	13.9	23.21	35.4	15.2	18.7
LSD (0.05)	1065.3	1063.2	715.2	707.5	1013.6	646.4	932.3	278.4

Source: (Keneni *et al.,* 2016, unpublished).

Conclusions and Recommendation

Based on the present review, the following conclusions can be drawn

- Application of lime to acid soil brings about remunerative legume crops production under moderately acidic conditions. However, under strongly acidic conditions, lime application seems not beneficial, as observed in this review. Therefore, apart from the application of other alternative management options are required for legumes production in such areas.
- Soybean and haricot bean are relatively less responsive to lime application as compared to faba bean and field pea.
- Soil pH only gives a clue whether a particular soil acidic or not. Therefore, lime recommendation

should be based on the exchangeable acidity of the soil.

- The rhizobia that fix atmospheric nitrogen in legumes thrives and nodulate well above 5.5 pH.
- In addition to interspecific variability, there is a large degree of intraspecific variability among many legumes for Al^{3+} tolerance. There is a need to harness this potential in the future.
- National database of published articles in different fields required
- Generally, to harness the full potential of acid soils for sustainable food production in the highlands of Ethiopia, management practices that entail combined application of lime and phosphorus is beneficial.

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Effects of Legume Precursors on Yield and Nitrogen Economy of Cereal Crop Production in Ethiopia: A Review

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Abstract

Prolonged and continuous cultivation without proper soil management is posing problems to soil fertility and maize production. The use of legume precursor crops improved performance of subsequent cereal crops. The biological N_2-fixation of legumes as precursor crops reduced the amount of nitrogen fertilizer applied to cereal crops. Higher mean grain yield of maize was obtained following faba bean and soybean without and with rhizobia inoculation than maize after maize. The total nitrogen uptake of different maize varieties was improved following leguminous crops with application of lower amounts of nitrogen fertilizer. Higher agronomic efficiency, fertilizer N recovery efficiency and nitrogen use efficiency of maize were obtained from 55 kg N ha^{-1} application as compared to 110 kg N ha^{-1}. Production of both highland and mid altitude maize varieties following faba bean and soybean with half recommended rate of 55 kg N ha^{-1} improved mean maize grain yield has been recommended for maize production in western Ethiopia. Therefore, fertilizer management practices following legumes that increase nitrogen use efficiency and improve yield of cereals will likely be more effective and desirable options for cereal production. Improved biomass and grain yield of wheat were obtained following faba bean and field pea. Production of maize and sorghum following haricot bean with recommended fertilizer rate is significantly improving grain yield and recommended for sustainable production of maize and sorghum. Planting of maize following sole haricot bean with 75 % (69/15 kg NP ha^{-1}) of the recommended rate gave higher mean grain yield and economically feasible for maize production. Further research can be undertaken on the interaction of nitrogen rates and legume precursor crops to determine economically optimum nitrogen rates for cereals after legumes and nitrogen economy of cereal production in Ethiopia.

Keywords: Faba bean, legume precursor crops, nitrogen, soybean

Introduction

Pulses are the most widely cultivated crops next to cereals in terms of area coverage (14.04%) and production (11.37%) in Ethiopia (CSA, 2014). They are the major protein and cash source supporting livelihood, and nitrogen sources for cereal based cropping system in the country. The diversity of pulses grown in the country includes faba bean *(Vicia faba),* field pea (*Pisum sativum*), chickpea (*Cicer arietinum*), lentil (*Lens culinaris)* grass pea (*Lathyrus sativus*), haricot bean (*Phaseolus vulgaris)*, soybean (*Glycine max*) and groundnuts (*Arachis hypogaea*). Different cereal-based cropping systems, such as maize, wheat and barley-based cropping systems are practiced in the country based on soil type and agroecology. However, cropping systems involving monoculture of cereals can cause reduction of yields and depletion of soil nitrogen. This can be improved by different methods, such as use of inorganic nitrogen fertilizer and use of legumes in cropping systems. The consistent increase in prices of synthetic fertilizers has made difficult for smallholder farmers to use inorganic nitrogen fertilizers for crop production. In addition, the nitrogen applied is not fully used by the crop, lost each year through volatilization, leaching and other factors. In cropping systems, in addition to the direct use of legumes as agricultural produce, they also contribute to the maintenance and restoration of soil fertility by fixing a large proportion of N from atmosphere (Giller and Wilson, 1991).

The use of leguminous green manures, crop rotation and intercropping are traditional, and the inputs from biological nitrogen fixation often promote significant increases in subsequent grain or other crops. The input of fixed N from grain legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Giller *et al*., 1994; Giller, 2001; Sanginga, 2003). Different scholars have reported nitrogen fixing capacity for instance Giller (2001), (Yusuf *et al*., 2006) and (Ali *et al*., 2002) have respectively reported the N_2-fixing potential range of soybean as 88-188 kg N/ha/year, 41-50 kg ha^{-1}; and 31- 64%. On average, 50 to 60% of soybean N demand was met by biological N_2 fixation (Salvagiotti, 2008). The extent to which a legume crop can benefit a subsequent crop depends on the quantity of biologically fixed N which is incorporated into the system by the legume, and the proportion of residual N left over for the subsequent crop, rate and time of decomposition of residues or synchrony with crop need and its efficiency of utilization (Boddey *et al*., 1997; Giller *et al.*, 1998). Soybean biological N_2-fixation accounted for 50% of N uptake without N application, but it reduces to 32-38 %, when N is applied (Salvagiotti, 2008).

Legumes can increase crop yields and enhance soil fertility, whilst reducing the negative monetary costs and environmental impacts associated with nitrogen fertilizer use (Canfield *et al.*, 2010; Hirel *et al*., 2007; Peoples *et al.*, 2009). Glasener *et al*. (2002) suggested that legumes are used commonly in agricultural systems as a source of N for subsequent crops and for maintaining soil N levels. Inclusion of grain legumes in rotations provides nitrogen inputs into the systems in addition to valuable grain yields (Giller, 2001). Safeguarding of the soil fertility at the economic optimum level with appropriate cropping system and affordable fertilizer rate is essential for sustainable cereal production in Ethiopia. To exploit the advantages of various legumes in cropping systems, different research findings have been done using various legumes in different parts of the country. The objective of this paper is to review the role of legumes as precursor crops in performance and nitrogen economy of cereal production, and to recommend future research direction in different cereal-based cropping systems.

Procedure of Review of Literature

The purpose of this review paper is to compile the role of pulses as precursor crops on performance and nitrogen economy of crop production in cereal based farming system in Ethiopia, mainly research works conducted in the past for more than a decade. Information was collected from different sources, including internet, published literature and books. Subsequently, the collected literature on legumes as precursor crops and technologies/recommendations in relation to legume/cereal rotations were arranged together for this review. Finally, future research interventions have been suggested for legumes as precursor crops in cereal based crop production system in the country.

Research Achievements

Legumes as precursor crops with different fertilizer sources on cereal production

Higher grain and straw yields of wheat were produced in Shambo and Arjo highlands following field pea and faba bean than wheat after wheat (Tables 1, 2 and 3). Therefore, faba bean and field pea as precursor crops improved wheat yield in Shambo and Arjo highlands and recommended for wheat producers in the area.

Wheat grain yield responses to N were minimal or non-significant; and P occasionally enhanced after faba bean and in the first wheat crop after any precursor crop. Improved soil NO_3 and soil structure was observed following legumes as break crops with application of lower amounts of nitrogen fertilizers at Kulumsa (Taa *et al.*, 2003). Bread wheat after pulses produced a higher grain yield with a yield advantage of 8-14% than application of 41- 46 kg N-$P_2 0_5$ ha^{-1} at Sinana (Geleto *et al.*, 2000*)*. 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 (Liben *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 economically optimal system of wheat production, even without fertilizer application for the central highlands (Tarkegn *et al*., 1996). Nitrogen fertilizer requirement of wheat because 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 legumes as precursor crops significantly reduced the application of nitrogen fertilizers for different cereal production systems.

Table 1. Effects of precursor crops and management levels on straw yield of barley (kg ha^{-1}) at Shambo (combined over two years), in 1998-1999.

Treatment	Management levels						Mean
Precursor crop	FVFP-FE	IVFP-FE	FVIP-FE	IVIP-FE	FVFP+FE	IVIP+FE	
Barley	1217	1385	1713	1427	2290	1763	1632
Field pea	2142	2283	2260	2450	2743	2350	2438
Mean	1679	1834	2187	1938	2517	2057	
% Change	76	65	32	72	20	33	49

	Precursor crop	Management levels	Precursor crop vs. Management levels
LSD (5%)	121	280.3	Ns
CV %	12.87	16.69	

FVFP-FE= farmers variety and farmers traditional cultural practices without fertilizer, IVFP-FE = Improved variety and farmers traditional cultural practices without fertilizer, FVIP-FE= farmers variety with improved agronomic practices without fertilizer, IVIP-FE= Improved variety with improved agronomic practices without fertilizer, FVFP+FE = farmers variety with all improved agronomic practices with fertilizer, IVIP+FE = improved variety with all improved agronomic practices with fertilizer
Source: Abera and Belisa (2005)

Table 2. Effects of cropping sequence on straw biomass and grain yield of wheat and barley at Shambo in 2004, 2005 and combined over years

	Straw biomass (kg ha^{-1})			Grain yield (kg ha^{-1})		
Precursor crop	2004	2005	Mean	2004	2005	Mean
Faba bean	1532	11203	6367	635	2897	1766
Barley	1423	9907	5665	373	2819	1597
Continuous wheat	1404	10277	5840	559	3388	1724
CV (%)	7.11	7.99	12.76	27.66	6.17	14.05
LSD (5%)	114	718	464	155	155	147

Source: Abera *et al*. (2007)

Table 3. Effects of cropping sequence on straw biomass and grain yield of wheat and barley at Arjo in 2004, 2005 and combined over years

Previous crops	Straw biomass (kg ha^{-1})			Grain yield (kg ha^{-1})		
	2004	2005	Mean	2004	2005	Mean
Faba bean	1922	12176	7049	1379	4624	3002
Barley	1165	11805	6485	742	4372	2553
Wheat	1208	11425	6317	791	4111	2451
Mean	2364	11894	7130	1662	4522	3090
CV (%)	28.92	10	13.66	23.88	5.45	10.55
LSD (5%)	579	Ns	566	336	208	189

Source: Abera *et al.* (2007)

The grain yield of maize was improved following haricot bean precursor crop with NP fertilizer application in Bako area (Table 4) (Abera *et al.*, 2009). Production of maize and sorghum following haricot bean with recommended fertilizer rate gave higher mean grain yield than maize after maize or sorghum after sorghum and recommended for sustainable production of maize and sorghum in Bako area (Table 5) (Abera 2012). Soybean, climbing bean and bush haricot bean precursor crops improved plant height, useable ears and grain yield of maize (Table 6 and 7) (Abebe *et al.*, 2013)

Table 4. Effects of rotation crops and N-P fertilizer rate on grain yield of maize at Bako.

Rotation crops	N-P fertilizer rate	Grain yield (kg ha^{-1})		
		2001	2003	Mean
Niger seed	Half recommended	6228	5488	5858
	Recommended	7594	6884	7239
Haricot bean	Half recommended	6484	3263	4874
	Recommended	8231	4333	6282
Tef	Half recommended	5839	3909	4874
	Recommended	6569	4858	5713
Continuous	Recommended	5544	3390	4467
LSD (5%)	Rotation crops	Ns	496.1	930.7
	N-P rate	995	405	503
	Rotation crops x N-P rate	Ns	Ns	Ns
CV (%)		13.89	8.05	12.46

Recommended= 110/20 kg N-P ha^{-1}, Half recommended= 55/10 kg NP ha^{-1}, Ns= non-significant
Source: Abera *et al.* (2009)

Table 5. Effects of haricot bean cropping system on subsequent plant height and grain yield of maize and sorghum at Bako.

Cropping system	Maize		Sorghum	
	Plant height (cm)	Grain Yield (t ha^{-1})	Plant height (cm)	Grain Yield (t ha^{-1})
Intercropping	208	5671	187	3590
Sole haricot bean	220	7395	189	4630
Continuous monocrop	208	6718	197	3782
LSD (5%)	6.15	613	Ns	401
CV (%)	6.10	19.89	8.61	20.67

Source: Abera (2012)

Table 6. Effects of precursor crops on useable ears and grain yield of maize at Bako

Precursor crops	Useable ears (ha^{-1})	Grain Yield (t ha^{-1})
Tef	48136	8.2
Climbing bean	50254	8.6
Soybean (TAL-378)	47785	7.8
Continuous maize	45095	7
LSD (5%)	2093	0.4
CV (%)	11	13

Source: Abebe *et al.* (2013)

Higher grain yield of maize was produced from maize planted with application of half recommended rate of nitrogen fertilizer following soybean (Abera *et al.*, 2016). Soil amendment with crop rotation and N-P fertilizer rate improved the pH of the soil (Abera *et al.*, 2007, 2012). Soil NO_3^-N and NH_4^+N (ppm) were improved following soybean (Abera *et al.*, 2016). Higher shoot and grain N accumulation of maize varieties were obtained from application of half and full recommended rate of nitrogen fertilizer following soybean (Table 8) (Abera, 2016). Therefore, planting of maize varieties following soybean reduces the amount of nitrogen fertilizer for maize production in mid altitude areas of Bako.

Table 7. Effects of precursor crops on useable ears and grain yield of maize at Bako

Precursor crops	Plant height (cm)	Useable ears (ha^{-1})	Grain Yield (t ha^{-1})
Niger seed	308	47838	9.4
Soybean (No inoculation)	318	47047	8.5
Bush haricot bean	311	49601	10.1
Continuous maize	278	42375	8
LSD (5%)	5.5	1820	0.42
CV (%)	6	10	12

Source: Abebe *et al.* (2013)

Table 8. Effects of nitrogen rates following soybean on grain yield, shoot N accumulation and grain N accumulation of two maize cvs at BARC, in 2014 cropping season

	Grain yield (kg ha^{-1})		Shoot N accumulation (kg ha^{-1})		Grain N accumulation (kg ha^{-1})
N (kg ha^{-1})	BH-543	BH-661	BH-543	BH-661	
0	6133	6840b	10.62b	10.72c	8.86b
55	6690	7352ab	12.30ab	14.17b	10.14a
110	6947	7600a	13.42a	17.85a	9.96a
LSD (5%)	1275^{Ns}	568.32	2.0973	2.9345	0.7503
CV (%)	15.51	6.27	13.88	16.51	9.18

NS=non-significant difference between means in the same column at 5% probability level, Numbers followed by same letter in the same column are not significantly different at 5% probability level, BH= Bako hybrid maize
Source: Abera (2016)

The mean grain yields and harvest index of maize varieties were significantly ($P<0.05$) higher following faba bean with the application of 55 and 110 kg N ha^{-1} in both farms compared to the control (Table 9) (Abera 2016). Application of nitrogen rates to maize varieties following faba bean precursor crop improved dry biomass yield of highland maize varieties (Table 9). Higher agronomic efficiency, fertilizer N (recovery) use efficiency and nitrogen use efficiency of maize varieties following faba bean and soybean were obtained from 55 kg N ha^{-1} application as compared to 110 kg N ha^{-1}, which matched with higher grain yields of maize in highland and mid altitude varieties (Table 10 and 11). Agronomic studies confirmed increased yields of maize following faba bean and soybean precursor crop and applying half recommended rate of nitrogen fertilizer (55 kg N ha^{-1}) in high altitude areas of western Ethiopia. Shoot and grain N accumulation were obtained for maize varieties following faba bean precursor crop in both farms in highland areas of western Ethiopia (Table 12). Thus, yield and nitrogen use efficiencies of highland and midaltitude maize varieties were produced from maize planted following faba bean and soybean precursor crop with application of half recommended rates of nitrogen fertilizer in western Ethiopia.

Legumes as Green Manure Crops

Integrated use of cover crop and multiple purpose trees, and herbaceous legumes in different cropping systems have increased the availability of organic resources and consequently improve crop yields. It could be applied at green succulent stage and chopped to small pieces to facilitate its incorporation. Integrated use of green manure (*Mucuna pruriens*) as improved fallow with low doses of inorganic fertilizer or farmyard manure (FYM) increased maize grain

Table 9. Effects of nitrogen rates following faba bean precursor crop on yield and yield components of subsequent maize in Toke Kutaye in 2014 cropping season

N (kg ha^{-1})	Farm 1					Farm 2			
	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})		Harvesting index (%)		Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvesting index (%)	
		Wenchi	Jibat	Wenchi	Jibat			Jibat	Wenchi
0	5934b	29270	33558	20.72b	17.51b	3804b	13045b	29.15b	29.38
55	7718a	33190	38704	26.42ab	18.20b	4349b	14127b	34.67a	27.00
110	8115a	26739	35484	30.58a	25.04a	5132a	16217a	33.94a	30.08
LSD (5%)	1393	10414^{NS}	9977^{NS}	8.3137	6.0047	558	1685	3.5132	6Ns
CV (%)	22.99	28.08	22.27	25.73	23.77	15.10	15.95	8.64	15.34

Source: Abera (2016)

Table 10. Effects of nitrogen rates following faba bean precursor crop on nitrogen agronomic efficiency and N use efficiency of subsequent maize in Toke-Kutaye in 2014 cropping season

N (kg ha^{-1})	Farm 1				Farm 2			
	Agronomic efficiency (Kg grain kg N applied^{-1})		Nitrogen use efficiency (Kg N uptake kg N applied^{-1})		Agronomic efficiency (Kg grain kg N applied^{-1})		Nitrogen use efficiency (Kg N uptake kg N applied^{-1})	
	Wenchi	Jibat	Wenchi	Jibat	Jibat	Wenchi	Jibat	Wenchi
55	42.85a	49.28	4.86	5.01a	19.40a	14.09a	3.01a	1.55
110	18.76b	29.99	2.63	3.39b	10.66b	10.50b	1.61b	1.48
LSD (5%)	15.216	23.34^{Ns}	2.30^{Ns}	0.71	3.4588	3.32	1.052	0.72^{Ns}
CV (%)	17.36	21.60	15.55	21.02	17.29	12.94	14.07	15.85

Source: Abera (2016)

Table 11. Effects of nitrogen rates following soybean precursor crop on nitrogen agronomic efficiency, nitrogen use efficiency and Fertilizer N (recovery) use efficiency of maize at BARC, in 2014 cropping season

N rate (kg ha^{-1})	Nitrogen agronomic efficiency (kg grain kg N applied ha^{-1})	Nitrogen use efficiency (kg N uptake kg N applied ha^{-1})	Fertilizer N (recovery) use efficiency (%)
55	9.72a	1.86a	194a
110	7.16b	0.69b	69b
LSD (5%)	0.94	0.459	106
CV (%)	12.74	23.83	21.62

Source: Abera (2016)

Table 12. Effects of nitrogen rates following soybean on shoot and grain N accumulation of subsequent maize in Toke Kutaye in 2014 cropping season

N (kg ha^{-1})	Farm 1			Farm 2		
	Shoot N accumulation (kg ha^{-1})		Grain N accumulation (kg ha^{-1})	Shoot N accumulation (kg ha^{-1})		Grain N accumulation (kg ha^{-1})
	Wenchi	Jibat		Jibat	Wenchi	
0	5.58b	4.53b	7.00b	3.64c	4.79	4.76c
55	8.02ab	4.82b	9.82a	6.95a	4.54	5.95b
110	8.31a	7.54a	10.98a	6.19b	4.66	7.30a
LSD (5%)	2.6394	2.070	1.6954	0.555	0.75^{Ns}	0.6243
CV (%)	18.92	24.49	21.61	7.95	12.92	12.28

Source: Abera (2016)

yield and yield components, and improved important soil properties (Negassa *et al*., 2007). Similarly, supplementing improved fallow *Mucuna* for soil fertility restoration with low doses of NP fertilizers or FYM could be recommended for maize production in the area (Negassa *et al*., 2007). Furthermore, integrated use of *Dalichos lablab* as green manure with 50% of the recommended NP fertilizer rate gave comparable grain yield of maize with the application of the recommended NP fertilizers for maize production (Negassa *et al*., 2007).

Similarly, green manure legumes such as *Dolichos 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 urea source (Bogale *et al*., 2012). The authors further realized that green manure of sole legumes had potential to substitute for more than 70 kg N ha^{-1} commercial urea in Jimma. Moreover, the application of *Sesbania* biomass and dry FYM greater than 5 t ha^{-1} gave comparable to or greater mean maize yield than application of 69 kg N ha^{-1} as urea fertilizer (Bogale *et al*., 2012). Likewise, intercropped green manure legumes with cereals could at least offset the cost of 46 kg N ha^{-1} for smallholder farmers who do not have enough land. Nitrogen fixed by soybean, *Sesbania* and *Crotalaria* had 50% yield advantage over continuous maize without N-application and produced comparable yield to plots of continuous maize with recommended N. In addition, the mean yield advantage of biomass N from 5t ha^{-1} dry biomass of *Sesbania*, soybean and *Crotalaria* was increased by 49% over the control and it rendered comparable yield to plots of continuous maize with recommended N (Bogale *et al*., 2009). Similarly, the integrated use of 5 t ha^{-1} *Tithonia* with 30 kg P ha^{-1} gave comparable maize yield with the recommended NP fertilizers of 69/20 kg NP ha^{-1} and could be recommended for low cost and sustainable maize production at Areka area (Haile *et al*., 2009). Therefore, the use of legumes as precursor crops significantly reduced the application of nitrogen fertilizers for the production of different cereal crops in western Ethiopia (Table 13).

Table 13. Integrated use of precursor crops, N/P fertilizers and FYM on maize grain yield on West Showa Ultisol

Precursor crop	Maize variety	N/P/FYM[a]	t ha^{-1}	Location	Sources
Mucuna pruriens	BH-660	0/0/0	4.74	Bako	Negass *et al.,* 2007
Mucuna pruriens	,,	55/10/0	5.91	,,	,, ,, ,,
Mucuna pruriens	,,	37/7/0	5.78	,,	,, ,, ,,
Mucuna pruriens	,,	0/0/4	6.25	,,	,, ,, ,,
Maize	,,	110/20/0	4.41	,,	,, ,, ,,
Mucuna pruriens	BH-660	0/0/ 0	5.11	,,	Abera *et al.,* 2005a
Mucuna pruriens	,,	46/5/8	7.53	,,	,, ,, ,,
Maize	,,	110/20/0	8.55	,,	,, ,, ,,
Niger seed	BH-660	110/20/0	7.24	,,	Abera *et al.,* 2009
Haricot bean	,,	110/20/0	6.28	,,	,, ,, ,,
Tef	,,	110/20/0	5.71	,,	,, ,, ,,
Maize	,,	110/20/0	4.47	,,	,, ,, ,,
Niger seed	,,	0/0/ 0	5.85	,,	,, ,, ,,
Niger seed	,,	46/5/8	8.97	,,	,, ,, ,,
Soybean	BH-543 and BH-661	55/20/0	6-7	,,	Abera *et al.,* 2015
Haricot bean, Niger seed and Soybean	BH-660	89/15/0 or 12 FYM	9.3	,,	Abebe *et al.,* 2013
Faba bean	Jibat and Wenchi	55/20	5-7	Toke Kutaye	Abera, 2016

N/P: kg ha^{-1}; FYM: t ha^{-1}, Negassa *et al.* (2012)

Economic feasibility of legumes precursor crop

The use of legumes as precursor crops in cropping systems offers a possible profitability and reducing dependence on external chemical inputs for cereal production. This approach usually resulted in the maintenance of long-term productivity and profitability of the land by gradual build-up of the nitrogen status through biological nitrogen fixation. Higher grain yields of wheat and maize were obtained after field pea and haricot bean (Table 14). Planting maize after haricot bean resulted in higher net benefit of maize compared to following haricot bean intercropped with maize (Table 15). Higher net benefit of 16698 ETB ha^{-1}, marginal rate return of 203 % and values to cost ratio of 5.80 ETB per unit investment were obtained from maize produced with recommended rate of fertilizer after haricot bean followed by maize fertilized with 75% of the recommended fertilizer rate (Table 16). Economic analyses confirmed the profitability of production of maize with recommended rate of fertilizer following legumes.

Sorghum produced following sole planted haricot bean gave a net benefit of 20835 ETB ha^{-1} as compared to sorghum produced following haricot bean intercropped with sorghum (Table 17). Sorghum produced following sole planted haricot bean gave a net benefit of 4680 ETB ha^{-1} or 22.46 % as compared to sorghum produced following intercropped haricot bean (Table 17). Therefore, economic analyses confirmed that production of maize and sorghum following sole planted haricot bean was profitable for the area as compared to following haricot bean intercropped with the maize or sorghum.

Table 14. Partial budget and net of benefit analysis for precursor crops on the mean grain yield of wheat at Shambo

Items	Break crops	
	Barley	Field pea
Average yield (kg/ha) wheat	1493	1970
Adjusted yield (kg/ha) wheat	1344	1773
Gross field benefit of wheat (ETB/ha)	1921	2535
Average straw yield (kg/ha)	1632	2438
Gross field benefit of wheat straw (ETB/ha)	81.6	121.9
Total field benefit (ETB/ha)	2003	2657
Net benefit	2003	2657

Note: Grain price= ETB 1.43 /kg, Seed price = ETB 2.40 /kg for improved variety, Seed price = ETB 1.43/kg for local variety, Straw cost= ETB 0.05 /kg, Yield was down adjusted with 10% coefficient; Source: Abera and Belisa (2005)

Table 15. Partial budget analysis for the effects of cropping system on the mean grain yield of maize at Bako

Items	Cropping system	
	Sole cropping	Intercropping
Average yield (kg ha^{-1}) maize	7395	5671
Adjusted yield (kg ha^{-1}) maize	6655	5104
Gross field benefit of maize (ETBha^{-1})	19965	15312
Net benefit (ETB ha^{-1})	19965	15312

Note: Grain price= ETBB 3.00 kg^{-1}, Yield was down adjusted with 10% coefficient, 1$ = 17.35 EB. Source: Abera (2012)

Table 16. Partial budget and marginal rate of return (MRR) analyses for the effects of fertilizer rate on the mean grain yield of maize following haricot bean and continuous maize at Bako

Items	Fertilizer rate (kg NP ha^{-1})			
	46/10	69/15	110/20	110/20 (continues)
Average yield (kg ha^{-1}) maize	5903	6444	7251	6123
Adjusted yield (kg ha^{-1}) maize	5321.7	5799.6	6525.9	5511
Gross field benefit of maize	15965	17398.8	19577.7	1653
P cost (ETB ha^{-1})	540.00	810.00	1080.00	1080.00
N cost (ETB ha^{-1})	900.00	1350.00	1800.00	1800.00
Total costs that vary (ETB ha^{-1})	1440	2160	2880	2880
Net benefit (ETB ha^{-1})	14525	15238.8	16697.7	-1,227
Values to cost ratio	10.09	7.06	5.80	
Marginal rate of return (MRR%)		99.14	202.63	

Note: Grain price= ETB 3.00 kg^{-1}, Phosphorous price = ETB 10.80 kg^{-1}, Urea price= ETB 9.00 kg^{-1} Yield was adjusted down with 10%, d= dominated treatment, 1$ = 17.35 ETB.
Source:Abera (2012)

Table 17. Partial budget analyses for the effects of cropping system on the mean grain yield of sorghum at Bako.

Items	Cropping system	
	Sole cropping	Intercropping
Average yield (kg ha^{-1}) sorghum	4630	3590
Adjusted yield (kg ha^{-1}) sorghum	4167	3231
Gross field benefit of sorghum (ETB ha^{-1})	20835.00	16155.00
Net benefit (ETB ha^{-1})	20835.00	16155.00

Note: Grain price= ETB 5.00 kg^{-1}, Yield was adjusted down with 10%, 1$ = 17.35 EB.
Source: Abera (2012)

Conclusion and Future Research Direction

Cereal yields were improved following legume precursor cops. The integrated use of different legumes as precursor crops reduces rates of nitrogen fertilizer application with improved cereal yields. The integration of legumes as break crops in farming systems could have reduced considerable amount of inorganic fertilizers and helped farmers to reduce the expense of chemical fertilizers that could be spent for maize production. Planting maize following soybean and faba bean with 50% of the recommended nitrogen fertilizer rate could be recommended for maize production. The economic analyses confirmed the profitability of cereals production following legumes. Therefore, promising research results on cropping sequence involving legumes should be verified, demonstrated and scaled up under on-farm condition in different agroecology of the country for adoption and wider use by farmers. Further studies are suggested to find out the potential contribution of different legumes as precursor crops for improving yield of cereal crops and nitrogen economy of different cereal-based cropping system in the country

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Integration of Forage Legumes into the Farming System in Ethiopia: A Review of Some Research Results

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Abstract

Mixed crop-livestock farming systems in the highlands of Ethiopia are constrained by animal feed shortage and land degradation in the form of soil erosion and nutrient depletion resulting in low agricultural productivity. With their multi-faceted uses viz., supply of better quality animal feed, recovering denuded lands, improving soil nutrient status through biological N-fixation and green manuring, erosion control, live fencing, firewood supply and as sources of nectar and pollen for honeybees; forage legumes play an important role for the sustainable integration of crop and livestock enterprises. Out of the 46 improved forage varieties so far released by the national research system in the country, 23 of them were legumes of which 16 varieties belong to herbaceous forage legumes while the rest 7 belong to browse and shrub legumes. Despite the availability of adaptable and high yielding forage legume species/varieties, their adoption and utilization in the farming system has been very much limited due to various factors of which land shortage is the most limiting one. In view of this, various research efforts have been made on alternative mechanisms/strategies for integrating forage legumes into the farming system without imposing much competition for land with food crops. Therefore, this review paper summarizes the major research efforts and important achievements made with respect to different mechanisms to integrate forage legumes into the farming system of Ethiopia.

Keywords: Crop rotation, farming systems, food-feed, forage legumes, intercropping, under-sowing

Introduction

Livestock production is an integral component of the agricultural system and constitutes a key livelihood activity for the agricultural, agro-pastoral and pastoral communities, which account for about 85% of the Ethiopian population. Despite the large livestock resource base and importance of the sector to millions of smallholder farmers and pastoralists, livestock productivity has remained very low and the available potential has not been fully exploited. Livestock development in the country has been constrained by a number of interrelated factors encompassing: technical, infrastructural, organizational, institutional, environmental and policy aspects. The major technical constraints include: under-nutrition, high disease prevalence, low genetic potential of the indigenous breeds for productive traits, poor husbandry practices and weak marketing system. Among these, shortage of feed supply, low quality and seasonal fluctuations in feed availability are the most limiting factors on account of the fact that feed cost accounts for about 60 to 70% of all costs associated with livestock production.

In the mixed farming systems of the country, livestock and crop production are closely integrated and commonly constrained by feed shortage and land degradation in the form of soil erosion and nutrient depletion with the consequent low agricultural productivity (Kruseman *et al*., 2002; Tangka *et al*., 2002). Forage legumes provide high quality forage for ruminants, improve soil nitrogen status and reduce soil erosion when intercropped with cereals. Forage legume mulches are also used as important sources of nutrient-rich organic matter and nitrogen for crop production. Moreover, forage tree legumes can serve as sources of shelter/wind break, fuel wood and bee forage, besides providing quality livestock feed. Forage legumes contribute high protein herbage to supplement crop residues and other low quality feeds available to resource-poor farmers. Therefore, integrating well-adapted forage legumes into the farming system offers a ray of hope for small-scale and resource-poor farmers in developing countries, like Ethiopia.

Through successive research efforts over the last four to five decades, various adaptable and high yielding forage species/varieties belonging to grasses, herbaceous legumes and browse trees have been identified and recommended for use in different agro-ecological zones of the country. Out of the 46 improved forage varieties/species so far released by the national research system in the country, 23 of them were legumes of which 16 varieties belong to herbaceous forage legumes while the rest 7 belong to tree and shrub legumes. Despite the availability of well adapted and high yielding forage legumes, their adoption and utilization in the different farming systems of the country has been very much limited, due to various factors, of which land shortage is the most limiting one. In view of this, various research and development efforts have been made on suitable mechanisms/strategies of integrating forage legumes into the farming system without imposing much competition for land with food crops. Therefore, this review paper summarizes the major research outputs/information generated with respect to the different mechanisms of integrating forage legumes into the different farming systems of Ethiopia.

An Overview of Research in Forage Legumes in Ethiopia

Formal research on cultivated pasture and forage crops including forage legumes was started in the mid-1960s, with the establishment of the Institute of Agricultural Research (IAR) in 1966 (Mengistu and Assefa, 2012; Assefa, 2012). Other governmental and non-governmental organizations, such as ARDU/CADU and ILCA (the present ILRI) have also played important roles in supporting the national forage research and development efforts. Especially, ARDU which was established in 1967 at Asela has been recognized for its pioneer livestock research and development in the Arsi highlands (Mengistu, 2002). The project introduced different temperate and tropical forage species and made significant contributions to the national forage and pasture research by IAR in addition to its development efforts in promoting improved forage crops along with crossbred heifers in Arsi highlands. Generally, forage research efforts over the last four to five decades have been focused on germplasm introduction/collection, evaluation and selection of promising species for the different agro-ecologies, forage agronomic studies, micro-seed multiplication, on-farm demonstrations and promotions to users.

The ultimate goal of improved forage introduction, collection and evaluation is to release superior species/varieties/ cultivars for wider utilization as feed and natural resource conservation in the farming system in a suitable agro-ecology. Previous forage research works, including forage legumes have progressed without formal variety release mechanism for a long period of time in Ethiopia. However, various promising forage species/varieties have been promoted via different livestock development projects, like the Fourth Livestock Development Project (FLDP) and being developed and utilized under varying scales in different parts of the country. To this effect, about nine forage species/varieties (four legumes), which were informally promoted and accepted by the different users (ex-state farms, private farms and smallholder farmers) were registered in the crop variety register book of the Ministry of Agriculture (MoA).

Official variety release procedures and guidelines for forage crops have been established and implemented in the country, since 2009. Since then, about 37 forage varieties (of which 19 varieties belonged to forage legumes) have been released by NARS (EIAR, Regional Research Institutes) following the guidelines. The forage species/varieties officially released and registered have been summarized and documented (Feyissa *et al*., 2015). So far, a total of 46 forage species/varieties have been officially released, out of which 23 varieties belongs to forage legumes (Table 1). Still, it has been perceived that the number of released varieties is few relative to the number of forage legume species recommended for different agro-ecological zones of the country. For instance, some forage legumes, such as stylosanthes species, desmodium species and leucaena species, which have been found promising in the mid and lowland areas of the country, have not been officially registered.

Table 1. Lists and herbage productivity of released forage legume species and varieties in Ethiopia

SN	Species	Variety	Common name	Altitude (masl)	DMY* (t/ha)	Year registered	Breeder Institute
			Herbaceous Legumes				
1	*Vicia dasycarpa*	Lana	Vetch	1500-3000	5- 7	1976	HARC*
2	*Vicia sativa*	ICA-61509	Vetch	2200-2004	5-6	2012	HARC*
3	*Vicia sativa*	Gebisa	Vetch	2300-3000	4.3-5.1	2011	SARC*
4	*Vicia villosa*	Lalisa	Vetch	2300-3000	6.6-8.4	2011	SARC*
5	*Vicia narbonensis*	Abdeta	Narbon vetch	2300-3000	3.1-3.4	2011	SARC*
6	*Trifolium quartinianum*	(Native)	Clover	1500-3000	3-6	1976	HARC*
7	*Lablab purpureus*	-	Lablab	1000-2004	3-5	1984	HARC*
8	*Vigna unguiculata*	Sewinet	Cowpea			2009	PARC*
9	*Vigna unguiculata*	Temesgen	Cowpea			2014	Humera
10	*Medicago sativa*	DZF-552	Alfalfa			2014	DZARC*
11	*Lupinus angustifolius*	Sanabor	Sweet blue Lupin			2014	Andassa
12	*Lupinus angustifolius*	Vitabor	Sweet blue Lupin			2014	Andassa
13	*Medicago sativa*	Alfalfa-1086	Alfalfa			(2015)	HARC*
14	*Medicago sativa*	ML-99	Alfalfa			(2016)	HARC*
15	*Lablab purpureus*	ILRI-14417	Lablab			(2016)	Bako
16	*Lablab purpureus*	ILRI-14455	Lablab			(2016)	Bako
			Browse Trees and Shrub Legumes				
17	*Chamaecytisus palmensis*	MoA	Tagasaste	2000-3000	6-10	1992	HARC
18	*Sesbania macrantha*	DZF-092	Sesbania	400-2000	8-10	2012	DZARC
19	*Cajanus cajan*	Dursa	Pigeon pea			2009	MARC
20	*Cajanus cajan*	Kibret	Pigeon pea			2014	Humera
21	*Cajanus cajan*	Tsegab	Pigeon pea			2014	Humera
22	*Cajanus cajan*	ILRI-Acc#11575	Pigeon pea		5-7.5	(2017)	Bako
23	*Cajanus cajan*	ILRI-Acc#16527	Pigeon pea		5-7.5	(2017)	Bako

DMY (t/ha)= Dry matter yield in ton per hectare, HARC, Holetta Agricultural Research Center, SARC=Sirinka Agricultural Research Center, PARC=Pawe Agricultural Research Center, DZARC=Debre Zeit Agricultural Research Center, MARC=Melkassa Agricultural Research Center

Mechanisms of Integrating Forage Legumes into the Farming System

Land scarcity for sole forage cropping has been among the major bottlenecks limiting adoption of cultivated forage crops, despite critical livestock feed shortage in mixed farming systems of Ethiopia. It is, therefore, essential to explore and exploit possible options in which forages, in general, and forage legumes, in particular, can be grown within the spatial and temporal constraints of complex and resource-limited crop–livestock mixed farming systems, such as the case of Ethiopia.

One feasible option for introducing forage legumes into such farming systems could be through integrating feed production with the cropping venture. Rotational and/or double cropping within a season and forage legume-cereal intercropping/ under sowing are the most important mechanisms for feed-food crops integration in the farming system. Moreover, backyard plantation as live fences, alley cropping (forage hedgerows/strips in crop fields) and establishment on conservation structures (conservation-based forage development) are the viable strategies for integrating forage tree legumes into the farming system. Some of the research efforts and achievements with regard to mechanisms of integrating forage legumes into the farming system are highlighted below:

I) Forage Legume – Cereal Rotations

One of the options available to introduce improved forage legumes to smallholder production systems is by integrating them into the existing cropping system through forage-food crops rotation. This practice is potentially useful, as it helps to provide a substantial amount of mineral N to the succeeding crops grown during the forage legume-based rotation. This system generally enables farmers to obtain a better harvest of both grain and biomass; while at the same time improving the quality of soil and the environment. Besides the improvement in livestock production via provision of quality feed, forage legumes also help increase the yields of subsequent cereal crops grown in rotation, through improving the soil chemical, physical and biological properties (Haque *et al*., 1995). The primary role that forage legumes play, when incorporated into crop rotation is fixing the atmospheric N through their symbiotic relationship with bacteria called *Rhizobium*, usually associated with the host`s root system. Nitrogen fixation is the process in which forage and other legumes capture nitrogen (N) from the atmosphere via their nodules and make it available for plant growth and development. This contributes nitrogenous compounds to the soil, either directly by nodule excretion, or indirectly by decomposition of root nodules and tissues.

N-fixation by nodulated forage legumes is fundamental for the economic and environmental sustainability of mixed farming systems in Ethiopia. The quantity of N fixed by forage legumes differ widely between species and environments (Unkovich and Pate, 2000). The quantity of N-fixed by different forage legumes under Ethiopian conditions is presented in Table 2. It is noted that the quantity of N-fixed by the studied forage legumes varied from as low as 44.7 kg/ha by *Trifolium steudneri* to as high as 214.6 kg/ha by *Lablab purpureus*. One reason for the observed disparity in N-fixation by the different forage legumes could be attributed to differences in lifecycles and growth habits of the legumes. For instance, semi-perennial legumes, like lablab have relatively a tap/branched root system, which allows the formation of more nodules, thereby, resulting in more N-fixation. Moreover, high biomass producing forage legumes can retain more nutrients to the subsequent crops via decomposition of their parts, such as leaves and roots. In general, nitrogen produced, as a result of rhizobia is the most cost-efficient way to supply the nitrogen needs of the forage legumes and to provide additional nitrogen benefits to the subsequent cereal crop in a rotation.

Table 2. Forage yield and N fixing performance of different forage legumes

No	Forage legume	Forage yield (DM t/ha)	Amount of N fixed (kg/ha)
1	*Trifolium steudneri*	4.72	44.7
2	*Trifolium steudneri*	3.19	44.7
3	*Vicia dasycarpa*	7.11	163.0
4	*Vicia atropurpurea*	5.23	103.6
5	*Lablab purpureus*	9.49	214.6
6	*Lablab purpureus*	8.15	140.1
7	*Medicago scutellata*	6.80	140.1
8	*Medicago trancatula*	6.46	108.5
	LSD (P<0.05)	1.89	46.8

(Source:- Haque and Lupwayi, 2000)

Some results of the forage legume-food crops rotational experiments conducted in different parts of Ethiopia are presented in Tables 3–6. Table 3 indicates average herbage yields of different forage crops grown during the fallow phase and grain yield of the subsequent barley crop at Galessa in the central highlands of Ethiopia. When averaged over two years, highest herbage yield (12.0 t DM/ha) was obtained from oats/vetch mixture; followed by the fallow plot (5.1 t DM/ha). Such yield from the fallow plot was obtained by resting the land for at least four months, during the cropping season (July – October). Otherwise, average herbage productivity of the arable fallow lands assessed under the prevailing continuous grazing system in the area was only about 0.9 t DM/ha (Feyissa *et al*., 2008). This implies that an estimated six-fold increment in herbage yield could be achieved by resting the arable fallow lands for about four months in the area. This shows strategic management systems, such as resting; followed by feed conservation in the form of hay could help to enhance livestock feed supply from arable fallow lands at Galessa and similar highland areas. Among the forage legumes, *Vicia dasycarpa* gave comparatively better herbage yield.

The average productivity of the subsequent barley grain did not show significant difference following the fallow plot, oats/vetch mixture and the *vicia* species. The basic principle behind food-feed crop integration via crop rotation is to identify components compatible with the existing farming system; while optimizing both food and feed production on the same plot of land. In view of this, incorporating oats/vetch mixture in the barley-fallow cropping system could be an ideal approach to improve livestock feed supply without significant reduction in barley grain yield in the Galessa area. On average, about 7 t DM/ha more feed was obtained from oats/vetch mixture, as compared to the fallow; while sacrificing only 0.2 t/ha in grain yield of the subsequent barley.

Table 3. Two years average herbage yields (DM t/ha) of selected forage legumes established during the fallow phase and grain yield (t/ha) of the succeeding barley crop at Galessa, central highlands of Ethiopia

Forage species (precursor treatments)	Herbage yield	Barley grain yield		Barley grain mean
		With fertilizer*	Without fertilizer	
Vicia villosa	0.90	2.50	2.00	2.30
Vicia dasycarpa	2.10	2.40	2.20	2.30
Vicia sativa	0.40	2.40	2.10	2.30
Trifolium quartinianum	0.10	2.30	1.90	2.10
Trifolium tembense	0.50	2.00	1.50	1.80
Oats-vetch mixture	12.00	2.10	2.30	2.20
Fallow	5.10	2.40	2.40	2.40
Mean	**--**	**2.30**	**2.10**	**2.20**

*41/46 kg/ha N/P; (**Source:- Feyissa *et al*., 2008**)

In a similar study conducted at upper Dinsho in Bale, southeastern highlands of Ethiopia (Abate *et al*., 2003), forage legume-barley rotation has resulted in better barley grain and straw yield performance than the barley-barley and fallow-barley cropping (Table 4). Vetch-barley rotational cropping resulted in significantly higher barley grain and straw yields, followed by snail medics-barley and fallow-barley rotations, respectively. Barley grain yield recorded in the vetch-barley rotational cropping was 77% higher than the grain yield recorded in the barley-barley mono-cropping, even with fertilizer application. When the amount of quality feed produced by the legume component is added, the overall benefit obtained from vetch-barley rotational cropping could considerably surpass the figure indicated above.

Table 4. Effect of different crop rotation systems on barley grain yield (kg/ha), straw (DM t/ha) and herbage (DM t/ha) yields of precursor forage legumes at upper Dinsho district, Bale

Rotation systems	Previous year			Subsequent year	
	Barley grain yield	Barley straw yield	Forage yield	Barley grain yield	Barley straw yield
Fallow – Barley	--	--	--	1178^{bc}	4.03^{b}
Barley (F1) – Barley	1900	8.4	--	955^{d}	3.44^{b}
Barley (F0) – Barley	1150	6.0	--	1033^{cd}	3.65^{b}
Vetch – Barley	--	--	2.0	1691^{a}	5.56^{a}
Snail medics – Barley	--	--	0.7	1330^{b}	4.24^{b}

Means with the same letter within a column do not differ significantly (p>0.05); F1 – 100 kg DAP and 50 kg urea/ha; F0 – No fertilizer was applied; (Source:- Abate *et al*., 2003)

A study was conducted at Ginchi vertisols to assess the possibility to produce some amount of feed by growing annual forage legume-grass mixture as precursor crops to chickpea/ lathyrus while maintaining or improving grain productivity of the subsequent crops. As shown in Table 5, growing oats/vetch mixture as precursor crops to chickpea/lathyrus was found to be a viable option than the fallow-chickpea/lathyrus cropping system practiced by farmers in the area. The result showed that substantial amount of feed can be produced from oats/vetch mixture; while improving grain productivity of the subsequent crops as compared to the fallow-chickpea/lathyrus cropping system. When averaged over two years, oats/vetch mixture gave threefold (206%) more herbage dry matter yield than the fallow (3.40 Vs 1.11 t/ha). Similarly, average grain yields of chickpea and lathyrus were increased by 250 kg/ha (69%) and 242 kg/ha (23%), respectively following oats/vetch mixture, as compared to the fallow chickpea/lathyrus cropping system.

The result of the study, generally, implies that incorporating oats/vetch mixture, as precursor crops to chickpea/lathyrus could be an ideal strategy, not only to produce high quantity of livestock feed, but also to improve grain yields of the succeeding crops in chickpea/lathyrus growing highland areas. For instance, the feed that can be produced from a hectare of land, according to the study (Table 5), could support two mature cattle (oxen or milking cows) for about half a year, if properly collected and conserved as hay. It could also sustain large number of animals for a short period of time, if used for cut-and-carry green feeding system.

Table 5. Average herbage yield (DM t/ha) of oats/vetch mixture grown as a precursor to chickpea and lathyrus and grain yields (kg/ha) of the succeeding crops grown using residual moisture in highland vertisols at Ginchi

Year	Preceding treatment	Herbage yield	Grain yield of succeeding crops	
			Chickpea	Lathyrus
2004	Oats/vetch mixture	4.42	553	1510
	Farmers` practice*	1.12	170	890
2005	Oats/vetch mixture	2.30	660	1094
	Farmers` practice*	1.10	550	1220
Year mean	Oats/vetch mixture	3.40	610	1302
	Farmers` practice*	1.11	360	1060

* - Ploughing the land once during the commencement of the main rains in June and leaving it fallow until planting of chickpea/lathyrus as of mid September; (Source: HARC, 2006; Minta *et al.*, 2014)

Sequential cropping (i.e. growing two or more crops one after the other in a year) is the other type of rotational cropping, in which forages can be incorporated. In areas where there are reliable short rains, forage crops could be grown in the short rains and cereals could follow during the Meher season.

On the other hand, forage crops could be grown during the early onset of the main rainy season and food crops, which are usually grown with residual moisture (chickpea and lathyrus) will follow towards the end of the main rainy season. A study was conducted to assess the forage yield of oats/vetch mixture, and grain yield of chickpea, sequentially grown within a year, and their effect on grain yield performance of wheat, during the second year on vertisols. As shown in Table 6, oats/vetch mixture was successfully grown as first crop during June–August and produced high quantity of feed; while also improving grain yield of chickpea grown as a second crop using residual moisture. Moreover, sequential cropping of oats/vetch mixture-chickpea-wheat had a positive effect on grain yield of wheat grown during the second year, as compared to the fallow-chickpea-wheat cropping system. Hence, such practice could be potentially adopted in chickpea growing highland vertisols to improve livestock feed supply without significant reduction in grain yield of the subsequent crops.

Table 6. Performance of oats-vetch and chickpea grown sequentially in the first year and their effect on wheat grain yield in the second year

First year				Second year	
First crop	Forage yield (DM t/ha)	Second crop	Grain yield (kg/ha)	Crop	Grain yield (t/ha)
Fallow	--	Chickpea	1170	Wheat	3770
Oats-vetch	6.00	Chickpea	1260	Wheat	4190
LSD (0.05)	--		0.021^{ns}		1.12^{ns}

(Source:- Abate *et al*., 1996)

II) Forage Legume-Cereal Intercropping and Under-sowing

The other important means of integrating forage legumes to the smallholder mixed farming systems is through intercropping/under sowing with food crops; mainly cereals. It is a crop management system involving two or more crop species grown together for at least a portion of their respective productive cycle and planted sufficiently close to each other, so that inter-specific competitions occurs (Innis, 1997). The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available resources using a mixture of crops of different rooting ability, canopy structure, height, and nutrient requirements based on the complementary utilization of growth resources by the component crops.

Results of the forage legume-food crops intercropping/under-sowing research works done in different parts of Ethiopia are summarized in Tables 7 – 12. The results of the compatibility of selected annual forage legumes (*Vicia dasycarpa*, *Vicia villosa* and *Trifolium rueppellianum*) with barley when intercropped simultaneously or under-sown at the first weeding of barley with and without fertilizer application under farmers` fields in selected central highland areas of Ethiopia is presented in Table 7. The forage legumes were established very well and gave higher herbage yield, when sown simultaneously with barley than when under-sown at first weeding of barley (Assefa *et al.*, 2011). When averaged over the study areas and the forage legumes, 505% and 817% more herbage yield was obtained, when the legumes were simultaneously intercropped with barley than when they were under-sown at first weeding of barley with and without fertilizer application, respectively. The poor performance of the forage legumes under-sown at first weeding of barley may be attributed to the cool and wet soil conditions, which slowed down germination coupled with high competition from weeds after germination.

Use of fertilizer resulted in higher grain yield of barley and herbage yields of the companion legumes in all the study areas. Among the forage legumes, vetch was highly responsive to fertilizer application and found to dominate/depress barley, mainly when they were sown simultaneously. Especially, at Adaberga, barley was highly dominated by vetch and has undergone significant reduction in grain yield. However, reasonable forage yield was obtained from the vetches without significant effect on barley, even under fertilized conditions at Menagesha. In general, the result showed that simultaneous cropping of the annual forage legumes with barley was found to be more advantageous in terms of the overall performance of the legumes with no significant effect on barley grain yield. Hence, this practice may be adopted by farmers, mainly in relatively less fertile soils in order to minimize the dominating effects of some vigorous legumes, like vetch, as was noticed in more fertile soils at Adaberga area.

Table 7. Effect of intercropping annual forage legumes simultaneously or by under-sowing at first weeding of barley on grain yield of barley and herbage yield of the legumes

Treatment	Forage legumes	Barley grain (kg/ha)				Forage DM yield of the legumes (t/ha)			
		Adaberga		Menagesha		Adaberga		Menagesha	
		F1	F0	F1	F0	F1	F0	F1	F0
Simultaneous cropping	*V. dasycarpa*	1207	731	1487	1100	3.72	2.73	1.55	1.28
	V. villosa	1117	901	1477	971	4.26	2.68	2.28	1.43
	T. rueppellianum	2288	1132	1278	932	0.45	0.40	--	--
	Mean	1537	921	1414	1001	2.81	1.94	1.92	1.36
Under-sowing at first weeding	*V. dasycarpa*	1863	1244	1534	1086	0.48	0.04	0.51	0.22
	V. villosa	1939	945	1594	845	0.30	0.10	0.42	0.30
	T. rueppellianum	1755	930	1666	938	0.16	0.14	--	--
	Mean	1852	1040	1598	956	0.31	0.09	0.47	0.26
Sole barley		2096	761	1581	921	--	--	--	--

Note: F1=41/46 kg/ha N/P fertilizer; F0=No fertilizer; (Source: Assefa *et al*., 2011)

There could be inherent differences among the intercropped/under-sown forage legumes, and also among different varieties of the companion barley crop which could have a considerable impact on compatibility of the forage legume-cereal intercropping system. In-line with this, a study was conducted to evaluate the compatibility and yield performances of two vetch species (*Vicia villosa* and *Vicia narbonensis*) intercropped with three varieties of barley (HB 42, 'Shege' and 'Baleme') under on-farm conditions at four locations in the central highlands of Ethiopia (Assefa *et al*., 2011). The experiment was conducted with and without the application of the recommended fertilizer rate for barley. Herbage yield performance of the intercropped forage legumes and grain yields of the barley varieties were presented in Tables 8 and 9, respectively. The results showed that herbage productivity of the intercropped forage legumes was affected by location; while both location and fertilizer had marked effects on grain yields of the barley varieties. The forage legumes, especially *Vicia villosa* gave better forage yield at Addis Alem, as compared to the other locations (Table 8), and grain yield performances of the barley varieties were also higher at Addis Alem and Rob-gebeya (Table 9). Moreover, when averaged across the study locations and varieties, about 80.4% more barley grain yield was obtained in response to fertilizer application.

Vicia villosa, generally, had better performance than *Vicia narbonensis* in the experiment. It was found to be better compatible and gave considerably high forage yield, when intercropped with the barley variety 'Baleme', though it depressed performances of the other varieties, such as HB 42 and 'Shege', especially at Rob-gebeya. This could be due to the relatively vigorous early growth of 'Baleme', which allowed it to compete with the companion legume (*Vicia villosa*). It was, however, observed that the intercropped legumes were tended to depress the barley varieties including 'Baleme' in unfertilized plots. The results, generally, showed that compatibility of forage legume-cereal intercropping (barley in this case) is considerably affected by species of the forage legume, varieties of the cereal crop (barley), location (soil effect) and fertilizer application. This calls for the need to consider these and other factors for successful integration of forage legumes into the cropping system without substantial sacrifice in grain production.

Table 8. Effect of fertilizer and intercropping (vetch species and barley varieties) on dry matter forage yield (t/ha) at Addis Alem, Menagesha, Rob-Gebeya and Wolmera

Barley + Forage legume	Addis Alem		Menagesha		Rob-gebeya		Wolmera		Mean	
	F1	F0	F1	F0	F1	F0	F1	F0	F1	F0
HB 42 +*V. villosa*	3.11	2.13	1.06	0.83	1.36	0.97	1.22	1.52	1.69	1.36
Shege +*V. villosa*	2.52	2.69	1.62	0.82	1.36	1.44	1.41	1.77	1.73	1.68
Baleme +*V. villosa*	1.29	2.57	0.95	0.68	0.69	0.99	0.63	1.48	0.89	1.43
HB 42 +*V. narbonensis*	0.01	0.14	0.11	0.49	0.14	0.41	0.17	0.77	0.11	0.45
Shege+ *V. narbonensis*	0.05	0.05	0.08	0.36	0.13	0.33	0.15	0.55	0.10	0.32
Baleme+ *V. narbonensis*	0.03	0.04	0.09	0.30	0.16	0.18	0.14	0.96	0.11	0.37

Note: F1=41/46 kg/ha N/P fertilizer; F0=No fertilizer; (Source:- Assefa *et al*., 2011)

Table 9. Effect of fertilizer and intercropping (vetch species and barley varieties) on barley grain yield (kg/ha) at Addis Alem, Menagesha, Rob-gebeya and Wolmera

Barley - Forage legume	Addis Alem		Menagesha		Rob-gebeya		Wolmera		Mean	
	F1	F0	F1	F0	F1	F0	F1	F0	F1	F0
HB 42 +*V. villosa*	2220	1240	1710	440	2190	1530	1710	780	1960	1000
Shege +*V. villosa*	2220	1170	1190	550	2190	1300	1500	460	1780	870
Baleme +*V. villosa*	2210	1090	1300	540	2420	1640	1620	570	1890	960
HB 42 +*V. narbonensis*	2600	1860	1830	820	2550	1860	1600	670	2150	1300
Shege + *V. narbonensis*	2420	1600	1780	240	2220	1540	1430	680	1960	1010
Baleme + *V. narbonensis*	2180	1500	1370	650	2390	1970	1900	840	1960	1240
HB 42 alone	2460	1830	1710	560	2340	1340	1780	530	2070	1060
Shege alone	2450	1470	1670	580	2030	1790	1340	750	1870	1150
Baleme alone	2430	1630	1250	580	2480	1800	1960	800	2030	1200

Note: F1=41/46 kg/ha N/P fertilizer; F0=No fertilizer; (Source:- Assefa *et al*., 2011)

Besides forage legume-small cereal crops integration in the highlands of Ethiopia, various research works have also been conducted on the possibilities of integrating forage legumes in maize based cropping systems in the low to mid-altitude agro-ecologies of the country. Results of the forage legume-maize integration (intercropping, under-sowing) experiments conducted in the different areas are presented in Tables 10-12 below. Table 10 indicates results of a study conducted to evaluate the effects of under-sowing three forage legumes (*Vigna unguiculata, Lablab purpureus and Vicia atropurpurea*) with maize on the performances of maize and the forage legumes under irrigation at Megech, North Gondar. The result showed that under-sowing forage legumes with maize resulted in an increase in both maize grain yield and total biomass production, as compared to sole maize cropping (Tarekegn and Zelalem, 2014). Among the under-sown forage legumes, *Lablab purpureus* gave higher herbage yield contributing to higher total biomass production (maize stover + legume biomass), which was about 31% higher than the biomass produced in the case of sole maize cropping. On the other hand, higher maize grain yield was recorded, when *Vicia atropurpurea* was under-sown with maize though the biomass yield of the legume was comparatively lower. The result, generally, showed the possibility of producing substantial amount of feed by intercropping/under-sowing forage legumes with maize; while also improving grain yield of the main crop (maize).

Table 10. Effect of under-sowing forage legumes on maize grain and biomass productivity, and herbage yield of the forage legumes under irrigation at Megech, Dembia, North Gondar

Treatments	Maize grain yield (t/ha)	Maize stover yield (DM t/ha)	Legume biomass (DM t/ha)	Total biomass (DM t/ha)
Sole maize	5.63	7.10	-	7.10[b]
Maize + *Vigna unguiculata*	5.75	6.33	1.73[b]	7.81[b]
Maize + *Lablab purpureus*	5.85	6.34	2.89[a]	9.31[a]
Maize + *Vicia atropurpurea*	6.08	7.36	1.23[c]	8.17[b]
Mean	5.83	6.78	1.95	8.10
SE (±)	1.63	0.24	0.09	0.20
Significance	NS	NS	***	*

[abc] *Means with different superscript letters within a column differ significantly (p<0.05); SE= standard error; *p<0.05; ***p<0.001; NS= not significant (p>0.05)*; (Source:- Tarekegn and Zelalem, 2014)

A similar maize-forage legumes under-sowing experiment was conducted at Baresa watershed in Meskan woreda, Gurage Zone in Southern Nations, Nationalities and Peoples Regional State using vetch (*Vicia dasycarpa*), cowpea and lablab (Abera, 2012). As shown in Table 11, maize-forage legumes under-sowing has resulted in higher maize grain yield, maize biomass yield and total biomass yields. The under-sown forage legumes also gave considerable forage yields, though their yield performances were significantly higher, when they were solitarily grown. However, forage legume-maize under-sowing was found to be promising in terms of the overall plot productivity, and thereby, supporting better food and feed production.

Table 11. Effect of under-sowing forage legumes on maize grain and biomass productivity, and herbage yield of the forage legumes at Baresa watershed

Treatments	Maize grain yield (t/ha)	Maize biomass (DM t/ha)	Legume biomass (DM t/ha)	Total biomass (DM t/ha)
Maize + Vetch	5.26	8.95	1.90[c]	10.85[a]
Maize + cowpea	5.19	8.83	1.37[c]	10.20[a]
Maize + Lablab	5.15	8.78	1.99[c]	10.77[a]
Sole Maize	4.90	8.74	--	8.74[ab]
Sole Vetch	--	--	6.98[ab]	6.98[b]
Sole Cowpea	--	--	6.32[b]	6.32[b]
Sole Lablab	--	--	8.85[a]	8.85[ab]
Mean	5.12	8.83	4.57	8.96
SEM	3.59	0.57	2.64	0.52
P- value	0.5996	0.9819	0.0001	0.0155

(Source:- Abera, 2012)

Three forage legumes (*Desmodium intortum*, *Stylosanthes guianensis*, *and Macrotyloma axillare*) and one grass (Rhodes grass) were used to assess the feasibility of integrating different forage crops with maize through under-sowing at Bako, Western Oromia, Ethiopia (Diriba and Lemma, 2002). The forage crops were under-sown with maize both in pure form and as grass-legume mixture along with sole maize, undersowing-maize and fallow-maize cropping system. As shown in Table 12, significantly ($P<0.01$) highest maize grain yield (7.64 t/ha) was obtained from the plots in which *Stylosanthes guianensis* was under-sown with maize, and the lowest mean grain yield (5.24 t/ha) was recorded from the sole maize grown without fertilizer application. On the other hand, highest maize residue DM was obtained in the maize-*Macrotyloma axillare* under-sowing treatment; while lowest residue DM was recorded in unfertilized sole maize.

Among the under-sown legumes, *Macrotyloma axillare* gave highest herbage yield, followed by stylosanthes; while the lowest legume DM yield was obtained from the under-sown Rhodes-axillaries mixture during the establishment phase of the forages. Highest overall total fodder yield was recorded from the treatment, where Rhodes/stylosanthes mixture was under-sown to maize, and the lowest quantity of forage was obtained from the fallow plots. The result, generally, revealed that the forage legumes had better performances, when they were under-sown with maize in pure stands than under-sown in mixture with Rhodes, which may be attributed to the competition effect from the grass component. Low yield of the under-sown forages, during the establishment year could be associated with the competition by the maize crop itself under which the forage crops were sown.

Table 12. Effect of under-sowing forage crops in maize on grain (t/ha) and residue (t/ha) yields and DM yield (t/ha) of the under-sown forage crops

Treatments	Grain yield	Residue yield	Legume yield	Grass yield	Total forage
Maize (fertilized)	7.5[a]	9.37[bcd]	--	--	9.37[e]
Maize (unfertilized)	5.24[b]	8.00[d]	--	--	8.00[e]
Maize +Rhodes	6.49[ab]	10.23[abc]	--	2.99[ab]	13.36[bc]
Maize +*Stylo*	7.64[a]	9.13[cd]	2.48[ab]	--	11.52[d]
Maize +Desmodium	7.29[a]	9.80[abc]	2.28[ab]	--	12.08[cd]
Maize +axillaries	7.52[a]	11.17[a]	2.90[a]	--	14.07[ab]
Maize + Rhodes +*Stylo*	6.76[ab]	10.84[ab]	0.97[b]	3.29[ab]	15.10[a]
Maize + Rhodes +*Desmodium*	6.49[ab]	9.08[cd]	1.20[ab]	2.09[b]	12.37[cd]
Maize + Rhodes +*axillaries*	5.90[ab]	9.34[bcd]	0.96[b]	2.23[b]	12.53[bcd]
Traditional fallow	--	--	--	4.68[a]	4.68[f]
P- level	0.01	0.001	0.05	0.01	0.001
S. E.	0.45	0.43	0.43	0.44	0.42

S.E: standard error of treatment means; means within column followed by common letters do not significantly vary; (Source:- Geleti and Gizachew, 2002)

III) Forage Tree Legume-Cereal Alley Cropping

One other mechanism for integrating forage legumes, especially tree legumes into the farming system is through alley cropping with cereal crops. Alley cropping is a cropping system in which leguminous trees are planted in hedgerows between small crop-plots to provide nitrogen (N) for the soil and/or high-quality supplementary feed for livestock. In short, it involves inter-cropping fodder trees and food crops, where the crops are grown in between rows of trees. Besides, supplying high quality livestock feed, forage tree legumes have various other multiple roles, including provision of fuel wood, nutrient-rich mulch, erosion control and land stabilization, as well as, other products, such as human food, fencing materials and pollen and nectar for honeybees.

In mixed crop-livestock farming systems of Ethiopia, green fodder is, usually, scarce, during the dry season and the inclusion of tree legumes could help to supplement low quality roughages (crop residues, hay, etc), as well as, increase crop yields by improving soil N status. Leguminous trees also help to recover leached nutrients and protect the soil from erosion, as well as, help to sustain the ecosystem. Tagasaste/tree lucerne in the highlands; and sesbania, leucaena and pigeon pea in the lower and mid-altitude areas are some of the promising fodder trees recommended for fodder production and other uses in Ethiopia.

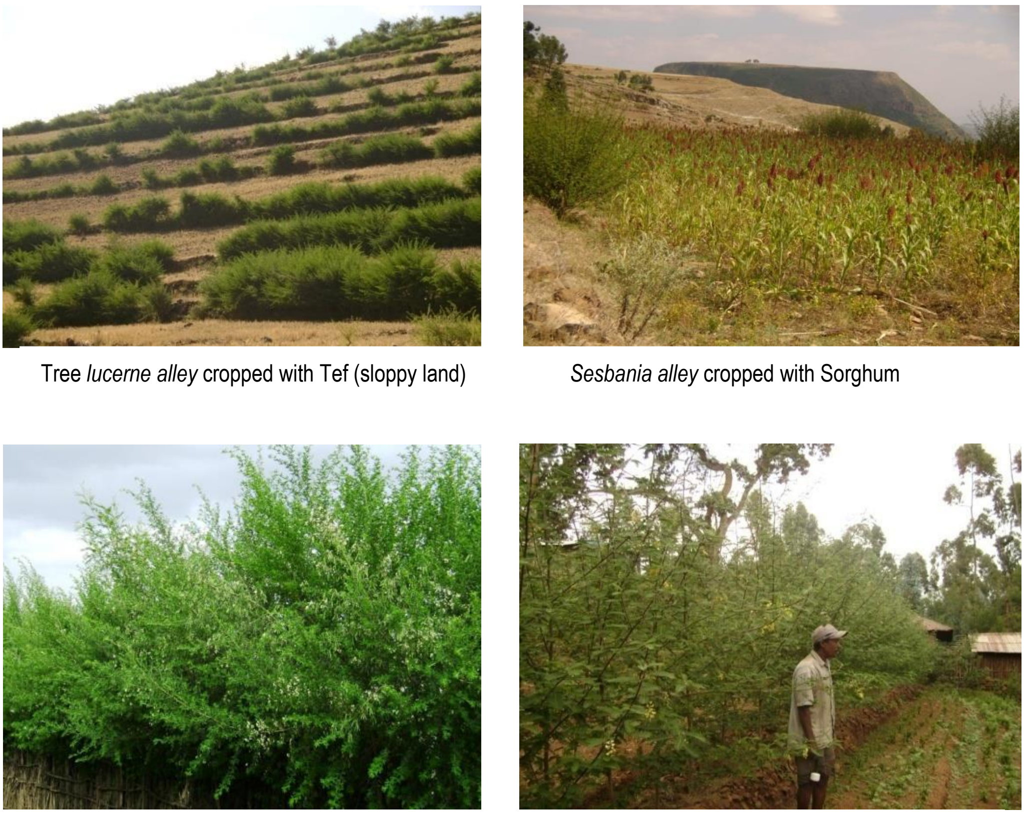
The suitable strategies recommended for integration of the fodder trees into the farming system include alley cropping, backyard plantations and development on conservation structures (conservation-based forage development). For instance, an experiment on alley cropping of tree lucerne with barley at Holetta showed that high amount of green fodder can be produced without reducing barley grain and straw yields (Table 13).

Similar strategy is also possible and works with other crops, such as tef and sorghum (Figure 1). Moreover, fodder trees can be successfully grown on farmers` backyards, where they serve dual purpose roles including supplementary feed supply, live-fencing/wind breaks, fuel wood supply and source of pollen and nectar for honey bees, as they can stay green throughout the dry season.

Table 13. The effect of tagasaste alleys and fertilizer on barley grain and biomass yield of tagasaste at Holetta

Treatment	1996		1997	
	Barley grain yield (kg/ha)	Tagasaste DM yield (t/ha)	Barley grain yield (kg/ha)	Tagasaste DM yield (t/ha)
Barley + no fertilizer	1870	-	544	-
Barley + fertilizer	2300	-	1045	-
Barley + alley + no fertilizer	1840	4.00	1057	6.80
Barley + alley + fertilizer	2240	3.40	1076	7.60
Mean	2063	3.70	931	7.20

(Source:- HARC, 1998)



Tree *lucerne alley* cropped with Tef (sloppy land)

Sesbania alley cropped with Sorghum

Tree *lucerne* on backyards

Sesbania on backyards

Figure 1. Different strategies for integrating fodder trees into the farming system

Conclusions

The National Forage and Pasture Research Program in Ethiopia has, so far, released about 46 improved forage varieties suitable to different agro-ecologies of the country, out of which 23 varieties belongs to herbaceous and browse forage legumes. Despite this, improved forage crops, in general, and forage legumes, in particular, have not been adopted and utilized in the farming system to a considerable scale, due to various factors, of which land scarcity is the most limiting one. The research program has exerted tremendous efforts in order to device suitable strategies in which forage legumes can be integrated into the farming system without imposing much competition for land with staple food crops. Some of the strategies researched include: forage legume-cereal rotations, forage legume-cereal intercropping/under-sowing, browse forage legume-cereal alley cropping, backyard development and planting on soil and water conservation structures (conservation-based forage development). All the studied strategies, as documented in this review paper, have shown the possibility of integrating forage legumes into the farming system with a very minimum competition for resources, such as land. Results of the various research works conducted in different parts of the country indicated that integration of forage legumes via the different mechanisms described above, not only, helps to produce substantial quantity of high quality livestock feed, but also can potentially improve grain yields of the companion food crops and contribute to the overall farm productivity. Moreover, inclusion of forage legumes in the farming system has an added advantage of maintaining soil fertility and sustainability of the environment through biological N fixation and protection of the land from erosive forces. Hence, concerted efforts should be made in promoting the promising results of forage legumes-cereal integration to end users in improving the livestock feed supply; while contributing to overall agricultural productivity and environmental sustainability. Applicable research results should also be extracted and published in simple and easily understood communication materials, such as production manuals to facilitate dissemination of information to various target groups. Side by side, further research is required for refinement of the different forage legume integration strategies given the inevitable dynamism in farming systems.

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Overview of Rhizobial Inoculants Research and Biofertilizer Production for Increased Yield of Food Legumes in Ethiopia

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Abstract

This review paper presents the progress of research on rhizobia innoculants, biofertilizers and host legumes N fixation efficiency in Ethiopia. Rhizobial research on selected legumes (faba bean, field pea and chickpea) was first initiated by the Institute of Agricultural Research (IAR) in 1980's. Currently, the National Soil Testing Center (NSTC), Menagesha Biotech Industry (MBI) plc and the Ethiopian Institute of Agricultural Research (EIAR) have capacities to produce rhizobia-based biofertilizer in Ethiopia. Research activities so far were focused on rhizobial inoculants collection, characterization, selection and evaluation. Strains were developed for biofertilizer packaging with baseline information on symbiotic effectiveness of indigenous rhizobia of almost all important pulse crops and a few leguminous trees. Post graduate studies at Addia Ababa, Haramaya, and Hawassa Universities have played significant roles in these activities. As the result, more than 1000 symbiotically effective rhizobial and non-rhizobial isolates from different food legumes, forage legumes and forest tree legumes were examined. In general, this review work showed major scientific contributions of microbial research at EIAR, and various universities ,and revealed the potential of the local isolates to serve as microbial inoculants (biofertilizers) at a commercial level to increase yield of different leguminous crops . The application of the starter amount of additional inorganic N and P for efficient utilization of the rhizobial inoculants, to increase the nitrogen level and obtain quality seed yields are discussed. The paper stresses the need for quality control mechanism in the process of biofertilizer production and putting in place inoculant release/registration mechanism.

Keywords: *MBL, NSRC,* quality control, soil microbiology

Introduction

Food legumes are high-value crops to smallholder farmers in Ethiopia. They are sources of cash income and diet (protein). Moreover, they replenish natural soil fertility through biological nitrogen-fixation (BNF) in association with root nodule bacteria generally known as rhizobia. Thus, legume crops are integrated into low input cropping systems and improve yields of non-nitrogen fixing cereals and reduce fertilizer use, thereby contributing to savings of smallholder farmers.

Werner (2005) reported variations in BNF of more than fifteen food and feed crops ranging from 50-250 kg/ha/yr, indicating that the efficiency (the amount of fixed nitrogen) by the legume-rhizobium symbiosis depends upon the host, the rhizobia and the environmental factors.

Thus, rhiziobia adaptive to any given micro-ecosystem are selected and developed as inoculants to enhance legume crop production and improve soil fertility. For this reason, rhizobia inoculants are commercialized for more than 100 years in the world over the last decades.

Hence, the general objective of this paper is to review the status of rhizobia research towards inoculant development, production and utilization in Ethiopia.

Major Food Legumes and Rhizo-bacteria

In Ethiopia, pulse crops are the second most important crops in terms of volume of production after cereals. The dominant pulse crops grown in Ethiopia include: faba bean (*Vicia faba*), field pea, (*Pisum sativum*) haricot bean (*Phaseolus vulgaris*), chickpea (*Cicer arietinum*), lentil (*Lens cultinaris*), grass pea (*Lathyrus sativus*), lupin (*Lupinus albus*), fenugreek (*Trigonella foenum-graecum*), soya bean (*Glycine max*), cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*) and mung bean (*Vigna radiata*) (CSA, 2013). The area coverage of these pulses contributed to almost 85% of the total land share of food legumes for five years (CSA, 2013 - 2017). Likewise, the production of these pulses during the last two decades by volume increased by almost 72% (Atnaf *et al.*, 2015), which is mainly attributed to increment in productivity per unit area because of the recent technological backstopping (Keneni *et al*., 2016).

These legumes are able to form symbioses and consequently fix nitrogen with the *Rhizobium* harbored in the different agro-ecological locations of the country.

Several studies showed that Ethiopian soils harbor diversified and effective rhizobia associated with their legume hosts (Beyene *et al*., 2004; Hailamariam and Tsige, 2006; Belay and Assefa, 2011; Jida and Assefa, 2012; Tena *et al*., 2016; Temesgen *et al*., 2017; Kensa *et al*., 2017).

Unlike inorganic fertilizers, bio-fertilizers such as rhizobial inoculants supply nitrogen directly to their legume host plants and, through nodule senescence sloughing off dead root and leaf release nitrogen, to the soil to make it available to subsequent non-fixing plants during crop rotation. Past studies clearly showed the wide variation of natural rhizobial population capable of forming symbioses with different legume crops. Thus legume distribution across the diverse agro-ecological regions of Ethiopia provide ample opportunities to select and use microbial inoculants for legume production and improvement of soil fertility to the low-input agriculture in the country.

History of Rhizobial Inoculants Research and Biofertilizer Production in Ethiopia

The collection of root nodules, isolation of best rhizobial strains and evaluation and selection of superior types as inoculants is part-and-parcel of the research activities in the research institutes and universities in Ethiopia. To this end, soil microbiology courses were introduced in the universities starting from early 1970s. Consequently, human and research capacity building in soil microbiology or legume-rhizobiology have been made at different higher learning and research institutes.

Most microbial inoculant research in the country thus far has been limited to inoculation trials with and without the application of nitrogen/ phosphorus fertilizers on different soil types. In Ethiopia, Abebe (1986) made the first rhizobial collection and isolation work from different pulse growing locations. The different isolates were obtained from field pea, faba bean, lentil, haricot bean, soybean, chickpea and clover (*Trifolium spp.*) (Table 1).

Table 1. The first *Rhizobium* collection from important pulse crops at then Nazreth (now Melkassa) Agricultural Research Center (NARC) in Ethiopia

Cross-inoculation group	*Rhizobium* / Bradyrhizobium species	Host legume	Number of collection sites	Number of strains
Pea group	*R leguminosarum*	Faba bean	9	80
	R leguminosarum	Field pea	3	20
	R leguminosarum	Lentil	4	10
Bean group	*R phaseoli*	Haricot bean	3	20
Cowpea group	*Bradyrhizobium*spp	Soybean	6	200
Chickpea	*Rhizobium* spp	Chickpea	10	128
Clovers	*R. trifollium*	Clovers	4	34
	Total		**39**	**492**

Source:Abebe (1986)

In the 1980's, systematic collection of thousands of nodules were made by the Holetta Agricultural Center to isolate more than 108 strains of which 23 faba bean strains were found to be superior, and a few isolates were promoted for field inoculation (Mamo and Dibabe, 1994).

Since then several workers and graduate students have been involved in the collection, isolation and characterization of native rhizobial inoculants harbored in Ethiopian soils from Oromia, Amhara, Tigray, Benshangul and the Southern Nations Nationalities and Peoples (SNNP) regional sates.

Host Plant Diversity for Traits of Symbiotic Nitrogen Fixation

Crop productivity can basically be improved by genetic modification of crops or by altering the growing environments (Wallace and Yan, 1998). Genetic modification of crops to increase yields is often preferred to the continual manipulation of the growing environment not only because of cost but also because of concerns for agricultural sustainability (Keneni, 2007).

Symbiotic nitrogen fixation can be improved, among others, by host plant breeding for enhanced nitrogen fixation, selection of effective strains able to fix more nitrogen and use of different agronomic methods that improve soil conditions for the crop, microbial symbionts and their favorable synergy (Brockwell *et al*., 1988; Montañez, 2000).

As stated above, legumes are produced for different purposes in Ethiopia including for the replenishment of soil fertility. Genotypic differences for attributes of nodulation and symbiotic nitrogen fixation have been observed in many legumes (Ali *et al*., 2002; Krasilnikoff *et al*., 2003; Walley *et al*., 2005). However, it is advisable to define a mutually beneficial set of compatible host genotypes and strains as the development of better strains or host genotypes alone may not provide the required productivity gains (Crouch *et al*., 2004; Giongo *et al*., 2007). Some reports indicated that host plants play more important roles than strains in enhancing the symbiotic process (Shantharam and Mattoo, 1997; Hardarson, 2004).

Apart from strain evaluations made with a limited number of legume varieties by the soil microbiologists, systematic efforts made to exploit host effectiveness and host-strain compatibility in Ethiopia have been very crucial. These include determination of genotype difference, genetic variability/diversity, selection efficiency and interrelationships between characters for symbiotic traits in faba bean (Mamo and Dibabe, 1994), chickpea (Keneni *et al*. , 2012; Keneni *et al*.; 2013a) and genetic diversity for symbiotic traits in *Abbysinian* field pea (*Pisum sativum var. Abyssinicum*) (Keneni *et al*., 2013b). The amount of nitrogen fixed in 155 chickpea genotypes, for instance, ranged depending on host genotype from 13-49% ($\bar{x}$=30%) in foliage, 30-44% ($\bar{x}$= 36%) in grain and 28-40% ($\bar{x}$= 34%) in total above ground biomass. The best chickpea fixer hosts of nitrogen from among the Ethiopian chickpea collections were identified as: Acc. Nos. 41222, 41029, 41021, 41074, 41075, 41129, 41320 and 41026. Likewise, MColl-7/07, MColl-8/07, TKColl-6/07, MCColl-4/07 and TKColl-3/07, were the best fixer hosts under both Vertisol and Nitisol soils with a fixation range of 41- 45 % for Abyssinian field pea (Keneni *et al*., 2013b). Comparison of genotypes from *P. sativum var. Sativum* and *P. sativum var.*

Abyssinicum showed the superiority of the former over the latter (Keneni *et al*., 2013b). Differences in nitrogen fixation were also observed in Ethiopian and German field pea (Adgo and Schulze, 2002) and Ethiopian faba bean genotypes (Gebremariam and Assefa, 2018), including under acid soil conditions (Tsegaye *et al*., 2016). These studies clearly established the comparative advantage of host plant selection for improving symbiotic nitrogen fixation. Another study on the estimation of the magnitude of heterosis for nitrogen fixation in chickpea also revealed existence of heterotic crosses between parents (Girma *et al*., 2017). This indicates the possibilities for improving host symbiotic efficiency through breeding for effective host plants as reported by a number of workers elsewhere (Pearson *et al*., 1995; Hardarson, 2004; Winter *et al*., 2004).

The success of symbiotic nitrogen fixation, no doubt, depends on the genetic potential of the host and strain and on how they interact with each other and with other components of the growing environment (Abaidoo *et al*., 1990; Bohlool *et al*., 1992; Pearson *et al*., 1995; Lindemann and Glover, 2003). For instance, some reports indicated existence of host genotypes whose nitrogen-fixing effectiveness may not be impaired by the application of nitrogen to the soil (Herridge and Rose, 2000; Singh and Usha, 2003), and such genotypes are considered desirable as they may impose less competition when they are intercropped with cereals. It is generally advisable that legume breeders better mainstream important nodulation and biological nitrogen fixation related traits into their regular breeding programs.

Advances in Research on *Rhizobium* Inoculant production in Ethiopia

It is nearly three decades since the beginning of research in *Rhizobium* inoculant technology in Ethiopia. Thus the pioneer post graduate work of Abebe (1982) at Addis Ababa University had been considered as the prelude to the introduction of research and development of effective strains of rhizobia and associated technologies. He extended the Rhizobium study at Melkassa Agricultural Research Center and collected root nodules of different legumes and characterized them as indicated in Table 1 (Abebe, 1986). *Rhizobium* research shifted its center from Melkasa to the soil microbiology laboratory at Holetta Agricultural Research Center (HARC) in 1984, where much emphasis was given to inoculants associated with highland pulse crops. This practice continued till 1986 and, in 1990, in collaboration with the establishment of microbial laboratory at the National Soil Testing Center (NSTC) under the then Ministry of Agriculture (MoA), the rhizobial inoculant technology went up substantially and started to produce packages of biofertilizers at least for research purpose. Slowly the production of biofertilizer packs increased both in volume and quality. The first biofertilizer technology packs (N fixing strains) were the property of the NSTC under the EIAR (then Ethiopian Agricultural Research Organization, EARO). The research activities included both laboratory work and field trials on faba bean, chickpea, field pea, and lentil with and without starter doses of nitrogen and phosphorus fertilizers application. The different studies showed that the inoculation trial of the most effective local *Rhizobium* strain number 18 and three other strains, namely 414, 420 and 481, together with P application enhanced rhizobial activity and increased faba bean yield (Mamo and Dibabe, 1994).

The currently available commercial strains were from local collections. According to the National Soil Testing Center (NSTC), a total of 350 rhizobia strains specific to different pulse crops were collected from the major pulse growing parts of the country. Out of these, 40 strains were identified as promising. There have been a number of inoculant strains under mass production for different legumes by NSTC and MBI plc, including EAL-29, EAL-110, EAL-332, EAL-600, EAL-429, EAL-379, EAL-301, EAL-302 and EAL-300. The inoculation and fertilizer trials with selected rhizobia showed a 60-100% increase in dry matter and 30-45% increase in grain yield of, for instance, faba bean. In addition, there are also other inoculants recently finished their greenhouse and on farm validation tests (Table 2).

Table 2. List of inoculants currently readily available to be transferred to biofertilizer industry for mass production

Legume crop	Strain	Current Mass Production Status (Produced by)				
		NSTC	MBI plc	EIAR	Hawassa University	Haramaya University
Faba bean	FB-1018			X		
Faba bean	FB-1035			X		
Faba bean	FB-1017			X		
Faba bean	FB-04			X		
Chickpea	CP-029		X			
Chickpea	CPM-41		X			
Chickpea	CP-41				X	
Chickpea	CP-18	X				
Chickpea	CP-17			X		
Chickpea	CP-11			X		
Groundnut	AS24L03			X		
Groundnut	PRCR04			X		
Groundnut	MCLC			X		
Mung bean	MB-001		X			
Mung bean	MB-002		X			

Although many of the earlier studies focused on cool season food legumes such as faba bean, field pea and chickpea, major breakthroughs have been recently made on tropical pulse crops such as soybean (Temesgen *et al*., 2017; Abera and Assefa, 2018) and cowpea (Kensa *et al*., 2017).

According to these studies, 22% of the soil samples from northwestern Ethiopia (Temesgen *et al*., 2017), and almost all soil samples from southwestern and western Ethiopia (Abera and Assefa, 2018) harbored effective and very effective rhizobia both at greenhouse and field conditions. These studies also forfeited the long-held assertion of the absence of compatible *B. japonicum* in African soils that may limit nitrogen fixation and productivity of different varieties of soybean (Kueneman *et al*., 1984, Pulver *et al*., 1985; van Heerwaardena *et al.,* 2018). Despite the different opinions regarding to the absence or presence of native soybean *Rhizobium* to infect soybean and form root nodules, this crop may form nodules in African soils where the crop is grown on the same area for at least five or more years (Muhammad *et al.,* 2010). Since in some soils soybean rhizobia are not common or abundant, inoculating soybean seed with the correct rhizobium increases biological nitrogen fixation and gives a good yield for very little cost. Aragaw (2014) reported the importance of inoculating soybean crops with elite isolate of *Bradyrhizobium* sp. even if the crop grows in saline soils. Inoculation very remarkably improved the productivity of soybean.

The research system at the Ethiopian Institute of Agricultural Research (EIAR) introduced inoculants of soybean and evaluated their efficacy in greenhouse and under on farm conditions. These soybean strains were MAR1495, SB12, and Legumefix, which came through COMPRO I and II project implementation period at Holetta Agricultural Research center. These strains were tested on many farmers' fields around Assosa and Jimma. However, the soybean, faba bean, and field pea candidate strains have been with research system until now. According to Aragaw *et al.* (2015), common bean inoculation with *Rhizobium* significantly increased the seed yield when the inherent soil fertility treated with a starter N from inorganic N fertilizer. In another study, Aragaw and Muleta (2017) showed the need for a specific strain of common bean *Rhizobium* development in order to obtain good yield.

Rhizobium inoculant for the *Abyssinian* field pea (locally called *dekeko* or *yeagereater*) has been tested on farmers' fields for two consecutive years and ready for transfer for mass production by HARC in collaboration to Mehoni Agricultural Research Center. In addition, two mung bean strains (MB-001 and MB-002) were developed for commercialization by a graduate student of Haramaya University sponsored by MBI plc.

The important watershed in the development of rhizobia inoculants in the country was the pilot scale commercial production at the National Soil Research Center (NSRC) in collaboration with the National Fertilizer Industry Agency (NFIA) sponsored by the World Bank (NSRC, 2002). The study included field trial of elite rhizobial strains, selection of alternative growth substrates for rhizobia, and carrier materials from local sources for commercial production of rhizobial inoculants (Hailemariam, 2003).

In general, there have been many selected local *Rhizobium* strains that were found to be as efficient as commercial strains in nitrogen fixation. However, the response of chickpea to inoculation with indigenous rhizobia was limited and showed significant differences on their symbiotic effectiveness depending upon chickpea cultivars and other soil factors. Keneni *et al.* (2012), for instance, clearly showed differences in chickpea genotypes in nodulation abilities. On the other hand, Tena *et al.* (2016) reported their finding of new chickpea indigenous rhizobial strain (CP41) as potential commercial inoculant. Muleta and Assefa (2015), also identified two effective isolates (NSCPR13 and NSCPR14c) of chickpea. Demissie *et al.* (2018) showed the importance of endophytic bacteria from 50 chickpea root nodules brought from very diverse agro-ecologies in Ethiopia. Rhizobial and non-nodulating endophytic bacteria harboring these chickpea root nodules were almost at equal proportion in chickpea nodules and the endophytes were showing all the desirable physiological characteristics that exhibited with chickpea *Rhizobium* except for the re-infecting action on sterilized chickpea nodules. Thus, examination on chickpea endophytic bacteria needs to be studied more carefully since they play important role in plant yield and growth promotion.

Contributions of Universities to Development in Rhizo-biology

According to Assefa (1993), most of the earlier researches focused on screening symbiotically effective *Rhizobia* from fewer highland pulse crops in Ethiopia. Thereafter, Addis Ababa, Haramaya, and Hawassa Universities played important roles in human capacity building and installing microbiology courses in their faculties. Many graduate students published their findings in peer-reviewed national and international journals, and tried to select isolates to recommend for technology incubations. From the year 2000 to 2015, over 1700 isolates were processed; nearly 75 articles were published and made available to users by graduate students and faculty members of these universities. Universities also organized different workshops and conferences on rhizobial inoculant technology. Several research outputs, articles and posters were presented in these workshops and conferences.

Research by universities was extended to include the diversity and symbiotic association of other Plant Growth Promoting Microorganisms (PGPM), Phosphate solubilizers, bio-control agents and *Mycorrhiza* that are also important for plant health and productivity in relation to integrated soil fertility management. The research works were undertaken in collaboration with many local and international partners and financially supported (facilities, equipment, and chemicals) by the Ministry of Education, Ministry of Science and Technology and others.

Commercial Production of Biofertilizers in Ethiopia

Rhizobial inoculant (Biofertilizer) production requires nodule collection, isolation, characterization, selection, evaluation, and package formulation to end-users. The production of biofertilizers begun in USA and UK in 1985 and then adopted elsewhere in Europe and Australia (Marufu *et al*., 1995). Herridge *et al*. (2000) estimated that about 2000 tons of inoculants were produced annually, equivalent to USD$ 50 million and this volume was enough to fertilize 20 million hectares of legumes. In Southern and Eastern Africa countries, microbial inoculants have been produced for different pulse crops since the early 1960s, with a radical increase as a function of time (Table 3).

In Ethiopia, the commercialization of strains is a recent phenomena, only started since the year 2000 (Hailemariam and Tsige (2006). The first commercial rhizobial biofertilizers for faba bean and chickpea (2,069 packets) were produced by the National Soil Test Center (NSTC) and distributed to smallholder farmers in 2003 through Ambasel plc. The inoculants produced were enough to cover only 74,087 hectares (5.51%) of the total pulses' land coverage in the country. The NSTC still mass produces biofertilizers side by side with the recently established Menagesha Biotech Limited PLc (MBL). From the year 2012-2017 for the last 6 years NSTC and MBI plc produced 344,619 and 768,348 packets of biofertilizers, respectively. This constitutes overall 1,112,967 packs of biofertilizers that used for 278,242 hectares of legume production. During the same period, the proportion of the volume of inoculants to the area coverage also grew from 1.07% to 5.51% (Table 4). A considerable volume of inoculants was also produced by the HARC between 2014 and 2017 for use in EIAR's extension program (Table 5). Extension of the inoculants to smallholder farmers in different parts of the country showed significant yield increments on different legume crops.

All taken together, the total volume of biofertilizer produced by NSTC and MBI plc in general, and the current inoculants marketing and distribution practice, in particular, lag far behind the national demand.

Table 3. Inoculants production, cost, and area covered with inoculation in some Eastern and Southern African countries in the 1990s

Country	Legumes/pulse crops	Potential area for inoculation (ha)	Total area inoculated (ha)	Cost per unit (US$)	Proportion of potential area inoculated
Brundi	Common bean, soybean, pea, leucaena	50000	8000	0.30	0.16
Kenya	Common bean, Soybean, Lucerne	90000	21500	0.90	0.24
Rwanda	Soybean, pea, leucaena	84000	20000	0.25	0.24
Zambia	Soybean	95000	22000	3.61	0.23
Zimbabwe	Various grains and pasture legumes	180000	70000	0.25	0.39
Ethiopia	Various grains legumes	1,680,000	182,055*	1.8	0.10

Source: Marufu *et al*. (1995)

Table 4.Total *Rhizobium* inoculants production by NSTC and MBI with areas covered with inoculation between 2012 and 2017

Year	Total Production of inoculants	Total area coverage (Ha)	Percentage area coverage
2012	58,833	14,708	1.07
2013	127,446	31,862	2.00
2014	165,073	41,268	2.68
2015	209,895	52,474	3.79
2016	255,023	63,756	4.41
2017	296,697	74,174	5.51
Total	1,112,967	278,242	3.21

Table 5. Inoculant strains produced by the HARC and used for pre-extension scale-up activities

Year	No of packets of Inoculants	Area coverage (Ha)
2014	3,441	860.25
2015	6,000	1500
2016	7,500	1875
2017	1,000	250
Total	17,941	4485.25

Constraints in Rhizobial Biofertilizer Production in Ethiopia

The available *Rhizobium* inoculants mentioned above and others developed from research system have been shelved for many years without transfer to the biofertilizer industry for further mass production and use at farm level. Some important strains developed earlier were lost in the process of long preservation and contamination. The lack of effective technology release, registration, mass production and transfer, coupled with the disorganized market, was a missed opportunity in utilizing these readily available genetic resources. Neither the commercial nor the candidate strains own proper accession number and history well documented as a reference as well as for further inoculum production. However, recently the draft by-laws for strain release/registration is prepared and ready for the final approval by the Ministry of Agriculture and Livestock Resources.

Prospects and Way Forward for Biofertilizer Production in Ethiopia

This review article, even though not exhaustive, showed that still there is a high demand for microbial inoculants for the different legume crops. Although chickpea and faba bean were the most focused crops so far, the search for candidate rhizobia for inoculant production for other pulse crops such as soybean, common bean, field pea, mung bean and cowpea is currently well underway. Commercial inoculant production was mainly focused on rhizobia to increase nitrogen in the soil and boost production of food and forage leguminous crops. However, quite recently attention has been given to other group of microorganisms that directly or indirectly influence plant health and productivity. These researches are currently undertaken mostly in universities showing promising results at pilot levels. Quality control in commercial inoculant production should be a responsibility of producer companies and an external public regulatory body. To this end, COMPRO projects made remarkable contributions a to the formulation of a draft on quality control and rhizobial inoculant registration protocol for this country. Based on COMPRO's initiative, recently the Ethiopian Authority (ESA) approved standards for biofertilizers in Ethiopia. Definitely, this and the draft competency assurance certification protocol setup by the Ministry of Agriculture and Livestock Resources (MoALR), may also attract young entrepreneurs to create small and medium sized enterprises (SMES) for biofertilizer production and distribution.

Currently, the production of commercial inoculants in the country is in the right track, even though it is lagging behind in terms of satisfying the smallholder farmers' demand for biofertilizer supply. Thus, it is important to work on adequate policy setup on value chain linkage between improved pulse seeds, biofertilizers production, dissemination, market and extension support to farmers. There is a need to increase biofertilizer production in order to meet its potential demand across the country through creating a conducive environment for the private sectors. Production of microbial inoculant or biofertilizer requires both internal and external product quality control. Currently, it is a formidable task to the nation and the public to establish quality control laboratory or a responsible institution handling the quality control of biofertilizers produced in the country. Released rhizobial inoculants may need to be characterized and given identity at molecular level in order to read and document their genome sequences. There is also a dire need to strengthen trainings for both extension personnel and farmers on biofertilizer handling and application. Efforts by research institutions and universities need to be coordinated for effective new strain generation and promotion at the national level.

Acknowledgement

We would like to thank Dr Asnake Fikre, ICRISAT Regional Chickpea breeder; Dr Asfaw Hailemariam, Technical Director of Menagesha Biotech; and Anteneh Argaw and Kassa Bayeh, from Haramaya University for providing us with various information on rhizobia research of their respective institutes.

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Physiological and Modeling Research in Food and Forage Legumes in Ethiopia: A Review

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Abstract

This review provides highlights of physiological and modeling studies related to various food and forage legume crops (common bean, field pea, chick pea, cowpea, faba bean, etc.) in Ethiopia. Major production constraints including drought, temperature, light, waterlogging, salinity, and crop management practices and cropping systems are focused. Limited works have been done on the effect of various environmental stresses on dry matter production and seed yields and genotypic variability was observed in different legume crops to different environmental stresses including drought, salinity, temperature and light. Adaptive mechanisms to various environmental stresses were identified but more efforts are required to identify suitable traits conferring tolerance to various stresses to increase and stabilize yield of legume crops across various environmental conditions in the country. Plant growth simulation models that integrate various physical and physiological processes of plant growth and development can be used to assess growth and yields of different crop cultivars in different environments by using environment-specific weather, soil and agronomic management data. A simulation model run for chickpea kutaye indicated a good agreement between observed and simulated days to first flowering (dap), days to physiological maturity (dap), grain yield (kg ha^{-1}) and total biomass (kg ha^{-1}), except for LAI (maximum) m^{2}m^2 and HI (harvest index). Further simulation models are required to predict and quantify the potential and actual gap of various legume crops under various environmental conditions.

Keywords: Crop management, environmental stress, food legume, modeling, physiology

Introduction

Ethiopia is primarily an agrarian country that has been heavily relying on rain-fed, small-scale, traditional subsistence and low input farming practices based on multiple cropping systems, including trees, permanent crops and annual cultivated crops as integrated elements of farm management. The contribution of irrigation is insignificant both in amount and land size. Livestock is an integral part of the farming system. Among the sub-sectors of agriculture, crop production is a major contributor to GDP accounting for approximately 28% in 2014/2015 (CSA, 2014/2015).

In Ethiopia, field crops cover the largest cultivated land area and out of which cereals share is nearly 67%, pulses being the second most important crops both in terms of area coverage and total production after cereals (CSA, 2014/15). There are a wide range of legume crops grown in the country in different agro-ecologies among which faba bean, common bean, chick pea, field pea, lentil, grass pea, lupine, fenugreek and soybean are important ones (Mulugeta, *et al*., 2015). Other minor food and forage legume crops include cowpea, pigeon pea and mung bean. The national yield averages obtained from these crops is low and far below the potentially achievable yields of, for example, 2.9 t/ha for chickpea and 4 t/ha for common bean and faba bean, respectively (IFPRI, 2010). The low yields are due to several factors, including use of inadequate farm management practices, low soil fertility conditions resulting from depletion of soil organic matter contents, overgrazing in between cropping seasons) (CIMMYT., 2009) and soil erosion (Zeleke *et al*., 2010). In addition, the yield reductions inflicted by biotic and abiotic stresses are also high.

For the past several years, improvement of the yield performance and ability to withstand the effects of various environmental stresses of legume crops has been addressed through conventional plant breeding. With this approach, a reasonable yield increase has been achieved. It is strongly believed and several scientists have demonstrated that crop physiology research also plays an important role in improving yields of crops (El-Sharkawy, 2006; Furbank, 2013). The threatening scenario imposed by climate change highlights the need for concrete research approaches in order to develop crops that are able to cope with environmental stresses, while increasing yield and improving quality. During the last decade, some physiological components and molecular players underlying abiotic stress responses of a broad range of legume species have been elucidated.

Plant physiology approaches provided general outlines of plant responses, identifying stress tolerance-related traits or elite cultivars (El-Sharkawy, 2006). Plants under various stressful environmental conditions responded by a number of physiological mechanisms at the molecular, cellular, tissue, morphological and whole-plant levels (Anjum *et al*., 2008; Husen, 2010; Husen *et al*., 2014; De Ollas *et al*., 2015). These responses vary with the species and genotype/cultivars, the length and severity of stress conditions and the plant developmental stage. For instance, water stress affects leaf area expansion, and reduces photosynthesis activity (Flexas *et al,* 2004). Reduction in the quantum yield of photosystem is influenced not only by light intensity but also by the superimposition of other environmental stresses such as high temperature, salinity, water availability or CO_2 supply (Souza *et al.*, 2004; Ribeiro *et al.*, 2008; Husen *et al.*, 2014, 2016). Under these stressful conditions, plants develop several adaptation strategies to avoid inhibitory processes, and resume growth and produce relatively higher yields. Among these, mechanisms to prevent reduction in leaf and root growth, stomata closure and continue photosynthetic activity at reduced rate, light absorption or mechanisms to consume the reducing power generated by PS II are a few (Demmig-Adams and Adams, 1992). However, the contribution of crop physiology research in Ethiopia is negligible because of very limited research efforts. The purpose of this review is, therefore, to give highlights of previous physiological studies related to various food and forage legumes in Ethiopia, with a focus mainly on the major production constraints (drought, temperature, light, waterlogging, salinity, and crop management practices and cropping systems) related to different environmental stresses.

Research Achievements

Response of Legume Crops to Drought and Soil Salinity Stresses

Drought stress

Moisture deficiency stress is considered as one of the most important causes of reduced plant growth, grain yield and yield components (Menezes-Benavente and Texeira, 2004). Generally, limited studies on the response of various legume crops to drought stresses indicated that there was a noticeable reduction in growth, total dry matter production, yield and yield components (Shenkut and Brick, 2003; Gebeyehu *et al.*, 2011; Rezene *et al.*, 2013; Embiale *et al.*, 2016).

Rezene *et al.* (2013) examined 49 small red seeded common bean genotypes under drought stress and non-stress conditions and reported that drought stress induced reduction in seed yield and harvest index as compared to the non-stressed condition (Table 1). The study also revealed existence of genotypic variability in response to drought stress for seed yield. Drought-induced reduction in seed yield of the tested genotypes ranged from 9% in ECAB-0427 to 89% in Red Welaita. The superior performance of ECAB-0427 under drought stress was attributed to better maintenance of higher leaf area index (LAI) (2.8) and pod harvest index (PHI) (67.6) as compared to Red Wolaita which showed relatively lesser LAI (0.8) and PHI (22.1). Gebeyehu *et al*. (2011) suggested that seed yield gains from drought tolerance are related to growth, partitioning and water-use-efficiency and are used as selection criteria in breeding beans for drought conditions.

Embiale *et al*. (2016) reported that water stress adversely affected growth and biomass production of various field pea (*Pisum sativum* L.*)* cultivars (Table 2). The result revealed significant differences among the cultivars, water-stress treatments and their interaction, indicating the cultivars variability and differential response to water stress. Remarkable reductions in yield components have also been reported on various grain legumes including common bean (Worku and Skjelvag, 2005; Rezene *et al*., 2013) and field pea (Embiale *et al*., 2016).

The crop responses to drought stress depend on the intensity and duration of the stress and stage of growth and/or developmental phases (Acosta and Shibata, 1989; Shenkut and Brick, 2003). Worku and Skjelvag (2006) studied the effects of moisture availability on an indeterminate common bean cultivar during three developmental phases (vegetative, flowering and seed filling) and two temperature regimes(18 ^{0}C and 24 ^{0}C). The results of the study revealed that moisture stress significantly reduced flower bud numbers and seed yield of common bean. The reduction in flower bud numbers was significant at the end of the vegetative and flowering phases, while the reduction in seed yield due to water stress was highest (28%) during the seed filling phase followed by flowering. The study suggested that moisture level during seed filling accounted for the largest portion of seed yield variation at both temperatures. Worku and Skjelvag (2006) examined different levels of water stress at different developmental phases under different light regimes and they found that the highest seed yield loss due to water stress was observed at seed filling phase followed by flowering and vegetative phases (Table 3).

The authors also reported a significant interaction between water availability and light intensity for seed yield. Accordingly, shading reduced seed yield under full water supply or early drought and it increased seed yield under terminal and season long drought.

Table 1. Seed yield under non-stress (NS), drought stress (DS) and seed yield based geometric mean (GM), percent reduction (PR) and drought susceptibility index (DSI) for 49 small red common bean genotypes grown under non-stress (NS) and drought stress (DS) conditions

Genotype	Seed yield (kg ha^{-1})				
	NS	DS	PR	GM	DSI
ARS-R-93002	1830.7	890.5	0.51	1276.7	0.85
DOR-740	711.4	420.5	0.42	546.9	0.7
790 RAA-34	288.9	129.9	0.55	193	0.9
ECAB-0427	1765.6	1365.7	0.22	1548.8	0.35
ECAB-0424	1192.2	262.2	0.76	551	1.35
ECAB-0410	982	290.1	0.71	532.6	1.15
MN-12643-1	2170	958.2	0.56	1441.8	0.9
ECAB-0412	993.1	114.1	0.89	335.8	1.35
ICTAJU-95-14	2144.5	1260.9	0.42	1643.6	0.55
LR-93201338	693.4	198.8	0.72	363.2	1.2
DOR-721	537.7	500.1	0.09	518.4	0.15
T842 6F 12-3	875	412.7	0.51	597.	6 0.9
RCB-592	3002.6	975	0.68	1698.5	1.3
SER-48	1437.9	1220.8	0.17	1323.7	0.25
SER-78	1901	660.6	0.66	1116.8	1.1
SER-95	1559	457.6	0.69	830.2	1.15
SER-118	1753.8	730.6	0.58	1127.6	0.95
SER-119	2082.5	808.5	0.6	1287.6	0.95
SER-125	2015.9	1183	0.41	1542.8	0.45
SER-128	1873.7	828.2	0.55	1243.7	0.9
SER-176	621.3	278.6	0.52	415	0.9
SER-180	894.2	500.7	0.44	669	0.75
SER-194	2632.8	999.3	0.62	1615.9	1
NASIER	2029.7	908.2	0.54	1350.4	0.85
DINKNESH	1467.5	456.7	0.68	816.8	1.1
CAW-02-03-8-11	1619.7	381.9	0.77	786.3	1.25
CAW-02-05-2-7-5	1945	569.1	0.7	1046.4	1.2
CAW-02-04-7-6-7	1868.2	581.4	0.69	1042.2	1.1
SNNPR1-35	1522.9	727.6	0.42	984.6	0.7
CAW-02-04-11-2-4	2264.9	773.6	0.66	1319.7	1.1
CAW-02-03-1-6-44	1701.8	545.5	0.68	963.3	1.1
CAW-02-04-4-11-4	1241.8	420.2	0.69	720.7	1.25
SER-43	1810	650.1	0.63	1079.8	1.05
SER-16	2791.8	1225.1	0.56	1849.4	0.78
CAW-02-04-8-3-1	1666.6	857.1	0.44	1183.3	0.75
SEA-5	1152	595.4	0.5	813.5	0.8
VAX-6	720.3	412.4	0.35	531.3	0.55
OMO-95	1255.3	251.3	0.8	535.7	1.4
LR-93201347	918.3	304.3	0.67	528.3	1.1
CAW-02-01-1-1-3	944.5	165	0.69	362.9	0.95
SER-109	2131.6	891.5	0.59	1375.5	1
CAW-02-01-5-1-2	552.4	131.2	0.69	253.8	1.1
ECAB-0416	1484.7	431.1	0.72	796.5	1.2
SER-178	1931.4	258.7	0.87	703.1	1.45
K 26/35 CF 10-9	1267.2	257.6	0.81	567.1	1.3
CAW-02-01-1-1-1	649.8	198.9	0.69	349.3	1.15
RED WOLITA	948.8	112	0.89	325.1	1.45
HAWASSA DUME	2005.3	356.5	0.83	834.8	1.35
LOCAL VARIETY	1279.4	405.5	0.65	679.6	1.05
MEAN	1492	577.9	0.59	902.4	0.98
LSD 0.05	696	373.8	0.56	0.3	3.05
CV	23.2	30.3	26.05	20.6	28.88

Source: Rezene *et al*. (2013)

Table 2. Effects of water-stress treatments on different growth and leaf characteristic features in selected cultivars of field pea

	Water stress treatments (irrigation intervals in days)*				
Parameter	**Cultivars**	**Control**	**6 days**	**9 days**	**12 days**
Height (cm)	Brukitu	65.00±3.18a	52.33±3.18c	42.11±3.28e	27.89±1.68g
	Tegegnech	68.89±3.02a	56.28±2.17b	45.85±3.21d	32.00±2.04f
	Adi	62.78±2.79a	49.86±3.06c	40.11±2.77e	26.00±1.95g
Stem basal diameter (mm)	Brukitu	2.43±0.71a	1.72±0.32b	1.28±0.31d	1.08±0.12e
	Tegegnech	2.85±0.74a	2.03±0.28b	1.49±0.36c	1.21±0.38d
	Adi	2.34±0.67a	1.82±0.29b	1.37±0.30d	1.04±0.10e
Number of leaf	Brukitu	75.00±3.17b	64.00±2.21c	59.22±3.74c	53.77±2.65d
	Tegegnech	85.88±4.53a	64.88±2.81c	60.66±4.87c	54.88±2.73d
	Adi	72.86±3.87b	64.22±2.17c	54.88±3.11d	50.06±2.17e
Number of branch	Brukitu	16.66±2.87a	13.66±3.62a	12.42±2.71a	11.55±1.05b
	Tegegnech	18.77±2.93a	14.88±2.85a	13.11±1.78a	11.77±2.01ab
	Adi	15.88±2.73a	13.35±2.94a	12.00±1.62b	11.00±1.62b
Leaf area (mm^2)	Brukitu	13573.37±465.93a	13186.37±426.01b	12077.38±412.16b	10054.37±454.05d
	Tegegnech	13782.23±547.48a	13373.25±551.48a	12445.97±379.68b	11611.38±479.82c
	Adi	12768.17±564.25a	11726.72±462.07c	11448.63±473.73c	9565.78±586.39d
Leaf length (mm)	Brukitu	105.10±3.59a	97.56±3.64b	85.23±4.96c	76.16±4.83d
	Tegegnech	108.28±3.28a	105.34±3.84a	98.75±3.95b	80.20±3.43c
	Adi	104.10±3.87a	94.36±3.02b	80.47±3.94c	72.94±4.28d
Leaf width (mm)	Brukitu	145.90±4.74a	129.77±5.53b	127.83±4.74b	107.20±4.63d
	Tegegnech	147.43±4.88a	131.63±4.86b	130.63±4.81b	115.50±5.52c
	Adi	145.97±4.95a	128.77±5.73b	127.07±5.42b	106.93±5.07d

*Control: Control plant and uniformly irrigated with tap water (400 mL kg^{-1} soil) at 3 days intervals to maintain 100% FC, T2: Irrigated at 6 days intervals (slight-water stress), T3: Irrigated 9 days intervals (mild-water stress) and T4: Irrigated at 12 days intervals (severe-water stress). Means within a column followed by the same letters are not significantly different according to LSD test ($p<0.05$). Source: Embiale *et al*. (2016).

Table 3. Effects of moisture level during the vegetative (Mv), flowering (Mf) and seed filling (Msf) phases and temperature (T) on the seed yield and yield components of haricot bean*

Treatment		Yield plant (g) $^{-1}$	Relative reduction (%)	Pod No plant $^{-1}$	Seed No pod $^{-1}$	100 seed wt (g)
Temperature (^{0}C)	18	6.47a		4.2a	5.5a	27.33a
	24	5.29b	18.2	4.6a	4.2b	26.77b
Mv	W	6.38a		4.7a	4.8a	26.84a
	D	5.48a	14.1	4.1b	4.9a	27.26a
Mf	W	6.42a		4.9a	4.8a	26.55a
	D	5.34b	16.8	3.9b	4.9a	27.56b
Msf	W	6.87a		4.8a	5.1a	28.20a
	D	5.89b	28.8	4.1b	4.6b	25.90b

*Means with the same lower case letters (a, b) are not significantly different at 5% level of significance; W, wet; D, Dry; n=48; Source: Worku and Skjelvag (2006)

One of the most obvious morphological changes following water deficit stress is a marked reduction in leaf area development through its effect on the rate of new leaf emergence and/or the rate of individual leaf expansion, or by reducing the number of leaves. Embiale *et al.* (2016) reported a significant leaf area, leaf width and leaf length reduction due to moisture stress in field pea (*Pisum sativum*) (Table 2). A reduction in LAI has also been reported in small red-seeded common bean cultivars (Rezene, *et al*., 2013). Differential responses were also observed among cultivars in response to water stresses of various intensities in these legume crops. Reduction in total leaf area durations (LAD) was reported when common bean plants were subjected to water stress during flowering and seed filling, with the reduction being greatest when plants were subjected to season long and terminal water stress (Worku and Skjelvag, 2006) (Table 4).

Among the three phases, the impact on LAD due to terminal stress (25%) was higher than early stress (17%). In addition, shading did not affect total LAD significantly, although the contribution in phases to total LAD was increased by shading during the vegetative phase (34%) and reduced during seed filling phase (36%). It has been well documented that reduction in leaf area has long been recognized as an adaptive mechanism of many crop species including legume crops in response to water deficit (Levitt, 1980; Turner, 1986). This response could enhance survival by reducing transpirational water loss, but on the contrary, is detrimental to crop productivity upon relief from dehydration. As a result, maintenance of leaf area is considered as a desirable trait contributing to yield under water limiting conditions (Ludlow and Muchow, 1990).

Table 4. Effects of water availability and light intensity on leaf area duration (LAD) and intercepted Photosynthetically active radiation (PAR)*

Treatment	Total LAD (days)	LAD/veg	LAD/fl	LAD/sf	IPAR/Total (Mjm v^3)	IPAR/veg	IPAR/fl	IPAR/sf
Moisture								
WWW	200a	34a	59a	106ab	394a	106a	115a	170a
DWW	190ab	28b	55ab	106ab	374ab	96b	109a	169a
WDW	184bc	34a	54ab	95b	384ab	106a	113a	161ab
WWD	174c	34a	59a	79c	366b	106a	115a	143b
DDD	145d	28b	50b	66c	342c	96b	109a	137c
Light								
F	220a	29b	61a	129a	525a	133a	154a	237a
S	181a	39a	58a	83b	262b	8b	77b	104b
Moisture × light	0.181	0.999	0.807	0.037	0.815	0.597	0.699	0.554

*Means with the same letter are not significantly different at 5% level of significance. WWW, well-watered; DWW, stressed during vegetative phase; WDW, stressed during flowering phase; WWD, stressed during seed filling phase and DDD, stressed throughout. F= full light and S= 50% light; LAD, leaf area duration; veg, vegetative; fl, flowering; sf, seed filling; IPAR, intercepted photo-synthetically active radiation; (Walelign and Skjelvag, 2006)

Plants balance water loss with gas exchange through stomatal openings. Stomata allow atmospheric $C0_2$ to enter leaves for carbon fixation and oxygen to escape. Water evaporates from mesophyll and diffuses through open stomata. Stomatal water loss is specific to the leaves of vascular plants, in which, under non-stressed conditions, stomatal transpiration represents approximately 90% of total water loss (Monneveux and Belhassen, 1996). Under water deficit, stomatal closure is the earliest response in crop plants and is a powerful tool for reducing water loss by adjusting the evapo-transpirational demand to the water supplying capacity of the roots, thereby maintaining turgor (Sinclair and Ludlow, 1986). In *Pisum sativum*, for instance, relative water content (RWC) was decreased under water-stressed plants as compared to well-watered plants, which was more as the stress level was increased from slight to severe-water stress condition (Table 4). Genotypic variation in the reduction of RWC (%) in response to severe water stress condition ranged in the order of 31.71, 34.16 and 37.25% in Brukitu, Tegegnech and Adi, respectively (Embiale *et al*., 2016).

Water stress also adversely affected leaf gas characteristics such as stomatal conductance, photosynthetic rate and transpiration rate in all field pea cultivars, as stress level was increased in comparison to the control plants (Embiale *et al.*, 2016). Differential variations in response to water stress intensities were also observed among Brukitu, Tegegnech and Adi cultivars of field peas where the relatively less decline in the studied parameters of Tegegnech exhibited reasonable tolerance ability, whereas Brukitu and Adi proved to be more sensitive to water-deficit condition (Table 5).

Stomatal sensitivity to water deficit may improve yield stability and internal water status and lowers the probability of exhausting the soil water before maturity, but it will reduce yield potential, as it has been shown to decrease net assimilation as a consequence of reduced $C0_2$ influx. However, the degree of yield reduction due to stomatal closure is not yet clear. Since there is genetic variability of stomata behavior in various crop species including food legumes, genetic manipulation of this trait may be possible. It has been reported that water stress can directly influence the rates of photosynthesis due to the decreased CO_2 influx resulting from stomatal closure (Flexas *et al.,* 2006; Chaves *et al.,* 2009) and/or from changes in photosynthetic metabolism (Lawlor, 2002). In this study, however, it was not clearly explained if the reduction in gas exchange characteristics of these field pea cultivars were due to stomatal closure or directly by the effects of water deficit depending on the intensity and magnitude of the stress that causes disruption in photosynthetic metabolism (Smirnoff, 1993, 1995).

Table 5. Effects of water-stress treatments on the various physiological attributes in selected cultivars of field pea

Parameter	Cultivars	Water stress treatments* 6 days	9 days	12 days	Mean
Relative water content (%)	Brukitu	69.440±4.73b	62.010±4.49c	53.620±4.74d	47.420±5.42e
	Tegegnech	76.460±4.82a	70.950±5.78a	65.080±5.27bc	50.340±4.84d
	Adi	67.320±4.39b	60.440±5.48c	50.890±5.12d	42.240±4.75e
Maximum quantum yield of PS II efficiency (Fv/Fm)	Brukitu	0.795±0.05b	0.772±0.04b	0.765±0.02c	0.708±0.03d
	Tegegnech	0.813±0.04a	0.808±0.05a	0.786±0.04b	0.763±0.051c
	Adi	0.793±0.03b	0.769±0.05b	0.747±0.03c	0.697±0.04d
Photosynthetic rate (μ mol CO_2 mG2 sec^{-1})	Brukitu	4.270±0.23b	4.210±0.22b	3.650±0.21d	2.020±0.21e
	Tegegnech	5.850±0.21a	5.230±0.27a	3.990±0.27bc	2.890±0.28d
	Adi	4.220±0.25b	4.110±0.19c	3.440±0.24d	1.900±0.27e
Stomata conductance (mol mG2 sec^{-1})	Brukitu	0.068±0.031a	0.064±0.03b	0.037±0.03c	0.026±0.03e
	Tegegnech	0.070±0.020a	0.068±0.02a	0.040±0.03c	0.028±0.04e
	Adi	0.067±0.024a	0.063±0.03b	0.033±0.02d	0.021±0.02f
Transpiration rate (m mol m^{-2} sec^{-1})	Brukitu	1.600±0.11a	0.970±0.12d	0.670±0.18e	0.420±0.17f
	Tegegnech	1.600±0.12a	1.220±0.13c	0.870±0.16d	0.680±0.16e
	Adi	1.540±0.11b	0.880±0.14d	0.580±0.19e	0.400±0.13f

*Control: Control plant and uniformly irrigated with tap water (400 mL kg^{-1} soil) at 3 day intervals to maintain 100% FC, 6 days: Irrigated at 6 day intervals (slight-water stress), 9 days: Irrigated 9 day intervals (mild-water stress) and 12 days: Irrigated at 12 day intervals (severe-water stress). Means within a column followed by the same letters are not significantly different according to LSD test ($p<0.05$) Source: Embiale *et al*., 2016)

The responses of physiological traits in field crops to water stress depend on the species and genotype/cultivars, the length and severity of water stress and the stage of crop development (Nayyar and Gupta, 2006; Husen, 2010; Ghane *et al.,* 2012; Loutfy *et al.,* 2012; Husen *et al.,* 2014). Tesfaye *et al.* (2008) compared common bean (*Phaseolus vulgaris* L. cv. Roba-1), cowpea (*Vigna anguiculata* L. cv. Blackeye bean) and chickpea (*Cicer arietinum* L. cv. ICC-495) for response to three water stress treatments, *viz.* well-watered control (C), water stress imposed at flowering (MS) and pod filling periods (LS) and reported that mid-day leaf water potential (ψ_L) of chickpea was significantly more responsive to water stress than that of beans and cowpea. Stomata closure was initiated when available soil water (ASW) declined to 51.5, 41.6 and 56.7% which corresponded to ψ_L -1.33, -2.26 and -1.23 MPa and stomatal conductance (g_s)of 0.066, 0.055 and 0.083 mol m^{-2} sec^{-1} in beans, chickpea and cowpea, respectively (Tables6 and 7). With respect to other gas exchange characteristics, they further revealed that both water stresses at flowering and pod filling period were critical in reducing both photosynthesis and transpiration rates in all species. Most of the variation among the species in photosynthesis was explained by the ASW in chickpea and cowpea, while it was largely explained by ψ_L in common bean. The first sharp decline in photosynthesis was observed when g_s declined below 0.29, 0.38 and 0.33 mol m^{-2} sec^{-1} in beans, chickpea and cowpea, respectively. A significant reduction in leaf gas exchange characteristics (g_s and photosynthesis) of common bean genotypes has also been reported due to water stress imposed during reproductive stages (Gebeyehu *et al*., 2011).

Table 6. Mean leaf water potential (ψ_L), stomatal conductance (g_s), internal C0$_2$ concentration(C_i) and rates of mid-day photosynthesis (A) and transpiration (E) of bean, chickpea and cowpea at different levels of available water (ASW) during the flowering period*

Season	Species	ASW (%)	ψ_L(MPa)	g_s(mol m^{-2} sec^{-1})	C_i (vpm)	A (µmol m^{-2} sec^{-1})	E (mmol m^{-2} sec^{-1})
2002	Bean	>90	-1.23±0.06	0.48±0.055	247±20.7	15.10±0.90	8.11±0.38
		60	-1.44±0.04	0.05±0.020	395±9.20	7.48±0.79	3.40±0.46
		50	-1.48±0.02	0.04±0.003	145±6.60	4.22±0.35	2.73±0.18
		32	-1.58±0.03	0.02±0.001	181±22.4	2.50±0.59	2.54±0.37
	Chickpea	>90	-1.43±0.10	0.47±0.039	257±26.1	20.63±0.94	10.71±0.78
		60	-2.34±0.04	0.06±0.010	375±8.90	5.12±0.46	3.58±0.67
		50	-2.74±0.07	0.04±0.020	202±25.4	2.66±0.91	2.84±0.71
		32	-3.37±0.10	0.02±0.010	198±27.9	2.27±0.81	1.65±0.28
	Cowpea	>90	-0.99±0.14	0.52±0.129	227±17.8	17.61±1.10	7.95±0.93
		60	-1.48±0.03	0.06±0.020	230±11.3	8.80±1.15	4.94±0.69
		50	-1.57±0.04	0.05±0.020	165±10.2	5.87±1.10	3.28±0.52
		32	-1.57±0.04	0.01±0.010	158±20.0	3.70±0.85	1.82±0.49
2002/03	Bean	>90	-107±0.03	0.41±0.087	174±21.6	18.40±0.28	8.45±0.50
		60	-1.30±0.02	0.14±0.037	131±23.6	11.40±0.96	4.30±0.71
		50	-1.38±0.01	0.04±0.009	130±19.6	7.40±0.46	2.90±0.33
		32	-1.49±0.02	0.03±0.004	127±28.3	3.90±0.50	1.74±0.14
		25	-1.66±0.02	0.01±0.003	150±14.5	1.75±0.30	0.69±0.10
	Chickpea	>90	-1.21±0.06	0.41±0.070	180±18.8	16.42±0.89	6.47±0.59
		60	-1.76±0.01	0.16±0.069	178±13.1	8.40±1.23	3.20±0.39
		50	-211±0.02	0.08±0.007	154±40.6	5.82±0.42	2.38±0.49
		32	-2.57±0.03	0.02±0.004	152±43.6	2.73±0.36	1.20±0.21
		25	-3.02±0.02	0.01±0.002	206±31.2	2.66±0.61	0.57±0.14
	Cowpea	>90	-0.93±0.04	0.38±0.090	190±16.6	16.85±0.21	6.23±0.22
		60	-1.20±0.03	0.05±0.003	174±9.30	10.00±0.37	4.80±0.21
		50	-1.35±0.02	0.01±0.003	131±26.0	7.83±0.29	2.64±0.21
		32	-1.50±0.02	0.01±0.003	114±23.7	4.64±0.28	235±0.12
		25	-1.46±0.02	0.02±0.004	188±19.6	3.22±0.43	191±0.18

*The ASW values indicated range ±2%. The ψL, g_s, A and E values at the high ASW (>90%) are means for measurements taken between 90-100% ASW. Values next to means are standard errors. Measurements taken on a day with very low vapor pressure deficit; (Source: Tesfaye *et al*., 2008)

Table 7. Mean leaf water potential (ψ_L), stomatal conductance (g_s), internal CO_2 concentration(C_i) and rates of midday photosynthesis (A) and transpiration (E) of bean, chickpea and cowpea at different levels of available soil water (ASW) during the pod filling period*

Season	Species	ASW (%)	ψ_L(MPa)	g_s(mol m^{-2} sec^{-1})	C_i (vpm)	A (µmol m^{-2} sec^{-1})	E (mmol m^{-2} sec^{-1})
2002	Bean	>90	-1.13±14	0.46±0.140	174±12.3	16.70±1.02	9.46±0.38
		60	-1.40±0.03	0.08±0.008	156±7.20	8.75±0.52	4.00±0.29
		50	-1.57±0.04	0.04±0.003	140±10.6	4.62±0.46	3.62±0.24
		32	-1.70±0.03	0.03±0.010	179±27.5	2.97±0.86	3.32±0.65
	Chickpea	>90	-0.63±0.36	0.91±0.222	196±14.6	21.85±1.26	10.94±0.45
		60	-2.35±0.09	0.18±0.030	172±12.3	10.54±1.04	7.59±0.48
		50	-2.50±0.15	0.10±0.010	163±15.7	8.22±1.12	6.25±0.55
		32	-2.90±0.03	0.09±0.009	164±23.6	3.53±1.06	4.44±0.22
	Cowpea	>90	-0.84±0.15	0.52±0.122	176±11.2	18.92±1.15	8.67±0.77
		60	-1.43±0.04	0.17±0.030	172±7.70	1.68±1.29	6.09±0.63
		50	-1.53±0.02	0.07±0.020	133±16.1	7.36±1.36	4.93±0.65
		32	-1.60±0.03	0.05±0.020	120±7.20	5.70±1.42	3.19±0.51
2002/03	Bean	>90	-0.76±0.02	0.57±0.070	176±16.8	19.70±0.60	8.70±0.30
		60	-1.18±0.04	0.15±0.022	143±19.6	13.30±0.57	4.90±0.35
		50	-1.21±0.02	0.03±0.005	82±20.70	5.78±0.54	1.73±0.22
	Chickpea	>90	-1.00±0.17	0.44±0.048	195±17.8	19.41±0.55	6.97±0.98
		60	-1.23±0.02	0.22±0.029	102±19.8	11.70±2.08	5.28±0.40
		50	-1.55±0.07	0.15±0.039	144±21.1	5.25±0.50	1.77±0.07
	Cowpea	>90	-0.67±0.05	0.56±0.014	179±17.7	18.69±1.43	7.21±0.84
		60	-0.85±0.03	0.19±0.026	173±25.3	12.22±1.20	4.70±0.21
		50	-1.05±0.02	0.07±0.008	111±17.2	9.66±0.86	3.40±0.13

*ψ_L= leaf water potential, gs = stomatal conductance, Ci = internal C02 concentration, A = rate of midday photosynthesis and E = transpiration (Source: Tesfaye *et al.*, 2008)

Response to soil salinity stress

Salinity is one of the most serious factors limiting the productivity of agricultural crops, with adverse effects on germination, plant vigor and crop yield (Munns and Tester, 2008; Hamdia and Shaddad, 2010). Salinity lowers the water contents of the roots, and this quickly causes reductions in growth rate, along with a range of metabolic changes identical to those caused by water stress (Munns, 2002). The detrimental effects of high salinity on plants can be observed at the whole-plant level in terms of plant death and/or decrease in productivity (Parida and Das, 2005). Grain legumes are relatively sensitive to salinity where salinity damage to pulse crops is shown by characteristic symptoms of excess ion accumulation (Shannon, 1997).

In Ethiopia, research information on the effects of salinity on grain legumes is inadequate and the limited efforts are mainly restricted to the effects of salinity on germination and seedling growth. The available limited research results indicated that salinity decreased the relative seedling shoot and root water contents in common bean (Ashagre, 2013) (Figure 1). Despite similar trends, the decrease in relative shoot water content (RSWC) due to NaCl was higher than relative root water content (RRWC), indicating the prime significance of salinity on shoot part of plants. There was also differential response of relative shoot and root water contents between the tested cultivars, with the highest decrease in relative seedling shoot and root water content observed in Lehade compared to Chercher (Geressu, 2011). Geressu (2011) also reported that, based on final germination percentage (FGP%), seedling shoot length (SSL), seedling root length (SRL) and shoot to root ratio (SRR), existence of broad intra-specific genetic variation in haricot bean varieties for salt tolerance. Likewise, Ashagre (2013) reported differential variation between two haricot bean cultivars for seedling vigor index (SVI) and shoot vigor index (SHVI) and root vigor Index (RVI) (Figure 2). Similar findings were also reported for grasspea (*Lathyrus sativus* L.) (Haileselasie and Gebreselasie, 2012) and chickpea (Ashagre, 2013). The authors have suggested that there are scopes for the improvement of these legume crops for tolerance to salinity, thereby increase and stabilize seed yields under salinity stress conditions

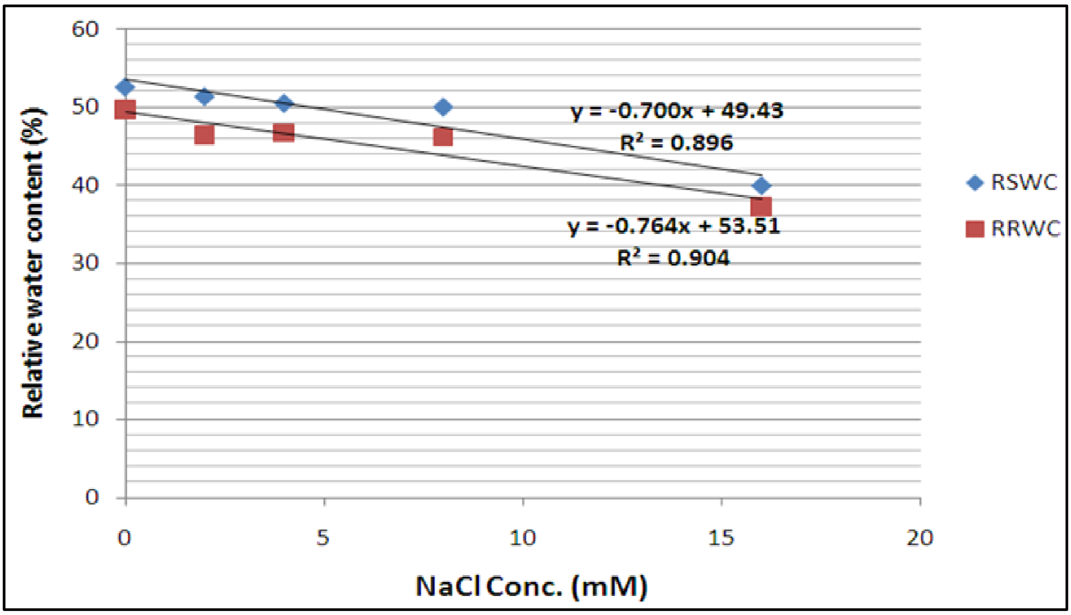

Figure 1. Effect of NaCl on shoot and root moisture content averaged over cultivars (**RSWC** = Relative shoot water content, RRWC = Relative root water content); (Ashagre, 2013)

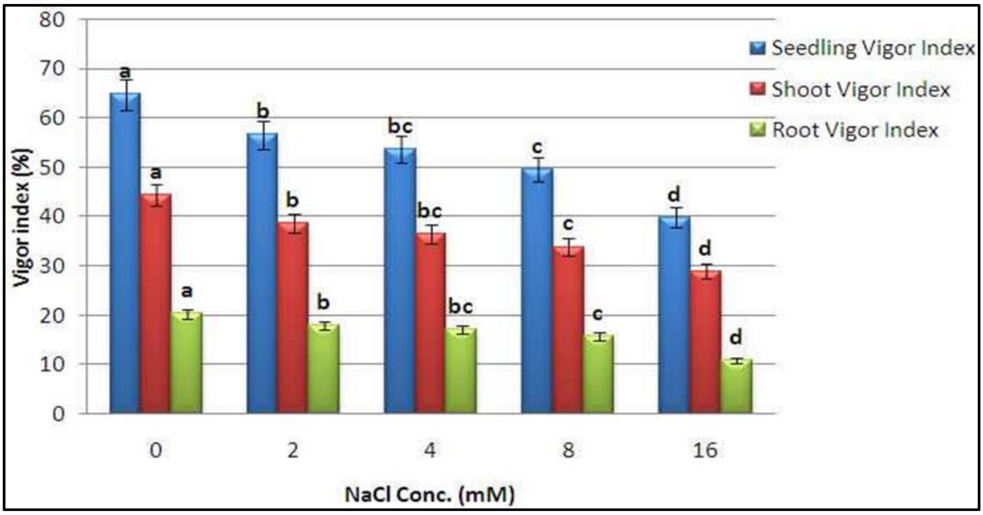

Figure 2. Effect of NaCl on seedling vigor indices averaged over cultivars; (Ashagre, 2013)

Resource Use of Food Legumes

It is well documented that the amount of available soil moisture and radiation intercepted are important natural resources for plant growth and development that remarkably influence dry matter production and final seed yield (Squire, 1990). Moreover, the reduction in the final yield of the crop is negatively affected by the distribution of its assimilates to various sinks (Worku and Skjelvag (2006). Tesfaye *et al.* (2006) reported that dry matter production was highly associated with the fraction of photosynthetically active radiation (PAR) intercepted, which, in turn, is positively correlated with LAI in common bean, cowpea and chickpea and water regimes. Various adaptation characteristics were observed in common beans subjected to reduced irradiances. These include chlorophyll a/b ratios, reduced stomatal density, increased specific leaf area, leaf area ratios and increased shoot: root ratio (Worku *et al.*, 2004). There was significant interaction between water stress and shading effects where radiation use efficiency (RUE) under water stress was reduced by 33% while shading increased RUE by 27% (Worku and Skjelvag, 2006).

Crop management plays an important role in improving crop productivity and production. Yield potential of field crops can substantially be enhanced if grown under improved agronomic practices. It is understood that improving agronomic practices is aimed at maximizing use of growth resources like water, radiation, nutrients and others. Previous experiences indicated that improved agronomic practices are powerful management tools in influencing use of resource and enhance crop growth (Ball *et al.*, 2000; Worku and Skjelvag, 2006). Worku and Demisie (2012) found that planting density increased LAI, cumulative intercepted photosynthetically active radiation (CIPAR), extinction coefficient (k) and radiation use efficiency (RUE) in pigeon pea, with increased dry matter production per unit area (Table 8).

Table 8. The effect of planting density and variety on crop phenology, growth and cumulative Intercepted PAR (CIPAR) of pigeon pea*

Treatment	Days to flower	Days to maturity	Plant height (cm)	Dry matter (gm^{-1})	Dry matter ($gm\ m^{-2}$)	CIPAR ($MJ\ m^{-2}$)
Density (plants ha^{-1})						
166666	103.67	160.30	88.10a	51.10a	525.90a	329.10c
200000	103.83	161.30	88.00a	46.00b	578.70b	364.40d
250000	103.67	161.30	87.40b	37.70bc	657.70.b	405.10c
333333	103.83	160.50	82.70c	36.90c	721.20c	444.10b
500000	102.67	160.17	81.40c	22.70d	1010.70d	538.30d
LSD (0.05)	ns	ns	5.19	8.33	62.52	17.76
Variety						
ICPL87091	103.20	157.90b	78.30b	40.80	709.20	432.10
ICP15027	103.80	163.50c	92.70c	37.00	688.40	400.30
LSD (0.05)	ns	3.88	3.73	ns	ns	ns

*Means with the same letter within columns are not significant at ≤0.05% level, ns: not significant;
(Source: Worku and Demese 2012)

From a sowing date study on mung bean, Laekemariam and Worku (2013) reported that early sowing of mung bean extended duration to attain physiological maturity, larger leaf area index (LAI) and greater dry matter accumulation, which resulted in the interception of high amount of radiation, radiation use efficiency (RUE) and better grain yield as compared late sowing (Table 9). Comparisons of the effect of planting density and row-spacing under two moisture regimes indicated that although row-spacing had no effects on the grain yield and biomass production, an increase in grain yield and total biomass yield was observed with increasing planting density under wet-regime, suggesting that matching appropriate planting density per unit area with available resource can remarkably improve the yield potential of crops (Lemma *et al.*, 2009).

Table 9. Crop phenology, growth parameters and intercepted light by mungbean as influenced by sowing date and cultivar*

Treatment	Days to Flowering	Days to maturity	Plant height (cm/plant)	Total Dry Matter ($t\ ha^{-1}$)	Cumulative Intercepted PAR (MJ^{-2})
			Sowing Dates		
08 July	60.0^{b}	112.3^{a}	52.0^{a}	4.308^{a}	454.12^{a}
18 July	64.0^{a}	103.8^{b}	56.5^{a}	3.249^{b}	408.49^{b}
28 July	58.0^{c}	97.6^{c}	55.2^{a}	2.967^{b}	403.45^{b}
07 August	57.3^{d}	97.6^{c}	58.0^{a}	3.153^{b}	406.1^{b}
LSD (0.05)	0.5	3.3	ns	0.61	44.18
			Cultivars		
MH-97-6	60.1^{a}	104.0^{a}	59.3^{a}	3.736^{a}	433.94^{a}
Gofa Local	59.5^{b}	101.7^{a}	51.9^{b}	3.104^{b}	420.6^{a}
LSD (0.05)	0.35	ns	4.9	0.43	ns
CV (%)	0.6	2.6	10.1	14.4	8.34

*Means with the same letter within columns are not significantly different at P<0.05; Laekemariam and Worku (2013)

Crop Modeling

Crop models provide a means to quantify the effects of climate, seasonal weather conditions, soil, management and genotype and their interactions on crop growth, yield, resource use efficiency and environmental impacts (Boote *et al.*, 1996). They can be used to quantify the gaps between potential and actual yields, to evaluate management options and to determine likely environmental impacts. Plant growth simulation models that integrate various physical and physiological processes of plant growth and development can be used to assess growth and yields of different crop cultivars in different environments by using environment-specific weather, soil and agronomic management data (Boote *et al.,* 2001).

Models need to be properly calibrated and validated before they are used for simulation and serve as a decision making tools (Mote *et al.,* 2016). In this aspect, few experiments were conducted for calibration and validation of models in Ethiopia. Tesfaye and Walker (2006) reported the CROPGRO model simulated leaf area index (LAI), crop evapo-transpiration (ET),and above-ground biomass at harvest with reasonable accuracy for dry beans and chickpea while the simulation at harvest was very good for both beans and chickpea. The models showed good performance in simulating these variables under conditions of well-watered and water deficit conditions during the reproductive period of the crops. However, the simulation of yield components at harvest, and biomass accumulation during crop cycle under high temperature conditions was very poor in both crops, suggesting the need for further improvements of the models to suit the study environment.

The calibration and testing of the CROPGRO in chickpea and faba bean model for the experimental conditions were performed by adjusting genetic coefficients that characterize the essential aspects of chickpea and faba bean, as recommended by Hogeboom *et al*. (2003) and Jones *et al*. (2003).

Genetic coefficients of the crop cultivars were determined following Hunt and Bootee's (1988) approach. This was accomplished iteratively by executing the model with approximate coefficients, comparing model output with actual data and then re-adjusting the coefficients and repeating the process until acceptable fits were obtained. Genetic coefficients were calculated from the field data using GENCALC, a utility module embedded in DSSAT v4.6 (Hoogenboom *et al*., 2014).While applying such procedures, Mohammed (2017) reported a good agreement between observed and simulated performances for chickpea (var. *Kutiye*). The parameters considered were days to first flowering, days to physiological maturity, grain yield (kg ha^{-1}), total biomass (kg ha^{-1}) and by-product yield (kg ha^{-1}) with the exceptions of LAI (maximum) m^2m^2 and harvest index (HI%)as shown in Table 10, using root mean square error (RMSE), index of agreement (D-stat), and coefficient of variation (CV (%).

Table 10. Estimate of calibration of chickpea variety Kutaye in 2014 for seven variables from field experiments conducted in Ethiopia

Variable	Simulated	Measured	RMSE	CV (%)
Days to first flowering	51	48	3	6.3
Days to maturity	111	116	1	7.6
Grain yield (kg ha^{-1})	3830	3590	240	6.7
Total biomass yield (kg ha^{-1})	7681	9623	1342	13.9
By-product yield (kg ha^{-1})	3850	5345	1495	27.9
LAI (maximum) m^2m^2	4.83	4.89	0.09	23.5
HI (%)	0.42	0.34	0.08	23.5

Source: Mohammed .A. (2017).

The CROPGRO-Chickpea model was evaluated with an independent data collected at Sirinka and Chefa sites in 2014 main cropping season and data obtained from chickpea variety trial in 2005 and 2006 conducted in both locations and seasons. The simulated result showed a good agreement between simulated and observed values as presented in Table 10and Figure 3. Hence, it was established that the CROPGRO-Chickpea model was able to simulate the observed duration to flowering and physiological maturity of chickpea reasonably well almost for all the treatments.

Thus, the CROPGRO-Faba bean and chickpea models could be adopted for the major growing environments. According to Mohammed *et al.* (2017), the highest grain yield at Sirinka was predicted for a short duration cultivar and at Chefa for a long duration cultivar using the CROPGRO-Chickpea model. Early sowing of chickpea at both sites is predicted to significantly increase grain yield as compared to delayed sowing. The study indicated that short duration cultivars are more appropriate in areas where terminal drought is a major constraint for crop production, as they could easily escape terminal drought condition which usually occurs at flowering and grain filling stages.

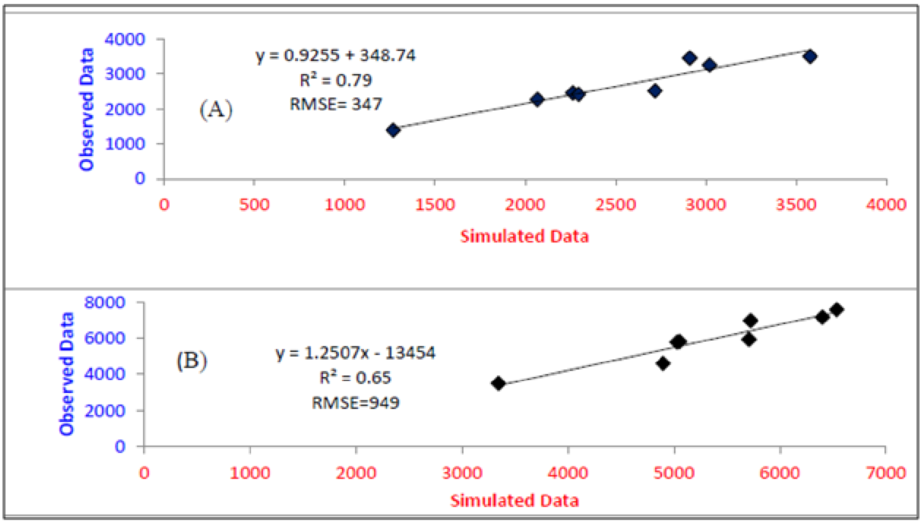

Figure 3. Linear relationship between observed and simulated grain yield (kg/ha) (A) and above-ground biomass yield (kg/ha) (B) of chickpea for the data sets of 2005, 2006 and 2014 at Chefa and Sirinka; Source: Mohammed *et al*. (2017).

On the other hand, long duration cultivars are more appropriate in areas where high temperature is a major constraint for crop production. High temperature can speed up growth and development stages of crops and finally shorten their life cycle. This condition ultimately reduces the productivity of crops. The reduction in productivity of long maturing cultivars under high temperature stress could probably be due to retardation of carbohydrate translocation for grain filling.

Mohammed *et al.* (2017) recommended that, in order to increase grain yield of chickpea, new chickpea varieties with both shorter and longer growth habits are required depending on the moisture regime and temperature of the given growing areas. The effectiveness of other crop management options in counteracting the adverse impacts of terminal drought and high temperature need to be assessed and quantified in the future.

Conclusions

One of the main goals of crop simulation models is to estimate agricultural production as a function of weather and soil conditions as well as crop management. Crop simulation models are useful to extrapolate the results obtained under particular experimental conditions over time and space.

This review clearly indicated that there were only limited studies on the physiology of food and forage legumes, particularly on crop growth modeling. Results obtained from the limited studies indicated that site-specific calibration and evaluation of models is essential in countries like Ethiopia where diverse agro-ecology prevail. Crop simulation model were found to be effective tools to predict the phonological occurrence, grain yield and biomass of chickpea and faba bean.

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Development of Farm Implements for Pre- and Post-harvest Legume Crop Production in Ethiopia

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Abstract

This paper reviews previous research and recent attempts to develop technologies to enhance bean production and productivity at the Ethiopian Institute of Agricultural Research. About15 years ago erf and mofer attached mold board plow and single row planter have been developed. Mold board plow was successful in terms of field capacity, pulverization and timeliness but the popularization and utilization was low due to lack of local manufacturers and distributors nearby the farmers. The single row planter, was successful in the field but not popular with the farmers due to operational problems. Surveys conducted in three common bean producing woredas (districts) of Oromia and SNNP regions, in 2015/6 season, found that tillage implements, crop establishing technologies(such as seeders and weeders) and threshing technologies were high priority mechanization problems for bean production by farmers. Harvesting and storage technologies also came out as major problems by some farmers. The Agricultural Engineering Research Directorate of EIAR has developed pre- and post-harvest bean mechanization technology options. The technologies have been evaluated against the conventional methods both on-station and on-farm. Field evaluation results showed that most of these technologies (tillage implements, planters, threshers, and storage technologies) are found promising. The post-harvest loss reduction technologies need also to be given emphasis in the bean mechanization technology development. Future bean mechanization research should focus on technologies that are engine operated and tractor drawn. Training should also be part of the scaling up these appropriate technologies to the end users using different participatory farmers' research groups and rural youth groups.

Keywords: Bean, harvest, mechanization, metal silo, planter, thresher

Introduction

In Ethiopia, farming is subsistence and small-scale where more than 91% of the cultivated land is categorized in less than or equal to 1 ha (CSA, 2012). Agricultural crop production and different farm operations such as tillage, planting, harvesting, threshing or shelling is done using traditional methods. These operations are the main cause of low productivity due to high labor demand, longer working hours and low quality of work.

Common bean (*Phaseolus vulgaris* L.) is grown for its green leaves, green pods, and green and/or dry seeds. It is a major staple crop in eastern and southern Africa and the second most important source of human dietary protein and third most important source of calories of all agricultural commodities produced in the region (Pachico, 1993). Bean, is a near-perfect food (CIAT, 1995) and the "meat" of the poor (Sperling, 1992) with good nutritional properties, easily prepared for consumption and have a long storage life.

Although annual production of pulse crops deceased unlike the major crops (teff and maize), there is an increasing trend in recent years (CSA, 2013). Recently, attempts were made to enhance bean production and productivity. The use of improved mechanization technologies reduces the drudgery of both humans and animals, enhance the crop intensity, increase precision and timeliness to increase productivity at different operation levels.

In the previous decades, there was no significant research carried out on mechanization in the country. Oxen drawn single row bean planter was developed by Melkassa Agricultural Research Center. However, three people are required to operate (one person for the *maresha* plow to open furrows, a second person to drop seeds and a third person to drop fertilizers) and it took 26 hours ha^{-1} for manual seed placement and fertilizers (Melese, 2007). The oxen drawn single row planter for seeding and band placement of fertilizers requires two people (one person operating and another person guiding the animal) and it took 12 hours ha^{-1} reducing the labor hour by more than 50%. Although this planter saves time it was not popular by the farmers as the operator uses both hands to operate the planter (Figure 2.). In recent years, the need for appropriate mechanization technologies has been critically felt by farmers and the Agricultural Mechanization Research Directorate embarked in conducting a full-fledged research project to address the mechanization problems in bean production.

Approaches in technology development

The research on agricultural mechanization involved farmer survey to identify their needs and developing and testing of prototypes on-station and on-farm with participation of farmers.

Conduct surveys to identify and prioritize the needs

Surveys were carried out in major bean producing *woredas* at Meki, Shashemene and Zeway in Oromia region and at Borcha *woreda* in SNNP region to identify and prioritize mechanization research for bean production in 2015/6.

Design and validate prototypes

For economic production of crops and livestockthe demand for technological processing (mechanical planting, harvesting, storage handling, etc.) iscontinuing to increase.During technological processes agricultural materials may be exposed to various mechanical, thermal, electrical and optical effects.To insure optimal design of such processes, the interactions between biological materials and the physical and the physical effects, acting on them, as well as the general laws governing the same, must be known.The Agricultural Engineering Research Directorate has carried out a study to investigate the engineering properties of 29 bean varieties. Size, sphere city, mass, density, surface area, volume, major and minor diameters were studied and become the fundamental design parameters for developing planters and threshers.

Results and Discussion

Survey results

The results on prioritization of mechanization in selected *kebeles* (lowest administrative unit) in different *woredas* were presented for Oromia (Table1) and SNNP (Table 2) regions. The results showed that tillage, crop establishment and threshing technologies were the major mechanization problems mentioned by the farmers. On the other hand, storage technologies appeared to have low priorities across the two regions.

Table 1. Prioritization of mechanization at selected *kebeles* of Meki, Zeway and Shashamene *woredas,* Oromia Region

Mechanization issues	Meki				Zeway				Shashamene	
	Shewi *kebele* (n=29)		Tuche *kebele* (n=30)		*Woyiso kebele* (n=30)		*Haleku kebele* (n=28)		*Oine Chefo kebele* (n=30)	
	No of farmers	Percent	No of farmers	Percent	No of farmers	Percent	No of farmers	Percent	No of farmers	Percent
Tillage	*14*	*48.3*	*8*	*26.7*	*8*	*26.7*	*8*	*28.6*	*14*	*46.7*
Crop establishment	*6*	*20.7*	*15*	*50.0*	*11*	*36.7*	*11*	*39.3*	*4*	*13.3*
Harvesting	*4*	*13.8*	*4*	*13.3*	*2*	*6.7*	*1*	*3.6*	*1*	*3.3*
Threshing	*3*	*10.3*	*3*	*10.0*	*8*	*26.7*	*7*	*25.0*	*11*	*36.7*
Storage	*2*	*6.9*	-	-	*1*	*3.3*	*1*	*3.6*	-	-
Total	***29***	***100***	**30**	**100**	***30***	***100***	***28***	***100***	***30***	***100***

Table 2.Prioritization of mechanization at Borecha *woreda,* SNNP Region

Mechanization issues	Sidama *kebele* *(n=29)*		Hanja Goro *kebele* *(n=27)*		Borecha Shandoi *kebele (n=29)*	
	No of farmers	Percent	No. of farmers	Percent	No of farmers	Percent
Tillage	*15*	*51.7*	*11*	*40.7*	*11*	*36.7*
Crop establishment	*5*	*17.2*	*9*	*33.3*	*8*	*26.7*
Harvesting	*2*	*6.9*	*2*	*7.4*	*3*	*10.0*
Threshing	*6*	*20.7*	*4*	*14.8*	*5*	*16.7*
Storage	*1*	*3.4*	*1*	*3.7*	*3*	*10.0*
Total	***29***	***100***	***27***	***100***	*30*	*100*

Porotypes developed, validated and disseminated

Improved tillage implements

Tillage loosens and aerates the top layer of soil, which facilitates planting the crop. It also helps in incorporating crop residue, organic matter (humus), and nutrients into the soil. Most importantly tillage controls weeds mechanically. The experiment on plow type and frequency of tillage in Adami Tulu, Shalla and Bora *woredas* showed 30%, 18.56% and 17% increase in common bean yield with the use of *erf* and *mofer* attached to mold board plow (Figure 1) over the traditional plough when ploughing twice with mold board plough and using conventional tillage using *maresha* plough (AMRD, 2008).

Figure 1. *Erf* and *mofer* attached mold board plough for land preparation

Improved bean row planter

The first single row animal drawn bean planter was developed at Melkassa at the end of the 1990's. It had a good performance in plant emergence but due to low field capacity and difficulty in manoeuvring the handle and the animal at the same time, it was necessary to develop a multi row and relatively easy operating animal drawn bean row planters. Two versions of seed planters-cum-fertilizer applicators were developed by the Agricultural Engineering Research Directorate: (i) manually operated, push type two row planter (MBRP), and (ii) animal drawn, three row planter (ABRP).In the 2015/16 season, the implements were evaluated at Melkassa Agricultural Research Center (MARC) on sandy-loam soil with average moisture content of 20.25%. The results showed that the mean seed spacing, seed per hill, seeding depth of MBRP were found to be 10.92±0.38 cm, 1.03±0.58 seeds and 4.05±0.25 cm respectively. The field capacity, average plant population achieved, seeding rate and fertilizer application rate were also found to be 14.70±1.85 hour.ha^{-1}, 246,330±55 plants.ha^{-1}, 91.41±5.23 kg.ha^{-1} and 100.31±13.00 kg.ha^{-1} respectively. On the other hand, ABRP achieved 9.77±0.25cm, 1.71±0.34 seeds and 5.50±0.17cm seed spacing, seed per hill and seeding depth, respectively. Its field capacity, average plant population, seeding rate and fertilizer application rate were also found to be 8.73±1.1 hour.ha^{-1}, 273,356±67 plants.ha^{-1}, 112.35±4.38 kg.ha^{-1} and 99.23±9.78 kg.ha^{-1}, respectively. The time it takes to plant using human labor is 117.95±9.23 hour.ha^{-1} and the plant population and seeding depth were 249,281±26 plants.ha^{-1} and 5cm, respectively.

Figure 2. a) *Erf* and *mofer* attached row planter and b) recently developed *Erf* and *mofer* attached three row planter

Bean thresher

Manual cutting and threshing of small grains are tedious and time consuming for farmers and mechanizing harvesting had been a challenge. Threshing of bean is carried out manually by hand or by trampling by animals or driving tractor making the grain susceptible to postharvest and quality losses in addition to the drudgery to humans. There was no research carried out in developing a mechanical thresher for bean until recently. An engine driven bean thresher has been developed by EIAR for small holder farmers to reduce drudgery and post-harvest losses (Figures 3 and 4). The first prototype was developed and tested at Shashemene and Zeway with Nasir and Awash 1 bean varieties. The capacity of the thresher was 247.5 kg ha^{-1} for Awash 1 and 306 kg ha^{1} for

Nasir bean varieties. The main reason for the capacity difference was that the grain to straw ratio for Nasir was 0.93 whereas for Awash 1 it was 1.05. The percent of damaged grains for Nasir and Awash 1 was 3.74% and 5.02%

with a cleaning efficiency of 92.30%and 90.98%, respectively. Currently, the capacity of the thresher has increased by increasing the inlet of the thresher and its breakage has been reduced to zero by optimizing the size of the driving pulleys on the engine and on the threshing drum.

On-farm evaluation at Shashemene and Zeway, showed farmers willingness to use the technology and their satisfaction with the performance (Figures 4 a, b & c).

Figures 3 a) thresher after the pulley size is optimized b) the first pulley before its size is optimized for drum speed

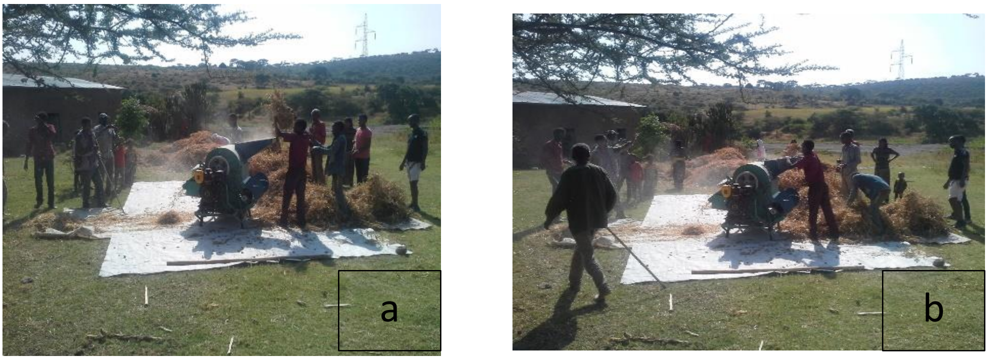

Figure 4. On-farm evaluation of engine driven common bean thresher at (a & b) at Shashemene and (c) at Ziway

The performance of the thresher was improved further by incorporating a wheel in the design. They want to use the thresher not only for grain threshing but also the chaff for animal feed since it is chopped to the desired size.

Grain storage

Common bean storage is a very critical problem in most parts the country. EIAR has conducted a research on storage structures like metal silo (Figure 5) and evaluated at Melkassa, Shashemene and Zeway. After two months storage period, the metal silos have better germination percentage than the local storage on the samples taken at the top, middle and bottom of the storage structures.

Participatory demonstration and evaluation was also carried out for PICS (Purdue Improved Crop Storage), metal silos (capacity of 600 kg) and sacks at Adami Tullu *woreda* in Oromia and at Loka Abaya *woreda* in SNNP regions. The results showed that PICS bags and metal silos perform superior than the storage with sacks by reducing the insect infestation. Samples taken from the grain stored in the middle and bottom of metal silos are less likely to be infected than the top stored grain.

Figure 5. Metal silo storage prototype (1 ton capacity)

Germination tests conducted after 60 days of opening storage with metal silos and conventional storage did not show much different in germination as shown in Table 3.

Table 3. Germination of common bean (var. Nasir) stored in metal silos and conventional storage

Position of sampling	No of samples (N)	Germination (%)	
		Silo storage	Conventional storage
Top	30	93.3	93.33
middle	30	100.0	93.33
bottom	30	93.3	90

Conclusion and Recommendations

Some recent research interventions made by EIAR, aimed at developing pre-harvest technologies (tillage and row planters) and post-harvest technologies (threshers and storage). Many bean mechanization technologies were developed more recently including a multi-crop planter that can also be used for seeding other crops. All technologies developed can be widely scaled up to improve the mechanization of bean production by smallholder farmers. Apart from development and validation of mechanization technologies for bean production, the demonstration, fabrication and commercialization of the prototypes is very critical to ensure the availability, access and affordability for successful adoption by smallholder farmers.

Mechanization technologies are cost intensive and the cost- benefit and access to technology is more important rather than ownership of the technology. Thus, owning seeders and threshers individually may not be feasible for smallholder farmers. For example, ownership of engine powered threshers by group of farmers (cooperative) who produce and sell bean, service providers or exporters is more desirable.

Apart from reducing drudgery and costs, increased productivity and production, better product quality, reducing post-harvest losses and increased profitability are some of the benefits for adoption of mechanization technologies. Another important point to consider in mechanization technology adoption is the skill to use and operate a technology together with the availability of spare parts and repair shops in the rural communities.

Engineering property of beans need to be further investigated for various physical and mechanical properties as function of moisture content before designing of the technologies. The size, shape and mechanical behavior of bean are important in the design of harvesting, separating, sizing, grinding and oil extraction machines in the future.

Acknowledgement

Authors would like to acknowledge the financial and infrastructural support received from Ethiopian Institute of Agricultural Research (EIAR) through Agricultural Engineering Research Directorate to conduct the research.

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Part IV. Crop Protection Research in Food Legumes of Ethiopia

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Progresses in Diseases Management Research in Highland Food Legumes of Ethiopia

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Abstract

Highland food legumes (faba bean, field pea, chickpea, lentil, grass pea, and Lupin) are vital components of the crop-livestock farming systems in the highlands of Ethiopia. The Highland food legumes dominate the food legumes' area (80%) and production (81%) in the country. However, diseases cause an annual monetary loss of more than USD $219 million. The Ethiopian pulse industry is experiencing devastating epidemics of diseases such as chocolate spot, rusts, Ascochyta blights, powdery mildew, and wilt/root rots. In addition, a new faba bean disease had appeared in central and northern highlands becoming an alarming threat to faba bean production. Besides, parasitic weeds are emerging as increasing problem, attacking highland legumes. The new faba bean disease and parasitic weeds are not only reducing production and productivity of faba bean, but they also threaten the genetic diversity of the crop. Some diseases like chickpea chlorotic dwarf are increasing in their incidence and severity on chickpea in the central highlands. This review addresses advances made in managing existing and emerging diseases affecting food and forage legumes over the past decade and future areas of emphases for effective disease management that can play key role in narrowing yield and quality gaps.

Keywords: Highland food legumes, diseases, research, yield gaps, Ethiopia

Introduction

Highland food legumes are vital components in the crop-livestock farming systems in the highlands of Ethiopia. The major highland food legumes in the country are faba bean (*Vicia faba*), chickpea (*Cicer* *arietinum*), field pea (*Pisum sativum*) and lentil (*Lens culinaris*). The highland food legumes dominate food legumes' area and production in the country (CSA, 2015).

The Ethiopian highland pulse industry has experienced devastating outbreaks of diseases, which include outbreak of lentil rust (*Uromyces viciae-fabae*) in lentil; *Ascochyta* blight (*Ascochyta rabiei*) and *Fusarium* wilt (*Fusarium oxysporum* f.sp. *ciceris*) in chickpea; and faba bean galls (*Olpidium viciae* Kusano) in faba bean. Managing diseases of the food legumes at the right time, with the right control methods, can substantially reduce their impact, thereby improving the role of these crops as profitable break crops, soil fertility enhancers, income generators, animal feed source and nutrition security crops.

Faba bean galls disease (*O. viciae*) (Gorfu *et al.*, 2012), which has first appeared in central and northern highlands of Ethiopia, has become an alarming threat not only to the crop's production but also to the genetic resource of the legume species in high-risk elevations (≥ 2400 m.a.s.l.). Also, emerging diseases on highland food legumes include chickpea chlorotic dwarf in central highlands and *Stemphylium* blight in south-eastern highlands of the country. Moreover, foot rot of faba bean is also emerging as an increasing problem on Nitosols in the South.

This paper addresses advances in diseases management research related to existing and emerging fungal and viral pathogens in faba beans, field peas, chickpeas and lentils over the past decade. In addition to disease control studies, the paper covers significant developments in the field of highland pulse pathology, including disease diagnosis, pathogens, host-pathogen interactions, epidemiology and ecology, and breeding for resistance. Furthermore, areas that require future emphases in pulse pathology research endeavour are suggested.

Yield and economic losses in highland food legumes due to diseases

In Ethiopia, grain yield loss estimates have been reported for each of the major highland food legume crop in the respective crop/host disease pathosystem, which ranges from 10 to 100% (Tadesse *et al.*, 2008). And, diseases, either singly or in combination, incur an annual yield loss of 15% in highland food legumes. Production area and average national yield of all highland food legumes (faba bean, field pea, chickpea and lentil) are 1, 740, 952.33 ha and 1.4 tons/ha, respectively (CSA, 2015). The absolute yield loss figure would then be 0.21 tons/ha, and this results in a total annual grain yield loss of 365, 600 tons. In terms of monetary loss, the annual grain yield loss, taking an average international market price of US $ 600/ton (FAOSTAT, 2014), amounts to more than US $219 million.

Chickpea diseases reported

A total of 16 diseases have been reported in the country until 2005 (Tadesse *et al.*, 2008). Of these, 47% and 41% are caused by fungal and viral pathogens, respectively. In 2015, additional viral disease, chickpea chlorotic dwarf, was observed around Alem Ketema, North Showa (personal observation). No new fungal disease record has been made in the country. However, data from a recent survey showed that wilt and root rots are still widely occurring and increasing in magnitude of incidence in central and northwestern (particularly East Gojam) highlands of Ethiopia (Abera *et al.*, 2011a; Damte and Ojawo, 2016; Yimer *et al.*, 2018).

Both the desi and the kabuli chickpea (*C. arietinum*) are mostly affected by soil-borne [*Fusarium* wilt (*F. oxysporum* f.sp. *ciceris)*, dry root rot (*Rhizoctonia bataticola*), soft rot (*R. solani*), collar rot (*Sclerotium rolfsii*)], and foliar fungal diseases [*Ascochyta* blight (*A. rabiei* = *Didymella rabiei*), and rust (*Uromyces ciceris-arietini*)]. Moreover some viruses, mycoplasma-like organisms, and root knot nematode (*Meloidogyne incognita*) are known to attack chickpea (Tadesse *et al.*, 2008).

Fusarium wilt

Distribution

Fusarium wilt incidence in 36 districts in Shewa, Wollo, Tigray, Gondar and Gojam ranges from 8 to 38%, the highest being in Gojam and the lowest in Shewa (Yimer *et al.*, 2018). Genomic research on the pathogen has started and the output will help in an overall understanding of genotypic and phenotypic diversity of the pathogen and will ease the breeding for resistance to the diversity present in the Ethiopian *F. oxysporum* f.sp. *ciceris* population (Mohammed *et al.*, 2017).

Disease control

Cultural control

Broad-bed and furrow (raised bed), and ridge and furrow are widely used as drainage systems by smallholder farmers, who grow chickpeas in waterlogged areas, and in areas where chickpea is sown early in the season. Although results were inconsistent, application of different quantities of green manure and dried plant residue partially reduces chickpea plant mortality due to *Fusarium* wilt (Abera *et al.*, 2011b). Apparently, this control method may not be adopted by smallholder farmers to control chickpea wilt because farmers primarily use crop residue or plants intended for green manure to feed their livestock.

Host plant resistance

Sick-plot and pot-culture screening techniques are used to evaluate a large number of breeding lines twice a year. The selection intensity is often less than 10%, and 18 sources of resistance have been identified over the decade (Table 1) (Tadesse *et al.*, 2015a).

Table 1. Sources of resistance to chickpea fusarium wilt identified at Debre Zeit, Ethiopia

Reaction (Level of resistance)*	Chickpea genotype
Resistant (X ≤ 10%)	FLIP-01-47C, FLIP-01-57C, FLIP-01-52C, FLIP-07-241C, FLIP-07-293C
Moderately resistant (10 % < X < 20%)	FLIP-01-2C, FLIP-01-37C, FLIP-01-40C, FLIP-01-58C, FLIP-03-108C, FLIP-03-125C, FLIP-98-121C, FLIP-07-240C, FLIP-07-260C, FLIP-07-281C, FLIP-07-70C, FLIP-08-65C, ICCV-96836

*X = Plant mortality.

These resistance sources were either directly advanced to yield trials or used in crossing program as donor parents. In a latter case, the nature of resistance has to be known in a resistant donor line before using that line as a source of resistance in a breeding program. Knowledge on virulence spectrum is also important to breed for, especially, resistance against chickpea wilt caused by the most damaging and widespread *F. oxysporum* f.sp. *ciceris* race(s) in the country. Of the eight known races of the pathogen worldwide, five of them [races 0, 1 (not differentiated into 1A and/or 1B/C), 2, 3 and 4) exist in Ethiopia with race 3 dominant in central highlands of the country (Shehabu *et al.*, 2008, Tadesse *et al*., 2008). This race is also dominant at Adet and Debe Zeit chickpea wilt/root rots-sick plots (Shehabu *et al.*, 2008), although the one at Adet had been abandoned. Moreover, Tadesse *et al*. (2008) reported that the popular chickpea cultivar Arerti is resistant to *F*. *oxysporum* f.sp. *ciceris* races 0, 2, 3 and 4, which indicates the existence of *F*. *oxysporum* f.sp. *ciceris* races in Ethiopia. However, the race determination was based on biological (conventional) method whose output is subject to environmental influences and response of *Fusarium* wilt differential chickpea varieties. Additionally, maintenance or conservation of pure type (representative) culture for reference requires facilities and institutional commitment.

Chemical control

Chickpea seed treatments with Apron Star (20% Thiamethoxam, 20% Metalaxyl-M + 2% difenoconazole) or Thiram provides protection to chickpea against wilt at seedling stage (DZARC, 2006). The treatments are particularly beneficial for kabuli chickpea type, which has seedling establishment problem.

Biological control

A few microorganisms that might be useful for biological control of chickpea *Fusarium* wilt have been isolated in Ethiopia. The fungus *Trichoderma* spp., especially *T. harzianum* is the most frequently reported antagonistic on *Fusarium* wilt (Shehabu *et al.*, 2011). However, further developments in formulation are needed to bring these microorganisms to practical use for chickpea wilt control. A potential strategy would be to change the microorganisms into biocontrol products through commercialization.

Testing of a multi-purpose product, which consisted of microorganisms (bacteria such as acitinomycetes and lactic acid bacteria, and fungi such as *Penicillium spp*. and yeasts) and commercial product known as Effective Microorganisms (EM®), reduced fungal growth by 40% and chickpea fusarium wilt incidence by 76% (Tadesse, 2015).

Integrated management of wilt/root rots

Management of chickpea wilt and/or root rots heavily depended on the use of host plant resistance. Effectiveness of this method, however, dramatically increases if combined with other effective control methods, and vice-versa. For instance, integration of raised bed, moderately resistant variety and optimum time of planting provides good protection against *Fusarium* wilt (Tadesse *et al*., 2008). *Trichoderma* species applied as seed treatment reduce *Fusarium* wilt incidence by 30 to 40% when integrated with moderately susceptible cultivars (Shehabu *et al*., 2008). At Debre Zeit, it was observed that combination of EM, Apron Star (20% Thiamethoxam (insecticide), 20% Metalaxyl-M + 2% difenoconazole), stubble free seedbed, and resistant variety suppressed *Fusarium* wilt of chickpea and have significant effect on yield and yield components (DZARC, 2009).

Ascochyta blight

In Ethiopia, *Ascochyta* blight (*Ascochyta rabiei = Didymella rabiei*) is one of the most important foliar diseases of chickpeas, particularly on the desi type chickpea. A complete yield loss is common if chickpeas are sown early during *Meher* [main cropping (June to October)] season or the *Belg,* [short rain (February to May)] season. However, varying levels of losses should not be ruled out depending upon the growing environment, response of the variety to the disease, and occurrence and virulence of the pathogen in the production area.

Control

Cultural control

Ascochyta blight is a residue-borne disease; therefore, intuitively a minimum of two to three years between two crops of chickpea is suggested to allow residue decomposition. The chickpea-tef-wheat rotation, for example, practiced by smallholder farmers in the central highlands of Ethiopia plays a significant role in the management of Ascochyta blight.

Ascochyta blight is also a seed-borne disease; therefore, the disease is best managed by using disease free seeds and prevented by not introducing the pathogen into a new area via seed transmission. Zero percent seed-borne *Ascochyta* infection is the tolerance limit (threshold). Certified chickpea seed must either satisfy this standard or receive seed treatment to protect seedlings from primary infection. Testing the levels of seed-borne *Ascochyta* in chickpea seed samples is used as a decision support tool in seed certification.

Early plantings, from late June to first week of August, exposes chickpea to severe *Ascochyta* blight infection, whereas delayed sowing in September, known traditional method practiced by farmers, effectively prevent occurrence of the disease by synchronizing the crop growing period with unfavorable climatic conditions for disease development (low relative humidity and dry weather). However, delaying sowing date implies shortening pod filling due to terminal drought, which is detrimental for yield (Bejiga *et al.*, 1995).

Chemical control

Foliar and seed dressing fungicides recommended in the past were still effective during the decade. These were chlorothalonil-based fungicides (foliar fungicides), and Thiabendazole and benomyl (Tadesse *et al.*, 2008). However, these fungicides in general and the seed dressing ones in particular are not available in the market.

Host plant resistance

In the past ten years, 22 sources of resistance have been identified (Tadesse *et al.*, 2015b). Of the desi resistance sources, ICCV-96836 and ICCV-10515 have expressed high level of seedling and adult plant resistance for several seasons in lowland (Dhera), mid (Debre Zeit) and highland (Chefe Donsa) areas. Consequently, they were directly promoted to preliminary variety trial (PVT). Among the kabuli resistance sources, FLIP-01-2C, FLIP-01-32C, FLIP-01-46C, FLIP-01-52C, FLIP-01-57C, and FLIP-01-58C were promoted to PVT. The genotypes FLIP-01-46C, FLIP-01-52C, FLIP-01-57C and FLIP-01-58C possess seedling and adult plant resistance (Tadesse *et al.*, 2015b).

Some of the sources could be used as donor parents in either improving existing popular cultivars lacking resistance to *Ascochyta* blight or developing new *Ascochyta* blight resistant varieties with other desirable traits through hybridization and appropriate selection method(s). Nevertheless, knowledge is needed that unlocks nature of resistance in the source(s) selected as a donor parent in a crossing program and the targeted *A. rabiei* race(s). For example, the nature of resistance in some of the 15 internationally known chickpea accessions, resistant to race 4 of *A. rabiei* is simple (monogenic) whereas in others it is polygenic (Labdi *et al.*, 2013).

Integrated Ascochyta blight management

Over the decade, management options that combine the yield benefit of early sowing (≥ 4000 kg/ha) were verified and scaled out first in East Shewa and later in northern Ethiopia. The components that made significant contribution to the noticeable reduction of *Ascochyta* blight infections and increased chickpea yield included early plantings, high yielding and *Ascochyta* blight resistant varieties like Arerti and Habru (Tadesse *et al.*, 2008) and seed treatments with Apron Star.

Rust

Rust (*Uromyces ciceris-arietini*) is season and location specific disease of chickpea in Ethiopia. But, in recent years, the disease seems to have established itself in diverse agro-ecologies with regular occurrence both during the Belg [short rainy (February to May)] season and the Meher [main cropping (June to October)] seasons (Tadesse *et al.*, 2015c).

During the past decade, severe rust infections were observed on breeding lines and released cultivars in trial fields at Debre Zeit, and single outbreak was noted in Bale Zone (Tadesse *et al.*, 2015c). The rust prevalence and frequency of occurrence are on the rise, probably due to climate change and/or variability and due to changes in production system. This is more due to irrigated chickpea in some areas and unusual rainfall/ cloudy days in October to December. Genotypes FLIP-03-123C, FLIP-97-281C, FLIP-03-108C, FLIP-03-130C, FLIP-05-152C, FLIP-98-121C, FLIP-04-3C, FLIP-05-127C, ICCV-10308, FLIP-04-09C, FLIP-03-125C, FLIP-99-66C, FLIP-0163C and Habru are resistant to rust. The majority of these genotypes are kabuli types with tall and erect plant architecture (Tadesse *et al.*, 2015c).

Usually, the disease occurs at reproductive stage of the crop. Therefore, it requires further studies to determine its distribution, quantify the yield losses and thereby embark upon anticipatory resistance breeding. Also, determination of weather elements that have direct influence on chickpea rust epidemics is a pre-requisite for the disease management.

Viral diseases

In the past, six chickpea viral diseases were known to occur in Ethiopia (Tadesse *et al.*, 2008). Recently, one additional virus has been detected in the central highland. However, the majority of them remain minor in their importance, although in the past two years, in fields in and around Alem Ketema, North Shewa, chickpea plants (cultivar *Arerti* (FLIP 89-84C), with an incidence of 85%, have shown severe symptoms of leaf narrowing and yellowing, stunting and axillary bud profusion. Infected sample plants that were blotted on to Nitrocellulose membrane were sent to International Center for Agricultural Research in the Dry Areas (ICARDA) virology laboratory for identification and the Enzyme Linked Immunosorbent Assay (ELISA) test revealed the presence of a geminivirus belonging to species of chickpea chlorotic dwarf virus (Saafa Kumari, personal communication).

Lentils

In Ethiopia, a total of 20 lentil diseases have been reported before (Tadesse *et al*., 2008). Recently, a new foliar disease, probably *Stemphylium* blight that attacks leaves of lentil crops in the early pod setting stage was observed in Ilu Sanbitu, Sinana, Bale in *Bona* [Meher (August to January)] season (personal observation). Of the diseases documented on lentils, rust and wilt/root rots are the major ones, while *Ascochyta* blight is serious in mid and low altitude areas.

Rust

Rust (*Uromyces viciae-fabae*) is still the most economically damaging lentil disease in Ethiopia (Tadesse and Pretorius, 2012). Complete yield loss due to frequent rust outbreaks is common in some lentil growing areas, where landrace lentils are produced. This was evident in 2014 cropping season when lentil crops were devastated in the central highlands of Ethiopia (Tadesse *et al*., 2014). The huge crop loss costed the industry millions of Ethiopian Birr, and as a result, lentil price increased from only ETB 15/kg in 2013 to ETB 70/kg in 2015.

Molecular barcoding of *U. viciae-fabae*

A diagnostic protocol, which consisted of morphological and molecular methods for accurate identification of the lentil rust fungus, has been developed (SPHD, 2015). The molecular diagnostic protocol compares lentil strain *U. viciae-fabae* sequences of Large Subunit (LSU) region of rDNA with LSU sequences of *U. viciae-fabae* on GenBank (AB115592-AB115611, AY745695, KJ716343) using a nucleotide BLAST search. According to the protocol, a 99-100% specimen sequence identity to any of those *U. viciae-fabae* sequences on GenBank indicates the specimen is *U. viciae-fabae*. However, the host must be identified to confirm the *U. viciae-fabae* identified this way is the lentil strain.

Crop loss assessment

Lentil rust incurs both yield and quality loss of the affected crop (Tadesse *et al.* 2007; Tadesse and Pretorious, 2008). A yield loss prediction model (critical-point) has been developed by which yield loss could be estimated using disease severity assessed on the upper canopy layer in the early flowering stage (Tadesse and Pretorious, 2008). A cumulative model based on area under the disease progress curve (AUDPC) has also been worked out for loss assessment in lentil due to rust. Rust severity ≥ 4.7% at the critical early flowering stage of the crop has a detrimental effect on grain yield.

Disease control

Chemical control

The fungicide Tebuconazole (Folicur) is effective against lentil rust (Tadesse and Pretorious, 2008). Since the product Folicur is not registered in the country, any of the systemic foliar fungicides in the Triazole group such as Propiconazole (Tilt) could be sprayed when necessary. Decision to spray depends on the variety, the time of infection, the incidence (percent of plants infected) and severity (percent of tissue area with symptoms) of infection.

Host plant resistance

Rust resistant lentil varieties have been successfully used since 1998 following countrywide rust outbreak in 1997 that had caused complete yield loss throughout the major lentil growing areas (Bejiga *et al.,* 1998; Tadesse *et al*., 2008). The majority of released rust resistant varieties, which includes Gudo, Alemaya, Assano, Derso (Derash) and Jiru, are of Macrosperma type. Breeding for rust resistance requires accurate phenotyping of breeding material for resistance to lentil rust both under field condition and glasshouse. In this regard, the following findings are considered as the greatest achievements of the decade.

Firstly, development of a scale for scoring infection type (IT), and the scale is an ideal tool for measuring resistance components (Tadesse *et al.,* 2005a). The scale was pre-tested in pre-emptive resistance breeding project activities under field condition at Chefe Donsa, Ethiopia and worked quite well in differentiating resistance among Ethiopian and Australian lentil breeding lines and cultivars (CU, 2015); secondly, construction of automated dew chamber at DZARC, a facility that ensures formation of fine drops of water on plant surfaces (leaves and stems) after inoculation essential for spore germination and penetration (Tadesse *et al.*, 2005b); and thirdly, invention of a settling tower for quantitative study of lentil rust resistance (Tadesse and Pretorius, 2005), and fourthly, discovery of resistance mechanism in lentil rust (Tadesse *et al*., 2012).

Resistance screening work is conducted under field condition at rust hot spot areas such as Akaki, Chefe Donsa and Enewary in the central highlands, and Sinana in southeastern highlands of Ethiopia. This technique ensures rust infections due to the presence of sufficient amount of inoculum in nature and exposure of test genotypes to the virulence spectrum of the rust pathogen in the country. This way, more than 200 Australian and Ethiopian lentil germplasm accessions, breeding lines and cultivars were screened for resistance to rust at Chefe Donsa and Sinana. The majority of the Ethiopian landraces were susceptible, whereas the resistant entries are the cultivars released in Ethiopia (CU, 2015). Although, most Australian breeding lines and cultivars had low disease severity (≤ 10%), their ITs were between 3 and 4, i.e. susceptible reaction type (CU, 2015; Lichtenzveig *et al*., 2015).

Lentil wilt

Fusarium wilt of lentil caused by *Fusarium oxysporum* f. sp. *lentis* has a wide distribution in major lentil growing areas of Ethiopia (DZARC, 2007).

Disease control

Cultural

Delayed sowing reduces disease incidence, but delayed planting dramatically reduces lentil yield, and its effect on disease development differ from location to location, and from season to season (DZARC, 2009).

Host plant resistance

Annually, several lines of lentil are screened at Debre Zeit sick plot and promising ones are further evaluated or are advanced to the breeding program as resistance source (DZARC, 2009; 2014).

Chemical control

In lentil, in which *Fusarium* wilt can appear at the seedling stage, the use of seed dressing fungicides can be effective in reducing disease incidence. Lentil seed treatment with thiram + pentachloro-nitrobenzene + carboxin reduced the incidence of the disease (Bayaa and Erskine, 1998). However, seed treatments may reduce losses by eliminating or reducing seed borne inoculum sources.

Ascochyta blight

Ascochyta blight caused by *Ascochyta fabae* f.sp. *lentis* is problematic in warm environments (mid and low altitude areas) both in traditional and non-traditional lentil growing areas. Some basic studies on the pathogen biology and disease control were made in the past and the results were reported by Ahmed and Ayalew (2006).

Stemphylium blight

Stemphylium blight, probably caused by *Stemphylium spp*., seems an emerging disease on lentils in some localities in Ethiopia. The disease was first observed in trial fields at Ilu Sanbitu Bale during 2016/17 *Meher* (*Bona*) cropping season, i.e. August to January (Aynewa *et al.*, 2017). Currently, it is considered as minor and yield loss due to the disease and other aspects such as identity of the pathogen not well understood.

Stemphylium blight may become a serious problem in the future. Lentil cultivars Alemaya and Checkol had a severity rating of 5% (resistant) as opposed to other cultivars like Alem Tena and Denbi, which had severity score of 80% (susceptible). And the two resistant cultivars, Alemaya and Checkol, may have a potential for use in managing the disease when the need arise.

Faba bean (*Vicia faba* L.)

About 26 diseases are known to attack faba bean in Ethiopia (Tadesse *et al*., 2008). The main ones posing severe constraints to production of the crop are chocolate spot caused by *Botrytis fabae,* rust caused by *Uromyces viciae-fabae,* black root rot caused by *Fusarium solani*, and foot rot, specifically on acid soil, caused by *F. avenaceum*, and faba bean necrotic yellows virus. Faba bean galls disease caused by *Olpidium viciae* Kusano has appeared in recent years and became a severe constraint to faba bean production in central and northern highlands of Ethiopia.

Chocolate spot

Estimate yield losses in faba bean due to chocolate spot in sole and mixed cropping system ranged, depending up on season, from 35.8 to 67.5%, whereas in sole crop the loss was 55% (Sahile *et al*., 2010). The disease is prevalent in major faba bean growing areas with incidence ranging between 5 and 100% (Sahile *et al*., 2008a; Hailu *et al.*, 2014).

Disease control

Cultural control

Although not verified in multi-location trials, faba bean grown in mixture with cereals such as barley and maize reduces chocolate spot infections (Sahile *et al*., 2008b; 2010).

Chemical control

At Sinana, the fumgicide Mancozeb 80% WP controls chocolate spot on faba bean, when applied two to three times between flowering and podding stages at the rate of 2.5 kg/ha (Teshome, 2016; unpublished data). However, three to four sprays of Mancozeb at lower rate (0.7 kg/ha) is also effective in controlling the disease (AARC 1996). The efficacy of Mancozeb was recently confirmed in a test done in Wollega, western Ethiopia (Guta, 2017).

Biological control

Fungal and bacterial species of Ethiopian origin, which are antagonistic to *B. fabae,* have been reported by Sahile *et al.* (2009; 2011). It has also been demonstrated that chocolate spot infection can be reduced by seed treatment with *Trichoderma harzianum*, though the mode of action was unclear (Guta, 2017). At present, however, there are no commercially formulated biocontrol agents of any sort in the country.

Host plant resistance

To expose test entries to high disease pressure, natural infections are supplemented by artificial inoculations. For artificial inoculation, inoculum is propagated using faba bean dextrose agar (FDA) (Terefe *et al*., 2015). These authors also indicated that transferring pure *B. fabae* culture from FDA to MnPDA medium (PDA medium supplemented with 20 g of faba bean seed meal per 1 L of the medium) and incubating the culture with alternating 12 h light/darkness and natural light regimes at 22 °C for three to five days enhances spore production.

The national faba bean breeding program has released two varieties Dide'a (EH01048-1) and Gora (EK 01024-1-2), which are moderately resistant to chocolate spot and rust (MoA, 2014). The former variety is also tolerant to waterlogged condition, while the latter variety had large seed size.

Black root rot

Biological control

Some *Rhizobium* strains such as FB 1035 have been reported to decrease black root rot (*F. solani*) infection by delaying disease onset and reducing total plant mortality (Dinsa, 2017).

Host plant resistance

In the past decade, two resistant breeding lines (EH06107-1 and EH07009-7), with mortality level of < 20%, were included in variety trials. If these varieties perform well in terms of yield and other agronomic traits across location, especially in areas with waterlogged fields, then they will be advanced to variety verification trial for release. Otherwise they will be used as source of resistance in the breeding program.

Foot rot

Foot rot has a widespread distribution in southern Ethiopia, where the majority of the soil is Nitosol and is characterized by low soil pH. The foot rot is prevalent in the upper and lower Gana in Lemo, Hadiya; Kokate in Wolayita, and Hagere Selam in Sidama zones.

Viral diseases

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

Galls disease of Faba bean

Distribution

Faba bean galls (= Broad bean blister) caused by *Olpidium viciae* Kusano was first reported in Ethiopia by Gorfu *et al.* (2012). These workers reported the occurrence of the disease first in Degem area and later in Fitche, Debre Berhan, Gudoberet, and Ankober areas at an altitude of 2500-3000 m a.s.l. It has become a serious threat to faba bean production and productivity in those high elevation areas since 2011 causing a yield loss as high as 100%. The disease is also taking its toll in genetic wipeout of the species *Vicia faba* in the country.

Recently, the disease has gained a wider distribution throughout the major faba bean growing regions of the country in central and northern highlands (≥ 2400 m.a.s.l). The geographical distribution include Awi, East Gojam, North and South Gondar, North Shewa and South Wollo zones of the Amhara National Regional State, Arsi, North Shewa and West Shewa zones of the Oromia National Regional State, and East Tigray and South Tigray zones of the Tigray National Regional State (Figure 1) (Hailu *et al.*, 2014).

The pathogen

Environmental requirements for growth and development

Most of the aspects presented and discussed under this topic are based on summary of English translation by Huazhi Ye of publications on *O. viciae* in Chinese. Biological studies on *O. viciae* indicated that mature zoosporangium in epidermal cells of disease spots is able to release zoospores in the presence of rain water. The temperature requirement for germination of zoosporangium ranges from 0 to18℃, and it will be significantly inhibited above 18℃, and unable to germinate at temperatures ≥ 20℃. Light or darkness has no influence on germination of zoosporangium. Potassium and sodium (K^+ and Na^+) inhibit the germination to some degree, and zoosporangium germination is completely inhibited when their concentration reaches 80 mmol/L. pH also affects the germination of zoosporangium to some degree and it germinates well at pH values between 5 and 8, with optimum value between 7 and 7.5.

Identification: morphological method

The morphology of *O. viciae* is similar to other *Olpidium* spp. (Figure 2) in that the fungus body is unicellular and round protoplast. *Olpidium* spp. is the only flagellated terrestrial fungi.

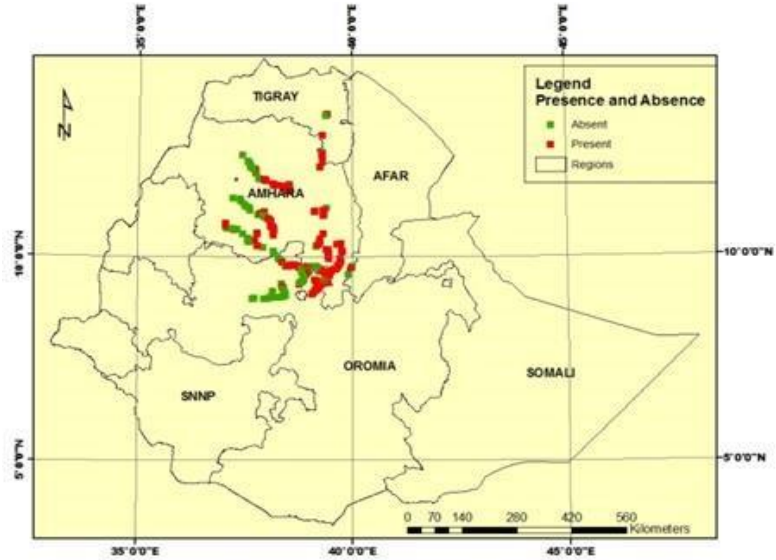

Figure 1. Distribution of the faba bean galls in Ethiopia. Map courtesy by Hailu *et al.* (2014)

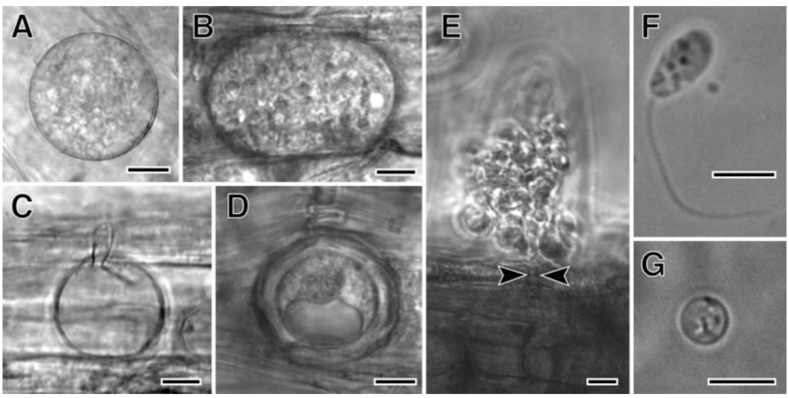

Figure 2. *Olipidium bornovanus*, a unicellular fungus, obligate parasite of plants, and reproduces with flagellated, swimming zoospores. A-B: vegetative unicellular thalli in cucumber root cell. Thalli differentiate into sporangia with zoospores, or into resting spores. C. An empty sporangium, after zoospore release. D. A thick-walled resting spore. E. Zoospores being released from a sporangium, showing the sporangium exit tube (arrowheads). F. A swimming zoospore with a single posterior flagellum. G. An encysted zoospore. Bars: A-E = 10 μm; F,G = 5 μm. Image Source: Sekimoto *et al*., (2011).

Microscopic identification

The pathogen of faba bean galls is an obligate parasite that grows as unicellular thalli in epidermal cells of leaf, stem, and carpopodium. The fungus body is unicellular and round protoplast with holocarpic reproduction. The zoosporangium of *O. viciae* is usually a sphere with a diameter ranging from 12.95 to 62.16μm with an average value of 28.84μm. Zoospores germinate from mature zoosporangium and liberated through spore tubes (holes) (Figure 2). Zoospores are oval or spherical, 4.1-5µm in diameter size, with an average value of 4.47µm. Each zoospore is constituted of a long posterior cilium, 24-31µm long with an average value of 26.56µm. Zoospore is able to function as motile isogamete and fused together to form zygote with two cilia. Resting sporangia are found in epidermal cells after zygote infected faba bean. Resting sporangium is spherical in shape with thick wall (average wall thickness value of 3.81µm). Resting sporangium is mainly formed at the later period of infection and its number could exceed 60 in a host cell. Washing leaves and stems with mature sporangia in distilled water triggers zoospore release.

Using the above mentioned microscopic characteristics, Prof. Huazhi Ye of Sichuan Agricultural University, 46 Xinkang Road Yaan, 625014, Sichuan China identified the causal fungi and detected resting sporangia and zoosporangia of *O. viciae* in epidermis of 58% and 17%, respectively, of faba bean leaf and stem samples from Ethiopia in 2014. Zoosporangia were associated with deep brown tumors; whereas zoosporangia with those of light brown tumors on stems and leaves.

Molecular methods

The Internal Transcribed Spacer (ITS) region of DNA from Chinese *O. viciae* isolate was most closely related to *O. brassicae* (= *O. virulentus*) and *O. bornovanus* (= *O. radical*), and this sequence is available on NCBI GeneBank under accession number HQ677595.1. Comparison of ITS sequences of *O. viciae* (broad bean blister) samples collected from different regions of China with sequence of *O. viciae* ITS sequence HQ677595.1 resulted in high homology (identity), i.e. > 99% and this indicates the specimens are *O. viciae*.

ITS sequences of Ethiopian faba bean galls samples maybe compared with *O. viciae* ITS sequence HQ677595.1 in the GeneBank using appropriate sequence data analysis program or nucleotide BLAST search, and a 99-100% sequence identity likely be considered a positive identification of *O. viciae*. *Olpidium* DNA extraction is commonly done using a Qiagen DNeasy Plant Mini Kit (Qiagen Inc., Valencia, CA) and following manufacturer's instructions, and primers used to amplify target *Olpidium* spp. are ITS1 and ITS4 (Macarone *et al*., 2010; White *et al*., 1990).

Symptoms

Faba bean galls infection starts at the seedling stage and continues through to the flowering stage. Symptoms appear on leaves and stems. At the initial stage, symptoms usually appear on the upper side of leaves as depressed blisters and gradually develop to small tumor-like galls on the lower side (Figure 3A). The galls progressively enlarge and become light brown in color and circular or elliptically shaped spots (Figure 3B). On mature leaves, coalescing spots on the upper side that are surrounded by white lesions and necrotic galls on the lower side results in rolling up and abnormal growth of leaves (Figures 3F and 3G). At a later stage, the disease can easily be confused with chocolate spot infections. Leaves with more galls usually die earlier (Figure 3C). Similar galls can form on the middle or lower parts of the stems (Figure 3H).

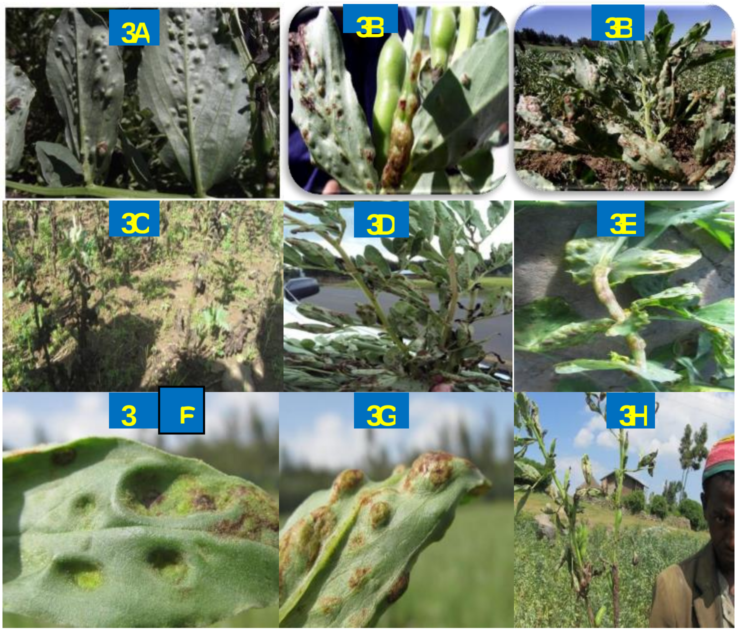

Figure 3. Typical symptoms of faba bean gall (*Olpidium viciae*): 3A. Initial stage; 3B. Middle stage; 3C. Advanced stage; 3D. Late infection; 3E. Symptoms on the field pea; 3F. Upper side of mature faba bean leaflet showing sunken lesions due to infection; 3G. Lower side of faba bean leaf showing necrotic and tumor-like galls; and 3H. Faba bean plant infected by *O. viciae* showing irregularly shaped brown lesion on stems and leaves.

Host range

Besides faba bean, the disease is now known to infect field pea (*Pisum sativum*) in Ethiopia (Figure 3E). The pathogen has a wide host range; it infects rapeseed, cabbage, cucumber, spinach and buckwheat (Li-juan *et al*., 1993).

Disease control

Cultural control

In Ethiopia, late planting, crop rotation and weed control reduced the disease intensity in faba bean fields.

Chemical

Seed treatments with fungicide [Celest Top (Difenoconazole + Fludioxonil + Thiamethoxam) and Apron Star (Difenoconazole + Metalaxyl-M + Thiamethoxam)] alone were not effective in controlling faba bean galls in Ethiopia (Wondwosen, 2015). The author also stated that for foliar sprays in fields, Metalaxyil 8% + Mancozeb 64% WP and Triadimefon 250 g /L are effective in controlling faba bean galls and increasing grain yield. Three applications of the two fungicides at 10 days interval starting from first disease appearance are also cost effective. These foliar fungicides were demonstrated for use in North Shewa and South Tigray for controlling the disease.

Host plant resistance

Although little is known about the pathogen and faba bean galls pathosystem in Ethiopia, some promising results have been obtained in terms of identifying good sources of resistance. Breeding for faba bean galls resistance started with screening of breeding lines and genotypes under field condition in faba bean galls disease hot spot areas, which are Mush and Ankober in North Shewa, Were Ilu in South Wollo, Debark in North Gondar and Endamehoni, South Tigray.

There were three sets of faba bean galls screening nurseries: (1) 500 breeding lines obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA), (2) about 1500 faba bean genotypes (gene pool) assembled by the National faba bean breeding program, Holetta Agricultural Research Center (HARC), and (3) 17 breeding lines in the form of faba bean preliminary variety trial from HARC. From these screening efforts several sources of resistance to faba bean galls were identified. Remarkably, three lines namely EH010058-1, EH010008-3 and EH010008-5 had high level of resistance to the disease with grain yield of 2.7, 2.8 and 4.1 tons/ha, respectively (HARC 2016). The three faba bean varieties which combined galls disease resistance with high yield were promoted to a national variety trial for testing in many locations across the major faba bean growing and galls disease prone areas of the country (HARC, 2016).

Lupine

Sweet lupine varieties, which are recently released for cultivation as forage crops in Ethiopia, and white local lupines are severely attacked by wilt/root rot (*Fusarium* sp.) in West Gojam (Likawent, personal communication). Probably, some of the wilt/root rots control methods developed for the highland food legumes such as cultural, chemical and biological methods could be used for controlling lupine *Fusarium* wilt/root rot.

Conclusions

Commendable progresses were witnessed in the past decade but much research is needed to develop new methods of controlling diseases of highland food legumes in general and provide scientific basis that help to diagnose, prevent and control emerging diseases in particular. Future areas of emphasis are given as follow:

- Surveillance to monitor the occurrence and distribution of diseases and dynamics of disease causing organisms
- Use of aerial reconnaissance of diseases and their environment via drones to quickly get information about status of food legume diseases in general and emerging diseases in particular and the associated environmental factors whose data will be used to design appropriate disease management research
- Manpower capacity building in bioinformatics which will enable collection, storage, analysis and interpretation of data on pathogens of highland food legumes. This will aid in pathogen and race identification, studying genetic diversity, and origin and evolution of pathogens of highland food legumes diseases. Universities will have a big role to play in this area by offering courses in molecular pathology/biology
- Genomic research of pathogens of major diseases of highland food legumes to understand pathogens variation in Ethiopian populations of the various pathogens with an eventual goal of breeding for resistance
- Investigating the benefits of Rhizobium strains in controlling highland food legume diseases, especially root diseases
- Study the efficacy of native biocontrol agents for their effectiveness in controlling seed to seedling transmission of seed-borne diseases and mass production of effective ones at small scale. This has great contribution in preventing introduction of seed-borne disease to new areas
- Establishment of microscopy unit equipped with confocal, fluorescence and scanning electron microscopes. The facility could be shared across commodities and disciplines with priority to pulse pathological research
- Establishment of controlled environment facilities (glasshouse, inoculation and incubation facilities)
- Use of molecular markers and biotechnologies for resistance breeding in highland food legumes
- Thorough study into the genetics of disease resistance to understand the nature of inheritance of resistance to the major diseases of highland food legumes such as *Ascochyta* blight and *Fusarium* wilt of chickpeas. This will help in breeding for resistance
- Determination of race spectrum of pathogens of major diseases of highland food legumes such as blights, rusts and wilts in the country

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Progresses in Diseases Management Research in Lowland Food Legumes of Ethiopia: A Review

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Abstract

Lowland food legume crops production and productivity is affected by several foliar and soil-borne diseases. These diseases have both global and regional importance depending on the environmental conditions that support their distribution and epidemic development. Cognizant of the importance of the diseases on these crops, different plant pathological research undertakings (disease surveys, management options, epidemiological and yield loss studies on major diseases of specific crops) have been carried-out in Ethiopia since 1970. However, diseases have continued to be the major constraints of production. In the last decade, lowland food legumes plant pathological research activities in the country have been conducted with the emphasis on updating the information with regard to the status of diseases and development of disease management options. Therefore, this paper reviews the achievements, mainly on common bean diseases, of pathological researches in lowland food legume crops. Moreover, the review outlines recommendations and future plant pathological research direction on food and forage legumes.

Keywords: Disease survey, disease management, Ethiopia, lowland legumes, yield loss

Introduction

The major and most important lowland food and forage legumes in Ethiopia includes common bean *(Phaseolus vulgaris L.),* cowpea (*Vigna ungiculata L.*), mung bean (*Vigna radiata*) and pigeon peas (*Cajanus cajan*).These legumes are important components of crop and livestock production systems where they serve as food for human and feed for livestock mainly in the dry land areas of the country; whereas their prime importance in crop production includes replenishing soil fertility by fixing nitrogen that helps to reduce the requirements for inorganic commercial fertilizers.

The production and supply of legume crops has increased due to increased demand both in local and in international markets, thus enhancing smallholders' income (Yirga *et al.*, 2010; Karanja, 2016). In this regard, the common bean is the most important lowland legume in Ethiopia and the country ranks 13th among common bean producing countries in the world (FAOSTAT, 2014).

However, the average yield of common bean in Ethiopia is 1.6 tons/ha (CSA, 2016), which is lower than the productive potential of the crop (FAOSTAT, 2014).This low production is largely due to the negative effects of many biotic and abiotic factors that limit the genetic potential of the crop (Singh and Schwartz, 2010). Diseases, mainly foliar and soil-borne, and insect pests are among the biotic factors affecting the production and productivity of common bean in Ethiopia (Kutangi *et al.,* 2010). Almost all important diseases on lowland food legume crops have global and regional importance depending on the environmental conditions that support their distribution and epidemic development (De Luque and Creames, 2014).

Stewart and Yirgou (1967) reported more than 47 fungal, bacterial and viral diseases on lowland food legumes. Since then periodical and comprehensive reviews on major disease management researches in lowland food legume crops were made by Assefa and Gorfu (1986), Tilahun *et al.,* (2006) and Tadesse *et al.,* (2008).

Generally, the most important diseases of common bean known in Ethiopia so far include anthracnose (*Colletotrichum lindemuthianum*), rust (*Uromyces appendiculatus*), common bacterial blight (*Xanthomona*s *axonopodispvphaseoli* (syn*X. campestris pvphaseoli*), web blight (*Rhizoctonia solani* (=*Thanatephorus cucumeris*), angular leaf spot (*Phaeoisariopsis griseola*), leaf blight (*Phomaexiguavar diversispora*), halo blight (*Pseudomonas sysringaepv. phaeolicola*) and floury leaf spot (*Mycovelosiella phaseoli*). On mung bean, halo blight *(Pseudomonas phaseolicola*) and leaf spot *(Ascochyta boltshauseri)* and on cowpea Aschochtablight *(Aschochyta phaseo-lorum)* and leaf spot (*Phomaba keriana)* are the major diseases.

In spite of the many research achievements, diseases still remain as one of the major constraints on lowland food legumes production. As a result, agricultural research and higher learning institutions have been engaged in pathological research with the objectives of updating information on the status of diseases and identifying alternative disease management options.

Therefore, in this paper the achievements of pathological research on lowland food legume crops in Ethiopia that have been reported since the last decade (2006-2017) will be presented. The achievements were mainly on disease surveys, disease management options involving varietal (host) resistance, combination (integration) of cultural and chemical disease control measures and an integrated climate resilience strategy. In addition to the research achievements, the paper outlines some recommendations and aspects that need future attention in plant pathological research of these crops.

Status and importance of diseases

In earlier times field surveys were conducted and diseases of lowland food legumes were reported and categorized into major, medium and minor (Assefa *et al*., 1996; Tilahun *et al.,* 2006). Although no new diseases have been recorded, survey data on the status of lowland food legume crops are presented as follow.

Common Bean Diseases

A study conducted in 2012/13 main cropping season, using Awash-1, Awash-M and Nasser in Jimma, Bako, Ambo, Pawe, Melkassa and Shalla, showed that the prevalence and severity of diseases on the crop was generally low. In all the locations, angular leaf spot (ALS), common bacterial blight (CBB), rust, floury leaf spot (FLS), anthracnose (Anthr), Ascochyta blight (AscB) and halo blight (HB) were prevalent on all varieties. However, in Jimma area severity of ALS, CBB, rust and FLS greater (severity score of 2.3 to 5.7 in 1 to 9 scale) than severity in the remaining locations. Other than in Jimma, angular leaf spot appeared to be important in Pawe; while anthracnose was relatively important in Bako, Ambo and Pawe. As stated above, the occurrences of floury leaf spot and rust mainly confined to specific growing areas such as Jimma. Common bacterial- and halo- blights were most important in the central Rift Valley areas.

Further focused and systematic survey was carried out in the central Rift Valley areas of Ethiopia during 2015 and 2016. Survey data from the two years indicate that common bacterial blight (CBB) and halo blight (HB) were important in the Rift Valley. During the survey years, rust was less prevalent compared to previous years. The change in importance of the diseases could be due to change in host plant, cropping system and prevailing environmental conditions. However, the survey data reconfirmed the importance of CBB and HB in the central Rift Valley areas (Table 1).

In eastern Ethiopia, during 2016 cropping season, root rot appeared prominent in Western Hararghe (Abdella, 2017). The disease was prevalent with varied intensity in all the surveyed localities that had an altitude rang of 1040-2500 m.a.s.l (Table 2). In earlier times, the root rot disease on common bean was considered as minor in importance. Further investigation on the causative agents of root rot complex indicates that *Fusarium oxysporium* f.sp.*phaseoli, Sclerotium rolfsii, Macrophominapha seolina* and *Rhizoctonia solani* are the pathogens that cause the disease, although the species *F. oxysporium* was the dominant, which was followed by the *S. rolfsii* and *M. phaseolina* (Table 3).

Table.1. Occurrences and severity of common bean diseases during 2015 and 2016 in central Rift Valley of Ethiopia

		Disease type and mean diseases severity score(1-9)*											
		Rust		CBB		HB		ALS		ANTH		AscB	
Location	Parameter	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Boset	Mean	1.07	1.01	4.00	3.77	3.00	4.00	1.00	0.27	1.23	1.31	1.00	0.47
	SD	0.12	0.02	0.65	1.92	0.00	0.75	0.00	1.46	0.34	0.36	0.00	1.26
	N	15	30	15	30	15	30	15	30	15	30	15	30
ArisNegele	Mean	1.11	ND	5.26	ND	3.42	ND	1.13	1	1.41	1.00	1.00	1.00
	SD	0.19	ND	0.62	ND	0.44	ND	0.21	0.00	0.61	0.00	0.00	0.00
	N	20	ND	20	ND	20	ND	20	30	20	30	20	30
Miesso	Mean	1.06	ND	1.41	ND	3.03	ND	1.00	1	1.01	1.00	1.00	1.00
	SD	0.18	ND	0.52	ND	0.11	ND	0.00	0.00	0.05	0.00	0.00	0.00
	N	30	ND	30	ND	30	ND	30	30	30	30	30	30
Dugda Bora	Mean	1.33	1.51	3.28	2.97	4.04	ND	1.14	1.00	1.69	0.00	1.00	1.00
	SD	0.22	0.39	0.30	1.26	0.11	ND	0.27	0.00	0.57	0.00	0.00	0.00
	N	15	5	15	5	15	ND	15	5	15	5	15.	5.0
ATJK	Mean	1.37	1.06	4.62	1.78	3.05	ND	1.12	1.07	1.21	ND	0.97	1.00
	SD	0.39	0.12	0.67	0.93	0.13	ND	0.27	0.18	0.54	ND	0.16	0.00
	N	30	10	30	10	30	ND	30	10	30	ND	30	10
Shalla	Mean	1.87	1.73	4.37	1.58	3..06	ND	1.02	1.01	1.00	ND	0.99	1.00
	SD	0.72	0.70	0.34	0.27	0.29	ND	0.06	0.04	0.02	1.89	0.08	0.00
	N	40	18	40	18	40	ND	40	18	40	18.	40	18
Total	Mean	1.37	1.26	1.47	2.76	1.09	ND	1.06	1.05	1.19	ND	0.99	1.00
	SD	0.54	0.51	0.56	1.74	0.27	ND	0.18	0.14	0.44	ND	0.08	0.02
	N	150	63	150	63	150	ND	150	63	150	ND	150	63

Source: Own survey, *(CIAT. 1987, disease severity scoring scale (1-3) indicate no visible symptoms or very light symptoms (5-10%), 4-6, indicate visible and conspicuous symptoms resulting in limited economic damage (10-60%) and 7-9 shows sever to very sever symptom causing considerable yield losses or plant death (60-100%) ,§ATJK= Adamitulu, Jido Kombolcha, CBB= Common bacterial blight, Halo blight, ALS= Angular leaf spot, Anthr= Anthracnose and AScB= Ascochyta blight ND= No recorded data; SD= standard deviation, N= sample size.

Table 2. Common bean root rot prevalence and incidence across selected locations in Western Hararghe, Ethiopia

District	Altitude Range (m.a.s.l)	Number of fields inspected	Number of fields exhibited the disease	Prevalence (%)	Mean Incidence (%)
DaroLabu	1350-2450	13	10	76.92	35.50
Habro	1600-2400	17	14	82.35	45.00
OdaBultum	1040-2500	15	12	80.00	39.52
Total		45	33		

Source: Abdella (2017)

Table 3.Fungal pathogens associated with common bean root rot complex and their frequency of occurrences (average frequency (%) in some locations in Western Hararaghe, Ethiopia.

District	Fungal pathogen species				Nematode species
	Fusarium oxysporum	*Macrophomina phaseolina*	*Rhizoctonia solani*	*Sclerotium rolfsii*	
DaroLabu	45.56	16.77	7.91	23.10	5.37
Habro	29.80	15.29	15.88	24.11	2.35
OdaBultum	39.81	12.21	7.69	16.74	6.78
Mean	38.39	14.76	10.49	21.32	4.84
Range	29.80-45.56	12.22-16.77	7.69-15.88	16.74-24.12	2.35-6.8

Source: Abdella (2017)

Diseases of Cowpea, Mung bean and Pigeon pea

Surveys focused on disease assessments on cowpea, mung bean and pigeon pea have not been conducted in the last decade. However, a few reports indicate the occurrence of different diseases in association with these crops. For instance, Gebreyowhans, and Gebremeskel (2014) reported the occurrences of leaf spot (*X. axonopodispv.vignicola*) on cowpea in western zone of Tigray, northern Ethiopia. In other case, Walie *et al*. (2016) indicated the occurrence of Fusarium wilt or cowpea wilt (*F.oxysporum)* in mid August when there was high rainfall and moderate temperature. The incidence was slightly higher in some locality (Jabitehnan) as compared to South Achefer districts in northwester Ethiopia. Furthermore, Etana *et al*. (2015) have reported the occurrences of leaf spot at higher incidence on cowpea accession evaluated for fodder production quality in central Rift Valley of Ethiopia.

Tensay (2015) indicated diseases as one of the major biotic factors that limit mungbean productivity and production in major growing areas of Ethiopia. Furthermore, in southern Ethiopia, Eshete *et al*. (2015) assessed the importance of anthracnose and powdery mildew on cowpea and mung bean and found that the incidences of anthracnose varied from location to location. Thus, incidence of40 and 20 percent was reported in Konso and in

South Ari, respectively. Similarly, powdery mildew incidence was variable between 10% in South Ari and 28% in Konso.

Yield loss and epidemiological studies

In common bean, Mohammed *et al.*, (2014) reported relative yield loss of 70% due to bean anthracnose, although, compared to the untreated control, losses were significantly reduced by application of fungicides mancolaxyl (22.8%) or mancozeb (27.3%). Similarly, according to Lemmesa *et al.* (2011) angular leaf spot (ALS) causes a relative yield and seed weight losses of 2 to 47% and 15 to 33%, respectively.

In eastern Ethiopia, Hailu *et al.* (2015) studies the influence of common bean genotypes, cropping system and seasons on common bacterial blight occurrence (CBB). The susceptible variety Mexican 142 (56%) and Gofta (48%) had higher severity of CBBin sole planting than in row intercropping with compost application on Gofta (40%) and from a combination of row intercropping, compost application and furrow planting on Mexican 142 (42.9%). The rates of disease progress varied among different cropping systems, locations and seasons. Furthermore, at Haramaya and Babile, intercropping of common bean with sorghum reduced CBB severity and area under the disease progress curve compared to sole planting during 2012 and 2013 cropping seasons.

Diseases management options

Host plant resistance

Several common bean varieties with good level of resistance to the major diseases have been released (MoARD, 2007, 2008, 2009; MoA2010, 2011, 2012, 2014). For instance, common bean genotypes possessing multiple disease resistance against anthracnose, angular leaf spot and common bacterial blight includes EMP 219, TY 3396-6, TY 3396-7, TY 3396-12, RAB 404, ARA 21, TAR 3, BZ 1289-12, GLPX-92 (Ayenew) and A-176 (Roba-1) (Fininsa and Tefera, 2006). Besides, out of the 201 genotypes evaluated for resistance to individual diseases, 171 genotypes exhibited resistant to anthracnose, 117 to ALS, and 161 to CBB.

Similarly, efforts have been made to release other lowland food legumes varieties with resistance to commonly known diseases of the respective crops (MoARD, 2008; 2009; MOA, 2011; 2012; 2014).The mung bean variety N-26 (Rasa), which was released in 2011, has resistance to major diseases in its adaptation areas. Furthermore, variety NVL-1 that was released in 2014 is resistant to the major diseases of mung bean such as halo blight (MoARD, 2014). In case of cowpea, the variety Kanketi (IT99K-1122), which was released in 2012, possesses resistance to some viral and bacterial diseases (MoARD, 2012).

Cultural management

Hailu *et al.* (2015), using common bean varieties Gofta resistant to CBB and Mexican 142 susceptible to CBB and sorghum variety Teshale, studied a climate change resilience strategies consisting of sole planting (SP), compost application (CA), furrow planting (FP), row intercropping (RI), or combination of CA+FP, RI+CA, RI+FP and RI+CA+FP. It was found that intercropping of common bean with sorghum significantly reduced the severity of CBB compared with sole planting. Similarly, combination of RI+CA+FPorRI+CA significantly reduced CBB severity (13-36.2%) and area under the diseases progress curve (AUDPC) than the sole plantings during 2012 and 2013 cropping seasons. It was also found that furrow planting reduced the final disease severity during all trial seasons and all locations when applied singly (2.7-18.4%) or in combination (5.7-34.5%) with other resilience strategies such as compost application and intercropping. Furrow planting conserves soil moisture and enhance water availability in the root system of common bean that might favour crop growth and lower development of the disease epidemics due to creation of non-conducive environmental condition (micro-climate) for the pathogen. Similar to furrow planting, compost application reduced the final CBB severity by 3.9-17.3% when applied singly and by 14.2-36% when combined with other resilience strategies during 2013 cropping season.

In Jimma area, Getachew *et al. (*2015) found highest incidences of angular leaf spot (33.8%) and floury leaf spot (24.6%) on common beans sown on 2 August and 18 July, respectively, while early sowing (3rd July) of bean variety Melka-1reduced incidences of the two diseases and increased the crop yield.

Biological control

Although the research on biological control agents of diseases on lowland food Legumes is limited, Amin *et al.* (2014) reported that seed treatment of common bean seed with one of the biological control agents, *Trichoderma harzianum*, *T. viride* and *Pseudomonas fluorescence,* significantly reduced anthracnose severityand maximized seed yield. Moreover, botanicals (10% extracts of *Adenocalymma alliaceae, Azadirachta indica* and *Lawsonia inermis*, and biopesticides 0.4% talc formulation of *T. viride* and *Pseudomonas fluorescens* along with fungicides (Carbendazim (0.2%) and Mancozeb (0.4%) gave promising results in greenhouse and field experiments.

Chemical control

Under experimental condition, Mohammed *et al*., (2013) reported substantial reduction of yield losses due to bean anthracnose when common beans were treated with foliar fungicides (mancolaxyl and mancozeb). In fungicide unsprayed susceptible common beans cultivars Awash-1 and Mexican-142 the yield loss was about 69.7%. On the other hand, spraying fungicide at weekly interval reduced anthracnose severity by 76.9% and increased seed yield of Awash Melka.

Application of Folpan (80 WDG) at the rate of 2.6 kg/ha in three different spraying timings (every week, two weeks or three weeks interval) for the management of bean anthracnose reduced severity, incidence, infected pods per plant and area under the disease progress curve. In unsprayed plots, the severity, incidence, infected pods per plant and the area under the disease progress curve were the highest on the susceptible cultivar Awash-1 followed by Mexican-142, Awash Melka and Chercher. Interaction effects of cultivars by spray timings of fungicide were significant for pods per plant, discoloured seeds and seed yield and infected pods per plant, but not for seeds per pod and hundred seed weight. Relative yield losses of 52, 39, 28 and 23% were recorded on Awash-1, Mexican-142, Awash Melka and Chercher, respectively.

Economic analysis revealed that the net benefits of 47,912 Birr/ha (sprayed with Folpan weekly) and 44,700 Birr/ha (sprayed with Folpan bi-weekly) were obtained from the relatively resistant cultivar Awash Melka. The net benefits obtained from cultivar Chercher were 42,662 Birr/ha (weekly spray) and 41,373Birr/ha (bi-weekly spray), and the least benefit of Birr 10,935 per hectare was from unsprayed Awash-1. The highest and lowest marginal rate of return were obtained from Awash -1(374.3%) and Chercher (Birr 10.88%), respectively, when each of them were sprayed at 3 weeks interval. Spraying Folpan fungicide at weekly and bi weekly intervals had a favourable effect in reducing anthracnose epidemics. Data from the study by Hirpa and Selvaraji (2016) confirmed the findings of Mohammed *et al.* (2013).

Lemessa *et al.* (2011) also demonstrated that the use of fungicide application (Benomyl 50WP) at a rate 0.5 g per L^{-1} reduce angular leaf spot severity by 30 to 33% on all test varieties. Moreover, compared to the unsprayed control treatment, all fungicide sprays reduced angular leaf spot severity at all crop growth stages except at flowering stage. Further-more, supplementary foliar application of Tebucnazole at the rate of 2 Lha^{-1} at three bean growth stages (V4, R5 and R6) (CIAT, 1987) also reduced angular leaf spot. In the absence 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 (IDM)

Mohammed *et a*l. (2013) reported the possibility of managing bean anthracnose with a combinations of soil solarization, fungicide seed treatments(3g Mancozebg^{-kg} of seed) and foliar application of carbendazim (0.5 kg^{-ha}) at 10 days intervals. This IDM practice was effective in reducing anthracnose severity and AUDPC as well as infected pods per plant. Evidences exist for good management of CBB through integration of climate change resilience strategies (row intercropping, compost application, furrow planting (Hailu *et al*., 2015). In addition to this finding Kifle *et al.* (2015) also reported an effective IDM package to manage CBB in common bean. The IDM components that were found effective included host plant resistance, seed treatment with the fungicide (Apron Star) and cultural practice (row planting on ridges). In this regard, row planting and Apron star treated seed (2g Apron Star kg^{-1}seed) of Awassa dumme, AFR-702 and Ibado resulted in significant reduction of disease severity to below 26% as compared to farmers practice (local cultivar sown in broadcast) where CBB severity score was 72%. The IDM practice resulted in an average yield of 2.2 tons ha^{-1}. However, these advances in IDM approach to manage CBB need to be verified in the disease prone areas *via* demonstrations prior to full deployment the approach (IDM technology) forimproving the productivity and production of the crop in the country.

Recommendation and Ways Forward

It is anticipated that diseases, at least in the near future, will remain as one of the most important production constraints of food legumes crops in Ethiopia. On the other hand, the crops are integral components of the cropping systems in the dry land agriculture of the country. Therefore, it is important to give adequate attention to the crops and generate information on distribution, economic significance, and control methods against the existing and emerging diseases.

Plant diseases are dynamic in nature and shift can encounter because of many factors such as evolution of new biotype/race in diseases pathogen population, climate change, cropping system, and varietal selections. It appears that there is a limited information on the effect of the different interacting factors (biological, environmental, human and other factors) affecting the dynamism of diseases in the different agro-ecological zones (AEZs) of the country. Hence, current and future research work should focus on updating the information on the economic importance of existing and emerging diseases of lowland food legume crops in Ethiopia. It is also equally important to conduct epidemiological studies on diseases of interest together with their dynamism in different AEZs. Regular and random monitoring, identification and documentation of existing and possibly newly emerging diseases will help to have focused direction and prioritized research agenda. In addition, crop loss data in lowland food legumes need to be regularly quantified for prioritization purpose and making management decision.

The search for new, innovative and applied diseases management options that fit the prevailing situation should be the top priority in lowland pulse diseases research endeavour. This will entail development of ecology and crop based integrated disease management options. The use of host plant resistance plays a great role in managing the major diseases of the different lowland legume crops. Therefore, identification of new sources of resistance that counteract genes controlling virulence in the pathogens causing the major diseases should continue. As it has been the case for the management of many diseases in non-leguminous crops, search for durable resistance against major lowland food legume crops should be an integral part of the breeding program.

Disease management options beyond search of host plant resistance should consider development of appropriate agronomic practices and chemical control methods that could be used for grain and seed production of the crops. As diseases like CBB, HB and anthracnose are mainly seed-borne, developing effective seed treatment methods should be given priority research attention.

Lowland legumes production practices and their disease management methods should be designed to fit for commercial and large-scale production and marketing.

Research should also focus on variability of the major pathogens affecting lowland food and forage legumes through conventional and modern techniques (molecular methods) and thereby develop basic information for rapid disease diagnoses and devise effective control measures.

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Progresses in Insect Pest Management Research in Highland Food Legumes of Ethiopia

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Abstract

The highland food legumes of Ethiopia are faba bean (Vicia faba), field pea (Pisum sativum), chickpea (Cicer arietinum), grasspea (Lathyrus sativus), lentil (Lens culinaris), and lupine (Lupinus albus). The pea aphid (Acyrthosiphon pisum), pod borer (Helicoverpa armigera), and cutworm (Agrotis spp.) in the field and the Adzuki bean beetle (Callosobruchus chinensis) in the store attack almost all highland food legumes. The pea weevil (Bruchus pisorum) is the only major field-storage insect pest of field pea. Since the mid-2000, researches have been carried out on different management tactics and strategies against the major insect pests. In line with this, sources of resistance to pod borer in chickpea, and to pea aphid in lentil and pea weevil in field pea were identified. In addition to the search for pod borer resistance in chickpea, a large number of chickpea accessions were screened for their resistance to Adzuki bean beetle and resistant sources were identified. The identified sources of resistance to the various insect pests in the different highland food legumes might be utilized in resistance breeding programs of the respective crops. However, studies have shown that farmers gave more emphases to yield and yield related parameters than resistance to insect pests in chickpea production. In field pea, assessment of farmers' perception also showed that 68% of the farmers consider field pea weevil as a storage pest, whereas the remaining (32%) consider it as a field pest. During the past decade, a few insecticides with their application rates were recommended to control insect pests of highland food legumes. In line with this, applications of a quarter of the recommended rate of lambda cyhalothrin (1.2 Lha^{-1}) or dimethoate (1.5 Lha^{-1}) were effective in controlling pea aphid in lentil. Moreover, half of the recommended rate of dimethoate was effective in controlling pea aphid in grasspea. The present review encompasses some basic information on the major insect pests of the crop, and gives a brief outline of future research direction.

Keywords: Highland food legumes, insect pests, insect pest resistance, pest control

Introduction

Faba bean (*Vicia faba*), field pea (*Pisum sativum*), chickpea (*Cicer arietinum*), grasspea (*Lathyrus sativus*), lentil (*Lens culinaris*), fenugreek (*Trigonella foenum-graecum*), and lupine (*Lupinus albus*) are grown in the highlands of Ethiopia. Except lupine, which is produced in northwestern part of the country, the remaining pulse crops are widely distributed throughout the highland areas of the country. However, faba bean and field pea are dominantly grown on light soils, while chickpea, lentil, grasspea and fenugreek are grown mainly on Vertisols.

It is known that infestation of crops by insect pests in the field and during storage results in qualitative and quantitative losses. In Ethiopia, as it is in many other developing countries, there is no scientifically generated information on national yield loss attributable to the major insect pests of highland food legumes. However, it is apparent that the highland food legume crops, in Ethiopia, are attacked by many insect pests, and the magnitude of attack is tremendous and so frequent that had led to the extent of banning the production of some of the food legume crops. A case in point is the field pea in the Amhara National Regional State where most farmers have stopped field pea production due to pea weevil infestation.

These highland grain legumes are attacked by several insect pests, although the occurrence of these insect pests varies across seasons, geographical locations and crop species. As a result only a few of them are economically important (Table 1). Thus, the pea aphid, pod borer, and cutworm in the field and the Adzuki bean beetle in the store are common pest to most highland food legume crops. Although the pea aphid and cowpea aphid are minor pests of faba bean and chickpea, they are known to vector viral diseases in non-persistent manner (Bekele *et al.*, 2005; Abraham *et al.*, 2006).To mitigate insect pest problems in highland food legumes production system, research undertakings on pest management have been done in different parts of the country during the past decade. This paper, therefore, aims to review accomplishments of the decade in several aspects of research in food legumes insect pests.

Insect pests of chickpea

The information on research achievements on insect pests of chickpea was excised from Damte and Chichaybelu (2016).

Pod borer management research

Host plant resistance

Several accessions were evaluated at Debre Zeit center and they reached 50% flowering and maturity at about 42 to 65 and 122 to 130 days, respectively. Moreover, the number of days from 50% flowering to maturity ranged from 57 to 80 days. Even though, chickpea is infested by pod borer beginning from seedling stage, it was assumed that the extended time from 50% flowering to maturity provides prolonged feeding period for the insect. In reality, however, there was no apparent correlation between pod damage and days from 50% flowering to maturity.

Chickpea resistance to pod borer was assessed on a 1 to 9 scale, where 1 = < 10% pod damage and 9 = 100% pod

Table 1. Insect pests of highland food legumes of Ethiopia

Common name	Scientific name	Pest Status (loss %)[1]				
		Field pea	Faba bean	Chickpea	Lentil	Grasspea
Pea aphid	*Acyrthosiphon pisum*	major (37)	minor	minor	major (26)	major (100)
Pod borer	*Helicoverpa armigera*	major	major	major (34)	minor	minor
Cutworm	*Agrotis segtum*	minor	minor	minor	minor	minor
Adzuki bean beetle	*Callosobruchus chinensis*	minor	major	major	major	minor
Cowpea aphid	*Aphis craccivora*	-	minor	minor	minor	-
Thrips	*Caliothrips impusus*	-	minor	-	minor	minor
Pea weevil	*Bruchus pisorum*	major (85)	-	-	-	-
Bean bruchid	*Callosobruchus macualtus*	minor	minor	-	-	-
Black aphids	*Aphis fabae*	-	minor	-	-	-
Mendi termite	*Macrotermes subhualinus*	-	-	UD	-	-
Bean seed fly	*Delia cilicrura, D. platura*	minor	minor	minor	-	-
Dusty brown beetle	*Gonocephalum simplex*	-	-	minor	-	-
Lesser armyworm	*Spodoptera* sp.	-	minor	minor	-	-
Bean flower thrips	*Taeniothrips* sp.	-	minor	-	UD	-
Epilachna	*Epilachna* spp.	minor	-	-	UD	-
Blue butter fly	*Lampides boetucus*	minor	-	-	-	UD
Shiny cereal weevil	*Nematocerus brachyderes*	-	UD	-	-	-

[1] = not recorded, UD= undetermined, Compiled from Hill (1989) and Ali *et al.* (2008)

damage; and accessions that had less than 10% pod damage were considered resistant. Thus, except two accession, ICC-3137 and EC583250, the remaining (ICC4958, ICC867, ICC5383, ICC10393, ICC1356, ICC16903, ICC637, ICC4533, ICC14402, ICC14831, EC583250, EC583260, EC583264, EC583311, EC583318, ICCV07108, ICCV07113, ICCV07106, ICCV07104, ICCV07105, ICCVX960183-4, ICCVX960183-28, ICCVX960183-72, ICCVX960183-69, ICCVX 960186-1, ICC506, ICC37, ICCV10, and ICC4973) had pod damage of less than 10% and were considered resistant to pod borer. However, subsequent evaluations did not yield consistent results because of the sporadic incidence of the pest and poor establishment of the test genotypes due to wilt/root rot problem. All accessions were highly susceptible to wilt/root rot disease.

Although, the mechanism of chickpea resistance to pod borer has not been studied under Ethiopian condition, compensation for early losses, oviposition preference, larval preference and retention, and high level of malic acid content have been reported as some of the bases of resistance elsewhere (Lateef, 1985). Shahzad *et al.* (2005) indicated that trichome and plant height have negative effect on pod borer infestation. Moreover, Giri *et al.* (1998) stated that seeds in pods injured by pod borer have greater amount of trypsin - and proteinase - inhibitors than the seeds in undamaged pods, but pod borer is capable of deactivating these inhibitors.

Relative importance of insect pests in farmers' chickpea variety selection criteria

Farmers in East Shewa zone did not recognize early instars of pod borer larvae and their damage symptoms (browsing, nibbling or scraping) during vegetative and flowering stages of the crop. However, at maturity stage of the crop, most farmers were aware of damages done by pod borer, but still they did not include insect resistance in their variety selection criteria. According to Dadi *et al.* (2005) drought tolerance, high yield and early maturity are major traits that the farmers expect from improved chickpea varieties, whereas good food making quality, large seed size, frost tolerance, insect pest tolerance and market demand are less important. Similar ranking of insect pest tolerance among traits of farmers' interest in sorghum has been reported by Tefera (2004). This indicates that farmers might not be aware of the benefits derived from pest resistant varieties. Therefore, training farmers on the importance of insect pests and their biology in relation to crop phenology, the economics of pest management using resistant varieties and other methods, and the safe use and disposal of pesticides would be required as a package in extending improved chickpea varieties to farmers.

Botanicals

Lulie and Raja (2012) studied Diazinon 60EC along with different rates of aqueous extracts of neem (*Azadirachta indica* A. Juss.) seed, leaves of Birbira (*Milletia ferruginea* Hochst) and leaves of Bisana (*Croton macrostachyus* Hochst) separately or in combination under laboratory and field conditions for controlling pod borer in chickpea. It was found that, under laboratory condition, the botanicals either separately or in combination, significantly reduced pod damage by fourth instar larvae and they gave complete protection at 5% or 10%. However, among the various botanical treatments tested, the combination of *Neem* seed and *Birbira* leaf extracts was effective at 2.5% concentration. In the field trial, neither separate nor combined application of the botanicals significantly reduced pod borer larval population. Although none of the botanicals was comparable to the insecticide Diazinon in reducing chickpea pod damage due to the pest, two applications of neem seed extract resulted in reduced pod damage (3.9%); while on Diazinon treated chickpea pod damage level was less than one percent.

Aphids of chickpea

In many chickpea growing countries including Ethiopia, the pea aphid, *Acyrthosiphon pisum* and the cowpea aphid, *Aphis craccivora* are known to infest chickpea. These aphid species do not cause direct economic damage; rather they cause significant indirect damage through vectoring many of the viral diseases of chickpea. For instance, according to Bekele *et al*., (2005) the incidences of viral disease in Gondar and Gojam areas of the Amhara region and Bale zone of Oromia region were 12.3 and 1.9%, respectively. The major viral diseases reported by these workers were the Luteovirus (which includes bean leaf roll virus (BLRV), beet western yellows virus (BWYV) and chickpea chlorotic stunt virus (CpCSV)), Faba bean necrotic yellows virus (FBNYV), pea seed-borne mosaic virus (PSbMV) and alfalfa mosaic virus (AMV). The luteovirus and FBNYV are transmitted by aphids in persistent manner, while the PSbMV and AMV are transmitted both by seed and aphids in non-persistent manner (Bekele *et al*., 2005). The cowpea aphid colonizes the collar region, but the pea aphid colonizes the crown (own observation).

In 2008 cropping season, following the unseasonable rain in October, there was heavy pea aphid infestation on chickpea at Debre Zeit. At the beginning of the infestation there was an average of 6.7 pea aphids per plant. The aphids did not proliferate, as they do on other crops such as field pea and lentil, rather they totally disappeared one month after they began infestation. Therefore, appropriate sampling method (eg. beating on boards for pea aphid) must be followed to determine the presence or absence of aphids.

Adzuki bean beetle (*Callosobruchus chinensis*)

Biology

Biology of *C. chinensis* (Debre Zeit strain) was studied on chickpea by Tadesse (2008) under ambient temperature at Debre Zeit. The life-history traits statistics are indicated in Table 2. *C. chinensis* starts egg laying on the first day of emergence and continued at most for five days. The mean number of eggs laid per female during the first, second, third, fourth and fifth day was 19.9, 23.1, 10.4, 5.2 and 1.6, respectively. Although there was considerable variation among individuals in the total number of eggs laid, a female, on average, lays about 60 eggs within five days. Similarly, the mean number of eggs laid per female per day was about 12. Eggs require 4 to 6 days to hatch, and their hatchability varies between 36 and 92% and decreases as the age of the female increases.

Table 2: Life-history traits statistics of Adzuki bean beetle, *Callosobruchus chinensis*

Parameter	Average	Range
Eggs per female (total)	60	29-80
Eggs per female per day	12	up to 30
Oviposition period (days)	5	
Incubation period (days)	5	4-6
Egg hatchability (%)	70	36-92
Larval development period (days)	12	
Number of instars	4	
Pupal period (days)	6	
Development period (days)	23	22-27
Adult lifespan (days)		
Male	7.8	
Female	7.6	

(Source: Tadesse, 2008)

On the bases of head capsule width *C. chinensis* has four larval instars. The first, second, third and fourth larval instars have an average head capsule width of 0.12mm, 0.24mm, 0.34mm and 0.55mm, respectively. The larval stadium between the first and second instar is 4 days, between the second and third instar is 3 days, and between third and fourth instar is 4 days. On the other hand, the pupal stage lasts for about six days (Tadesse, 2008). Also the author reported that the mean developmental period of *C. chinensis* was 23 days, and the proportion (as percentage of total number of laid eggs) of adults emerged ranged from 41 to 89%. Moreover, similar to the egg hatchability and number of eggs laid, adult emergence decreases as the age of the female increases. The major shortcoming of the study was that the type of chickpea variety used is not known. Different varieties of chickpea had different impact on the biology of Adzuki bean beetle.

Host plant resistance

Keneni *et al*. (2011a) studied Ethiopian chickpea collection from

Arsi, South and North Gondar, East and West Gojam, West Harargie, North and West Shewa, South Wollo, and Tigray. The response of Adzuki bean beetle was affected by genotypes and test locations (Ambo, Debre Zeit, and Holetta). The tested genotypes differentially affected the insect's biological performance and accessions ACC41320, ACC41289, ACC41291, ACC41134, ACC41315, ACC207658, ACC41103, ACC41168, ACC41142, ACC41174, ACC41029, ACC41207, ACC209087, and ACC231327 were relatively resistant to Adzuki bean beetle. Moreover, the Ethiopian chickpea accessions were relatively more resistant to the insect than the introduced (improved) genotypes (Keneni *et al*., 2011b, c). However, these workers have not identified the mode of resistance in the genotypes to the Adzuki bean beetle.

With the exception of total seed weight loss, other parameters such as number of eggs per female, days to adult emergence, number of adults emerged and adult recovery were affected by location, although these responses are believed to be static across locations (Becker and Leon, 1988). Consequently, for most parameters, there were interactions between locations and genotypes in their response to Adzuki bean beetle infestation; and on the bases of these interactions, Keneni *et al*. (2011b; c) suggested replicating trials of similar nature over locations or having location specific breeding programs. However, to be conclusive, further studies are required on biochemical and physiological changes occurring in a non-germinating seed as well as the influence of environmental factors on the induction of differential biochemical and physiological changes in test genotypes in relation to the specific test location.

The improved chickpea varieties were more susceptible to Adzuki bean beetle than the local landraces (Keneni *et al.,* 2011b) and this was a result of the stable population of landraces and intensive selection for traits other than resistance to insects in improved varieties. For instance, the breeding program focused more on improving grain yield and seed size. However, seed size increment was positively correlated with susceptibility to Adzuki bean beetle and as a consequence, as seed size increased, eggs laid, adults emerged and grain weight loss also increased (Keneni *et al.,* 2011c). In the improved varieties, the premature larvae emerged from the seed instead of the adult beetle. Keneni *et al*., (2011c) speculated that large egg loads on thin seed coat, soft cotyledon and the presence of toxic substance in the seed coat as possible cause of larval expulsion from seeds. However, Adzuki bean beetles are known to lay eggs on smooth and curvature surfaces (the jar used for the study has such character) and their larvae have about three pairs of spines that help them attach themselves on the eggshell. Had these factors been considered in the study, it would have yielded a fascinating insight into chickpea type-larval expulsion relationship.

Heat treatment

Tadesse *et al.*, (2008) studied the effect of electrical heat source, hanged at a height of 60cm above the ground, on Adzuki bean beetle by exposing them for 0, 20, 30, 40, 50, 60, 70, 80 and 90 minutes. The exposure time and the inter-grain temperature were linearly related. Therefore, exposing chickpea seeds for 20, 30, and 40 minutes increased the inter-grain temperature from an average of 28°C to 49.6, 52.9 and 55.1°C, respectively. This amount of heat not only caused significant adult mortality (87 to 95%), but it also reduced the number of eggs laid by females that survived the heat. Moreover, exposing chickpea seed for 60 or more minutes completely killed the beetles before laying eggs.

Hatchability of Adzuki bean beetle eggs was reduced to 33 and 10% when heated for 20 and 30 minutes, respectively, while 80% of the control (unheated) eggs hatched. Eggs completely failed to hatch when chickpea seeds were heated for 40 or more minutes. In addition, chickpea seeds assumed to contain different larval instars (I to IV) and pupal stages were also exposed to heat. Generally, the survival rate of the different life-stages of Adzuki bean beetle decreased as time of exposure to heat increased from 20 to 50 minutes. However, beyond 50 minutes of exposure time, none of the life-stages survived the heat treatment. Application of heat treatment up to 90 minutes does not affect the moisture content and germination rate of chickpea seeds, as 96% or more of heat treated seeds were germinated (Tadesse *et al.*, 2008).

The major limitation of the study was that the amount of grain used for a particular treatment was about 100g, and this small quantity of grain does not give adult beetles a chance to move to the cooler part of stored grain. Besides, eggs hatched in heat treated chickpeas were not adjusted for the natural un-hatchability (as only 80% of the untreated eggs were hatched).

Insect pests of lentil

Pea aphid population structure and performance

The morph and age structure of pea aphid population on Alemaya and ILL7664 grown for three years at Chefe Donsa and Debre Zeit was composed of alate, apterae and nymphs throughout the growing season (Damte, 2014). The age structure was not affected by genotypes, rather it was affected by the crop stage at which sampling was done. Thus, in the 2011/12 season at Debre Zeit, the proportion of alates, apterae and nymphs ranged from 0.3 to 3.1%, 6.6 to 21.3%, and 75.6 to 92.9%, respectively. In the 2012/13 season, 0.7 to 14.8% of the pea aphids were alate, 3.7 to 27.2% were apterae and 68.8 to 87.6% were nymphs. The corresponding values in 2013/14 were 0.0 to 11.1%, 9.9 to 34.4% and 62.3 to 89.1%. The pattern of age composition at Chefe Donsa was similar to the

Debre Zeit pea aphid population age composition.

Alternate hosts of pea aphid

The pea aphid infests vetch (*Vicia spp*.), clover (*Trifolium ruepellanium*) and pigeon pea (*Cajanus cajan*), but not lupine (*Lupinus spp.*) and alfalfa (*Medicago sativa*) (Wale *et al*., 2003). However, they were not sure that if the pea aphid from these plant species is capable of infesting legume crops.

Insecticide efficacy

The efficacies of King 5EC at the rate of 0.4 Lha^{-1} and Lamdex 5EC at the rate of 1.2 Lha^{-1}, in spray volume of 200 and 500 Lha^{-1} of water, respectively, were assessed at Akaki, Chefe Donsa and Debre Zeit for two seasons (Damte and Chichaybelu, 2013).

The initial appearance of pea aphid on lentil was affected more by season than location. Thus, in the first season, it appeared at full bloom to early poding stage, while, in the second season, it appeared later at flat pod stage. But in terms of density, in both seasons, the pea aphid population density was high at Chefe Donsa, while it was intermediate at Akaki and Debre Zeit. Single application of either of the two insecticides effectively controlled pea aphid throughout the growing season in all locations. Moreover, although the return from insecticide application was generally positive, highest return (13,440 to 14,360 Birr/ha) was obtained at Chefe Donsa, where there was higher aphid infestation.

Lambda cyhalothrin and dimethoate were sprayed at the rate of ¼, ½, ¾ and full rate of the manufacturer's recommended minimum effective dose, i.e. 1.2 Lha^{-1} and 1.5 Lha^{-1} for lambda cyhalothrin and dimethoate, respectively. It was found that the reduced rate of each insecticide was as effective as the corresponding full rate of each insecticide in reducing pea aphid population. Net return due to insecticide application varied between -1,207 Birr/ha and 15,034 Birr/ha, and the highest return was obtained from lentils treated with reduced insecticide rates. Lambda cyhalothrin ¼ and dimethoate ¼ rates are cost effective and could be used in the prevailing subsistence farming system of Ethiopia (Damte *et al*., 2016).

Host plant resistance

Andarge and van der Westhuizen (2004) reported the presence of acceptable level of resistance to pea aphid in lentil in South Africa. In Ethiopia, the searches for resistance to pea aphid have been made intermittently since the early 1990s and over 500 genotypes were evaluated. Recently, 289 genotypes (including single plant selections), which were reported to have some level of field resistance to pea aphid from previous field evaluations, were screened using artificial infestation technique under lath-house condition at Debre Zeit (DZARC, 2010). Genotypes FLIP-87-68, ILL-356, ILL-

2595, ILL-3138, ILL-4416, ILL-4421, ILL-7458, ILL-7657, ILL-7664, ILL-7697, ILL-9947, ILL-9994, ILL-10021, FLIP-86-17l, LL-57 and Alemaya had good level of resistance. However, further studies are required to determine the mechanisms of resistance and confirm the expression of resistance under field condition.

Integrated management of pea aphid

The combined effect of Diammonium phosphate (DAP), seed dressing fungicide (Apron star® (20% Thiamethoxam, 20% Metalaxyl-M + 2% difenoconazole)), or insecticide with resistant genotypes (Alemaya or ILL7664) was evaluated at Debre Zeit and Chefe Donsa for three years (DZARC, 2015). At both locations and all years, neither fungicide dressing nor fertilization did affect pea aphid population, although pea aphid density tends to be greater on these treatments than the control. Therefore, the individual control options tested could not be taken as suitable components to formulate an integrated pea aphid management package. A similar experiment was also conducted at Enewari by Debre Birhan Agricultural Research Center, although the results were inconsistent over years because different treatments were used in different years (Mentesnot Worku, personal communication). In another experiment Worku (2017) found that whether seed dressed with Apron star or not, lentil sown in the last week of July, second week, and third week of August, in decreasing order, exposed the crop to more pea aphid damage than sowing in the last week of August. However, sowing date supplemented with single spray of dimethoate significantly reduced pea aphid population, although the economic return from lentil sown in the second week of August sprayed with insecticide was the highest.

Insect pests of field pea

Pea weevil (*Bruchus pisorum*)

Geographical distribution

Exploratory survey of pea weevil (*Bruchus pisorum*), in Oromia and Southern Nations Nationalities and Peoples (SNNP) revealed that only North Shewa and East Shewa zones in the Oromia, and the Gurage zone in the SNNP are infested by pea weevil (Figure1) (Kemal Ali, unpublished report). In earlier times, the distribution of pea weevil was limited to the Amhara region, but it gradually spread southward to Oromia (North, East, and Southwest Shewa zones). It further spreads to Butajira of the SNNP, which indicates the need to stop further invasion of other field pea growing areas in SNNP region. Bulk fumigation of field pea seed with aluminum phosphide is the most effective method, and one to three tablets per ton are recommended for the purpose. Moreover, training farmers on method of fumigating seeds destined for sowing is also recommended.

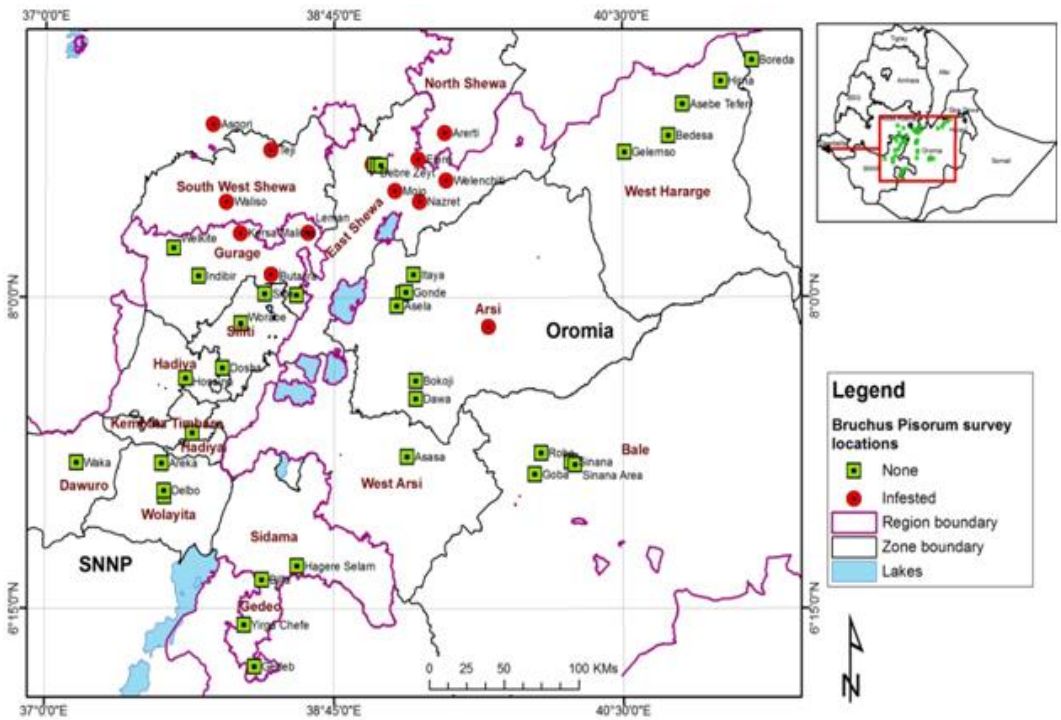

Figure 1. Pea weevil distribution in surveyed areas of Oromia and Southern Nations Nationalities and Peoples (SNNP) regions in 2014 (source: Kemal Ali, unpublished data).

In field pea yield trials at Holetta, 13 of the 15 tested entries were infested by the pest, while two entries (EHO5050-1#5 and EHO6016-4#19) were free of infestation. Similarly, at Kulumsa, although the level of infestation was lower than at Holetta, out of the 23 genotypes, only seven (30%) entries were infested and the highest number of both adults and larvae were recorded from variety Burkitu followed by genotype K-10 (Kemal Ali, unpublished report).

In the 2014 season, pea weevil infestation was not detected at Jeldu substation, while varying level of pea weevil infestation was found at Holetta and Adadi. At the Adadi substation, all genotypes in the National Variety Trial were heavily infested by pea weevil and level of infestation was higher than at Holetta main center.

Farmers' knowledge of pea weevil

Farmers' knowledge of pea weevil and its management practices was studied in Semen Achefer, Yilmana Densa, Farta and Ebnat *Woredas* (Districts) in the Amhara National Regional state (Mendesil, 2015; Mendesil *et al*., 2016a). The majority of the farmers (71%, n=400) know pea weevil as a serious pest of field pea causing shortage of grain for home consumption, seeds for planting and loss of income. Out of those who know pea weevil as a pest of field pea, most of them (68%) know the insect as storage pest, while the remaining 32% know it as field pest of field pea. Although there were differences among farmers on knowledge of pea weevil entrance hole, farmers were able to identify the sting hole (55%) – the first hole- and the exit hole symptoms of damaged field pea seeds. The study also revealed that the majority of the farmers don't know the source and means of pea weevil dispersion in their areas. But a few of them know that the insect is spread by seed. Farmers' pea weevil management practices include use of grain storage insecticides mainly Actellic and Phostoxin and rarely spraying standing crop in the field; mix field pea grain with tef, roast it or sell it early before damage symptoms become visible. There are also farmers (about 27%) who do not apply any control major against the pest.

Origin of Ethiopian pea weevil

The exact date, the place and the means of introduction of the Ethiopian pea weevil is not known. Thus, Scheepers (2012) determined the origin of Ethiopian pea weevil using molecular methods and by comparing pea weevil samples from Ethiopia, Germany, Australia, and the USA and gene sequence data from China and Japan using two mitochondrial genes (Cytochrome b (Cytb) and Cytochrome c oxidase subunit 1 (COX1)) and the nuclear protein-coding gene Elongation Factor 1-alpha (EF-1α). Phylogenetic trees constructed with the Bayesian analysis of phylogeny method using the genetic data from the 74 Ethiopian specimens revealed that the Ethiopian population is closer to the Australian and the USA pea weevil populations. However, on the basis of amount of food imported from the USA during the drought period between 1974 and 1984, Scheepers (2012) suggested that the USA is the likely origin of Ethiopian pea weevil and attributed the similarity between the Ethiopian and the Australian population to their place of origin, which is the USA.

It should be noted that undocumented field pea was imported to Ethiopia during the seventies and eighties from Australia, and according to informants from Ebinat, the place where pea weevil was first reported, pea weevil infested seed was introduced to their locality from Belesa (Seyoum *et al.*, 2012). Scheepers (2012) is also of the opinion that the insect might have been in the country for centuries since Ethiopia is known as a possible center of origin of *Pisum sativum* and which gave rise to a considerable genetic difference among Ethiopian pea weevil populations, but the pest status might have been aggravated by the introduced biotypes.

Host plant resistance

To identify sources of resistance to pea weevil, Mendesil (2015) and Teshome *et al.* (2015) evaluated germplasm accessions, breeding lines and released varieties of field peas (*Pisum sativum* and *P. abyssinicum*) under natural infestation at Ebinat, Liben, Sekota and Holetta. It was found that, all released field pea varieties are more susceptible than the germplasm accessions of *P. sativum*. The two *P. abyssinicum* accessions tested were also susceptible (percent seed damage > 50%) to pea weevil. The most pea weevil susceptible accessions (227141 and 227143) and varieties (Milky and Wolmera) have cream seed coat color. However, further study is required to determine if there is linkage between seed coat color and susceptibility and/or resistance.

Some genotypes derived from accessions 226037 and 32397 showed relatively consistent results across three generations (selection cycles) in their resistance against pea weevil. The overall mean percent seed damage (PSD) of moderately resistant genotypes selected from accession 226037 (4%) was much lower than that of susceptible genotypes selected from accession 32397 (58%). Similarly, some moderately resistant genotypes selected from accessions 236413 and 32410 were less infested as compared to susceptible genotypes selected from accession 32487 and variety Adet. Out of 100 accessions tested in Liben, only 32471, 230844, and 203084 had PSD value < 30%, while variety Adet was the most susceptible one.

Pea weevil egg-laying preference was studied under laboratory condition on field pea genotypes Adet, 235899-1, and 32410-1, and non-host species *Pisum fulvum* (NGB 102148) and *Lathyrus sativus* (Mendesil *et al*., 2016b). In no-choice test, the pea weevil laid maximum number of eggs (76) on variety Adet, followed by genotype 32410-1 (45), 235899-1 (20), *P. fulvum* (2) and *L. sativus* (1.5). In a dual test, the pea weevil preferentially lays eggs on Adet, when it was grown together with other field pea accessions, *P. fulvum* or *L. sativus.*

The accession 235899-1 is neoplastic (Np) genotype, which grows neoplasm- a non-meristematic tissue on the surfaces of its young pods (Figure 2). Moreover, this accession and *P. fulvum* have thicker (1.36 and 1.31 mm, respectively) pod wall than the other field pea genotypes and *L. sativus*. The degree of neoplasm formation and egg laying by pea weevil are negatively correlated (Teshome *et al.*, 2016), and thus, as the degree of neoplasm growth/coverage increases the number of eggs laid by pea weevil decreases.

Figure 2. Neoplasm formation on pods of field pea under greenhouse condition (source: Teshome *et al*., 2015)

Some field pea genotypes form neoplasm in the absence of UV light or in response to oviposition by pea weevil. In a greenhouse experiment out of 19 genotypes only five accessions consistently form neoplasm in the absence of UV light (Teshome *et al*., 2016). Moreover, in a field experiment in Sweden, they demonstrated that field pea intercropped with sorghum at inter-row spacing of 10cm led to threefold more neoplasm formation than the mono-crop field pea.

Pea weevil management

Harvesting field pea one to two weeks after maturity and threshing within one week after harvesting reduces the number of pea weevils that over-season in the seed (Mihiretu and Wale, 2013). In addition to cultural practices, they reported that fumigating field pea seed with phostoxin is effective in reducing the number of pea weevils that emerge from pea seeds.

Pea aphid, *Acyrthosiphon pisum*

Field pea resistance to pea aphid

According to Kemal Ali (unpublished report), in the national variety trial (NVT) plots at Holetta in 2009, 2010 and 2015, the intensity of pea aphid was generally low and varied between 1.35 and 8.0 aphids per plant, while in the advanced breeding lines test plots the genotypes EH-05016-2-1, EH-050041-2, EH-05024-4-1, EH-05035-1-1, EH-05002-3, EH-05018-5, EH-05019-55, EH-05024-2-1, EH-05024-3, EH-05027-2, EH-05029-6, EH-05033-3, EH-05034-1, EH-05041-1, EH-05048-3, and EH-05050-1 were free of pea aphid infestation. The shortcoming of these studies is that the phenological stage, at which the intensity was measured, is not known and if the experiments were conducted at one location, it is unclear why the aphid intensity was lower in the NVT than on the advanced breeding lines.

Pea aphid management

Melese and Singh (2012) stated that in Areka area pea aphid began to infest field pea in the second week of August (one month after planting) and reached peak (173 aphids per plant) in the first week of October as the crop reached flowering to poding stage. And also they indicated that pea aphid intensity was negatively correlated with rainfall and minimum temperature, while it was positively associated with maximum temperature.

The combined effect of early (first week of July), mid (third week of July) and late (first week of August) planting with varieties (Adi, Megeri, Markos, Milky and local) on pea aphid occurrence was investigated at Areka by Melese and Singh (2012). The early and the mid sowing times exposed field pea to severe infestation by pea aphid and all varieties died at poding stage.

On late planted field pea, depending upon variety, intensity of pea aphid ranged from 7.8 per plant on local variety to 12 per plant on variety Megeri. Although the pea aphid intensity was low in late sown field pea, the gain yield was also low on late plantings. The highest and the lowest yield was obtained from Milky (493kg/ha) and Megeri (334kg/ha) varieties, respectively. Therefore, integrating early planting (recommended planting dates) with other control option is feasible in managing the pest in field pea.

Effect of Botanicals on pea aphid

Aqueous extract of neem (*Azadirachta indica*), seed kernel (10%) and Birbira (*Milletia ferruginea*) seed (5%), cow urine (25%), and nimbicidine 0.03% along with malathion 50EC and untreated check were evaluated using variety Tegegnech at Areka (Melese and Singh, 2012). Except malathion, which was sprayed only once, the other treatments were applied twice as 35% of the plants were infested by pea aphid (Ali, 1997). The pea aphid intensity varied between 0.5 per plant on malathion 50EC sprayed plots and 10 pea aphids per plant on untreated plot. Yield of malathion 50EC and neem seed kernel extract sprayed field peas was the highest followed by nimibicidine, Birbra, cow urine and untreated check.

Similarly, pyrethrum flower (*Chrysanthemum cinerarifolium*), young leaves of eucalyptus (*Eucalyptus globules*), neem seed (*A. indica*), and matured leaves of aloe (*Aloe pubescens*) were evaluated each at 5% and 10% on variety Tegegnech and Mohandefer at Kulumsa Agricultural Research Center (KARC) for controlling pea aphid under irrigated condition (Gemmeda and Ayalew, 2015).The tested botanicals provided some level of control and percent plant damage ranged from 1.2 on pirimicrab 50wp to 83% on the untreated check. Pea aphid incidence on botanical sprayed field peas was nearly equal to the level of incidence on the untreated control.

Chili (*Capsicum annuum*), bulb of garlic (*Allium sativum*), rhizome of ginger (*Zingiber officinale*), leaves of tagetus (*Tagetus minuta*), Ethiotoate (at 1.5 L/ha) and untreated control were evaluated at Sinana Agricultural Research Center (SARC) (Kora and Teshome, 2016). Although, it was concluded that the botanicals were effective in reducing pea aphid number, the pea aphid intensity on both treated and untreated plots was very low in the post spray assessment. Similarly, garlic bulbs (*A. sativum*), endod (*Phytolacca dodecandra*) and neem seeds (*A. indica*) were tested against pea aphid along with endosulfan 35EC under laboratory condition (Megersa, 2016). However, the reported data seem unreliable and lack clarity.

The common problem to all these botanical efficacy evaluation is the employment of wrong method that was assumed to be measuring efficacy by all the researchers. For instance, in all cases, the pre-spray population intensity and the natural mortality in the unsprayed treatments were not considered in determining the efficacy of botanicals. In some cases, the frequency of application, time of application (phenology of the crop) and methods of sampling the pea aphid are not known.

Solvents- deionized water, acetic acid, acetone, chloroform, luene and hexanein efficiency in extracting active ingredients from the powder of Birbira, *M. ferruginea* seeds was assessed and toxicity of extracts to pea aphid was evaluated on field pea (Ararso, 2010). The birbira seed extract by each solvent type was toxic to pea aphid, although the deionized water extract was more toxic than the other solvents. In another laboratory experiment Kemal Ali (unpublished report) indicated that water extracted Birbira caused significantly higher mortality (88.63 ± 1.02) than the chloroform extract (76.57 ± 1.7), while the mortality caused by the residue from chloroform (52.25 ± 1.97) was less than the chloroform extract. The natural mortality in water treated pea aphid was only 5.42 ± 0.84.

The Birbira extracts, including Primor (standard check) and untreated control, were also evaluated as foliar applications under on-farm condition at Adadi Mariam. The chloroform and water extracts of Birbira were as effective as the standard Pirimor in controlling pea aphid under field condition. The number of pea aphids in the control plots increased by about 5%, while the chloroform extracted Birbira (@ 5.32 mg/ml), water extracted Birbira (@ 2.69 mg/ml) and Pirimor 50WP (@ 1kg/ha) caused 98.8, 88.0 and 99.9% aphid mortality, respectively.

Efficacy of entomopathogenic fungus against pea aphid

An entomopathogenic fungus, *Verticillium lecanii*, introduced from the International Panacea Limited, was tested in bi-plot (sprayed with the entomopathogenic fungi and untreated) arrangement for the control of pea aphid in three field pea farms at Holetta in 2011 (Kemal Ali, unpublished report).

Before spraying and one or two weeks post spray counts were made on tagged plants. Mummies were collected and put on PDA after surface sterilized and were incubated for one week to check for the development of mycelia on the aphid mummies.

A week after spray a natural mortality factors, other than *V. lecanii* , caused significantly higher mortality on the treated than the control plot ($F_{1,4}$ = 9.75, $p < 0.05$), whereas two weeks after treatment application, the difference in mortality between the two was not significant ($F_{1,4}$ = 0.19, $p > 0.05$). From aphid mummies, which were collected one week after spraying, mycelia of *V. lecanii* did not develop on the plates, instead healthy parasitoids emerged from all the incubated mummies. This is an interesting result, but requires more designed work to see whether it is possible to integrate both methods of control or not.

Insecticide verification

The insecticides tafgor 40EC and dimethoate 40EC were sprayed on Burkitu using the respective insecticide manufacturer's recommended rate, while the control plots were sprayed with tap water at the rate of 200 L/ ha, when the 35% of the plants were infested (Kemal Ali unpublished report). Pre- and post-spray mean aphid count data were subjected to efficacy calculation using formula of Fleming and Retnakaran (1985).

In all the three fields, the candidate insecticide tafgor 40EC and the standard check dimethoate 40EC caused almost 100% mortality of the pea aphid relative to the untreated control at 3, 6, and 9 days after treatment applications. However, the seed yield obtained from three sites in all treatments was not significantly different from each other. The highest seed yield of 818 kg/ha was obtained from tafgor 40EC followed by dimethoate 40EC. Phytotoxicity due to the insecticides was not observed in all the test fields. The major limitation of this study is that the crop stage (phenology) at which insecticide was applied is not known. Therefore, the lack of association between efficacy and grain yield might be due to the stage of the crop i.e. the crop stage at which insecticide was applied might not be susceptible to aphids.

Field pea resistance to Adzuki bean beetle

A study, to determine field pea resistance to Adzuki bean beetle (*Callosobruchus chinensis*), was conducted at Holetta using genotypes obtained from pulses breeding unit of the center (Kemal Ali, unpublished report). A standard procedure was followed to disinfest test grains and assay for resistance. The Adzuki bean beetle laid eggs on all tested varieties, but the highest number of eggs were laid on variety Wolmera followed by Adi, Tegegnech, and Burkitu. The insect laid relatively few eggs on variety Gume. Mean number of adults emerged from each genotype after 36 days was significantly variable, and the highest and the lowest number of adult emerged were on varieties Burkitu and Markos, respectively.

Insect pest of grasspea

Pea aphid management

The efficacy of reduced rate of dimethoate 40EC was assessed around Durbete in 2010/11 season (Wale and Gedif, 2013). On the unsprayed grasspea, the aphid intensity increased from less than one per plant at the seedling stage to 288 per plant at maturity stage. The half dose (0.6 L/ha) of dimethoate was as effective as the full dose (1.2 L/ha), but the pea aphid intensity tends to resurge at the pod setting stage (about 6.7 pea aphids per plant). Pea aphid predator and parasitoid were found in unsprayed grasspea, although their intensity was very low.

Grain yields from unsprayed, half dose and full dose sprayed grasspea were 560, 2920 and 3190 kg/ha, respectively. Although the rates of the insecticides were stated, the frequency of application, volume of spray and time of application were not explicitly indicated. Moreover, the method of efficacy determination and the way data were interpreted are incorrect.

Pea aphid feeding preference and performance

Pea aphid preference and performance on field pea, faba bean, lentil and grasspea was tested with no-choice, dual- and multiple-choice experiments under greenhouse conditions at Adet (Tesfaye, 2013). The pea aphids feed preferentially on field peas, lentils and grasspeas than on faba bean. Growth rate of pea aphids varied with crop varieties and plant growth stages. In the no-choice experiment, the mean pea aphid number per five plants ranged between 1.8 at 5 days after infestation (DAI) on improved faba bean and 321.5 at 20 DAI on local field pea.

The high pea aphid intensity on field pea - and lentil- varieties resulted in complete death of plants 30 days after infestation (Table 3). The pea aphid days on grasspea and faba bean were longer than on field pea and lentil. But the cumulative pea aphid number was greater on field pea and grasspea than on faba bean and lentil. In single choice condition, the pea aphid reached highest peaks 20 DAI on field pea, grasspea, and lentil, while it reached peak 25 DAI on faba bean. The peak values were 322, 247, 244, 200, 185, 79, 243 and 136 per 5 plants on local field pea, wassie, Adet 1, local grasspea, local lentil, Alemaya, local faba bean and Adet Hana, respectively.

Table 3: Mean number of pea aphids on selected legume crop varieties in greenhouse on no choice condition

Crops and varieties	Mean Number of pea aphids/ five plants					
	5 DAI **	10 DAI	15 DAI	20 DAI	25 DAI	30 DAI
Faba Bean-Local	2.8cB	14bB	64.3cdAB	144.8cdB	242.5aA	78.3abAB
Adet Hana	1.8cB	8.8bB	33.5dB	80.5bBC	135.3abA	134aA
Field Pea-Local	81.8aA	124.8aB	264aA	321.5aA	0cC (CCD*)	0cC (CCD*)
Adet 1	45abBC	104aB	157.8bcB	243.5abA	47.8bcBC	0cC (CCD*)
Grass pea- Local	38bcCD	96.3aBC	155.5bcAB	200.3abA	127a-cB	6bcD
Wassie	57abBC	106aA-C	237abA	246.8abA	124a-cAB	6.3bcC
Lentil- Local	29.3bcBC	40.8bAB	81.8cdA	185.3abAB	1cC	0cC (CCD*)
Alemaya	23.3bcBC	34.5bB	64.8caA	79bA	31. 8bcBC	0cC (CCD*)

*Complete Crop Death, **Days after infestation, Source: Tesfaye *et al.* (2013)
Means within a column (difference between crops and varieties) followed by the same lowercase letter(s) and those within a row (difference between sampling dates) followed by the same uppercase letter(s) are not significantly different according to Tukey HSD (P<0.05).

In dual test, the faba bean was least preferred when it was grown in combination with field pea, grasspea or lentil, while the aphid equally infested field pea, grasspea and lentil when they are in combination with each other or with faba bean. In multiple choice test, the pea aphid preferentially feeds on field pea and grasspea than on faba bean and lentil. However, whether it is dual or multiple choice, the number of days elapsed between the introduction and settlement of the pea aphid on field pea, grasspea and lentil was one day, but on faba bean it took longer days (4 to 11) in dual test and three to eight days in multiple choice test.

Although there was some difference in time to reach peak population intensity as well as fluctuation of population on different genotypes and on crop species, the pea aphid population growth was not affected by variety of a crop or crop species, which suggests that all the tested crops were suitable hosts of pea aphid. No variety was immune to infestation, but overall, field peas and grasspea were good hosts for culturing pea aphids. Growing susceptible crops in pea aphid hot spot areas may have to be avoided in favor of less preferred ones. In addition to that, the growth rate of pea aphid was variable on different varieties and growth stage of a crop. The maximum growth rate of pea aphid 153, 53, 137, 112, 131, 400, and 389 were recorded on local grasspea, Wassie, Alemaya, local Field pea, Adet 1, local Faba bean and Adet Hana, respectively.

Flight pattern of pea aphid

The flight pattern of pea aphid was studied at Woreta and Wondata using yellow pans filled with water (Tesfaye *et al.*, 2016). Trap catches varied between years (lower in 2009/2010 than in 2010/2011), locations and months in the growing season. At Woreta, the pea aphid flew between September and March with peak density in January, whereas at Wondata pea aphid catch peaked in October and November. Pea aphid numbers were also affected by land use system. Thus, there were more pea aphids on grasspea sown after fallow than when it was double cropped after tef or sown under maize. Taylor's power law coefficients (Taylor,1984), i.e., b values, were significantly greater than 1 on grasspea planted after fallow; the corresponding r^2 values ranged between 0.87 and 0.94, whereas coefficients were inconsistent on grasspea planted after tef and under sown in maize. The optimum sample size n (i.e. number of yellow traps) required in relation to the mean densities of the pea aphid was more or less the same for the three levels of accuracy (D = 20, 30 and 50%). At D = 0.5, numerical sample size curves showed 10 traps per hectare and the mean number of aphids per trap was 4 or 5, which is practical and affordable.

Population dynamics of pea aphids and reaction to the performance of grasspea

A study was conducted in Bahir Dar Zuria and in Woreta for two consecutive growing seasons to determine pea aphid population fluctuation and its effect on performance of local grasspea variety under insecticidal treatments and different sowing dates (Tesfaye *et. al., 2012)*. The sowing date spans from 4th week of September to 1st week of November. Both in Bahir Dar Zuria and in Woreta, aphid density increased exponentially from 60 days after emergence (DAE) to 120 DAE and then declined starting from 135 DAE. The mean pea aphid intensity and the pea aphid days in the first cropping season were significantly greater than the second cropping season, and insecticide unsprayed grasspea had significantly more number of pea aphids than insecticide sprayed ones. Besides, the pea aphid intensity and the pea aphid days in both cropping seasons were higher in Bahir Dar Zuria than Woreta. Data revealed that pea aphid intensity, pea aphid days, grasspea damage (%), biomass weight, and grain yield were significantly affected by location, season, insecticide treatment and crop growth stages.

In all cropping seasons and the first two sowing dates (Early and Mid), the percentage of damaged crops was significantly greater in insecticide unsprayed grasspea than in sprayed counterparts. Thus, the percentage of crop damage in unsprayed grasspea ranged from 42 to 53% in Bahir Dar Zuria, while it ranged from 16 to 20% in insecticide sprayed grasspea. On the other hand, in Woreta, crop damage was affected neither by season nor sowing date, even though the crop damage percent on unprotected plots (11- 26%) was greater than protected plots (8.3 – 20%). Similarly, biomass and grain yield from unprotected plot in Bahir Dar Zuria was significantly less than biomass and grain yield from protected plots. At Woreta, the biomass and grain yield trend was similar to the trend in Bahir Dar Zuria, although there was no significant difference between protected and unprotected plots and sowing date. The biomass and grain yield loss incurred in Bahir Dar Zuria ranged from 15.4 to 47.3% and 24.5 to 93.9%, respectively; whereas at Woreta, the corresponding loss values were 5.3 - 26.5% and 4.6 - 69.3%. Regression analysis of pea aphid days with crop damage percent showed significant linear relationship. Similarly, biomass weight with grain yield shows significantly linear relationships. However, regression analyses of mean pea aphid density and pea aphid days with biomass weight and grain yield shows significantly inverse relationship (Tesfaye *et. al*., 2012).

Determination of pea aphid susceptible growth stages

Local and improved grasspea and lentil varieties were tested in greenhouse to determine the susceptible growth stages to pea aphid damage (Tesfaye, 2013). Each variety was planted manually on pots of 30 cm x 25 cm x 30 cm. Then each genotype was infested with 10 to 15 alate pea aphids at growth stages of 6 leaves formation starts (6-LS), 50% flowering (50FS) and 50% pod swelling (50PS). The number of apterous and the number of alate pea aphids were influenced by crop varieties, plant growth stages and the time of observation. In any crop variety, and grasspea growth stages, the mean number of apterous (wingless) pea aphids was always greater than alate (winged) pea aphid. The highest peak mean number of apterous and alate pea aphids on various crop varieties and infestation stages was recorded 28 days after infestation; but the lowest mean number of apterous and alate pea aphids was recorded 7 days after infestation. In both crops, all improved varieties were susceptible at all infestation stages than the local ones. Infestation stages at 50 PS had more number of apterous and alate pea aphids than at 50FS and 6-LS. However, the losses in total pod number and filled pod, biomass and grain yield were higher when both crops were infested at 6-LS than at 50 FS and at 50 PS.

Host plant resistance

Tesfaye (2013) evaluated 12 grasspea genotypes in two seasons under two different farming systems using farmers' optimum planting time (Mid-September to mid-October). In both cropping seasons, the pea aphid infestation was higher on the local grasspea (3448.4 - 3955 pea aphids/ 5 plants) and Acc. # 473 (3280 – 3694.2 pea aphids/ 5 plants) than the other genotypes. The highest infestation in 2010/11 was recorded on Acc # 473, Acc # 481, Acc # ILAT - LS-LS-736, Acc # 397, Acc # 2262, Acc # 8 –A-2000 and local grasspea with ranges from 3740 – 3907 pea aphids per five plants per sampling, while low infestation was recorded on variety wassie, Acc # 451, Acc # 6 - A - 2000, Acc # 455 and Acc # 419 with ranges of 3062 – 3392 pea aphids/ five plants/ sampling dates. The problem with the above aphid data is that the number of branches per plant is not known (plants differ in the number of branches).

At Wondata, the pea aphid population on all tested genotypes and at various growth stages was significantly greater than the population at Woreta. Moreover, in all tested genotypes the pea aphid population reached peak at the end of January (105 days after emergence) at Woreta; whereas at Wondata it reached peak in late December (90 days after emergence). The mean number of pea aphid days for local grasspea and Acc # 473 was greater than other genotypes at all locations; whereas Acc. # 8 - A - 2000 and Acc. # 2262 had the lowest pea aphid days. The cumulative pea aphid day on local grasspea was also greater than the cumulative pea aphid day on other genotypes throughout the cropping season and in both locations. Pea aphid growth rate trend varied according to the reaction of grasspea genotypes and weather condition. Pea aphid damage (%) on Acc # 419 in 2009/10 cropping season and Acc # ILAT-LS-LS-736, Acc. # 2262 and Acc. # 473 in 2010/11 cropping season was significantly higher than the damage on other tested genotypes; whereas, in both cropping seasons and locations, the Acc. # 455, Acc. # 451, Acc. # 6 -A-2000, Acc. # 397 and Acc. # 481 had the lowest damage than others genotypes.

The biomass and grain yield of each tested genotypes was negatively associated with pea aphid population intensity and pea aphid days. The study showed the presence of high variability among genotypes of grasspea in their response to pea aphid infestation. Therefore, screening of more genotypes is required to search for lines with resistance or tolerance genes to pea aphids.

Challenges

Despite the many years of research efforts, full insect pest management packages for highland legume crops have not been developed yet. Some of the major challenges that limited the advancement of insect pest management research in highland food legumes of Ethiopia are: 1) low gene frequencies for insect resistance that makes difficult the development of insect pest resistant highland food legume crop varieties through conventional breeding approaches, which in turn warrant the use of modern tools (such as agricultural biotechnology), 2) sporadic nature of insect pest occurrence, 3) polyphagous nature of most insect pest of highland legume crops, 4) fragmented production system and host sequence, which provide continuous host for the insect pests. For instance faba bean and field pea are sown early in the season (end of May to mid-June), lentil in July, chickpea in mid-August to mid-September and grasspea or double cropped chickpea late in the season. It is obvious that such host sequence avails different host plant for the insect, but it is not known if it has any adverse effect on the insect pest performance, provides enemy free space etc, 5) inadequate knowledge base and 6) climate change.

Future Research Directions

The majority of Ethiopian farmers grow highland legume crops without insecticide application. On the other hand, those farmers who control insect pests use only insecticides and some of these insecticides such as endosulfan have been banned from use in some countries. There are also some changes in the existing farming system such as use of improved crop varieties, irrigation, shifts in sowing date etc, which requires new and improved pest management tactics and strategies. Therefore, future research efforts should be geared towards:

1. Host plant resistance development - host plant resistance to insect pests is relative and selecting relatively less susceptible genotypes should continue
2. Assessing the effect of changing cropping system on the incidence of major insect pests of highland legumes. For instance, do tomatoes and cottons grown under irrigation in the Rift Valley contribute to pod bore problem in highland legumes during the main season?
3. Develop sampling methods for major pests
4. Evaluate safe and effective insecticides

5. Evaluation of methods that enhances selectivity of insecticides (altering dosage, timing of application, spot application, etc.)
6. Development of monitoring and surveillance system/technique to assess environmental, insect pest and crop interaction
7. Determination of economic threshold levels
8. Integration of proven insect pest control tactics, i.e. development of integrated highland food legumes pest management programs

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Progresses in Insect Pest Management Research of Lowland Food Legumes in Ethiopia

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Abstract

Grain legumes are an important component of agriculture, food and feed systems all over the world, and they complement the cereal crops in several aspects. In Ethiopia, pulses are important crops next to cereals. They are cheap sources of protein and play modest role in export market. Grain legumes are divided into two based on the temperature requirements for their growth: lowland and cool season legumes. Haricot bean, cow pea, soya bean, pigeon pea and mung bean are the commonly grown lowland grain legumes in tropical and sub-tropical countries including Ethiopia. Several factors are limiting the production of grain legumes where ever they are growing with varying degree. Insect pests are among the most important factors limiting the production and productivity of lowland food legumes in the world in general and Ethiopia in particular. Insect pests are not only important in the production of grain legumes, but also in the chain of post-harvest including transportation, storage and processing. Several research activities were conducted to minimize the problem of major insect pests associated to lowland grain legumes in Ethiopia and elsewhere in the world. The major insect pests which received the attention of Ethiopian researchers on lowland grain legumes include bean stem maggot, African bollworm, pod borer, flower beetles, aphids and bean bruchids. In this paper, research progresses of lowland food legumes' insect pests will be reviewed and recommendations on viable insect pest management options and future research directions will be forwarded.

Keywords: Low-land pulses, insect pests, natural enemies, pest management

Introduction

Grain legumes in general and lowland pulses in particular are important components of agriculture and food systems worldwide. They are complementary to cereal crops and they are in the first category as far as global food need is concerned (Graham and Vance, 2003). In Ethiopia, lowland pulses are cheap sources of protein and plays a vital role in the export market. White colored and brown colored haricot beans are said to be a white gold and brown gold, respectively because of the high demand they have on the export market (CSA, 2004). Haricot bean or common bean (*Phaseolus vulgaris*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*) and mung bean (*Phaseolus mungo*) are some of the lowland pulses grown in Ethiopia. A few insect pests were found to be economically important although large number of insects were recorded on low-land pulses grown in Ethiopia (Getu *et al.,* 2003; Ali *et al.*, 2008). Different species of bruchids are problematic to different lowland pulses in the store. The main objective of this paper is to summarize entomological research activities done on major low low land pulses grown in Ethiopia in the last one decade.

Approaches and procedures

For preparing this paper, as much as possible individuals who are involved in pulse entomology research and extension in Ethiopia were consulted and requested to submit published materials on the subject for the last decade. Moreover, diverse types of publications were reviewed through literature survey, which were done at Ethiopian Institute of Agricultural Research Library and Libraries of different Universities. Moreover, senior entomologists who used to work on pulse entomology were consulted if in case they have unpublished data. All types of available information on pulse entomology including basic and applied research were considered and presented here.

Achievements

Survey

Over 40 different insect species were recorded on five different lowland pulses across Ethiopia (Table 1) with variable importance though most species are either minor pests or pests of unknown importance. The major pests include two species of bean stem maggot (*Ophiomyia phaseoli* and *O. spencerella*), bean bruchid (*Callosobruchus* spp.) and African bollworm (*Helicoverpa armigera*) on haricot bean; bean pod weevil (*Apion* sp.) on mung bean; bean bruchid (*Callosobruchus* spp.) and African bollworm (*Helicoverpa armigera*) on cowpea. The non-insect spider mite, *Tetranychus* sp. was also a major pest on haricot bean. Recent survey done on soya bean reported about 34 insect pests belonging to 8 orders and 18 families (Table 2). Of the insect orders recorded on soya bean the highest number of species belong to the order Homoptera followed by Lepidoptera and Coleoptera in that order. The order Homoptera was the highest also in terms of total number of insects counted, density of insect per plant and number of insect families recorded. Plant parts attacked by the insects were leaf, stem and root.

Pulse crops are very important in the diet and economic development of Ethiopia. However, few insect species limit their production and storage (CSA, 2004; Getu *et al.*, 2003; Getu *et al.*, 2006; Gram and Vance, 2003; Ali *et al*., 2008). The history of the pests associated to pulse crops are not very much changing, but we have to expect changes as there are possibilities where by minor pests could be shifted to major pests and at the same time exotic pests can invade the country.

Table 1. Insect and mite pests recorded on major lowland pulses grown in Ethiopia

Crop	Common name of the pests	Scientific name of the pests	Status
Haricot bean	Bean stem maggot	*Ophiomyia phaseoli*	Major
		O. spencerella	Major
		O. centrosematis	Minor
	African bollworm	*Helicoverpa armigera*	Major
	Groundnut aphid	*Aphis craccivora*	Minor
	Pea aphid	*Myzus persicae*	Minor
	Tobacco whitefly	*Bemicia tabaci*	Minor
	Cotton bud thrips	*Frankiniella schultzei*	Unknown
	Spotted bean borer	*Maruca testulalis*	Minor
	Bean bruchids	*Callosobruchus* spp.	Major
	Spider mite	*Tetranychus* sp.	Major
Cowpea	Cotton bud thrips	*Frankiniella schultzei*	Unknown
	Groundnut aphid	*Aphis craccivora*	Minor
	Bruchids	*Callosobruchus* spp.	Major
	Cotton leaf worm	*Spodoptera exigua*	Sporadic
	Cotton leafworm	*S. littoralis*	Sporadic
	Flower thrips	*Taeniothrips* spp.	Minor
	African bollworm	*Helicoverpa armigera*	Major
	Pod borer	*Etiela zinckenella*	Minor
	Spotted bean borer	Maruca testulalis	Minor
Pigeon pea	Cluster bug	*Agonoscelis pubescens*	Minor
	Spiny brown bug	*Clavigralla tomenticollis*	Unknown
	Pod borer	*Etiela zinckenella*	Minor
	African bollworm	*Helicoverpa armigera*	Major
Mung bean	Bean pod weevil	*Apion* spp.	Major
	Green stink bug	*Nezera verdula*	Unknown
Soybean	Green stink bug	*Nezera verdula*	Unknown
	Groundnut aphid	*Aphis craccivora*	Minor
	Cotton aphid	*Aphis gossypi*	Unknown
	Bean pod weevil	*Apion* spp.	Minor
	Greasy cut worm	*Agrotis ipsilon*	Minor
	Pineapple mealy bug	*Dysmicoccus brevipes*	Unknown

Source: (Getu *et al*., 2003; Ali *et al*., 2008).

Table 2. Summary of insects recorded on soya bean in Metekel zone in 2014/2015

Order	No. of families	Total number of insects	Insects per plant	Number of species	Plant parts attacked
Coleoptera	2	80	0.53	5	Leaf and stem
Diptera	1	1	0.10	1	Stem
Hemiptera	1	29	0.29	2	Sap sucker
Homoptera	6	666	4.45	11	Sap sucker
Isoptera	1	390	2.60	2	Stem and root
Lepidoptera	3	39	0.26	8	Leaf and pod
Orthoptera	3	29	0.19	3	Leaf
Thysanoptera	1	710	4.73	2	Sap sucker

The specific surveys conducted on soya bean (unpublished data) indicate that there are possibilities of a new association between the host and the pest because tremendous number of insects were recorded on soya bean. Hence, regular survey should be conducted to trace changes in pest status of pulse crops. Getu *et al*. (2003) and Ali *et al*. (2008) compiled detail lists of insects and mites associated to pulse crops grown in Ethiopia, showing the significance diversity and sizable existence.

Biology of *Lamprosema indicata* F

L. indicata requires an average of 43.2 days to complete its life cycle. However, there was great variation between the minimum (34 days) and maximum days (59 days) required for the insect to complete its life cycle. Biology study which may investigate other aspects of the pest may be recommended. The need of basic knowledge like biology of insect pest is a prerequisite for designing effective pest management tools (Getu *et al.*, 2003).

Haricot bean varietal resistance against *Z. subfasciatus*

Results of *Z. subfasciatus* interaction with local and improved varieties of haricot bean are shown in Table 3. The interaction showed great variability among the haricot bean varieties tolerance for the pest. However, varieties RAZ-white and Yellow Round found to be resistant to *Z. subfasciatus*. Getu (2003) and Kifle (2017) reported that there are genes responsible for resistance in haricot bean both on storage pests and field pests of the crop. Collaboration between the breeders and the entomologists is essential to come up with haricot bean varieties which are superior both in pest resistance and grain yield. Based on the record of the different parameters, it is well noticed that there is significant variability among cultivars for their tolerance or resistance to the insect pests. This could be verified by the number of eggs, level of damage and number of days taken for bruchid adult emergence.

Botanical control of *Z. subfasciatus*

Effects of different botanicals on the infestation of *Z. subfasciatus* are shown in Table 4. From the botanicals tested Jatropha seed powder was the most effective against *Z. subfasciatus*. Parthenium seed powder and neem seed powder showed promising results as well. Several authors demonstrated the effects of different botanicals on different species of storage pests (Getu, 2014; Getu, 2015; Kifle, 2017; Tesfu and Getu, 2013). In most cases, some botanicals are highly effective in the management of storage pests. The active ingredient (s) of the best botanical should be identified and synthesized in the factory to be applicable at large scale. Getu (2014) and Getu (2015) demonstrated the efficacy of some botanicals in the management of stored haricot bean which can be as effective as some insecticides such as Malathion.

Table 3. Mean number of eggs, percent adult emerged, percent seed infestation and development time of *Z. subfasciatus* in different haricot bean locals and varieties, 2016/2017

Name of variety	Number of eggs laid	% adult emerged	% damaged seed	No. of days taken to emerge to adult
Gojam red medium	168	88.7±9.4a	88.7±9.4a	43.2±1.0bc
Gojam red large	175	55.4±7.3abc	56.7±7.5ab	41.2±1.0b
Gojam red small	203	13.7±3.6bcde	22.0±4.6ab	34.2±0.4b
Small white	110	88.4±9.4a	52.0±7.1ab	41.2±1.0de
Aregonde	189	53.5±7.2ab	71.3±8.4ab	44.2±0.7bc
Awash-1	178	76.7±8.6ab	76.0±8.7ab	44.2±0.7bc
Black	175	94.5±9.7a	90.0±9.5ab	35±0.6b
Cream	123	28.9±4.9abcde	76.7±8.7ab	44.2±0.7bc
Cream medium	213	26.5±5abcde	83.3±9.1ab	45.5±0.9b
Batu	263	40.2±6.2abcd	90.7±9.5a	33±0.6b
Large red	182	33.3±5.8abcde	60.0±7.6ab	40.2±0.6b
Large yellow	127	38.0±5.3abcde	45.3±6.6ab	39.2±0.7cd
Pinto	240	9.7±3.1cde	34.7±5.6ab	38.2±0.7cd
RAZ-white	207	0.8±0.5e	0.0±0.00ab	48.7±0.9a
Red ranger	207	21.3±4.6abcde	36.0±5.8ab	35.2±0.7b
Society	206	2.8±1.6de	35.3±5.3ab	35±0.6b
Walkite medium red	185	26.6±4.4abcd	58.0±7.3ab	40.2±0.4e
Walkite small red	234	6.8±2.6abcde	72.0±8.5ab	44.5±0.9b
White ranger	194	38.1±6.1abcd	38.0±6.1ab	34.5±1.5b
Yellow round	171	0.7±0.5e	0.0±0.0ab	47.5±0.3a

Means followed by the same letter (s) within a column are not significantly different at 5%, HSD

Table 4. Effect of botanicals on mean percent seed damage and weight loss by *Z. subfasciatus* on two haricot bean local varieties

Name of variety	Treatments	Mean percent seed damage	Mean percent weight loss
Batu	Untreated control	82±1.15a	29.1±3.09a
	Neem Seed powder	18±5.36bcd	8±0.53b
	Jatropha seed powder	3±1.2de	1.1±0.6b
	Parthenium seed powder	14±3.61cde	1.9±0.3b
	Malathion	0±0e	0±0b
Black	Untreated control	80±1.15a	19.9±3.4a
	Neem seed powder	21±7.3bc	1.16±0.62b
	Jatropha seed powder	1.6±0.3de	0.6±0.32b
	Parthenium seed powder	32±5.04b	6.1±0.53b
	Malathion	0.0±0e	0±0b

Aging effect of technologies

Results of aging effects is shown in Table 5 for one site. In all parameters measured, Melkae bean variety become susceptible to BSM and cannot be used anymore as a resistant variety. From the result of the experiment, it can be concluded that Beshebeshe bean variety, high plant population and Imdalem seed dressing can be used as integrated management of BSM in Ethiopia in general and at the study sites in particular. Abate (1990) demonstrated that Melkae and Beshebeshe bean varieties were resistant to BSM. However, Wondimu and Getu (2017) found that Beshebeshe remained resistant to BSM, while Melkae became susceptible to BSM.

Table 5. Effect of different management options on percent dead seedling and severity score due to BSM and grain yield at Omonda in 2014 & 2015.

Treatments	Vigorousity of bean		Yield (kg/ha)	
	2014	2015	2014	2015
Beshbesh (resistant variety)	5±0.58^{a}	4±0.12^{a}	1757±12.50^{a}	77±10.82^{a}
Seeds dressed by Imdalem	5±0.5 2^{b}	5±0.22^{a}	1412±10.60^{a}	79±11.87^{a}
Melkae (resistance variety)	2±0.33^{b}	2±0.52^{b}	1167±7.70^{b}	56±0.54^{b}
High plant population	4±0.12^{a}	5±0.27^{a}	1511±11.80^{a}	73±11.87^{a}
Awash-1 (standard check)	4±0.11^{a}	±0.0.13^{a}	1451±10.89^{a}	63±11.78^{a}

Means followed by the same letters within a column are not significantly different from each other at 5%level (HSD)

From this, we learnt that technologies which proved good at one time may not be good at the other time, so that we must recheck the status of the technology in a decade or less time. Gram and Vance (2003) indicated that development of new biotypes of insect may lead to resistance breakage.

Conclusion

There are some results/technologies on the entomology of lowland pulses which can be scaled up and utilized by the stakeholders such as resistant varieties, botanicals and planting density among others. However, the activities under pulse entomology in the decade is not sufficient to address entomological problems of insect pests. Hence, due attention should be given to pulse entomology in the coming decade.

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Crenate Broomrape (*Orobanche crenata* Forsk.) Problem and its Management in Food Legumes

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Abstract

*Crenate broomrape (***Orobanche crenata Forsk***.) has become an alarming constraint to highland food legumes production in the northern parts of Ethiopia since the 1980s. Recent, surveys and field experiments on cultural, chemical, fertilizer and host plant resistance methods of controlling the parasite using faba bean (***Vicia faba L***.) as a test crop conducted by Adet, Alamata, Gondar and Sirinka Agricultural Research Centers revealed that O. crenata was widely distributed in major highland food legumes growing areas, the most affected districts of the South Wollo Zone being Dessie Zuria, Kutaber, Tenta and Mekdela where farmers in these four districts lose hope to the extent of abandoning growing faba bean. The population density of the parasite could range between 50 and 250 shoots m^{-2} in some of the heavily infested districts such as Mekdela and Tenta. Two other districts in South Wollo: (Legambo and Delanta) are also Orobanche risk areas. Likewise, in South Gondar the most affected districts are Tatch Gayint and Farta. The parasitic weed affected faba bean, field pea, lentil and to a lesser extent chickpea and grass pea crops including other weedy wild hosts. Mixed cropping of faba bean with Fenugreek and Lepidium, which are not affected by the parasitic weed did not protect faba bean from infections. Increased levels of inorganic (nitrogen) and manure applications reduced Orobanche infection. Integrating tolerant cultivar Hashengie (ILB-4358) and 1-2 sprays of sub-lethal glyphosate herbicide at flowering stages were found to be effective in managing Orobanche in faba bean and increased seed yield up to 3 t ha^{-1}.*

Keywords: Crenate broomrape, Ethiopia, faba bean, *Orobanche crenata*

Introduction

Parasitic weeds of the genus *Orobanche* (Orobanchaceae) are becoming major threats to the production of highland food legumes, in particular the crenate broomrape (*Orobanche crenata* Forsk) to faba bean in Ethiopia (Tadesse *et al*., 1999; Fessehaie and Nefo, 2009; Abebe *et al*., 2013). Other parasitic weeds attacking food legumes such as chickpea, faba bean and lentil include the dodders (*Cuscuta* spp.) (Fessehaie and Nefo, 2009). *O. crenata* was first detected in Dessie Zuria and Kutaber Districts in the early 1980s (Tadesse *et al*., 1999). Earlier survey results indicated that *O. crenata* is and to be an actual and potential threat to highland food legumes production particularly with more pronounced effect in faba bean and field pea (Fessehaie and Nefo, 2009). Of the highland food legumes growing areas of the country, two regions (Amhara and Tigray) were in severe infestation of this species (Tadesse *et al.*, 1999; Fessehaie and Nefo, 2009). The spread of this species in both regions within few years of its discovery demonstrates that a joint program to contain, control and if possible eradicate this parasite found essential as suggested by several authors (Fessehaie, 1998; Fessehaie and Nefo, 2009). However, being no adequate efforts have been made to implement the suggestions, the infestation of the weed has reached at the pick and causing considerable damage on susceptible crops (faba bean in particular). Many farmers already have been forced to abandon the growing of this crop in both regions.

There have been different *Orobanche* control methods including cultural methods, chemical control, breeding for resistant host plants etc., reported from elsewhere around the world. However, no single technology standalone reported would completely control this parasitic weed; and therefore, integrated parasitic weed management is the feasible approach that should be implemented to cope with the parasite (Rubiales and Fernández-Aparicio, 2012).

So far, surveys and field experiments on cultural, chemical, fertilizer (plant nutrition) and host plant resistance methods of controlling the parasitic weed using faba bean as a test crop have been conducted by Adet, Alamata, Gondar and Sirinka Agicultural Research Centers; and results from these experiments were reported by the respective Research Centers. Therefore, the aim of this paper is to review recent advances of studies on *O. crenata* problems and its management in food legumes production areas of the northern Highlands of Ethiopia.

Spatial distribution of the parasite and its genetic diversity

Distribution

Broomrape infested areas reported in Ethiopia are mostly in the northern parts of the country (Figures 1 and 2) especially fields with typical light soil (non-Vertisol) and altitudes ranging between 2300 and 2900 masl (Kemal and Olivera JR, 2016; Belay, G, 2015). In general, a couple of assumptions (theories) could explain the low incidence/infestation of Vertisols (black soils) by root parasitic weed species of *O. crenata*. The first assumption is natural systems regulation (NSR) which exploits antagonistic activity of naturally occurring microorganisms on parasitic weeds growth and development. For instance, *Fusarium solani* (causative agent of black root rot of faba bean) and *Fusarium oxysporum*, whose natural habitat is Vertisols, are reported to be pathogenic to parasitic weeds [broomrapes (Dor and Hershenhorn, 2009). The second one is asphyxiation theory which is related to the water logging nature of Vertisols, i.e. anaerobic environment, being able to inhibit either seed germination or seedling elongation due to lack of oxygen.

Results of surveys conducted in Gondar, Tigray and Wollo showed that *O. Crenata* was widely distributed in major highland food legumes growing areas, the most affected districts of the South Wollo Zone being Dessie Zuria, Kutaber, Tenta and Mekdela where farmers in these four districts abandoned growing faba bean (Kemal and Olivera JR, 2016). They further indicated the population density of the parasite could range between 50 and 250 shoots/m^2 in some of the heavily infested districts such as Mekdela and Tenta. Two other districts of South Wollo; Legambo and Delanta are also *Orobanche* risk areas. Likewise, in South Gondar the most affected districts are Tatch Gayint and Farta. The parasitic weed affected faba bean, field pea, lentil and to a lesser extent chickpea and grasspea crops including wild weedy plants such as *Rumex* spp., *Xanthium* spp and *Guizotia scabra* (Kemal and Olivera JR, 2016; Abebe *et al*., 2013; Ademe *et al*., 2017).

Genetic diversity

From samples collected during the survey, 11 simple sequence repeat (SSR) markers were identified for studying the intra- and inter-population genetic diversity in *O. crenata* (Belay, 2015), and has confirmed the existence of highest genotypic variation within the South Wollo *O. crenata* population compared to other locations. Most of the intraspecific molecular variations in *O. crenata* (97%) revealed neither among individuals or populations and nor within geographic origin (Belay *et al*., 2016) considered.

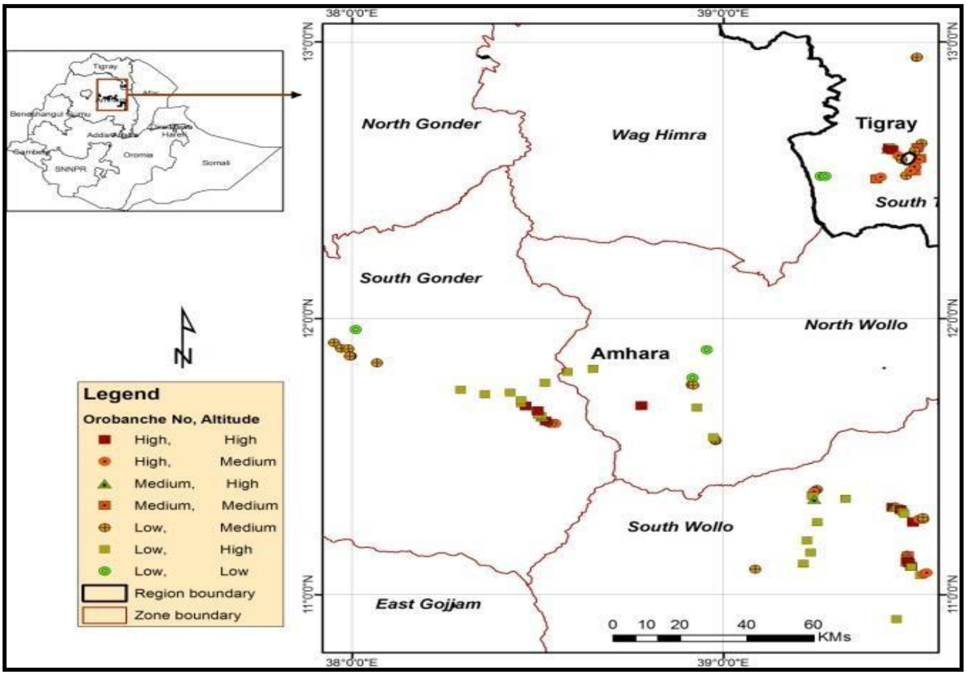

Figure 1. Distribution of *Orobanche crenata* in northern Ethiopia; Source: (Belay, 2015).

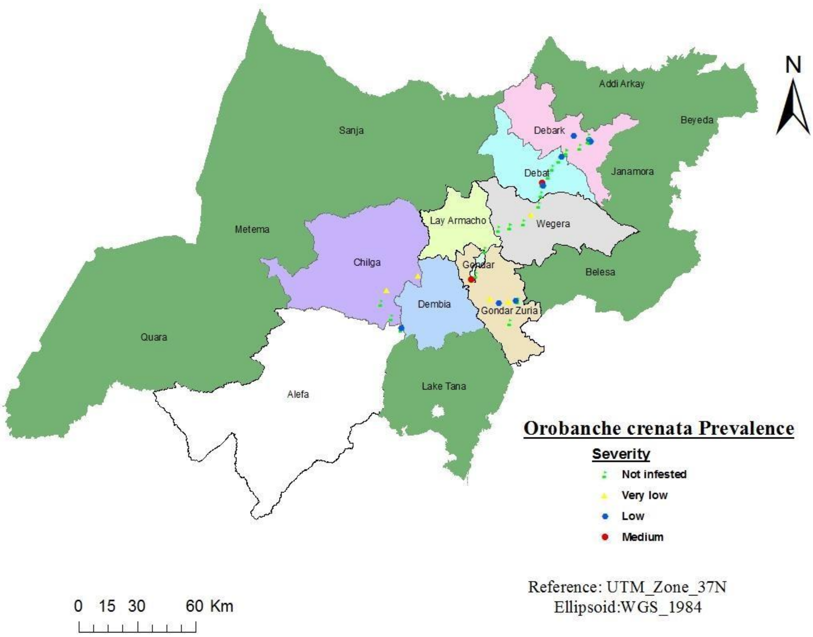

Figure. 2. Occurrence and distribution of and *Orobanche crenata* in North Gondar Districts assessed for parasitic weeds of food legumes. Very low: very few *Orobanche* shoots in the whole field, Low: few *Orobanche* shoots in the whole field, and Medium: Majority of host plants infested with 2 shoots; Source: (Ademe *et al*. 2017).

Seemingly, phenotyping of the host response is required to see if there is direct relationship between *O. crenata* genotypic variation and level of host susceptibility and/or phenotypic variation as this may have implications in resistance breeding. Although identification of primers for genotyping is a step forward, evidence on pathogenic variation (existence of host specialization and parasite races) is lacking. Knowledge on the latter is necessary for feasible progress in faba bean breeding against *O. crenata* in Ethiopia.

Control Methods

Avoiding seeds of parasitic weeds before their spread to new fields and areas through quarantine is the best documented preventive method. However, if a field is infested with parasitic weeds then a range of measures need to be employed in a combined manner, and these include sanitation and methods to prevent damage caused by the parasite and deplete the parasite seed bank in soil. In this connection, measures that have been tested and worked well in Ethiopia are reviewed in this section.

Host plant resistance

An indication of resistance to *O. crenata* is available within Ethiopian faba bean germplasm. Approximately, 10% of a gene pool, comprising of about 3000 genotypes, was reported to possess some level of resistance to *O. crenata* (Abebe *et al.*, 2015). Identification of the source of resistance was made using a field plot naturally infested with *O. crenata* at Ofla, South Tigray, Ethiopia. Tolerance to *O. crenata* was discovered after screening a number of genotypes received from ICARDA in the form of Faba bean International *Orobanche* Nursery (FBION). Genotypes Sel.F7/8975/05, ILB 4358, Giza 843 and Amcor appeared to be promising. Subsequent to repeated field evaluation and confirmation by the Alamata Agricultural Research Center, genotype ILB 4358 was released under the name Hashengie as an *Orobanche* tolerant faba bean variety in Ethiopia in 2015 (MoANR, 2016). This new variety (Hashengie) is moderately resistant to Chocolate spot and *Ascochyta* blight and moderately susceptible to faba bean Gall.

Several resistance mechanisms have been reported which can be used in faba bean breeding for resistance to *O. crenata*. These include: pre-attachment mechanism such as low induction of parasite seeds germination (Ejeta, 2007) and chemotropism, a wrong orientation of germinated *O. crenata* seeds within the potentially infective distance, (Pérez-de-Luque *et al.*, 2005a), pre-haustorial mechanisms of resistance consisting in lignifications of endodermal cells (Pérez-de-Luque *et al.*, 2005b), and post-haustorial resistance mechanisms, where attached parasites fail to develop due to chemical response consisting on delivery of toxic compounds such as phenolics into the host vascular system causing death of *O. crenata* tubercles on chickpea (Rubiales and Fernández-Aparicio, 2012).

Chemical control

Glyphosate, imidazolinones or sulfonylureas are the herbicides that are in use for parasitic weed control (Joel *et al*., 2007). Control of broomrape by foliar applications of glyphosate at low rates is recommended for faba bean (Mesa-García and García-Torres, 1985; Sauerborn *et al*., 1989). However, problem of phytotoxicity can arise due to non-selective nature of the chemical. Although little is known about the existence of tolerance to treatment of herbicides suitable to broomrape control in Ethiopian cool season food legumes germplasms, advances in multi-locational herbicides testing demonstrated the presence of tolerance to post-emergence treatment of glyphosate (72-144 g/ha) in faba bean cultivars Degaga and Hashengie (Kemal and Olivera JR. 2016; Misganaw, 2016).

Two foliar applications of glyphosate [Glyphosate-Isopropyl amine salt (144 g/ha)] are recommended, with the first application when faba bean is at early flowering stage when the parasite, *Orobanche crenata*, usually starts to appear above-ground (at emergence period) after completing attachment on faba bean root, followed by a second application 1-2 weeks later (Tadesse *et al*., 2015; Kemal and Olivera JR., 2016). The low dose of the systemic herbicide, glyphosate, is not degraded by the crop, instead it is absorbed through leaves and roots of the host plant, faba bean, with rapid translocation to the attached parasite which acts as a strong sink (Colquhoun *et al*., 2006; Pérez-de-Luque and Rubiales, 2009).

Cultural control

Early plantings of faba bean are more severely infected by *O. crenata* than delayed sowings of the crop in the infested areas of South Gondar, Ethiopia (Kemal and Olivera JR, 2016). However, experimental data from Tatch Gayint District (South Gondar Zone) indicate that delayed sowings result in reduced seed size and yield compared to early plantings. Perhaps, this might be due to sub-optimal (shortened) grain filling period remaining in the season. Therefore, other control methods need to be employed to combine the yield benefit of early plantings with a decreased *O. crenata* infestation.

Hand weeding, burning, production shift to small-grain cereals (barley, wheat and tef), crop rotation, intercropping, cultivation of the soil (ploughing), fallowing and manure application are the traditional methods smallholder farmers are using to control the parasitic weed in South Gondar Zone (Kemal and Olivera JR, 2016).

The possibility of controlling *O. crenata* in faba bean using nitrogen compounds and manure fertilization, and Rhizobium inoculant was investigated in Tatch Gayint District by Adet Agricultural Research Center. Results of this experiment revealed that of all the fertilizer components tested; only nitrogen fertilization at 75 kg N ha^{-1} can reduce *O. crenata* infection on faba bean with substantial increase of crop grain yield (Kemal and Olivera JR, 2016). In general, nitrogen in ammonium form is reported to affect negatively root parasitic weed germination and/or elongation of the seedling radicle (Rubiales and Fernández-Aparicio, 2012).

Integrated parasitic weed management (IPWM)

No single control method alone would provide satisfactory parasitic weeds management. Instead, employing a range of measures in integration, to prevent crop loss due to the parasites and eradicating the parasites seed bank in soil, is the only feasible approach to successfully manage the weeds. In this respect, credible achievement has been scored by the Sirinka Agricultural Research Center. The management of *O. crenata* in faba bean through integration of recommended control methods: employing host plant resistance (faba bean cv Hashengie), two applications of reduced rate of glyphosate (144 g ha^{-1}) and hand weeding before the parasitic weed flowers have been demonstrated (Negussie *et al.*, 2015; Figure 3).

Figure 3. Plots of Demonstration on Integrated Management of *O. crenata* in faba bean, Kutaber District, South Wollo Zone, Ethiopia; (*from top to bottom*): **[A]** stakeholders visiting the demonstration site; **[B]** (*foreground*) faba bean severely infected and damaged by *O. crenata,* (*background*) faba bean slightly infected by the parasite – (improved practice: integrated parasitic weed management). (Photo courtesy: Mulugeta Alemayehu).

IPWM Extension

An extension manual on IPWM in highland food legumes has been prepared, in local language, for use by farmers, extension workers and development agents as a guide in controlling *O. crenata* in faba bean. The manual was jointly prepared by ICARDA, ARARI and EIAR with a financial support of the Brazilian Agricultural Research Corporation (EMBRAPA) through ICARDA. The manual is intended for distribution to users in the *Orobanche* prone areas. This manual is also proposed to be made available on-line via ARARI and EIAR websites.

Conclusions

Notable parasitic weed control methods that can assist to re-introduce faba bean production in the *O. crenata* affected areas of the northern highlands of Ethiopia were developed. The control methods which will likely to be adopted by smallholder farmers are: tolerant variety, chemical control and nitrogen fertilization. It is expected that farmers will adopt the parasitic weed control technologies as a whole (whole adoption) which is essentially equivalent to adoption of integrated *O. crenata* management approach, because adoption of a single control technology alone would not bring about the desired control level. Further research is required to develop new control methods and narrow the existing knowledge rift. Thus, there is a very pressing need for more intensive studies in the following areas (*among others*): continuing and expanding the inventory, mapping and monitoring of *O. crenata* on the already identified affected areas including other uncovered important highland food legumes production areas assumed for risk of invasion; generating new information on the parasitic weed ecology and host interactions on faba bean and other important highland food legumes; strengthening the identification of research areas mainly on trap crops (non-host economical crops) and the need to study their mechanism of resistance and roles in establishing appropriate rotations that can minimize *Orobanche* seed bank; continuing and strengthening the development of IPWM and partially resistant genotypes of faba bean and lentil through research partnership among national and international partners. Surely, all these will play a significant role in minimizing faba bean yield losses due to *O. crenata*.

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Progresses in Weed Management Research of Food Legumes in Ethiopia

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Abstract

Weeds are among the major production constraints in food legume crops production in Ethiopia. These crops are usually heavily infested by a wide variety of early and late emerging annual grassy and broadleaf weed species. Recent survey records indicated that major highland food legumes, faba bean in particular, are vulnerable to damage by the parasitic weed species Orobanche crenata *L. in various localities of northern Ethiopia with crop losses ranging 80-100%. Other most serious parasitic weeds are the* Cuscuta *species mainly troublesome on lentil and chickpea production areas in West Shewa Zone and some localities in northern Ethiopia. To date, there is a serious challenge of developing appropriate and cost-effective weed control technologies in food legumes production for subsistence farmers with low resource base, and small and fragmented land holdings wherein, hand weeding and other cultural methods of weed control remain the most common methods in dealing with weeds over the years. Weed control innovations should be aimed at developing different alternative weed control options to be used as components of integrated weed management interventions to address the complex weed problems in the diverse ecologies and farming systems of the country. Thus, the aim of this paper is to give up-to-date information regarding different weed management research experiences under different food legumes cropping systems that have been added since the last decade, 2006 to 2016 in Ethiopia.*

Key words: Ethiopia, food legumes, weeds management

Introduction

In Ethiopia, various legume crops are grown under a wide range of environmental conditions representing mainly the highland and lowland ecologies. These include: faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), chickpea (*Cicer arietinun* L), grasspea (*Lathyrus sativus* L.), lentil (*Lens culinaris* Med.), common bean/haricot bean (*Phaseolus vulgaris* L.), soybean (*Glycin max* L. Merrill), mung bean (*Phaseolus radiatus* L.), cowpea [*Vigna unguiculata* (L.) Walp.], lablab [*Lablab purpureus* (L.) Sweet], pigeon pea [*Cajanus cajan* (L.) Millsp.] and fenugreek (*Trigonella foenum-graecum* L.) (ECSA, 2013).

Weeds are among the major production constraints in food legumes in Ethiopia. The weed flora is dependent on climate, soil type, crop rotation and time of sowing; with the exception of the parasitic weeds mainly *Orobanche crenata*, no weeds are specific to food legumes. Available survey records indicated that there are about 61 species in 53 genera and 21 plant families known to be problematic weed species in highland and lowland food legumes. Species of the plant family Asteraceae are the most common followed by Polygoniaceae, Poaceae and Solanaceae reported to have caused major problems in food legumes production (Fessehaie and Nefo, 2008).

Yield losses and time of weed removal have been assessed by many workers, and reviewed for faba bean, field pea, lentil and chickpea (Fessehaie, 1986 and 1994; Fessehaie and Nefo, 2006; 2008); common bean and cow pea, soybean (Reda, 2006). In some areas nearly complete crop loss can result from severe weed infestation or from the effect of the parasitic weed *O. crenata* on faba bean (Tadesse *et al.,* 1999; Kemal *et al.,* 2016).

Faba bean and lentil are very sensitive to weed competition from seedling establishment to early flowering stages. Full-season weed competition caused yield reduction up to 24% in faba bean in which the presence of weeds during the first 4, 7 and 10 weeks after sowing accounted for respective yield reduction of 13.1, 15.9 and 22.2% (Fessehaie, 1994). Field peas are not as sensitive to early weed competition as many of the other legumes. Particularly, there is no much competition from weeds once the crop is well established but, it is always important getting rid of all weeds when the peas are in the very early stages of growth as yield reduction can occur if there is no attention to weed control. Chickpea is sensitive to early weed competition and is less competitive than lentils. However, because it is sown late in the season and grown in residual moisture, it seldom encounters much weed competition (Fessehaie, 1994; Fessehaie and Nefo, 2006; 2008).

The results across different crops, years and locations invariably showed that lowland food legumes are especially sensitive to weed competition in the first four weeks after sowing. It was confirmed that soybean was a weak competitor with weeds compared to other lowland legumes. At Awassa, for example, exposure of the crop to prolonged weed competition resulted in up to 98% loss in grain yield (Zemichael, 1989) and two times hand weeding at 25 and 55 days after sowing was the optimum practice to enhance crop performance.

To date, there is a serious challenge of developing appropriate and cost-effective weed control technologies in food legumes production for subsistence farmers with low resource base, and small and fragmented land holdings wherein, hand weeding and other cultural methods of weed control remain the most common methods in dealing with weeds over the years.

The previous weed research activities in highland and lowland food legumes were reviewed by Fessehaie (1986 and 1994); Fessehaie and Nefo (2006); Reda, (2006) and Fessehaie and Nefo (2008). Thus, the aim of the present review is to give up-to-date information on weed management research experiences under different food legumes cropping systems that have been added since the last decade (2006 to 2016).

Status of Weed Management Research (2006-2016)

Weed surveys

Weed survey was done on farmers' fields to determine the distribution and relative importance of weeds affecting lentil and chickpea fields during 2014/15 crop season in East Shewa Zone (Gimbichu, Akaki, Adea, Lume and Minjar Districts). The specific objectives of this survey were: to identify and prioritize problematic weeds in lentil and chickpea; to determine species composition and quantify weeds and to assess farmers' perceptions on impact of weeds in the study crops and locations.

A total of 47 and 36 weed species were identified in chickpea and lentil fields respectively which belong to 16 plant families. Poaceae and Asteraceae contributed ten and eight species in lentil, and nine and seven species in chickpea respectively. Most of the weed species important in lentil and chickpea belongs to these families although there are other families with a single species that cannot be ignored. The survey results revealed further that broad leaved weed species were more dominant in chickpea fields, whereas, lentil fields were dominantly infested by grassy type weed species (composed of annual grasses and perennial sedge species). The most important weed species in both crops across the survey locations were: *Phalaris paradoxa, Setaria pumila, Scorpiurus muricatus, Cynodon dactylon, Argemone ochroleuca* and *Cyperus rotundus* (DZARC, 2015).

The similarity index (SI) matrix of weed species in chickpea growing areas of the surveyed locations is shown in Table 1. Tessema and Lema (1998) indicated that, if the index of similarity is below the threshold value, 60%, it is said that the two locations have different weed communities. This helps to use the same kind of management for the areas having similar weed communities (SI >60%) and different weed management systems for areas having different weed communities (SI <60%) (DZARC, 2015).

Table 1. Similarity Indices (SI) matrix of weed species in chickpea and lentil production areas

Locations	Akaki	Minjar	Ada	Gimbichu	Lume
Chickpea					
Akaki	100	64	62	65	60
Minjar		100	71	55	69
Adea			100	66	63
Gimbichu				100	72
Lume					100
Lentil					
Akaki	100	50	81	71	68
Minjar		100	63	40	63
Adea			100	81	72
Gimbichu				100	85
Lume					100

Source: DZARC (2015)

During the 2014/15 crop season wide spread occurrence of the parasitic weed Dodder (*Cuscuta campestris*) was observed in lentil fields of some districts of Southwest Shewa Zone and Sebeta Awas Special District of the Oromyia National Regional State. Problems with extensive infestation of *Cuscuta campestris* in lentil fields were observed in five *kebeles* of Ilu District: (Golane Kiltu, Tulu Mangora, Warerso Kanina, Mulu Setaye and Gibdu Mida); four *kebeles* of Sebeta Awas Special District: (Bonde Dabel, Awash Balo, Tefki and Weleka) but absent in Tulu Bolo District (DZARC, 2015).

This field observation revealed that the parasite caused most damage during massive infestation of recently established crop where it challenges the very feasibility of lentil production in these affected areas. In highly infested fields dodder-attacked plants gradually became weak, lush growth declined resulting to severe damage which ultimately led to destruction and death of the host plant (Figure 1).

Figure 1. Dense mat of stems of Dodder in lentil production areas of West Shewa Zone and Sebeta Special District entangling the host and ultimately lead to total destruction and death of the crop (Photo: Rezene Fessehaie)

In most localities of the Sebeta Special District infestation of Dodder were also observed in roadsides, boundaries of cropped areas and river banks. In particular, Dodder incidence in the margins of the Awash River could to lead for a long-distance dispersal of this parasite and is thought to be as major risk for its introduction and potential threat to the leguminous and solanceous crops production areas of East Shewa Zone, all along the downstream of the Awash River System (Figure 2).

Figure 2. Dodder incidence in the margins of the Awash River is thought to lead for a long distance dispersal of the parasite to the leguminous and solanceous crops production areas of Eastern Shewa Zone, all along the downstream of the Awash River System. (Photo: Rezene Fessehaie)

Crop-weed interference

Weed control requires better knowledge of effect of weed competition on crop productivity and the development of tools that can aids farmers' decision about weed control (Kropff *et al.,* 1993).

The critical period for weed control (CPWC) is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses. Knowing the CPWC is useful in making decisions on the need for and timing of weed control, and in achieving efficient herbicide use from both biological and economic perspectives (Knezevic *et al.*, 2002).

A field experiment was conducted by Mola and Belachew (2015) to determine the CPWC in common bean at Bonga Agricultural Research Center in 2013/14 cropping season. In this study, two common bean varieties; 'AFR-702' and 'Awassa-Dume' were used with two sets of treatments: In the first set of treatment; the crop was kept weed free until 10, 20, 30, 40, 50 and 60 days after crop emergence (DACE). In the second set; weeds were permitted to grow with the crop until 10, 20, 30, 40, 50 and 60 DACE. For each set, the farmers practice and recommended practice were also included in the treatments as control and standard checks.

The maximum value of bean yield (2984 kg ha^{-1} and 2720 kg ha^{-1}) was recorded from weed free treatment for AFR-702 and Awasa-Dume varieties respectively. The minimum value of bean yield (786 kg ha^{-1} and 629 kg ha^{-1}) was observed under the full season weed infestation condition for AFR-702 and Awassa-Dume varieties respectively. Weed infested conditions for the entire growing season led to common bean yield loss of 73.65% and 76.88% for variety AFR-702 and Awassa-Dume compared to full-season weed-free treatments respectively (Table 2).

From this study, it is possible to conclude that the critical period of weed competition period for the common bean varieties lasted when competition exceeds 30 DACE. Therefore, controlling weeds from 10-30 DACE reduces crop weed competition and gives higher bean yield under Kaffa Zone of Southwest Ethiopia and similar agro-ecologies.

In another study, Kebede *et al.* (2013) reported that to reduce the loss in grain yield of common bean by more than 10%, it is important to keep the crop weed free between 24 to 70 DAE at Haramaya and 14 to 70 DACE at Hirna, eastern part of the country.

Table 2. Seed yield and percent yield loss of common bean varieties: (AFR-702 and Awassa Dume) under different weed free (Control) and weed infested (Interference) treatments.

Weed removal Treatments* (DACE)**	AFR-702		Awassa Dume	
	Seed yield (kg ha^{-1})	Yield loss (%)	Seed yield (kg ha^{-1})	Yield loss (%)
Weed-free				
WF0	786	73.65	629	76.88
WF1	1290	56.76	1457	45.34
WF2	1591	46.67	1702	37.42
WF3	1857	37.76	1908	29.88
WF4	2116	29.08	2120	22.07
WF5	2368	20.63	2271	16.52
WF6	2627	11.95	2448	10.02
Weed-infested				
WI0	2994	0.00	2720	0.00
WI1	2883	3.39	2557	5.98
WI2	2781	6.79	2382	12.44
WI3	2585	13.36	2357	13.34
WI4	2270	23.92	1920	29.43
WI5	2081	30.95	1660	38.96
WI6	1794	39.87	1519	44.14
Two times weeding				
RP	2767	7.26	2190	19.50
FP	2030	31.96	1862	31.53
LSD (0.05)	4.97		7.65	

*WF0 = weed-infested season long (no weed control); WF1, WF2, WF3, WF4, WF5, WF6 = weed-free for 10, 20, 30, 40, 50 and 60 DACE, respectively; WI0 = weed-free season long (no weed infestation); WI1, WI2, WI3, WI4, WI5, WI6 = weed-infested for 10, 20, 30, 40, 50 and 60 DACE, respectively; RP = recommended practice; FP = farmers' practice; **DACE = days after crop emergence; **Source**: Mola and Belachew, 2015 - with modifications on arrangements of Tabular data.

Competitive effects of Parthenium on common bean

A field experiment was carried out at Haramaya University research farm during 2010 cropping season to determine the competitive effects of Parthenium weed (*Parthenium hysterophorus* L.) on yield attributes and yield of common bean (Woldesenbet *et al.*, 2012). The result showed that parthenium population significantly ($P<0.05$) influenced phenology, growth, yield attributes and yield of common bean. Parthenium parameters, such as plant height and dry biomass were increased, whereas number of branches and collar diameter decreased with increasing weed densities (Table 3). The days to flowering, physiological maturity and plant height of common bean increased with increasing parthenium population. The crop stand, number of pods plant^{-1}, seeds pod^{-1}and hundred seed weight were adversely affected with increasing weed density (data not shown). In the absence of competition, common bean gave a yield of 2599.1 kg ha^{-1} and this was reduced by 16.5 and 86.5% in the presence of competition with 3 and 21 plants m^{-2} of parthenium, respectively (Table 3).

Table 3. Effect of Parthenium densities on plant height, number of primary branches, collar diameter, final stand count and dry matter biomass weight of Parthenium

	Parthenium								
Density (plants m^{-2})	Plant height (cm)	Primary branches plant^{-1}	Collar diameter (mm)	Population (m^{-2})	Dry matter biomass (g m^{-2})	Total dry biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest Index (%)	Yield loss (%)
0						5630.8a	2599.1a	46.2a	-
3	140.0d*	15.9a	16.2a	2.2g	234.0e	5550.0ab	2117.5b	38.5b	16.0e
6	141.0d	15.7a	15.1ab	5.0f	324.3d	5505.0b	1835.2b	33.1bc	28.0d
9	161.0c	14.1b	14.3bc	7.5e	344.3c	5471.7b	1532.8c	28.0c	39.8c
12	167.0c	13.2b	13.4c	11.0d	436.0b	3987.5c	1500.3c	37.6b	40.8c
15	174.7b	13.2b	11.3d	13.1c	449.7a	3988.8c	743.5d	18.6d	70.3b
18	177.0b	11.4c	10.8ed	14.6b	456.3a	2824.9d	375.7e	13.3de	85.4a
21	189.7a	11.1c	10.7ed	18.9a	455.0a	2750.0ed	346.4e	12.6e	86.5a
24	190.0a	10.4c	9.7e	18.4a	448.0ab	2694.2e	353.7e	13.1ed	86.2a
LSD (5%)	6.05	1.30	1.44	1.00	13.47	97.7	299.03	5.7	9.86
CV (%)	2.1	5.6	6.5	5.1	2.0	1.3	13.6	12.3	11.6

*Within each column values followed by the same letter are not significantly different at 5% level according to LSD test.
Source: Woldesenbet *et al*. (2012)

Weed Control Methods

Studies on hand weeding frequencies and timings

Manual control experiments revealed that most crops exhibited significant yield response to one time weeding in the first four weeks of establishment. Some crop species varieties required more frequent weeding for optimum performance.

Experience has shown that proper timing of the weeding operation is critical to maximize benefits. According to the findings, crops are particularly sensitive to weed interference in the first four weeks of establishment and early weeding during this period significantly enhances yield performance.

Effect of hoeing and hand weeding frequencies on faba bean production

A study was conducted at Sinana on station and on farm sites in 2015/16 to evaluate the effect of hoeing plus hand weeding frequencies on the yield of faba bean. The treatments were composed of eleven weed management options: Weedy check; Twice hand weeding at 25-30 days after crop emergence (DACE) + 40-45 DACE; Hoeing at 7 DACE + twice hand weeding at 25-30 + 40-45 DACE; Hoeing at 7 DACE + hand weeding once at 25-30 DACE; Hoeing at 7 DACE + hand weeding once at 40-45 DACE; Hoeing at 14 DACE + twice hand weeding at 25-30 DACE + 40-45 DACE; Hoeing at 14 DACE + hand weeding once at 25-30 DACE; Hoeing at 14 DACE + hand weeding once at 40-45 DACE; Hoeing at 21 DACE + hand weeding once at 40-45 DACE; Hoeing at 28 DACE + hand weeding once at 40-45 DACE; and Hand weeding or weed harvesting at 50% pod setting stage. Results at both sites (Table 4) indicated that the test crop flowered and matured early in weed infested plots compared to well weed controlled plots. The result also showed that there was about 41 and 35% yield reduction occurred due to total weed infestation of faba bean as compared to the recommended two times hand weeding at on-station and on-farm respectively. Hoeing at 7 DACE plus twice hand weeding at 25-30 + 40-45 DACE and the recommended two times hand weeding at on-station gave a respective yield advantage of 51 and 17% as compared to weedy check. There was 51 and 41% yield penalty while farmers remove weed at 50% pod setting stage for the purpose of feeding their livestock as compared to hoeing at 7 DACE plus twice hand weeding and the recommended two times hand weeding at on-station. Similarly, there was a yield loss of 17% while weed removal at 50% pod setting stage as compared to the recommended two times hand weeding and hoeing at 28 DACE plus once hand weeding at 40-45DACE at on-farm. Thus, it was concluded that the use of weed management options as of hoeing at 7 DACE plus hand weeding at 25-30 DACE was more economically profitable and has an acceptable marginal rate of return at both locations (Wakweya and Dargie, 2017).

Chemical control

Weeds are a greater problem in legumes than in other crops in the rotation because the use of post-emergence grass herbicides is limited by their high cost, the ineffectiveness of available broadleaf herbicides, and the poor competitiveness of grain legumes. Prior to 1993 one post-emergence and six pre-emergence herbicides were recommended for highland food legumes weed control. But, at that time only one of these herbicides was officially registered (Fessehaie, 1994). Currently, there are six pre-emergence herbicides (four in soya bean and two in common bean) registered in lowland food legumes for controlling either broad leaf or grass weed species or both. Details of the weed spectrum for the specific respective crops indicated are shown in the List of Registered Pesticides (MoANR, 2017).

Table 4. Effect of weed management practices on faba bean seed yield at Sinana research station and on-farm fields during 2015 and 2016 main cropping season.

Treatments	Seed yield (kg ha^{-1}) †	
	On-station	On-farm
Weedy check	1990.2^{d}	2349 ^{b}
HW at 25-30 & 40-45 DACE	3387.8^{abc}	3616 ^{a}
Hoeing at 7 DAE+HW at 25-30 & 40-45 DACE	4068.8 ^{a}	3517 ^{a}
Hoeing at 7 DAE+HW at 25-30 DACE	3768.8 ^{ab}	3392 ^{a}
Hoeing at 7 DAE+HW at 40-45 DACE	3557.9 ^{abc}	3262 ^{a}
Hoeing at 14 DAE+HW at 25-30 & 40-45 DACE	2803.7 ^{bcd}	3338 ^{a}
Hoeing at 14 DAE+HW at 25-30 DACE	3517.1 ^{abc}	3231 ^{a}
Hoeing at 14 DAE+HW at 40-45 DACE	2635.8 ^{cd}	3422 ^{a}
Hoeing at 21 DAE+HW at 40-45 DACE	2988.5 $^{a-d}$	3212 ^{a}
Hoeing at 28 DAE+HW at 40-45 DACE	3229.0 ^{abc}	3621 ^{a}
Weed Removal at 50% Pod setting stage	1992.3 ^{d}	2987 ^{ab}
Mean	3085.44	3273.4
LSD (5%)	1125.7	706 51
CV (%)	31.49	12.67

†Means with the same letters are not significantly different

Source: Wakweya and Dargie (2017) with modifications on arrangements of tabular data.

Very little work has been done on herbicides test in the past decade. Among these, a field experiment was conducted by Dalga *et al*. (2011) at Areka Agricultural Research Center, during the main cropping season of 2010 to evaluate the effect of pre-emergence herbicides (pendimethalin and s-metolachlor) on weed control including on yield and yield attributes of common bean. Details of the test treatments are shown in Table 5. The most dominant weed species of the test location were: *Commelina benghalensis, Guizotia scabra, Galinsoga parviflora, Digitaria abyssinica* and *Eleusine indica*. Weed control treatments significantly influenced weed density and dry biomass accumulation. Application of s-metolachlor at 2.0 kg ha^{-1} and pendimethalin at 1.5 kg ha^{-1} significantly reduced the density and dry weight of weeds. Increasing herbicide application rates reduced both density and dry matter accumulation of weeds. In general, s-metolachlor was more effective on grass while pendimethalin was more effective on broadleaved weeds. Pendimethalin and s-metolachlor at 1.0 kg ha^{-1} each supplemented with one hand weeding at 35 days after sowing (DAS) resulted in lower weed dry biomass at harvest (data not shown). Crop growth, yield attributes and yield were significantly influenced by weed control treatments. The highest grain yield (2409 kg ha^{-1}) was obtained in complete weed free followed by s-metolachlor 1.0 kg ha^{-1} and pendimethalin 1.0 kg ha^{-1} each supplemented with one hand weeding at 35 DAS giving respective yields of

2231 and 2174 kg ha^{-1} compared to 1931 kg ha^{-1} from the twice hand weeded treatment during 20 and 35 DAS. The weed density and dry weight were negatively and significantly correlated with grain yield, except at 20 DAS (data not shown). Uninterrupted weed growth reduced the yield by 69.9% as compared to complete weed free treatment (Table 5). Application of s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand weeding (35 DAS) resulted in maximum relative net returns (ETB 12,296 ha^{-1}) followed by complete weed free (ETB 11,972 ha^{-1}) and pendimethalin at 1.0 kg ha^{-1} supplemented with one hand weeding (35 DAS) (ETB 11,718 ha^{-1}) (Table 6).

Table 5. Effect of weed control treatments on dry biomass, grain yield, harvest index, loss and gain (%) in yield of common bean

Treatments	Dry biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest Index (%)	Loss and gain (%)
Pendimethalin 1.0 kg ha^{-1}	2413	1081	44.8	55.2
Pendimethalin 1.25 kg ha^{-1}	3778	1360	36.0	43.5
Pendimethalin 1.5 kg ha^{-1}	3784	1513	40.0	37.2
S-metolachlor 1.0 kg ha^{-1}	4162	1105	26.5	54.2
S-metolachlor 1.5 kg ha^{-1}	4042	1332	32.9	44.7
S-metolachlor 2.0 kg ha^{-1}	3825	1500	39.2	37.7
Pendimethalin1.0 kg ha-1+ one HW 35 DAS*	4244	2174	51.3	9.7
S-metolachlor1.0 kg ha-1 + one HW 35 DAS	4647	2231	48.0	7.4
One hand weeding 20 DAS	5099	1776	34.8	26.3
Two hand weeding 20 and 35 DAS	6173	1931	31.3	19.8
Complete weed free	6363	2409	37.8	-
Weedy check	2069	724	35.1	69.9
LSD (P<0.05)	153.51	106	3.43	-
CV (%)	2.24	3.9	4.98	-

*DAS= days after sowing; **Source**: Dalga *et al.* (2011)

Table 6. Effect of weed control treatments on relative economic returns in common bean*

Treatments	Grain yield (kg ha^{-1})	Gross return (Birr ha^{-1})	Variable cost (Birr ha^{-1})	Relative net returns (Birr ha^{-1})
Pendimethalin 1.0 kg ha^{-1}	10.81	7351	1542	5809
Pendimethalim1.25 kg ha^{-1}	13.60	9248	1921	7327
Pendimethalin 1.5 kg ha^{-1}	15.13	10288	2173	8115
S-metolachlor 1 kg ha^{-1}	11.05	7514	1375	6139
S-metolachlor 1.5 kg ha^{-1}	13.32	9058	1706	7352
S-metolachlor 2.0 kg ha^{-1}	15.00	10200	1979	8221
Pendimethalin1.0kgha^{-1}+onehand weeding at 35 DAS**	21.74	14783	3065	11718
S-metolachlor1.0kgha^{-1}+onehand weeding at 35 DAS	22.31	15171	2875	12296
One hand weeding at 20 DAS	17.76	12077	2400	9677
Two hand weeding at (20 and 35 DAS)	19.31	13131	2930	10201
Complete weed free	24.09	16381	4409	11972
Weedy check	7.24	4923	724	4199

*Local market price for common bean Birr 680.00 /100 kg grain; ** DAS= days after sowing; **Source**: Dalga *et al.* (2011)

Another study was conducted by Tana *et al*. (2015) and reported that, s-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WACE significantly reduced the weed dry weight by 50% compared to the weedy check plots. S-metolachlor at 1.0 kg ha^{-1} supplemented with one hand hoeing and weeding 4 WACE had significantly higher number of pods plant^{-1}, number of seeds pod^{-1}, hundred seed weight, grain yield (4045.3 kg ha^{-1}) and aboveground dry biomass than the weedy check plots. Significantly higher grain yield (3878.6 kg ha^{-1}) was recorded at Hirna than at Haramaya. The highest net benefit of ETB 33,601 ha^{-1} was obtained by application of s-metolachlor at 1.0 kg ha^{-1} + one hand hoeing and weeding 4 WACE. According to the authors report, the economic benefit gained was 32.5% greater than the value obtained from the weedy check.

Integrated Weed Management

Weed management is always inherent in crop management and thus the interaction between weed management and other cultural practices in food legumes must be considered. The past research results demonstrated that integrated use of weed control and food legumes management practices adequately suppressed weeds growth and infestation, and enhanced better production and productivity of the crops at different agro-ecologies in Ethiopia.

Interaction effects of common bean varieties vs. frequency and time of hand weeding

A study was conducted at Bako Agricultural Research Center by Negash *et al.* (2008) to determine the interaction effect of common bean varieties (EMP, Roba-1 and BRC) vs. frequency and time of hand weeding. Significant differences were observed among common bean test varieties time and frequency of weeding on level of weed density, weed biomass dry weight, plant height, pod plant^{-1} seed yield and thousand seed weight. Roba -1 significantly reduced weed density and dry weed biomass weight compared to EMP and BRC. Interaction effect of variety, weeding time and frequency showed significant ($P<0.05$) differences for weed density, weed biomass dry weight, plant height, pod plant^{-1} seed yield and thousand seed weight but failed to show significant differences ($P<0.05$) across years for the same parameters. The weedy check treatment results in average losses of 46 and 57% in common bean seed yield and thousand seed weight respectively (Table 7). Overall results of the two years data revealed that there was no significant difference between the three levels weeding time and frequencies across all test common bean varieties. Therefore, once hand weeding at 30 DAS is recommended for the production of the test varieties at Bako and neighboring localities.

Table 7. Interaction effects of variety, weeding time and frequency on yield and yield components of common bean varieties at Bako

Treatments		Effect on crop yield and yield components			
Variety	Weeding time and frequency (DAS)*	Yield (kg ha^{-1})	Plant height (cm)	Pods plant^{-1}	1000 seeds weight (g)
EMP	0	345.7 efg	3.31 d	9.84 df	260.0 i
EMP	15	712.8 d	4.22 d	17.58 d	776.6 defgh
EMP	30	929.3 bc	3.05 d	12.95 d	1290.0 ab
EMP	45	504 de	3.68 d	10.70 df	742.8 defgh
EMP	15,30	1074 b	4.43 d	14.11 d	908.1 bcdef
EMP	15,45	764.7 cd	4.81 d	8.01 f	850.1 defg
EMP	30,45	863.6 c	2.77 d	9.68 f	1011.0 abcde
EMP	15,30,45	1003 bc	3.08 d	10.00 df	1005.0 abcde
Roba-1	0	196.1 g	14.06 c	19.25 d	250.9 i
Roba-1	15	224.2 fg	16.37 c	18.89 d	360.0 hi
Roba-1	30	467.7 ef	4.58 d	14.18 d	782.1 defgh
Roba-1	45	218.1 fg	13.60 c	10.05 df	544.2 fghi
Roba-1	15,30	370.2 efg	4.51 d	14.06 d	611.4 efghi
Roba-1	15,45	265.2 efg	13.10 d	8.93 f	469.0 ghi
Roba-1	30,45	354 efg	6.50 d	13.09 df	561.0 fghi
Roba-1	15,30,45	456.2 ef	3.42 d	12.63 d	530.8 fghi
BRC	0	960 bc	38.97 ab	25.30 c	605.4 efghi
BRC	15	1262.0 ab	41.68 a	29.40 bc	751.1 defgh
BRC	30	1263.4 ab	36.37 ab	30.00 ab	1265.0 abc
BRC	45	1159.9 b	43.97 a	27.20 abc	892.0 de
BRC	15,30	1280.5 ab	37.03 ab	29.00 abc	1292.0 ab
BRC	15,45	1214.3 ab	44.37 a	37.00 a	1146.0 abcd
BRC	30,45	1260.1 ab	38.50 ab	36.10 a	941.8 bcdef
BRC	15,30,45	1286.7 a	38.96 ab	29.80 ab	1357.0 a
	LSD	11.07	12.42	253..9	433.2
	CV (%)	9.88	4.6	13.1	12.4

*DAS = Days after sowing.
**= Means followed by the same letter within a column do not differ significantly according to LSD test (P = 0.05).
Source: Negash *et al.* (2008)

Interaction effects of fertilizer and weed control

Faba bean

The effects of phosphorus fertilizer and weed control on yield and major yield components of faba bean were studied on Nitisols of Ethiopian highlands. The test treatments were: factorial combinations of four levels of phosphorus fertilizer (0, 10, 20 and 30 kg P ha^{-1}) as triple super phosphate (TSP) and two levels of weeding (W1 = no weeding and W2 = hand weeding once six WACE). Results indicated that Phosphorus level × weed control interaction significantly ($P \leq 0.05$) affected faba bean seed yield. Phosphorus application at the rates of 10, 20 and 30 kg P ha^{-1} resulted in mean seed yield increases of 20, 41 and 53% compared to the control. Weeding once increased mean seed yields of faba bean by 25% on the average (35 and 17% at Welmera and Rob Gebeya, respectively) compared to weedy check (Table 8). Similarly, weed control significantly affected plant height, number of pods per plant and seeds per pod. Total dry matter of broad-leaf and grass weeds at weeding and harvesting were also significantly (P ≤0.001) affected by P fertilizer application at both locations. However, weed control had only a significant (P ≤0.001) effect on the total weed bio-mass of both weed types weeding at Welmera. In case of Rob Gebeya, total dry matter of grass weeds (GW) was significantly affected at harvesting only (Table 8).

The results of economic analysis indicated that the highest marginal rate of return was obtained from weeding once six weeks after crop emergence and application of 20 kg P ha^{-1}, which is economically the most feasible alternative on Nitisols of central Ethiopian highlands. (Agegnehu and Fessehaie, 2006).

Table 8. Mean biomass yield (BY), seed yield (SY) and thousand seed weight (TSW) of faba bean response to P fertilizer and weed control at Welmera and Rob Gebeya, 2001-2003.

Treatment	Welmera		Rob Gebeya	
	BY (kg ha^{-1})	SY (kg ha^{-1})	BY (kg ha^{-1})	SY (kg ha^{-1})
P (kg ha^{-1})				
0	3083 c†	1165 c	2171 d	1358 c
10	3358 bc	1314 c	3582 c	1710 b
20	3848 b	1545 b	4193 b	2013 a
30	4584 a	1763 a	4480 a	2001 a
Probability	***	***	***	***
Weeding (W)				
Un-weeded	3233 b	1231 b	3536 b	1657 b
Once weeded	4204 a	1662 a	3977 a	1934 a
Probability	***	***	***	***
PXW	NS	NS	NS	*
CV (%)	22.6	18.3	11.2	10.0

† Means in a column with the same letter are not significantly different (*P* < 0.05); *, **, *** Significant at *P* ≤ 0.05, *P* ≤ 0.01 and *P* ≤ 0.001, respectively; NS = Not significant; **Source**: Agegnehu and Fessahie (2006)

Field pea

The effects of four levels of P fertilizer (0, 10, 20 and 30 kg P ha-1) as TSP and two levels of weeding (W0 = no weeding and W1 = hand weeding once) were studied on yield of field pea at Welmera. According to Agegnehu and Beyene (2009), application of 20 kg P ha^{-1} and hand weeding once during the 4th week after sowing was identified to be the best option in improving productivity of field pea on acidic Nitisols of farmers' fields of Welmera District, West Shewa Zone (Table 9). The results of economic analysis in this study indicated that the treatment with three times tillage, application of 20 kg P ha^{-1} and weeding once by hand is the best option with a marginal rate of return of 423%, which is economically the most feasible alternative for field pea producers.

Table 9. Phosphorus fertilizer and weed control effects on mean dry matter of broad-leaf (BLW) and grass weeds (GW) at Welmera and Rob Gebeya, 2001-2003.

Treatment	Welmera				Rob Gebeya			
	BLW (g) at weeding	BLW (g) at harvesting	GW (g) at weeding	GW (g) at harvesting	BLW (g) at weeding	BLW (g) at harvesting	GW (g) at weeding	GW (g) at harvesting
P (kg ha^{-1})								
0	72.1 a†	549.9 a	3.9 c	105.6 a	18.9 c	74.3 c	5.3 c	116.4 b
10	30.4 c	162.1 d	8.9 b	27.4 c	24.1 bc	89.3 bc	6.5 bc	150.3 ab
20	44.6 b	396.1 b	7.8 b	44.6 b	26.0 b	117.5 a	8.7 ab	186.1 a
30	35.5 bc	263.6 c	11.5 a	33.0 c	31.9 a	95.6 b	10.8 a	126.6 b
Probability	***	**	**	***	**	**	**	**
Weeding (W)								
Un-weeded	50.1 a	438.4 a	7.2 b	71.0 a	25.0	97.4	8.1	210.7 a
Once weeded	41.3 b	247.4 b	8.8 a	34.4 b	25.5	90.9	7.6	79.0 b
Probability	*	***	*	***	NS	NS	NS	***
PXW	**	***	NS	**	NS	***	*	**
CV (%)	20.5	12.6	19.8	14.2	17.6	17.8	22.4	20.3

†Means in a column with the same letter are not significantly different ($P \leq 0.05$).
*, **, *** Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively; NS = Not significant.
Source: Agegnehu and Beyene, 2009

Common bean

The combined effect of weed management practices and phosphorus levels on weeds, common bean yield attributes, seed yield and net benefits of the treatments was studied at Haramaya University during 2011 cropping season under supplemental irrigation. The 18 treatment combinations included pre-emergence s-metolachlor (1.0, 1.5 and 2.0 kg ha^{-1}), s-metolachlor 1.0 kg ha^{-1}+one hand weeding and hoeing 35 days after crop emergence (DACE), one hand weeding and hoeing 20 DACE and weedy check in combination with phosphorus levels (0, 46 and 92 kg P_2O_5 ha^{-1}). The main effects of weed management practices and phosphorus significantly influenced the weed density at 20 DACE (data not shown) while their interaction significantly affected weed density at crop harvest and the weed dry weight (Table 10). The weed management practices significantly affected the final crop stand whereas phosphorus application showed such variation in 100-grain weight. The main effect significantly affected the number of pods plant^{-1} and grains pod^{-1}. S-metolachlor + one hand weeding and hoeing 35 DAE gave the highest (6047 kg ha^{-1}) grain yield, which was statistically at par with the yield (5847 kg ha^{-1}) obtained under one hand weeding and hoeing. Both these treatments showed a significant yield increase over the other treatments, although such difference was not found in straw yield. Application of 46 and 92 kg P_2O_5 ha^{-1} significantly increased the yield over the control. Managing weeds with the application of s-metolachlor at 1.0 kg ha^{-1} + hand weeding and hoeing 35 DACE without phosphorus application proved to be most profitable practice (Table 11); however, in a situation of non availability of herbicide on time, hand weeding 20 DACE seemed to be an alternate management practice whereas, under the condition of labor constraint but timely availability of the herbicide, pre-emergence application of s-metolachlor at 2.0 kg ha^{-1} should be preferred to preclude the yield loss and to ensure maximum benefits (Mosisa *et al*., 2013).

Table 10. Weed density (m^{-2}) and dry weight (g m^{-2}) as influenced by the interaction of weed management practices and phosphorus levels in common bean production at harvest

Weed management practices (WMP)	Phosphorus levels (P_2O_5 kg ha^{-1})					
	Weed density (m^{-2})			Weed dry weight (g m^{-2})		
	0	46	92	0	46	92
S-metolachlor 1.0 kg ha^{-1}	224.3	214.7	215.3	437.0	410.7	400.0
S-metolachlor 1.5 kg ha^{-1}	188.7	176.0	167.3	406.0	400.3	379.3
S-metolachlor 2.0 kg ha^{-1}	181.3	168.0	155.3	290.7	284.3	258.3
S-metolachlor 1.0 kg ha^{-1}+HW* 35 DACE**	136.7	130.3	121.3	114.0	113.3	88.7
Hand weeding 20 DACE	123.7	134.7	130.0	115.0	110.0	104.3
Weedy check	339.0	258.7	253.3	619.7	778.7	793.7
LSD (5%) WMP *x* P_2O_5		20.78				
CV(%)		12.0			10.9	

*HW = Hand weeding; **DACE = Days after crop emergence; **Source**: Mosisa *et al.* (2013)

Table 11. Gross return and net return as influenced by integrated weed management practices and phosphorus levels in common bean production (partial budget)

Treatment combinations	Total Variable cost (Birr ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (Birr ha^{-1})	Net benefit (Birr ha^{-1})
Met 1.0 kg ha^{-1} + 0 kg P_2O_5 ha^{-1}	3548	2427	12135	8587
Met 1.0 kg ha^{-1} + 46 kg P_2O_5 ha^{-1}	5199	2727	13635	8436
Met 1.0 kg ha^{-1} + 92 kg P_2O_5 ha^{-1}	6628	2936	14680	8052
Met 1.5 kg ha^{-1} + 0 kg P_2O_5 ha^{-1}	3906	2617	13085	9179
Met 1.5 kg ha^{-1} + 46 kg P_2O_5 ha^{-1}	5363	2772	13860	8497
Met 1.5 kg ha^{-1} + 92 kg P_2O_5 ha^{-1}	7172	3266	16330	9158
Met 2.0 kg ha^{-1} + 0 kg P_2O_5 ha^{-1}	4536	3011	15055	10519
Met 2.0 kg ha^{-1} + 46 kg P_2O_5 ha-^{1}	6081	3232	16160	10079
Met 2.0 kg ha^{-1} + 92 kg P_2O_5 ha^{-1}	7227	3604	18020	10793
Met 1 kg ha-^{1} + HW 35 DACE + 0 kg P_2O_5 ha^{-1}	7753	5202	26010	18257
Met 1 kg ha^{-1} + HW 35 DACE + 46 kg P_2O_5 ha^{-1}	9367	5475	27375	18008
Met 1 kg ha^{-1} + HW 35 DACE + 92 kg P_2O_5 ha^{-1}	10748	5648	28240	17492
HW 20 dae + 0 kg P_2O_5 ha^{-1}	8033	5081	25405	17372
HW 20 dae + 46 kg P_2O_5 ha^{-1}	9593	5313	26565	16972
HW 20 dae + 92 kg P_2O_5 ha^{-1}	10846	5390	26950	16104
Weedy check + 0 kg P_2O_5 ha^{-1}	750	562	2810	2060
Weedy check + 46 kg P_2O_5 ha^{-1}	2745	1120	5600	2855
Weedy check + 92 kg P_2O_5 ha^{-1}	4089	1265	6325	2236

Cost of s-metolachlor 208 Birr per kg; Spraying Birr100 per ha; Cost of hand weeding and hoeing 20 DACE 40 persons, 35 DACE 16 persons @Birr 31.25 per person; Cost of triple super phosphate Birr 11.50 per kg; Fertilizer application Birr 100 per ha; Sale price of common bean Birr 5 kg^{-1}; Field price of common bean (sale price- variable input cost-harvesting, threshing and winnowing Birr 125 100 kg^{-1}, packing and material cost Birr 3.5 100 kg^{-1}, transportation Birr 5 100 kg^{-1}; **Source**: Mosis *et al.* (2013)

Interaction effects of faba bean varieties, fertilizer and weed control

The effect of crop varieties, DAP fertilization and weed control methods on the yield and economic return of faba bean production were investigated by Beza and Tesfaye (2009) at Kosoye and Werk Demo sites in Wegera Woreda, North Gondar, Ethiopia in the main season of 2006. The test treatments were factorial combinations of two levels of variety (CS20DK and Local), fertilizer (1OO kg ha^{-1} DAP and no fertilizer) and weeding (twice weeding and no weeding). The results revealed that, stand count and number of nodes per plant increased by DAP application and weeding at both sites. Number of seeds per pod, total biomass, hundred seed weight, seed yield and harvest index significantly increased in the improved variety, DAP application and twice hand weeding treatment combinations at both sites except hundred seed weight which was affected by varietal difference only at Werk Demo. The use of improved variety, fertilizer application and weeding provided a seed yield advantages of 15, 38 and 29% at Kosoye, and 46, 65 and 58% at Werk Demo, respectively compared to the control (use of local variety with no fertilizer and no weed control). The use of improved variety under DAP fertilized and twice weeded condition gave the highest net return (Birr 9038.10 and 8048.54 ha^{-1} at Kosoye and Werk Demo, respectively) while the use of local variety under the farmers' traditional crop management practice gave the lowest net return (Birr 4061.16 and 1727.88 ha^{-1} at Kosoye and Werk Demo, respectively). Therefore, these findings indicated that the use of improved variety and improved crop management practices are economically feasible and profitable to the faba bean producers of Wegera Woreda (Beza and Tesfaye, 2009).

Interaction effect of ploughing, fertilizer application and weeding frequency on field pea productivity

A study was conducted at Angecha district in the south region of Ethiopia for two consecutive years; 2004 and 2005 to investigate the effect of ploughing, fertilizer rate and weeding on field pea production. The test treatments were: frequency of ploughing (P1= once, P2= twice and P3= three times) as main plot and the interaction of fertilizer rate (F0 = 0 kg DAP ha^{-1}, F1 = 50 kg DAP ha^{-1}, F2 = 100 kg DAP ha^{-1}) and frequency of weeding (W0= Not weeded, W1= weeded once, W2= weeded twice). The results revealed that the grain yield of field pea significantly affected by ploughing frequency and weeding frequency. The grain yield of field pea showed increasing trend with increased combinations of ploughing frequency and weeding frequency (Figure 3).

The highest seed yield was attained by ploughing twice, weeding once and applying 100 kg ha^{-1} of DAP fertilizer

(46% P_2O_5 and 18% N). In 2005, the interaction of ploughing frequency and weeding frequency affected significantly grain yield of field pea (Figure 4) (Negash and Mulualem, 2014).

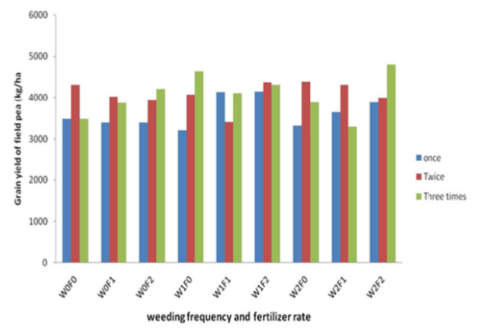

Figure 3. The interaction effect of ploughing frequency, weeding frequency, and fertilizer rate on grain yield of field pea in 2004.
Source: (Fisseha and Tewodros, 2014).

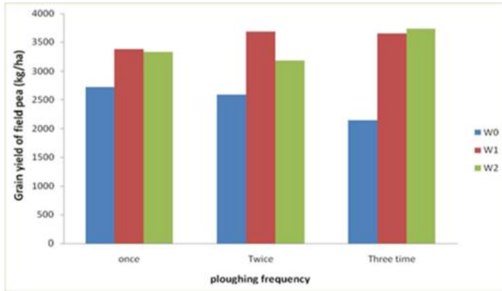

Figure 4. The interaction effect of ploughing frequency, weeding frequency, grain yield of field pea in 2005.
Source: (Fisseha and Tewodros, 2014).

On the other hand, interaction of ploughing frequency and weeding frequency had significant effect on number of pods per plant in 2004. The number of pods per plant showed increasing trend with increased weeding frequency in all ploughing levels.

The combined analysis over years (data not shown) indicated that the main effects of weeding frequency have significant differences on the grain yield of field pea. Un-weeded treatment caused significantly the lower grain yield. This reveals that, weeding at least once is necessary for the better yield of the crop. The three factors and their interaction have not showed significant differences on any yield components evaluated in this study.

As shown in Table 12, the highest net benefits of 38,323.00,40,120.00 and 37,636.00 ETB ha^{-1} with marginal rate of return 547%, 625% and 4% was also obtained from ploughing twice, weeding twice and applying 100 kg ha^{-1} of DAP fertilizer respectively (Negash and Mulualem, 2014).

Interaction effect of plant spacing and weeding frequencies on common bean productivity

This study was conducted in 2012 main cropping season at Haramaya and Hirna research fields, eastern Ethiopia, to determine the effect of plant spacing and weeding frequency on weeds, yield components and yield of common bean. The experiment comprised 18 treatment combinations (details have been shown in Table 13).

Table 12. Marginal rate of return analysis for ploughing frequency, weeding frequency and fertilizer rate

Treatment	Mean yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Gross cost (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	MRR (%) (ETB ha^{-1})
Ploughing frequency						
One time	3,383.00	3,044.70	36,536.40	400.00	36,136.40	
Two times	3,622.50	3,260.25	39,123.00	800.00	38,323.00	547
Three times	3,621.50	3,259.35	39,112.20	1,200.00	37,912.20d**	
Weeding Frequency						
One time	3,136.00	2,822.40	33,868.80	0.00	33,868.80	
Two times	3,807.50	3,426.75	41,121.00	1,000.00	40,121.00	625
Three times	3,683.50	3,315.15	39,781.80	2,000.00	37,781.80d	
Weeding Frequency						
Without fertilizer	3,478.50	3,130.65	37,567.80	0.00	37,567.80	
50 kg ha^{-1} DAP	3,497.00	3,147.30	37,767.60	900.00	36,867.60d	
100 kg ha^{-1} DAP	3,651.50	3,286.35	39,436.20	1,800.00	37,636.20	4

MRR=Marginal Rate of Return; d= dominated; price of field pea grain = 12ETB kg^{-1}; price of DAP= 18 ETB kg. Kg^{-1}; Labor cost =25 ETHB day^{-1}'; Once ploughing cost= 400 ETB ha^{-1}; once weeding cost 1,000 ETB ha^{-1}; **Source**: Negash and Mulualem (2014)

Table 13. Interaction effects of plant spacing, weeding frequency and site on dry weight at crop harvest during 2012 main cropping season*

Plant spacing	Weeding frequency (W)	Weed dry weight (g m^{-2}) Haramaya	Hirna
30 cm x 10cm	W1	7.4ij (54.2)	10.6g (111.3
	W2	5.8j- m (32.7)	0.7q (0.0)
	W3	4.1mno 16.0)	0.7q (0.0)
	W4	0.7q (0.0)	0.7q (0.0)
	W5	0.7q (0.0)	0.7q (0.0)
	W6	14.8de (220.3)	16.5d (273.7)
30 cm x 15cm	W1	13.3ef (183.7)	13.9ef (193.7)
	W2	7.1ijk (49.3)	9.3gh (86.0)
	W3	5.5klm (30.3)	0.7q (0.0)
	W4	3.2nop (10.0)	0.7q (0.0)
	W5	0.7q (0.0)	0.7q (0.0)
	W6	23.4b (549.2)	28.5a (812.0)
40 cm x 10cm	W1	7.6hi (57.3)	12.9f (168.3)
	W2	6.3i-l (39.0)	2.9op (10.7)
	W3	4.7lmn (21.7	0.7q (0.0)
	W4	2.0pq (4.3)	0.7q (0.0)
	W5	0.7q (0.0)	0.7q (0.0)
	W6	21.1c (445.0)	20.0c (407.0)
LSD (0.05)		1.7	
CV (%)		15.0	

*Numeric values in parentheses are the original values; Means followed by the same letter within each column and row for the parameters are not significantly different; LSD = least significant difference; CV = coefficient of variations; W = Weeding frequency; W1, W2, W3, are weeding by hand-hoeing at 2, 3 and 4 WACE, respectively; W4, W5 and W6 two weeding by hand-hoeing at 2 and 5 WACE, weed-free and weedy check, respectively; **Source**: Kebede *et al. (*2015)

It was observed that broad-leaved weed species were dominant at both sites with relative density of 61.2 and 73.2% at Haramaya and Hirna, respectively. Interaction of sites, plant spacing and weeding frequencies significantly affected weed density and dry weight. Days to flowering, days to physiological maturity, plant height, number of pods plant^{-1}, number of seeds pod^{-1}, hundred seed weight, grain yield, aboveground dry biomass, and harvest index significantly affected by weeding frequencies

(Kebede *et al.*, 2015). Combination of plant spacing of 30 cm x 10 cm and two weeding by hand-hoeing two and five WACE significantly reduced the weed dry weight by 95.3 and 95.8% at Haramaya and Hirna, respectively, as compared to the same plant spacing with no weeding throughout the season (Table 13). Significantly higher grain yield (2612.2 kg ha^{-1}) and (2718.8 kg ha^{-1}) were obtained from one weeding by hand-hoeing two WACE, and two weeding by hand-hoeing two and five WACE next to weed free check, respectively. However, the economic analysis revealed that the highest net benefit of 15924 ETB ha^{-1} was obtained in response to combining the spacing of 30 cm × 10 cm with twice weeding by hand-hoeing two and five WACE (Table 14). It could be concluded that planting common bean plants at the spacing of 30 cm between rows and 10 cm between plants and weeding the crop by hand-hoeing twice at two and five WACE resulted in optimum growth and grain yield of the crop (Kebede *et al.*, 2015).

Interaction effect of common bean varieties, planting method, tie ridging, fertilizer and weed control

Getaneh and Reda (2009) reported that integrated use of common bean varieties (Awash Melka and Red kidney), row planting (40cm by 10 cm inter- and intra-row spacing), combined with fertilizer (100 kg ha^{-1} DAP), tied ridging and two times hand weeding at (25 and 55 DACE) was the highest yielder for both Awash Melka (2.53 t ha^{-1}) and Red kidney (2.0 t ha^{-1}).

Table 14. Estimated net benefit data using partial budget analysis for weed management practices in common bean averaged for two sites in 2012 main cropping season.

Plant spacing	Weeding frequency (W)	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1})	Gross benefit (ETB ha^{-1})	Variable total Cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})
30 cm x 10cm	W1	2660	2394	18197	2295	15903
	W2	2515	2264	17206	2295	14911
	W3	2442	2198	16702	2295	14407
	W4	2763	2487	18899	2975	15924
	W6	2023	1820	595	13834	13239
30 cm x 15cm	W1	2557	2302	17493	2195	15298
	W2	2466	2219	16867	2195	14672
	W3	2294	2064	15690	2195	13495
	W4	2666	2399	18236	2875	15361
	W6	1583	1425	10828	495	10333
40 cm x 10cm	W1	2619	2357	17913	2144	15769
	W2	2495	2246	17069	2144	14925
	W3	2420	2178	16551	2144	14407
	W4	2727	2455	18655	2824	15831
	W6	1811	1630	12390	444	11946

ETB = Ethiopian Birr; Seed rates of 58, 48.3 and 43 kg ha^{-1} were used for 30 cm × 10 cm, 30 cm × 15 cm and 40 cm × 10 cm plant spacing, respectively; Cost of seeds for planting 10.25 ETB kg^{-1};Cost of labor 43 ETB $person^{-1}$; Sale price of common bean 9 ETB kg^{-1}; Field price of common bean 7.60 ETB kg^{-1}; Cost of harvesting, threshing and winnowing 130 ETB 100 kg^{-1}; Packing and material cost 4 ETB 100 kg^{-1} and transportation 6 ETB 100 kg^{-1}; WACE = Weeks after crop emergence; W = Weeding frequency; W1, W2, W3, are weeding by hand-hoeing at 2, 3 and 4 WACE, respectively; W4 and W6 two weeding by hand-hoeing at 2 and 5 WACE and weedy check, respectively. ETB = 0.0481 USD (August 12, 2015); **Source**: Kebede *et al. (*2015)

The lowest yield was obtained from the check treatment (broadcasting, no fertilizer and no weeding) with a value of 0.92 and 0.77 t ha^{-1} for Awash Melka and Red kidney varieties respectively.

Benefits of crop rotation in weed control

Weeds that cause problems in food legumes are problematic within a crop rotation and not to the legume crops alone. Local experience has shown that dicot-crop rotation system is one of the most effective and inexpensive practices for maintaining weed species equilibrium and avoiding competition in subsequent cereal crops. Large scale faba bean based rotation at Bale Agricultural Development Enterprise (BADE) showed marked reduction in weed density and biomass compared with continuous wheat. Benefits of faba bean rotations as measured by wheat productivity from sampled areas of initial tests during 2001/02, 2002/03 and 2003/04 gave average yield increase of 105% and weed free fields that persisted till crop harvest (Table 15) and Figure 5. Results of this intervention clearly indicated that short cycles of wheat rotations with either dicot crop (i.e., faba bean or rapeseed) proved to be beneficial from the perspective of minimizing weed populations and weed competition as well as increasing crop yield and drastically reducing cost of weed control (Gobezie *et al*., 2007).

Table 15. Benefits of faba bean rotation with wheat as measured by wheat productivity from sampled areas

Year	Area rotated (ha)	Yield of wheat		
		Before rotation (t ha^{-1})	After rotation (t ha^{-1})	Increment (%)
2002/03	139	1.9	3.2	68
2003/04	177	2.4	3.9	62
Average		**2.2**	**3.6**	**64**

Source: Gobezie *et al.* (2007)

Figure 5. Benefits of Faba bean rotation as measured by wheat productivity: **[A] Initially** rotation with faba bean started with 293 ha. This practice was found to be suitable for Robe and Sinana Farms and had been scaled-up up to 622 ha on both farms annually for 4 consecutive years; **[B]** Results of this intervention clearly indicated that short cycles of wheat rotations with faba bean were proved to be beneficial from the perspective of minimizing weed populations and weed competition with wheat as well as increasing crop yield and drastically reducing cost of weed control; (Photo: Rezene Fessehaie).

Benefits of intercropping in weed control

Agronomic and economic advantages of intercrops were evaluated over five years (2008-2012) at Awassa by Workayehu (2014). The test treatments were composed of: three weeding practices (0, 1, and 2 weeding), and single (MB) and double (MBB) rows of bean alternated with one row of maize were used in complete factorial experiment using randomized complete block design. Sole crop of bean (SB) and maize (SM) were included. Variability in rainfall influenced the effect of weeding and intercropping. Seasons with better rainfall had less weed but more pods plant^{-1}, plant density, dry matter, bean and maize yield, energy value and economic benefit. Weeds in intercrop were 30% less compared with sole crop bean. Weed biomass was 16 and 30% less in MBB than SM and MB, respectively. Weeding increased plant height (16%), pods plant^{-1} (19%), grain (60%) and dry matter (38%) yields of bean, energy yield (56%), and monetary benefit (59%). Bean yield was 52 to 68% greater with weeding compared to the weedy check. In the dry year of 2011, weeding increased grain yields of bean and maize by 44 to 124% and 33 to 121% more than the weedy check, respectively. Maize yield varied between 43 and 66% with weeding compared with weedy control. Bean yield and total land equivalent ratio (LER) in MB was 35 and 22% more than in MBB, respectively. Maize yield in MB was 15% lower than sole maize but 19% more than MBB. Energy yield and monetary benefit were 19 and 29% higher in MB than MBB, respectively. Intercropping resulted in LER of 20 to 67% yield benefit over sole crop and saved 38% more farm land. Overall, intercropping suppressed weeds and was more productive and economical than sole crop, which reduced risk of climate change and sustained crop production. This would benefit farmers in reducing the risk of climate change and alleviating food shortage (Workayehu, 2014).

Interaction effect of herbicides and supplementary hand weeding

Traditional method of manual weeding is constrained by increasing cost of labor and ineffective due to delay in operation. Chemical weed control with herbicides could be considered as a suitable alternative under such situations. Many herbicides that are chemically and functionally diverse are available for the control of weeds in food legumes. For successful and economical use, it is necessary to understand the dose of application of any new herbicide in combination with supplementary hand weeding. Hence, on-station and on-farm experiments on efficiency of herbicides (s-metolachlor and pendimentahalin) were conducted in faba bean at Kulumsa and Holetta during 2012–2013 and in cow pea at Sirinka and Jari in 2013 to investigate the possibilities of supplementing low doses of the test herbicides with hand weeding for efficient and cost-effective weed management.

Faba bean

The treatments comprised: s-metolachlor @ 1.0 l ha^{-1} + one hand weeding; farmers' practice (two hand weeding) and weedy check. The result showed significant ($p < 0.05$) reduction of the population density of the dominant annual weeds species: *Snowdenia polystachya, Avena fatua, Setaria pumila, Phalaris pradoxa, Galinsoga parviflora, Polygonum nepalense, Raphanus raphanistrum, Bidens pilosa, Guizotia scabra, Plantago lanceolata* and *Caylusea abyssinica* by pre-emergence application of s-metolachlor @ 1.0 l ha^{-1} with persistent control for prolonged time after application. The highest mean grain yield (2500 kg ha^{-1}) was obtained from farmers' practice followed by s-metolachlor (2300 kg ha^{-1}) with yield advantage of 55% over the weedy check treatment (Zewdie *et al.*, 2013).

Cow pea

During the early stage of the crop (3 WACE) pre-emergence application of s-metolachlor @ 2.0 kg ha^{-1} performed better at Jari and Sirinka with significant reduction of broadleaved weeds, sedge and total weed density (Mekonnen *et al.*, 2015). Pendimethalin failed to control the dominant weed species: *Commelina benghalensis* and *Xanthium strumarium*. The sequential pre-emergence application of the low doses of s-metolachlor and pendimethalin + one hand weeding at 55 DACE were as effective as the complete weed free treatment in reducing the broadleaved weeds and sedge density (Table 16).

The minimum weed dry weight was registered with the application 2.0 kg ha^{-1} of s-metolachlor in both locations; however, at 8 WACE and harvest, weeds accumulated significantly lower dry weight due to s-metolachlor and pendimethalin each @ 1.0 kg ha^{-1} supplemented with hand weeding. The maximum seed yield (4277 kg ha^{-1}) was obtained in the complete weed free treatment at Sirinka which was statistically equivalent with the complete weed free and two hand weeding treatments at Jari and Sirinka sites respectively. The weedy check treatment plots gave yield reduction of (70.8 and 47.5%) at Jari and Sirinka respectively. The highest gross benefit was obtained with the application of s-metolachlor @ 1.0 kg ha^{-1} + one hand weeding followed by two hand-weeding at 2 and 5 WACE (Table 17). Hence, results of this study indicated that managing the weeds with the application of s-metolachlor @ 1.0 kg ha^{-1} + one hand weeding / hoeing (5 WACE) proved to be the most profitable practice with highest net benefit (42879 ETB ha^{-1}) (Table 17). However, under the condition of labour constraint and timely availability of the herbicide, pre-emergence application of s-metolachlor @ 2.0 kg ha^{-1} should be used to preclude yield loss and to ensure maximum benefits (Mekonnen *et al.*, 2015).

Table 16. Effect of weed management practices in cowpea on weed density (m^{-2}) and weed dry biomass (g m^{-2}) at harvest and interaction effect of location and weed management practices on grain yield (kg ha^{-1}) and yield loss (%) in cowpea in 2013 main cropping season at Jari and Sirinka.

Weed management practices	Total Weed density at harvest (m^{-2})		Weed dry biomass weight at harvest (g m^{-2})		Grain yield (kg ha^{-1})		Yield loss (%)	
	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka	Jari	Sirinka
S-metolachlor at 1.0 kg ha^{-1}	136.7d	43.00c	312.3d	138.7b	1750l	2595hij	55.4b	39.4cde
S-metolachlor at 1.5 kg ha^{-1}	3.00de	73.0e	209.9e	98.7c	2144kl	3080efg	44.7cd	28.0fg
S-metolachlor at 2.0 kg ha^{-1}	1.67de	13.3f	146.9g	102.0c	2327ijk	3185def	39.9cde	25.6gh
Pendimethalin at1.0 kg ha^{-1}	4.33d	192.7c	541.0c	130.2bc	2373ijk	2582hij	39.2cde	39.6cde
Pendimethalin at1.3 kg ha^{-1}	13.67c	231.3b	574.4b	142.1b	1322m	2696ghi	66.1a	36.9 def
Pendimethalin at1.6 kg ha^{-1}	17.67b	186.0c	581.5b	144.8b	1282m	2555hijk	67.1 a	40.1cde
S-metolachlor at 1.0 kg ha^{-1}+ hand weeding at 5 WACE	3.00de	2.7f	43.5i	29.0d	3595cd	3769bc	7.9ij	11.8i
Pendimethalin at1.0 kg ha^{-1}+ hand weeding at 5 WACE	3.00de	1.3f	38.1i	32.3d	3017fg	3614bc	22.7gh	15.3hi
One hand weeding at 2 WACE	2.33de	67.3e	170.4f	126.8bc	2312ijk	2969fgh	40.1cde	30.5efg
Two hand weeding at 2 and 5 WACE	2.67de	8.0f	110.0h	98.0c	3452de	3864abc	11.6i	9.5ij
Weed free check	0.00e	0.0f	0.0 j	0.0d	3907ab	4277a	0.0j	0.0j
Weedy check	24.33a	370.0a	906.3a	247.6a	1134m	2241jk	70.9 a	47.5bc
LSD (%) L x WMP	3.37	20.28	16.36	32.30	422.0		10.57	
CV (%)	29.9	11.2	3.2	17.7	9.3		19.6	

CV= coefficient of **v**ariation, LSD= least significant difference, DAE= days after emergence, WAE= weeks after emergence. Means in columns of same parameter followed by the same letter(s) are not significantly different at 5% level of significance; **Source**: Mekonnen *et al.* 2015

Table 17. Partial budget analysis of weed management practices in cowpea based on total variable cost in main cropping season of the year 2013

Weed management practices	Total variable Cost (ETB ha^{-1})	Average yield (kg ha^{-1})	Adjusted yield (kg ha^{-1}) 10% down	Gross benefit (ETB ha^{-1})	Net Benefit (ETB ha^{-1})
S-metolachlor at 1.0 kg ha^{-1}	3935	2172.4	1955.2	29328	25393
S-metolachlor at 1.5 kg ha^{-1}	4841	2612.1	2350.9	35264	30423
S-metolachlor at 2.0 kg ha^{-1}	5283	2756.0	2480.4	37206	31923
Pendimethalin at1.0 kg ha^{-1}	5589	2477.5	2229.8	33447	27858
Pendimethalin at1.3 kg ha^{-1}	5339	2009.0	1808.1	27122	21783
Pendimethalin at1.6 kg ha^{-1}	5581	1918.6	1727.4	25911	20330
S-metolachlor at1.0 kg ha^{-1}+ HW at 5 WAE	6828	3682.0	3313.8	49707	42879
Pendimethalin at1.0 kg ha^{-1}+ HW at 5 WAE	7430	3315.8	2984.2	44763	37333
One hand weeding at 2 WAE	5620	2640.5	2376.5	35648	35649
Two hand weeding at 2 and 5 WAE	7742	3658.4	3292.6	49380	41638
Weedy check	2642	1687.3	1518.6	22779	20137

*Cost o*f s-metolachlor 417 Birr kg^{-1}; cost of pendimethalin 620 Birr kg^{-1}; Spraying Birr 99 ha^{-1}; Cost of hand weeding and hoeing 2 WAE 45 persons, 5 WACE 16 persons @Birr 33 $person^{-1}$; Sale price of cowpea Birr 15 kg^{-1}; Field price of cowpea (sale price- variable input cost-harvesting, threshing and winnowing Birr 165 100 kg^{-1}; packing and material cost Birr 4.0 100 kg^{-1}, transportation Birr 5 100 kg^{-1} ; ETB= 0.0498 USD; **Source**: Mekonnen *et al.* (2015)

Common bean

The study was conducted at Melkassa Agricultural Research Center during 2011–2013 crop seasons to determine the effect of weed managements, common bean varieties (Awash-1 and Nasir) and their interaction on weeds, and crop yield and yield components. Results revealed that, weed density and dry matter weight were significantly influenced by weed managements. The highest (129.50 m^{-2}) and the lowest (69.50 m^{-2}) weed density were recorded from weedy check and s-metolachlor at 0.96 kg ha^{-1} + hand-weeding respectively. Comparison of weed managements showed that the lowest weed dry matter (114.72 gm^{-2}) was recorded from the application of s-metolachlor with HW at 45 DAS while the highest weed dry matter (349.50 gm^{-2}) was obtained from weedy check. The highest weed control efficiency (67.17%) was obtained from combined use of s-metolachlor with supplementary HW (Table 18). The effect of crop varieties, weed managements and their interaction showed significant difference ($p<0.05$) on yield components and grain yield. The highest grain yield was obtained from s-metolachlor plus HW while the lowest grain yield was obtained from weedy check (Table 19). The relationship between weed dry matter and grain yield showed significant negative correlation. Interaction effects of years, variety and managements showed non-significant ($p <0.05$) difference for all parameters. The effect due to varieties and the interaction of variety and weed management did not show significant difference on weed density and dry matter though the yield components and grain yield were significantly affected (data not shown). This might be due to similar plant architecture or leaf canopy closure but difference in yielding potential of the test varieties. Hence, similar weed control practices can be recommended for both varieties (Fufa and Gebermariam, 2016).

Table 18. Effect of weed management and variety on weed density, weed dry matter and weed control efficiency

Management Practice	Density *(no m-2)*	Dry matter (g m-2)	WCE (%)	*Grain yield (kg ha^{-1})*	
				Awash-1	Nasir
Weedy check	129.50a	349.50a	0.00e	532.31^{h}	628.32^{h}
Twice HW at 25 & 45 DAS*	70.50e	118.57d	67.78a	2173.79^{c}	2575.35^{b}
S-metolachlor @ 0.96 kg ha^{-1}	119.11c	215.50c	34.72c	1828.39^{d}	1920.92^{d}
Glyphosate @ 1.08 kg ha^{-1}	123.28b	328.39b	26.44d	851.27^{g}	997.17^{f}
S-metolachlor @ 0.96 kg ha^{-1}+HW (45 DAS)**	69.50e	114.72d	69.94a	2244.53^{c}	2715.23^{a}
Glyphosate @ 1.08 kg ha^{-1}+HW (45 DAS)	73.44d	127.27d	64.94b	1002.71^{f}	1291.41^{e}
Mean	97.56	208.99C	41.97	1438.83^{B***}	1688.06^{A}
CV (%)	2.26	10.21	12.69	7.20	

*Standard check; **DAS-days after sowing; **Source**: Fufa and Gebermariam (2016)

Table 19. Mean grain yield and yield components as influenced by the interaction of management practices and common bean varieties

Management Practice	*Grain yield (kg ha^{-1})*		*Pod plant^{-1}*		*Seed pod^{-1}*		*100 seed weight (g)*	
	Awash-1	Nasir	Awash-1	Nasir	Awash-1	Nasir	Awash-1	Nasir
Weedy check	532.31^{h}	628.32^{h}	6.24^{gf}	6.87^{f}	532.31^{h}	628.32^{h}	6.24^{gf}	6.87^{f}
Twice HW at 25 & 45 DAS*	2173.79^{c}	2575.35^{b}	9.56^{c}	11.06^{b}	2173.79^{c}	2575.35^{b}	9.56^{c}	11.06^{b}
S-metolachlor @ 0.96 kg ha^{-1}	1828.39^{d}	1920.92^{d}	9.41^{c}	10.97^{b}	1828.39^{d}	1920.92^{d}	9.41^{c}	10.97^{b}
Glyphosate @ 1.08 kg ha^{-1}	851.27^{g}	997.17^{f}	6.81^{f}	6.60^{gf}	851.27^{g}	997.17^{f}	6.81^{f}	6.60^{gf}
S-metolachlor @ 0.96 kg ha^{-1} +HW (45 DAS)**	2244.53^{c}	2715.23^{a}	10.84^{b}	14.05^{a}	2244.53^{c}	2715.23^{a}	10.84^{b}	14.05^{a}
Glyphosate @ 1.08 kg ha^{-1} +HW (45 DAS)	1002.71^{f}	1291.41^{e}	7.53^{e}	8.63^{d}	1002.71^{f}	1291.41^{e}	7.53^{e}	8.63^{d}
Mean	1438.83^{B***}	1688.06^{A}	8.40^{B}	9.70^{A}	4.01^{B}	4.55^{A}	17.33^{B}	17.88^{A}

* Standard check; ***DAS- days after sowing; ***capital letter 'A' And 'B' indicate mean difference between varieties*
Source: Fufa and Gebremariam (2016)

Conclusions

Limited progress has been realized in the legume weed management both at scientific investigation including on investigating effective chemical options. So, all the works reported are dependably linked to traditional practice combinations. The weed control methods are limited by level of technological advancement, prevailing cropping systems, climatic and soil conditions and also by the resource base of small scale farmers. Efforts towards introducing chemical weed control were not successful due to lack of priceworthy and effective broad-spectrum herbicides for controlling annual grassy and broadleaf weed species. Judicious application of hand weeding practice was the core component of the overall integrated weed control recommendations in food legumes production over the years. Hence, concerted efforts must be made to select and integrate compatible and effective technologies into packages that would enable to deal with the dynamic changes in weed flora, which will occur in the future due to changes in cropping systems and crop management practices.

The major weed management research needs, and priorities are suggested as follows:

- The species of weeds that commonly infest food legumes vary with changing production environments. Soil characteristics, moisture amount, precipitation pattern, crop rotation, temperature, latitude, altitude, soil fertility, weed control technology and other factors interact to determine weed flora and intensity. In this context, periodic weed surveys to update their incidence, distribution and extent of losses are recommended particularly for areas and pulse crops not previously covered.

- In view of the increasing weed status and potential risks of invasive alien and other naturalized problematic weed species to food legumes production there is a need to develop prevention and control measures through which an integrated management can be formulated for the following species of priority importance: *Parthenium hysterophorus*, *Xanthium strumarium*, *Raphanus raphanistrum*, *Chrysanthemum segetum*, *Covolvulus arvensis*, *Snowdenia polystachya*, *Avena fatua*, *Bromus pectinatus*, *Bidens pachyloma*, *Cichorium intybus*, *Cyperus esculentus* and *Cyperus rotundus.*

- Except of one species specific study reported in this review all the past determinations of critical weed-crop competitions and crop loss assessment studies in food legumes were done under mixed weed population situations. Thus, more crop-weed competition and loss assessment investigations are required to be done under specific weed species invasions. Particularly parasitic weeds that seriously attacking legume crops in different parts of the country need to be well addressed with special attention to minimize their existing impact at the infested areas and prevent further expansion to new areas.
- Despite some technical limitations in its adoption in certain areas, chemical weed control in food legumes is promising. In the Ethiopian case, the present trend indicates that chemical weed control is must for large-scale commercial production of food legumes in the country. To date there are very few pre-emergence herbicides registered in some major food legumes like common bean, soybean and faba bean. Post-emergence herbicides particularly those for broad-leaf weeds are few. The new post-emergence herbicides for grasses seem effective though the choice is limited and thus, there is a need to identify more effective herbicides with broader spectrum of weed control and wide adaptability in the major food legume crops: Common bean, soybean, faba bean, lentil and chickpea. In line with this, integrated approach studies involving herbicides, and cultural and agronomic practices to improve crop competitiveness is needed to develop effective and economic control measure. The application of herbicides must be done with a great care to avoid crop phytotoxicity. Residual effect of herbicides and their effect on biological nitrogen fixation or cereals in rotation following food legumes should be given due attention before selecting herbicides as components of weed control package.
- Developing integrated crops management and weed control methods through multi-disciplinary approach should be the central theme in future pulse crops weed management research undertakings. Greater emphasis should be given to research capacity building, and generating and promoting comprehensive and applicable package of technologies that are sustainable and could effectively address the complex problem of food legumes weeds in the country.

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Emerging Pests of Grain Legumes in Ethiopia

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Abstract

In Ethiopia, grain legumes account for about 13 % of cultivated land and are critical to smallholder livelihoods income, food source and animal feed. Currently, production of grain legumes crop is highly constrained by emerging crop pests such as Faba bean gall (FBG), parasitic weeds and pea weevil. FBG, which was first reported from Far East (Japan and China), is a new epidemic plant disease to Ethiopia. The disease has now spread all over the faba bean growing areas and is threatening faba bean production. The disease was identified as FBG caused by the pathogen **Olpidium viciae** *Kussano. Management options have been reported from different research centers. The pea weevil (***Bruchus pisorum** ***L***.*) limits field pea production, especially in the northern and central part of Ethiopia. It causes up to 60-85% reduction of yield annually. Varietal screening and other management strategies were evaluated since its occurrence. Broomrape, the complete root parasitic weed is the other major yield constraint to grain legume crop globally. Crenate broomrape (***Orobanche crenata** *Forsk.) being the most damaging and widespread in Ethiopia (specifically in Amhara and Tigray regions) with estimated yield losses of 75-100%. A tolerant variety "Hashenge" was released for production in* **O. crenata** *infested areas. The variety consistently gave higher yield by 141% over the susceptible check (ILB 1814), 211% over local variety and 247% over Walki (standard check) and lower broomrape count than local.*

Keywords: Broomrape, faba bean gall, grain legume, new pests, pea weevil

Introduction

Grain legumes share approximately 13.2 % of cultivated land and about 10.4 % of the grain production in Ethiopia (CSA, 2015). Other than their use as food, sources of incomes and livestock feed, they play key roles for sustainable cereal production through improving soil fertility and health (Agegnehu *et al*. 2008). Grain legumes also play important role in fetching foreign currency after coffee and oil crops (NBE, 2015).

The current average productivity of grain legumes in Ethiopia is less than 2t/ha but it is planned to increase productivity to 2.3 t/ha by 2019/20 (GTP II, 2016). The yield gaps of all the important grain legume is very large due to various biophysical and technological factors. Pests are among the major biophysical factors that limit the production and productivity of grain legumes. Although the breeding activities focus on developing resistant cultivars for resident pests (insect pests, diseases and parasitic weeds), grain legumes are facing many challenges due to introduction of new pests and re-merging of minor pests (Table 1). The newly emerged pests are Faba bean gall (FBG) and parasitic weeds in faba bean, and pea weevil in field pea. The status and significance of these pests is reviewed in this paper.

Table 1. Number of insect pests, diseases and parasitic weeds reported on grain legumes in Ethiopia

Grain pulse Crops	Recorded pest		
	Insect*	Diseases*	Parasitic weeds
Faba bean	8	26	*Orobanche minor, O. ramose , O. crenata*
Field pea	6	23	*O. ramose, O. crenata*
Chickpea	9	17	*O. ramose, O. crenata*
Cowpea	8	4	INF
Lentil	7	20	*Orobanche ramose, O. crenata*
Common bean	15	10	INF
Soybean	7	3	INF
Grass pea	INF	8	INF
Mung bean	5	4	INF
Adzuki bean	INF	INF	INF
Fenugreek	INF	7	INF
Lupin			
Pigeon pea			

* INF=Information not found; Abate T (1985) and Stewart and Yirgu (1967)

Emerging pests of grain legumes

Faba bean gall (faba bean blister)

Faba bean gall (FBG), caused by *Olpidium viciae* Kusano in the class Chytridomycota, was first reported from Far East (Japan and China) (Xing, 1984; Li-juan, 1993). Although there is no exact record of FBG on faba bean, it was not known in Ethiopia before 2009. It was first reported from very few fields in North Shewa highlands (Degem area) in July 2010 (Gorfu *et al*., 2012). Two years later, it became epidemic in neighboring places and spread widely in different parts of the country.

Detection survey in main faba bean producing areas was carried out by Hailu *et al*. (2014) in 2013 cropping season. The disease was found wide spread in northeast and northwest highlands of the country. The mean disease severity index in Amhara, Tigray and Oromia region was 22.2%, 11.3% and 7.8%, respectively; while the prevalence (%) in north Shewa of Oromia region was 95.2, 91.7 in north

Shewa of Amhara region, 86.7 in south Wollo, and 85.7 in south Tigray. The severity of the disease is directly related to altitude and becomes severe at an altitude ≥ 2400 m a.s.l. (Hailu *et al*., 2014). While Hailemariam *et al*. (2016) reported that plant growth stages, plant density, weed population, soil type and drainage system have similar effect on the disease incidence and severity as does altitude. High disease incidence and severity were positively associated with high plant population, high weed density, and bad drainage system.

The pathogen

Based on light microscopy and field symptom the causal agent of the disease was identified as *O. viciae* by Dr Dereje Gorfu and his team at Holetta Agricultural Research Center (Gorfu *et al*., 2012). Morphological identification was done further at Ambo Plant Protection Research Center in consultation with Department of Crop protection in Bioscience Engineering Faculty of Ghent University, Belgium. Also the causal agent of FBG is *Olpidium viciae* (Kusano), which was first reported in 1912 in Japan on faba bean, attacks field pea (Xing, 1984). Yan and Hua (2012) reported that zoosporangiums reproduce constantly after the disease occurred in field; liberate zoospores with the presence of rain or dew for secondary infection, which cause highly repeated secondary infections.

Faba Bean Gall Disease Innoculum Sources

Crop residues and soil from previously faba bean sown fields had higher inoculum load of faba bean gall disease and inoculum free seeds planted in this fields showed symptom starting from the first month (unpublished). The severity was higher in the mid rainy season, but becomes lesser as the season progresses. Seeds from faba bean gall infected faba bean field, where the soil and the residue were collected, did not develop disease symptom when sown on sterile soil.

Faba bean gall management

Fungicides including Mancozeb, Ridomil, Chlorotalonil, Bayleton wp 25 (Triadimefon 250 g/ kg), Thiram, and Apron star were tested and high yield and low disease severity were obtained on Baylaton (3129.8 kg), Ridomil gold (2708.3 kg) and Mancozeb (2705.7 kg) sprayed fields.

In field trials, Wondwosen (2015) found that three times application of Metalaxyl 8% + Mancozeb 64% and Triadimefon 250 g/l reduced disease severity on faba bean. Bitew and Tigabie (2016) reported that three times application of Baylaton, Ridomil gold and Mancozeb each at seedling, flowering and podding growth stage reduced yield losses cause by FBG. The foliar application of Baylaton on varieties Adet Hana, Nc58, Kassa and Bulga 70 significantly reduce the disease severity at Farta and Tach gayint (Gonder) (Alemu and Tadele, 2017). Baylaton 25WP, Ridomil Gold MZ 68

WG, and Mancozeb 80% WP (each 2-4 spray) sprayed in combination with copper fungicide (Aster) were tested and the combination of Baylaton and Ridomil were effective (Abebe *et al*., 2018).

Difference in inherent genetic resistance of faba bean varieties to FBG, locally known as "*Qormid*", was reported by Wondwosen (2015). Varietal screening is being undertaken by Ethiopian Institute of Agricultural Research and Addis Ababa University.

Pea weevil (*Bruchus pisorum*)

The pea weevil, *Bruchus pisorum* (Coleoptera: Chrysomelidae) is neither true weevil nor true storage pest. It is distributed in the central and northern part of pea growing areas and globally it is reported almost in all continents.

There are conflicting views on the time at which pea weevil was first reported and the way it was introduced to Ethiopia. Thus, according to Scheepers (2012) it was first documented in 1985 and it is believed that it was accidentally introduced in the mid 1970s possibly with food aids (Abate, 2006; Scheepers, 2012). Others speculate that the insect might have been introduced with military rations and armaments during the civil war (Seyoum *et al.*, 2010). Currently, he pest has been reported in many field pea producing regions in the country.

Adult pea weevils enter field pea fields in early August and they feed on pollen as field pea plants begin flowering (Assayehegne, 2002). On average, the insect start laying eggs about two weeks after invading flowering field pea fields. The eggs are deposited singly or in small clusters on the outer part of green pea pods. The yield losses attributable to pea weevil ranged from 45-80% in Gonder and Wag Himra zones (Bekele *et al.,* 2006). It also causes about 30% reduction in germination when infested seeds are used for planting (Tadesse, 2008).

Pea weevil Management

Destruction of infested crop residues, early planting and harvesting earlier reduces the incidence of pea weevil in fields; while in the storage, seed fumigation is the best pea weevil management method (Capinera, 2001). Intercropping of field pea with chickpea, grass pea and lentil showed a reduction of 10% grain damage. Some efforts were made to select field pea lines resistant to pea weevil and some lines were selected (Mulatu, 2012; Teshome, 2015).

Pea weevil management is predominantly done by the use of insecticides when the crop is at flowering stages while insects are feeding on pollen. A single spray of cypermethrin applied to plots in a field pea crop at the rate of 40 g a.i./ha and endosulfan at the rate of 350 g a.i/ha reduced damage by pea weevil from 11% in the unsprayed plot to 4%; peas sprayed with methomyl (340 g a.i./ha) or fenvalerate (40 g a.i./ha) suffered

6% and 8% damage, respectively in Australia (Horne and Bailey, 1991).

Parasitic weeds (*Orobanche* sp.)

Broomrapes (locally known as *Yejib ras* or *dimerch*) are root parasites, which are completely dependent on the host due to the lack of chlorophyll and functional roots. Several broomrape species are known infect faba bean, lentil, field pea, chickpea, vetches and grass pea; although crenate broomrape (*Orobanche crenata* Forsk.) is the most damaging and widespread in northern Ethiopia (Tadesse, 2008). The damage caused by this parasitic weed is significant and estimated yield losses ranged from 75 to100% depending on host susceptibility, level of infestation and environmental conditions. Consequently, farmers in highly infested areas generally avoid growing cool-season food legume crops, resulting in substantial reductions to both the extent of cultivated areas and to food legume production (Besufikad *et al*., 1999; Fessehaie and Leta, 2006; Abebe *et al*., 2013; 2015). Parasitic weeds did not affect fenugreek and common bean. A healthy broomrape plant can produce 200,000 seeds and in exceptional cases, half a million. These seeds remain latent in the soil until they recognize the presence of a host root. The parasitic weed was introduced into Ethiopia in 1986 with seed (Damte, 2012). *O. crenata* is an actual and potential threat to faba bean production in North Wello, South Wello, South Gonder and South Tigray (Abebe *et al*., 2013).

Parasitic weed Management

Although parasitic weeds are spreading in major cool-season food legume areas of northeast and northwest part of Amhara region and many zones in Tigray, there are no strong research endeavors aimed at developing and extending management options to farmers. Farmers in south Wollo have replaced cool season food legumes with common bean and fenugreek, which are not affected by the parasite. The current recommended management practice elsewhere on faba bean is two applications of low dosage of Glyphosate 80 g a.i/ha at flowering stage supplemented with one hand weeding (El-Rokiek *et al.*, 2015). A cultivar “Hashenge” (ILB4358), which is moderately resistant to parasitic weed, was released in 2015 (MoANR, 2016) (Figure 1). The variety is adapted to highland faba bean growing areas of South Tigray and Amhara regions and similar agro-ecologies across Ethiopia, especially in areas infested with parasitic weeds. In highly infested soil, one to two times glyphosate application at flowering stage is recommended to maximize yield.

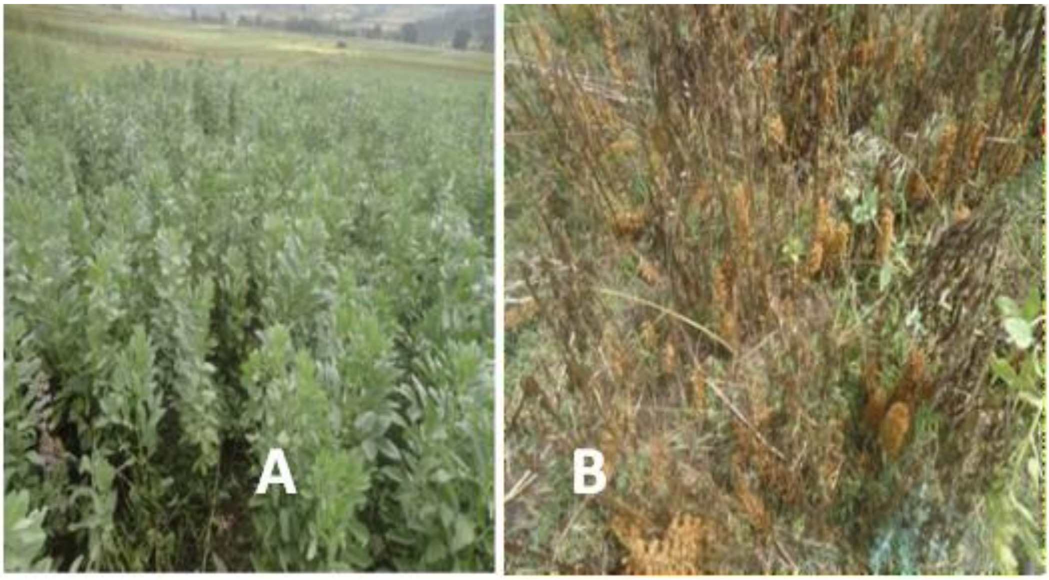

Figure 1. Management of *Orobanche crenata* using host plant resistance. A. parasitic tolerant cv. Hashenge and B. susceptible variety

Conclusion

The review clearly revealed that newly emerging pest posed aggressive problems on legumes production and productivity in Ethiopia and aggressive research and development measures are required to overcome them. The problems they pose are also not challenges themselves are also not static but, dynamic. As it is difficult or impossible to overcome them for a single country, single institute, single disciple and single method, concerted, integrated and consistent efforts are required at global level among universities, CGIAR Centers and agricultural research institutes.

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Part V. Agricultural Economics, Seed System and Extension Research in Food Legumes of Ethiopia

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Adoption of Improved Grain Legume Technologies in Ethiopia: Implications for Research, Extension and Seed System

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Abstract

This paper presents the status of adoption of improved legume technologies and national yield gaps in Ethiopia based on review of available literature. The coverage and scope of the adoption estimates are based on the available literature, which is in general limited due to the inadequate emphasis given to assess the adoption studies of these crops. Accordingly, the estimates are either at national or regional level in terms of area coverage and some are general at crop level and other estimates are at varietal level with diverse methods of estimation. The estimates show adoption of few old varieties across the different pulse crops, huge variability of adoption levels across the different pulse crops and farming systems, and considerable yield gaps compared to the potentials. These results imply the need to (i) enhance investment in demand creation for newly released varieties, (ii) explore different mechanisms for improved access to varieties; and (iii) promote integrated seed system where both the formal and informal seed systems co-exist to ensure increased adoption and narrowing the national yield gaps.

Keywords: Adoption, grain legumes, seed system, yield gap

Introduction

The Ethiopian Agricultural Research System (EARS) has invested significantly in research for the last several decades to develop improved grain legume varieties and complementary crop management practices (agronomy, crop protection and post-harvest), if adopted, would substantially increase production and productivity (Yirga and Alemu, 2016). Although a wide range of grain and forage legumes have been the focus of the research and development efforts, emphasis has been put on faba bean, field pea, chickpea, lentil and haricot been. These improved technologies have been made available to smallholder farmers through the national agricultural extension system and various technology scaling projects (Kassa and Alemu, 2016). Also, as a crucial means of ensuring access to available crop technologies, there has been considerable public engagement in the national seed system. However, available literature indicates the weak performance of the national seed system to ensure the availability of quality seeds of demanded crop varieties (Bishaw *et al*., 2008; Alemu *et al*., 2010). Furthermore, to ensure accountability for the investments made as well as guide future research and development endeavours, a number of technology adoption studies were conducted (Abebe and Bekele, 2015; Yirga *et al*., 2015, 2016; Bishaw and Alemu, 2017) to measure success towards reaching the national goals of reducing rural poverty, increasing food security and nutrition and improving foreign currency earnings.

Despite considerable investments in improving the technology generation, capacity of the research system, enhancing the effectiveness of the agricultural extension services and creating a vibrant and dynamic national seed system, wide spread use of grain legume technologies is limited (Odame *et al*., 2013).Consequently, the yield gaps between research-managed on-farm trials and national yield levels are still very high across all crops and agro-ecologies including grain legumes (Spielman *et al*., 2010). These anomalies trigger the need to better understand the level of use of improved legume technologies and the factors responsible for the low uptake.

This paper, based on a review and synthesis of improved grain legume adoption studies conducted in Ethiopia, documents the most important cases of farmers adopting new varieties and the yield impacts of legume technologies. The report also identifies research and development gaps that deserve due attention in future technology generation and promotion endeavours.

Methodology

The paper is based on a review and synthesis of grain legume technology adoption studies conducted by various individuals and institutions affiliated with the national agricultural research system. The review considered several commodities and employed complementary data collection techniques that capture the diverse nature of the commodities and hence the technologies considered. Overall, previous studies collected data in several ways including household surveys, community focus group discussions and expert surveys. In all cases, the collected data were from randomly drawn representative sample farm households. While household surveys form the basis for the adoption studies, in some cases data were collected from community surveys and experts in an attempt to compare with household responses (Yirga *et al.*, 2015).

The adoption literature suggests that several indicators are often used to illustrate the degree of use of improved agricultural technologies depending on the unit of analysis (Glover *et al*., 2016; Yirga *et al*., 2015; Doss, 2003). When the unit of analysis is a farm household, then the estimation would be the proportion of households using improved crop varieties. In case of land allocation, the estimation would be the proportion of total cultivated land covered with improved crop varieties. In case of estimation using a plot as a unit of analysis, the estimation could be presented in three ways assuming that a household has two or more plots allocated for the same crop. These are (i) full adopters, farmers who use improved crop varieties on all plots, (ii) partial adopters, farmers that allocate part of the plots with improved varieties, and (iii) non-adopters, who have not used improved varieties. 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.

Results and Discussion

Adoption estimates

Among the grain legumes, adoption studies concentrated on faba bean, field pea chickpea, lentil and common bean. Summary of results of recent adoption studies of these commodities are presented in Table 1. In general, the estimates indicate low level of adoption with considerable variations among the crops and across regions. Higher adoption estimates in some regions and locations suggest the localized nature of promotion efforts of improved legume varieties (e.g. chickpea and lentil in East Shewa).

Table 1 Estimates of adoption of improved varieties of major pulse crops

Crop	Estimated adoption rate (%)	Indicator	Area coverage	Year	Source
Chickpea	19.4	% of national chickpea area	National	2013	Yirga *et al*., 2015
	17.4	% of chickpea producers			
	25.6	% of chickpea area	Oromiya		
	20.0	% of chickpea area	Benishangul Gumuz		
	7.0	% of chickpea area	Amhara		
	4.0	% of chickpea area	SNNP		
Lentil	12.5	% of lentil producers	National	2013	Yirga *et al*., 2016
	15.6	% of lentil area			
	2.6	% of lentil producers	Amhara		
	2.2	% of lentil area	Amhara		
	30.1	% of lentil producers	Oromia		
	38.6	% of lentil area	Oromia		
Faba bean	19.6	Full adopters	National	2014	Bishaw & Alemu, 2017
	1.9	Partial adopters			
	22.38	% of faba bean area			
Common beans	79	% of common bean producers	Central Rift Valley	2015	Abebe & Bekele, 2015

A national chickpea varietal adoption study based on household survey revealed that about 17.4% chickpea growers used improved varieties on about 19.4% of the chickpea acreage. Nonetheless, intensity of adoption measured as proportion of chickpea area under improved varieties varied considerably across regions, ranging from 4% in SNNPR to 25.6% in Oromia. Further scrutiny of the data at zonal level indicate that, 3 out of the 9 most important chickpea growing zones included in the study, namely; North Shewa of Amhara region, East and West Shewa Zones of Oromia Region has the highest intensity of adoption of over 30% of the chickpea area.

Despite the release of a fairly good number of improved varieties, however, use of improved lentil varieties by smallholder farmers is still low. At a national level, adoption estimates based on household survey indicated that the adoption rates measured as proportion of households and area share of improved lentil varieties is low across the study locations estimated at 12.5% and 15.2%, respectively (Yirga *et al*., 2016). At a regional level, the share of lentil area under improved varieties is much better in Oromia with 38.6% compared to Amhara region estimated at 2.2% reflecting the influence of on-farm demonstrations and pre-scaling up activities conducted in the former. Further disaggregation of the data by zone revealed that adoption rates, are highest in East Shewa and West Shewa Zones of Oromia Region and North Shewa Zone of Amhara Region all of which are closer to Addis Ababa and have been the main targets of outreach programs of the lentil improvement program.

District level adoption figures also reveal that adoption of improved lentil varieties varied considerably within zones signifying adoption estimates at zonal level hide interesting results. At a national level, house hold and area weighted adoption rates are estimated at 12% and 15.6%, respectively (Yirga *et al*., 2016). In terms of efficacy of approaches, estimates from the expert panel, community and household survey correspond 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 (Yirga and Alemu, 2016).

Similarly, the adoption rate of improved varieties of faba bean, measured as share of land allocated to improved varieties is estimated at 22.4% while the proportion of households using improved varieties on all plots stand at 19% (Bishaw & Alemu, 2017).

Linked with the low adoption is the extent of use of released varieties. For example, a closer look at the most dominant improved chickpea varieties in terms of both area coverage and number of farmers that adopted them reveals that the top three improved varieties, namely; Arerti, Shasho and Habru cover more than 85% of total national area under improved chickpea varieties. Based on the household survey results, Arerti is the single most adopted variety covering 54% of total national chickpea area under improved varieties followed by Shasho covering 30% of total national chickpea area under improved varieties. These results are consistent in both the expert estimates as well as in the formal household survey results. As indicated in Table 2, the few varieties that are reported by the farmers are older varieties.

Table 2.Extent of varietal use in grain legumes in Ethiopia

Crop	No of varieties reported by farmers	Major varieties	% of farmers adopting	Year of release
Chickpea	Nine varieties of 23 released varieties	Arerti	9.61	2000
		Shasho	5.23	2000
Lentil	Two varieties of 11 released varieties	Alemaya	11.42	1998
Faba bean	Six varieties of 31 released varieties	CS-20–DK	2.54	1977
		Degaga	2.23	2002
Field pea	Three varieties of 35 released varieties (% of total area)	Adi	1.10	1995
		Mohanderfer	0.37	1979
		Tegegnech	0.06	1994
Haricot bean*	Five varieties from 57 varieties released	Awash 1	39.5	1990
		Awash Melka	5.6	1998
		Nasir	47.4	2003

Note: *Represents estimates from rift valley areas of the country (Melkassa Agricultural Research Center, 2016)

The limited literature available present diverse factors for the low level of adoption of new and old varieties (Doss, 2003; Alemu *et al*., 2010; Lakew and Alemu, 2012; Odame *et al*., 2013).

Among others, the key challenges related with the seed system limiting widespread adoption and use of diverse improved grain legume varieties include:

- **The capacity and nature of formal seed system**: The formal seed system in the country has skewed focus to cereals and hybrid varieties. Available data indicate that annually more than 80% of the total volume of certified seed produced in the country is for wheat and maize revealing the limited coverage given to other crops including legumes.
- **Limited investment in demand creation**: Except the attempts of the national agricultural research system, efforts to create demand for recently released varieties are limited. Consequently, awareness on the recently improved varieties

among farmers and hence the revealed seed demand remained very low.

- **Ineffective seed demand assessment and supply**: The formal seed system in the country is based on a bottom up approach where it assumes a farmer demands seed of a single variety. However, there are always shifts in demand given the changes in production and marketing conditions.

Adoption and yield gaps

Available literature allows evaluating the impact of improved grain legume adoption on productivity measured in terms of ton per hectare. Comparison of productivity levels attained at national level, farmers' field with traditional and recommended practices, and on-station with recommended practices may serve as indicators of the availability and access to technologies, knowledge and information, thereby reflecting on the performance of a seed system, other input delivery systems, and extension services (van Ittersuma *et al*., 2013; Spielman *et al*., 2010).

Error! Reference source not found. presents the estimated yield gaps for major grain legumes comparing the national average yield with yield level achieved at research stations and at farmers' fields with recently released variety and recommended management practices. The results clearly revealed substantial yield gaps due to the use of a range of crop management practices for all pulses with significant difference in magnitude across crops.

Chickpea: The national chick pea average yield of 1.83 tonnes per ha is lower than the productivity levels registered at farmers' fields and at research stations with improved variety and recommended practices by 17.5% and 44.8%, respectively.

Faba beans: The national average yield (1.91 tonnes ha^{-1}) is 68% and 88% lower than the yield achieved at farmers' fields with improved variety and recommended practices and at research stations, respectively.

Field pea: The national average yield (1.46 tonnes ha^{-1}) is 105% and 153% lower than the yield achieved at farmers' fields with improved variety and recommended practices and at research stations, respectively;

Lentil: The national average yield (1.33 tonnes ha^{-1}) is 20% and 58% lower than the yield achieved at farmers' fields with improved variety and recommended practices and at research stations, respectively;

Haricot beans (Red): The national average yield (1.56 tonnes ha^{-1}) is 86% and 124% lower than the yield achieved at farmers' fields with improved variety and recommended practices and at research stations, respectively

Haricot beans (White): the national average yield (1.41 tonnes ha^{-1}) is 43% and 66% lower than the yield achieved at farmers' fields with improved variety and recommended practices and at research stations, respectively

These trends indicate the potential of narrowing the yield gap through improved access to varieties and quality seed along with associated extension services on recommended agronomic practices. Further, the trends indicate that with the existing technology, there is huge potential to boost production. For some pulses like field pea and haricot beans, productivity level can be doubled.

Table 3. National yield gaps in major pulse crops

Crop	Average yield (tonnes/ha)			National yield gaps in % against		Variety considered	Source
	Research field	On-farm field with recommended practice	National yield (2016)	Research yield	On-farm yield with recommended practice	1	2
Chickpea	2.65	2.15	1.83	44.81	17.49	Dalota (Desi type)	MoA, 2013
Faba bean	3.60	3.20	1.91	88.48	67.54	Dide'a (EH01048-1)	MoA, 2014
Field pea	3.70	3.00	1.46	153.42	105.48	Bursa (EH05027-2)	MOANR, 2016
Lentil	2.10	1.60	1.33	57.89	20.30	Dembi	MoA, 2013
Haricot beans (red)	3.50	2.90	1.56	124.36	85.90	SER 119	MoA, 2014
Haricot beans (white)	2.34	2.01	1.41	65.96	42.55	Waju	MoA, 2014

Note: Yield at on-station implies yield levels achieved at research stations using improved variety, recommended practices, and researcher managed; on-farm implies yield in farmer's fields with improved variety, recommended practices, and farmer managed; and national yield estimates are from CSA (2016).

Conclusions

This review and synthesis paper revealed that most technology adoption studies were dedicated to estimating the level and intensity of improved variety use among smallholder farmers and the resulting yield gaps. The synthesis indicated that quiet a good number of studies were conducted using nationally representative samples. Furthermore, available studies besides providing adoption rates, illuminated the productivity gaps associated with the various level of use of the grain legume technologies. The synthesis has also brought into light several empirical research gaps that would likely contribute to enhanced technology generation, promotion and adoption by smallholder farmers. These are:

a) The huge variability of adoption levels across the different pulse crops and management systems implies:
   - The need to enhance adoption through stronger research-extension linkages for the different crops;
   - The higher adoption levels based on area compared to respondent which in turn implies the need for different targeting by farm size;

b) The yield gaps across the different adoption cases indicate the need for further investment on priority factors of adoption, which are related with:
   - Access to services (extension, credit, technology promotion events etc); and
   - Improving the performance of the formal seed system

The adoption of few new and old varieties across the different pulse crops implies the lack of demand creation for recently released varieties. To address these challenges, the following interventions are very crucial:

- Enhanced investment in demand creation for newly released varieties;
- Exploration of different mechanisms for improved access to varieties; and
- promotion of integrated seed system where both the formal and informal seed systems co-exist.

The available studies in general focus on assessment of adoption levels with limited targeting of identification of factors that determine the adoption process. Thus, it will be important to fill research gaps through further studies by also considering the demand side factors.

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Production and Marketing of Major Lowland Pulses in Ethiopia: Review of Developments, Trends and Prospects

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Abstract

The major lowland pulses include common bean, cow pea, mung bean, and pigeon pea. They are mainly cultivated in areas with high temperature, erratic rainfall, and short growing season. Farmers make multiple uses of them such as source of protein, animal feed, source of cash and soil fertilizers. Considering its economic importance common bean get more attention in terms of research and development and availability of data on its production, marketing and consumption. Its production, productivity and export value have showed consistent increase during the last decade. Mung bean is the next lowland pulse crop that contributes to national foreign earnings where there has been a sharp growth in the volume and value of export in the last two to three years. Growing demand in the international market resulted in common bean and mung bean to be identified among important export crops in the second Growth and Transformation Plan (GTP II) and to be traded in the Ethiopian Commodity Exchange (ECX) market. Cow pea, mung bean and pigeon pea get limited attention in research and development despite an increasing importance in the world market (mung bean), and strategic significance as feed and food crop (cow pea) particularly in drought prone areas of agro-pastoral farming system. Technology development efforts should target the traits demanded in the market and devise the research strategy accordingly. An in-depth analysis of the value chain, particularly of mung bean is required to understand the market and provide support in improving both the input (seed, fertilizer) and output (grain) markets. For common bean, more efforts are needed to speed up the replacement of old varieties on the hands of farmers. Moreover, expansion of lowland pulses to potential production areas should be carefully designed and a promotion strategy be developed to new areas where comparative advantages prevails.

Keywords: Lowland pulses, common bean, mung bean, cow pea

Introduction

In Ethiopia, lowland pulses comprise a wide range of crops including common bean (*Phaseolus vulgaris L.),* cowpea (*Vigna ungiculata L),* pigeon peas *(Cajanus cajan),* mung bean (*Vigna radiata),* aduziki bean (*Vigna angularis*), lima bean (*Phaseolus lunatus),* cluster bean (*Cyamopsis tetragonoloba*), moth bean (*Vigna aconitifolia*) and black gram (*Vigna *mungo*). They are grown in areas where there is high temperature, erratic rainfall, and short growing season (Amsalu *et al*., 2016). The first four are the major lowland pulses in Ethiopia. Common bean is the most widely grown and has widely adapted from sea level to 3000m above sea level (Broughton *et al*., 2003).Cowpea, pigeon pea and mung bean are heat and drought tolerant with the capacity to thrive and provide harvest in areas receiving below 600mm per annum (Onwoeme and Sinha, 1991).

Common bean is the most important food legume for human consumption globally. In Africa average per capita bean consumption is higher and estimated at 31.4 kg year^{-1} (Schoonhoven and Voysest, 1991). Common bean holds great promise for fighting hunger and poverty in sub-Saharan Africa including Ethiopia. Similarly, cowpea is widely cultivated and consumed particularly in Asia and in tropical Africa (Gebremariam *et al.*, 2009) as it fits well with the low input agriculture of most countries of the continent (Pasquet, 1998; Ba *et al.*, 2004).Cowpea has multiple uses where its seeds, pods and leaves are used as human food or the grains as feed for livestock, depending on economic or climatic situations (Gomez, 2004).

Lowland pulse crops have short maturity period and are useful in filling food supply and cash liquidity gaps during production seasons. Cowpea is known as the "hungry-season crop" because it is the first crop harvested before the cereals (Gomez, 2004). Common bean is preferred by Ethiopian farmers because it matures early enough to generate cash income when most other crops are still in the field (Legesse *et al*., 2006).

Lowland pulses are multipurpose crops providing many benefits to farmers as source of protein, animal feed, cash income and in improving soil fertility through N fixation (Bilatu *et al*., 2012). Lowland pulses are consumed either as grain or vegetables. The dry seed can be prepared in different forms like, *Nifro* (boiled beans) mixed with cereals, flour/split grain to prepare stew (*wat*), whole seed to prepare samosa or soup. All parts of cowpea are used as food where the green pods and seeds are used as vegetables and the grain is also used to prepare several main dishes (Agbogidi and Egho, 2012). Similarly, mung bean is also consumed as dry seeds, fresh green pods or leaves due to its high protein, vitamin and mineral content. It is also consumed as forage or green pods and seeds as vegetables (Tang *et al*., 2014).

Lowland pulses also offer economic benefits to farmers. Common beans and mung beans are among the major sources of income for smallholder farmers in the central rift valley (CRV), eastern, southern and northern parts of Ethiopia (Amsalu *et al*., 2016). Nationally, common bean has a critical role in the economy ensuring food security, export earnings, and employment creation (FAO, 2015). It contributes the highest share of export earnings among all pulses and ranks third export commodity contributing close to 10% of total agricultural export value (FAOSTAT, 2010). Currently, common bean and mung bean are among crops traded on Ethiopian Commodity Exchange (ECX) floor.

In the second Growth and Transformation Plan (GTP II) common bean and mung bean are identified among priority export crops where production and marketing is expected to increase. The plan envisages over 50% increment in the production and productivity of pulses by 2020 including these two crops (MoA, 2015). Although other lowland pulses are not in the priority list, they may ultimately draw attention as they fit well into one of the strategic pillars of the plan related to adaptation to climate change.

Previous research and development efforts have supported the release and commercialization of substantial number of improved varieties of major lowland pulses. To date a total of 75improved varieties were released of which60 (80%) are common bean, 10 cowpea, four mung bean, and one pigeon pea (EIAR, 2016). Common bean has received better attention in terms of research and development.

Moreover, there is national statistics on area, production, consumption, input use for many decades on common bean compared to mung bean where it has records only since 2014, and cow pea and pigeon pea which has none.

Cowpea is grown in drier parts of the country including the central rift valley, dry highlands of Hararghe and in southern and northeastern part of the country (Reddy and Kidane, 1993) whereas pigeon pea is grown in most of these areas including western Ethiopia, these two crops alongside other lowland pulse remain orphan (EIAR, 2016). Their production and marketing is not well recognized. They have not yet drawn enough research and development attention. Nonetheless, Ethiopian farmers cultivate these crops both for human consumption and animal feed.

This paper reviews the production and marketing of major lowland pulses over the last decade. It provides more information on common bean production and marketing but also of mung bean and cow pea based on availability of data.

While reviewing the achievements and challenges over the past ten years, we attempt to look forward on the opportunities and ways to enhance their contribution to household and national economy. Attempts are made to highlight important areas of research and development of major lowland pulses and the way forward.

Methodology

The study relies on national data from Central Statistical Agency (CSA) and complementary sources from FAOSTAT spanning one decade from 2006 to 2016.Published research reports, data retrieved from strategy documents and annual reports of relevant government offices such as the Ministry of Trade (MoT) are also used. The data is analyzed and presented using descriptive statistics, trends, figures, comparisons and geographic distribution. The analysis also draws from the experiences of the authors who are involved in research and development of low land pulses in the country.

Results and Discussion

Geographic distribution of lowland pulses

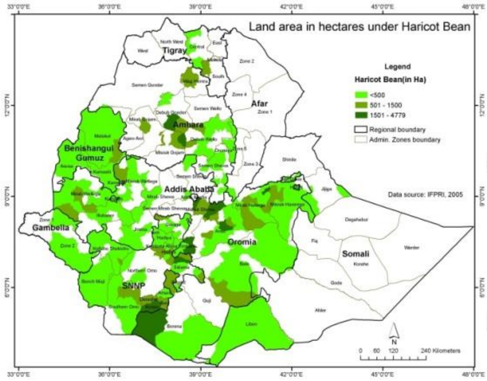
According to CSA (2016) common bean is grown in 10 zones in Amhara, 16 zones in Oromia, 19 zones in SNNPR, three zones each in Benishangul Gumuz and Tigray and two zones in Gambella regions (CSA 2016). Common bean is widely cultivated along the central rift valley of Oromia and Southern Nation Nationalities and Peoples Regions. The production is expanding to the southern, western and northwestern parts of Ethiopia, particularly in Amhara, Gambella, Benishangul-Gumuz, Somali and Tigray regions (Figure 1).

Mung bean is mainly produced in Amhara (North Shewa, Oromia, Argoba Special *wereda*, and South Wolo zones), Oromia (Bale and South-west Shewa zones), Benishangul Gumz (Asosa and Kamashi zones), and Gambella (Agnwak zone) (CSA, 2016).

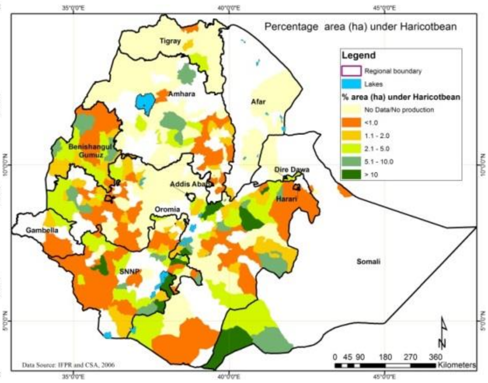
Cowpea is primarily produced in Amhara, Oromia, Tigrai, SNNP and Gambela regions (Alemu *et al.*, 2016; Beshir *et al.*, 2016).

Regional production distribution of lowland pulses

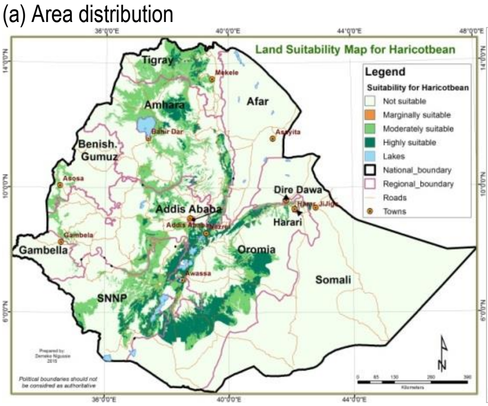
Area and production indicates importance of common bean across regions. The crop is mainly produced in Oromia and SNNP, particularly along the rift valley areas (Alemu *et al.*, 2010). Oromia and SNNP regions remain dominant in the share of total production and area cultivated. While the share of Amhara region has grown between 2006 and 2015that of Benishangul Gumuz region has shown a declining trend. Oromia, SNNP, Amhara and Benishangul Gumuz, contribute almost all production in the county (Table 1).



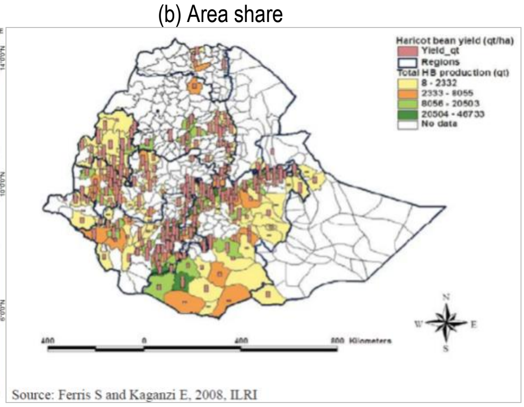
(a) Area distribution



(b) Area share



(c) Potential production areas



(d) Production and yield distribution

Figure 1. Distribution of common bean production in Ethiopia

Table 1. Regional distribution of common bean production

Parameter	Year	Oromia	SNNP	Amhara	BNSG	Others
Area share (%)	2006	46.6	27.6	21.2	2.2	2.4
	2010	47.5	32.4	16	2.5	1.6
	2014	47.1	29.8	20.4	1.3	1.4
	2015	41	33	23	1	2
Production share (%)	2006	50.2	25.6	20.4	2	1.8
	2010	49.9	31.2	15	2.6	1.3
	2014	50.6	27	20.1	1.4	0.9
	2015	43	31	23	2	1

Note: BNSG= Benishangul Gumuz; Source: CSA (2006, 2010,2014 and2015)

The distribution of beans cultivated shows that the white beans are mainly produced by Oromia and Amhara in a comparable proportion (Table 2). The red beans are mainly produced in Oromia and SNNP. Where the ecology permits and comparative advantage exists, it is wise to expand the production in the remaining potential regions to reap the benefits of scale. The data suggest that Tigray has the potential to expand common bean production.

Table 2. Regional distribution of common bean production in 2016 cropping season

	Common beans			
	White beans		Red beans	
Region	Area (ha)	Production (tons)	Area(ha)	Production (tons)
Oromia	36,230.50	58,485.37	80,466.44	149,649.83
SNNP	4,319.03	7,214.66	94,005.38	146,867.23
Amhara	33,878.13	53,390.50	30,089.11	52,429.30
BNSG	2,189.13	4,021.21	3,192.97	5,103.32
Tigray	1,851.37	2,248.18	2,348.51	3,090.21
Afar	57.43	95.08	69.43	ND
Gambella	4.77	ND	29.83	56.22
Somali	51.92	30.14	759.21	159.44
Hararai	8.38	11.47	10.29	3.45
Dire Dawa	319.46	483.13	321.13	583.49
Ethiopia	78,910.13	125,980.18	211,292.30	357942.48

Source: CSA (2016); ND=No data

Amhara region is a major producer of mung bean contributing 90% of the total production in 2015. However, with increasing contributions from Oromia (13% in 2016) the contribution from Amhara has declined to 82%. Benishangul Gumuz and SNNP are other producers of mung beans with four and one percent production in 2016, respectively (CSA, 2016).

Cowpea has no national official statistical records to show a quantitative regional distribution of its production in Ethiopia. However, the baseline survey conducted in five regions (Beshir *et al*., 2016) reported that Amhara had the highest share (25%) of land cultivated followed by Oromia and Tigray (19% each), SNNP (15%) and Gambella (8%).

Promoting technologies of lowland pulses

During the last decade there have been efforts to promote available technologies of lowland pulse crops to farming communities. Although the major lowland pulses have one or more improved varieties, the technology promotion was very noticeable only for common beans. Promotion and scaling up of improved technologies (Assefa *et al*., 2006) and decentralized seed production and distribution (Habte *et al*., 2012) were implemented in areas where common bean is important. These efforts addressed the information and seed supply constraints which limited the use of improved varieties among smallholder farmers.

Parastatal seed companies and community based seed production efforts could notable to satisfy farmers' seed demand (Rubyogo *et al*., 2007). The seed supply gap and information constraints necessitated the launching of technology promotion, scaling up and decentralized seed production through Tropical Legumes (TL II and III) projects and Farmer Research Group (FRG) to fill the gaps and improve access to quality seeds (Habte *et al*., 2016; Tumsa *et al*., 2013; Habte *et al.* 2012). Promotion activities include training, on farm demonstrations, field days, printed materials (posters, leaflets, manuals) and mass media (radio and TV) as shown in Figure 2a and 2b (Rubyogo *et al*., 2011; Habte *et al*., 2009a; Habte *et al*., 2009b; Habte *et al*., 2007; Assefa *et al*., 2006).

Figure 2a.Promotion of new bean varieties and management practices using print media

Figure 2b. On-farm demonstration of bean varieties, management practices and food recipes

The technology promotion and decentralized seed production efforts by FRG and TL projects are outlined to provide glimpse of the design followed (Table 3). The approach involves demand creation by promoting and providing information followed by multiplying of seeds of varieties demanded by farmers. Seed multiplication is carried out by farmers themselves in coordination with relevant actors who also facilitate the distribution of produced seed to other farmers. The cycle continues as new demand emerges for new varieties and quality seed. The decentralized seed production and dissemination initiative is born out of the aggressive common bean technology scaling up effort (Assefa *et al*., 2006) that gave rise to increased demand for improved varieties and associated practices.

The introduction of small packs for common bean seed production and distribution was an innovative feature of the TL II beans project. Accordingly, two sets of small packs of bean seeds were introduced (Figure 3). First, to create demand for new varieties small pack sizes were used which includes 0.05, 0.1, 0.25, 0.5, 1, 2 and 5kg. Second, for popular (commercial) varieties, relatively larger pack sizes of 5, 12.5 and 25kg were used and these packs were intended to provide access to bean seed by farmers of different purchasing power.

The framework for TL II intervention (Figure 4) and the range of partners and their roles are summarized in Tumsa *et al*. (2013). Agricultural research centers provide early generation seed for primary partners who coordinate seed production by individual or group of farmers and big private farms. The seed produced is recovered from seed producers by the primary partners (mainly FCUs) in kind or purchased in part or all and made available to grain producer farmers. Moreover, what is left with farmers reach other farmers through local networks either in direct exchanges, sales, gifts or local grain markets. Consequently, the new varieties and seeds reach a number other neighboring farmer or those living in distant areas as spillover effect.

The impact oriented decentralized bean seed production and dissemination has contributed to improved access to high yielding and market demanded bean varieties. About 771 tons of basic seeds of 10 common bean varieties were distributed for decentralized seed production during 2005 to 2012. This has made it possible to produce more than 9000 tons of bean seed with partners and were able to reach nearly one million farmers of which 21% were reached directly through partners while the rest as spill overs.

During and after the intervention period, access to improved bean varieties increased from less than 20% in 2004 to 68% in 2011 (Tumsa *et al*., 2013) and the area under common bean increased by 44%, total production tripled (from 172,153 tons to 387,802tons) and productivity was more than doubled (from 0.62 tons ha^{-1} to 1.4 tons ha^{-1}) (CSA, 2012).

(a) Commercial pack

(b) Small pack

Figure 3. Commercial and small seed packs used for decentralized seed dissemination and promotion

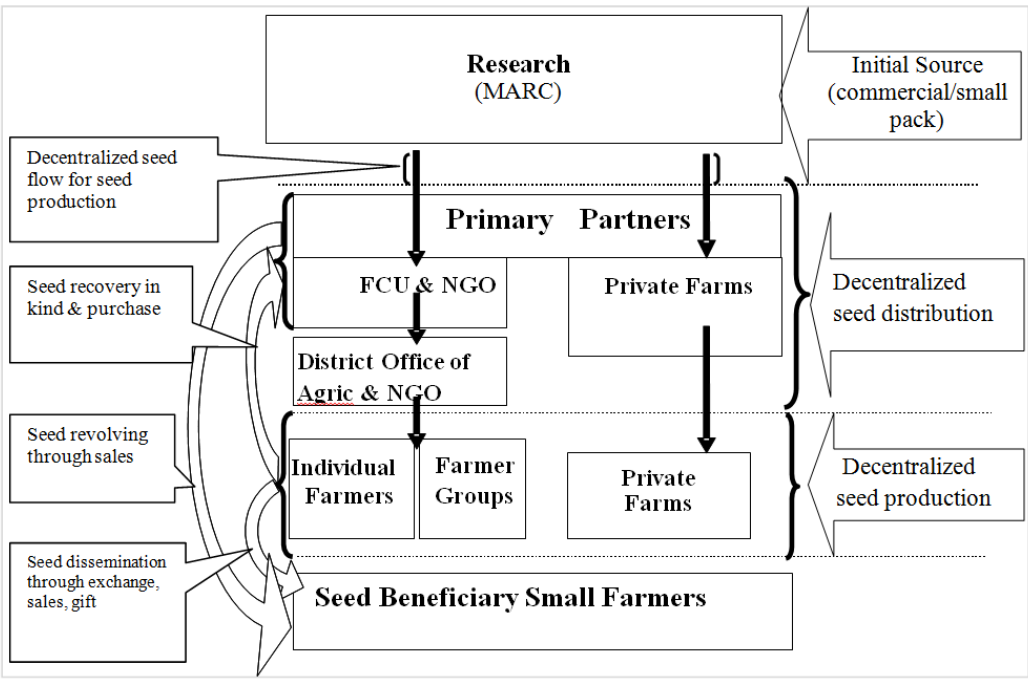


Figure 4. The framework of impact oriented decentralized bean seed production and delivery (TL II/III projects)
Source: Habte *et al*. (2010)

Table 3. Comparisons of decentralized seed production and dissemination

Activities	FRG (2005-2007)	TL II/III (2008-2017)
Demand creation for new varieties	Group based participatory planning, evaluation and demonstration, training, field day, promotional materials	Participatory variety selection (PVS), training, demonstrations, using small packs, promotional materials
Multiplication of early generation seed (breeder, basic)	On research station	On research station, private and public seed producers. Additionally, the seed was packed in small sizes (5, 12.5 and 25 kg) customised to the capacities of seed producers with the aim to stimulate development of seed enterprises
Seed distribution to seed producers	Planning with FRG member farmers and respective *Wereda* Agricultural and Rural Development Offices (WARDO); seed production embedded in field demonstrations of crop management practices; respective WARDOs does distribution to FRGs and copy farmers	Decentralised planning with all partners (p*rimary partners*: FCUs, NGOs and c*ollaborative partners*: farmers, extension experts, NGOs, private farms)and distribution through FCU, WARDO and NGOs. Steering and technical committees have been organized comprising different value chain actors to lead technology promotion nationally. This committee organized national planning and monitoring meeting annually with partners along the value chain
Seed recovery and redistribution	Recovered in kind by *wered as* and distributed to other farmers; Redistribution is mainly left for local networks (cash or non-cash based exchange)	Recovered in kind and via cash based procurement through primary partners (FCUs and NGOs) and redistributed by the same and through local networks (cash or non-cash based exchange)
Scale	Selected *wored as* in central rift valley (CRV)	Most bean growing areas in the country (Eastern (East &West Harergehe, southern (Sidama, Welaiyta, Kembata, Hadiya), central along the CRV (East Shewa, West Arsi, Halaba, Guraghe zone), Amhara region (East and west Gojjam, South Gonder, South and North Wollo)
Actors engaged	Research, *Woreda* Office of Agriculture, farmers	Research, *Woreda* to federal office of Agriculture, FCUs, NGOs, private farms, farmers, Public Seed Enterprise, Exporters, Seed Quality Laboratories, Private Agricultural PLCs (e.g Menagesha Biotech PLC)

Source: Habte *et al*. 2011; Amsalu etal., 2017 (unpublished report)

Correspondingly the quantity of common bean export rose by 23%; and the revenue grew by fivefold between 2006 and 2011, partly attributed to improvement in export price (Tumsa *et al*., 2013).

Rubyogo *et al*. (2011) elsewhere summarized the contribution of the partnership in decentralized bean seed production and dissemination to production and marketing of beans implemented from 2004-2010.

Use of improved inputs for low land pulses

The use of improved inputs includes quality seeds, chemical fertilizers and extension services. For common bean there is an increasing trend in the use of improved seed, chemical fertilizer and extension service (Table 4).The area covered increased from 1140 ha to 6740ha for improved seed and from 58,140ha to 140,810ha for chemical fertilizer. The share of improved seed use seems to have almost stagnated between 0.5% in 2006to 1.9% in 2015and that of chemical fertilizer grew from 26% to 39%over the same period. The share of common bean producing households participating in extension package showed a sharp rise from 3.7% to 24% probably due to the extensive deployment of village level extension workers.

The broader access to extension service should have been reflected with proportionate growth in use of improved seed. The average per unit area application of fertilizer has stagnated around 0.08 tons ha^{-1} over the same period indicating limited use of this input by farmers. The input use by bean farmers has changed over the period but the rate of the change, particularly for improved seed, seemed to have been underestimated. This may have to do with the working definition of improved seed used by CSA. Sluggish change in use of chemical fertilizer may result from the belief that common beans fix nitrogen and thus may not require as much chemical fertilizer as cereals do. Nonetheless, in-depth studies are required to identify the underlying reasons for input use behavior of common bean growers.

Trends in common bean production

Common bean is the second largest crop among all pulses in terms of both areas cultivated and quantity produced (Table 6). For example, it accounts for 22 and 20%, respectively of the pulse area and production in 2016 (CSA, 2016). Almost all common beans are produced under rain fed condition by smallholder farmers whose average holdings vary from 0.25 ha to 0.5 ha (Lemu, 2016).

From 2006 there has been an increasing trend of percentage changes in number of bean growing households, area cultivated, quantity produced and productivity per unit area (Table 6).

Table 4. Use of improved inputs in common bean production

Year	Improved seed			Chemical fertilizer					Coverage in extension package			
	Area ('000ha)	Change in area covered in improved seed over 2006 (%)	Annual share of total bean area covered by improved seed (%)	Area ('000ha)	% Over 2006	Annual share of total bean area covered by chemical fertilizer	Quantity applied in tons	Average quantity applied tons/ha	Number of HH (in million)	Area (in '000ha)	Annual share of total area (%)	% increase in area over 2006
2006	1.14		0.51	58.14		26.03	5,509.00	0.09	0.10	8.26	3.70	
2007	2.62	129.9	1.13	53.20	-8.51	22.98	3,518.80	0.07	0.06	6.27	2.71	-24.07
2008	8.48	644.0	3.18	77.91	34.01	29.17	4,008.80	0.05	0.10	14.92	5.59	80.62
2009	3.52	209.1	1.44	60.45	3.97	24.77	4,817.60	0.08	0.12	12.11	4.96	46.62
2010	1.95	71.2	0.82	93.10	60.14	39.22	5,749.00	0.06	0.13	14.37	6.06	74.02
2011	ND	-	-	ND	-	-	ND	ND	ND	ND	-	-
2012	ND	-	-	118.65	104.08	32.34	7,635.10	0.06	ND	ND	-	-
2013	ND	-	-	ND	-	-	ND	ND	ND	ND	-	-
2014	3.20	180.7	0.99	136.75	135.21	42.30	11,270.60	0.08	0.61	75.65	23.40	815.84
2015	6.74	491.2	1.89	140.81	142.19	39.41	10,675.70	0.08	0.61	84.94	23.77	928.29

Note: ND=no data
Source: CSA (2006-2015)

More than one million farm households had joined bean production and total annual production grew to 483,000 tons and the productivity reached 1.6 ton ha^{-1}. Among pulses, the share of common bean production grew from 14% in 2006 to 20% in 2016. Technological changes towards using improved bean seed and management practices are reasons for boosting productivity over the period. There are some fluctuations however in area, production and productivity which emanates from drought seasons or market prices.

Table 6. Common bean area, production and productivity from 2006 to 2016

Year	Producers (households) (millions)	Production		Productivity tons ha-1
		Area ('000 ha)	Quantity (in '000 tons)	
2006	2.34	223.36	222.70	1.00
2007	2.15	231.44	241.42	1.04
2008	2.46	267.07	329.78	1.23
2009	2.15	244.01	362.89	1.49
2010	2.25	237.37	340.28	1.43
2011	2.87	331.71	387.80	1.17
2012	3.14	366.88	463.01	1.26
2013	3.34	326.47	457.41	1.40
2014	3.21	323.32	513.72	1.59
2015	3.38	357.30	540.24	1.51
2016	3.95	290.2	483.92	1.69

Source: CSA (2006-2016)

Different common bean types are grown in Ethiopia: mottled, red, white and black beans. Most commercial varieties are pure red or pure white colored beans and they are increasingly demanded by market (Ferris and Kaganzi, 2008). Different common bean market classes are grown in different regions and for different purposes (Table 7). The small white (navy) beans are produced for export to the canning industries and the other types (small red, large red, large mottled and sugar) are mainly used for food in national and regional markets (Tumsa *et al*., 2013). The most popular and commercial red beans include Melka Dima (mottled and medium size), Red Wolaita (pure light red and medium size) and Naser (a small pure dark red) varieties (Ferris and Kaganzi, 2008). Mexican 142, Awash Melka, and Awash 1are highly commercialized white beans.

The red beans mainly come from the south-western CRV whereas the whites dominate in the north-eastern part of CRV. About 75% of the bean production is manly supplied from the CRV (Mulugetta, 2010).The number of households, area and production has become available since CSA started collecting disaggregated data in 2013

(Table 7). The red beans assume higher share in all the parameters. For example, during 2016 about 75% of the total bean production is red beans.

Table 7. Production and area of the two types of common beans (2013-2016)

Common bean type	Year	Producers (million households)	Area ('000ha)	Production ('000 tons)
White	2013	1.25	133.37	198.78
White	2014	0.97	126.19	202.12
White	2015	0.93	113.25	159.74
White	2016	1.04	78.91	125.98
Red	2013	2.10	193.09	258.63
Red	2014	2.24	197.13	311.61
Red	2015	2.46	244.05	380.50
Red	2016	2.90	211.29	357.94

Source: CSA (2013-2016)

Ethiopia's share of total bean production was stagnant and remains below 2% over the period 2006-2014 compared to global production while the total production showed a modest rise during 2006 to 2009 compared to Africa, East Africa and Kenya (FAOSTAT, 2017).On the other hand, the same data showed that Ethiopia had better average productivity which remained well above that of Kenya and other regions (World, Africa, East Africa and Kenya) which did not show much change over the period (FAOSTAT, 2017). This implies considerable potential to increase productivity (and thus production) by improving existing production and input use practices.

Trends in production and productivity of mung bean and cowpea

Mung bean and cowpea are among lowland pulses with limited information. Introduction of mung bean in the national crop statistics shows its growing importance in area coverage and production. The number of mung bean producing households and area coverage has more than doubled and total production tripled; productivity increased by 18% during 2014-16 (Table 8).

Mung bean received relatively better attention in research and development where there are few improved technologies and management practices. However, the coverage of extension service is low where one out of five mung bean producing households receives extension service. Given the deployment of large number of extension workers in almost all villages, this number should have been higher. However, the extension service could be constrained by the availability of technical information and relevant production technologies.

Table 8.Mung bean production statistics

Year	Producers (households)	Production (t)	Area (ha)	Productivity (tha-1)
2014	62,377	14,067.65	14,562.00	0.97
2015	136,392	27,158.98	27,085.92	1.00
2016	184,114	42,915.55	37,774	1.14

Source: CSA (2014-16)

There is no official CSA data on area coverage and production of cow pea. A recent national baseline survey (n=623), found that farmers cultivate landraces and the average productivity was about 0.8tonesha^{-1}, far below the achievable potential of 3.2tonesha^{-1}(Beshir *et al*., 2016).This productivity level is comparable to Nigeria- the leading cowpea producer whose average productivity for the period 2006-2014 was 0.9 tones ha^{-1}(FAOSTAT, 2017).There are 10 cowpea improved varieties released by the national lowland pulses research program. There is no sufficient information whether these varieties are in the hands of farmers or not.

According to FAOSTAT (2017) estimate, globally about 5.6 million tons of cowpea was produced in 2014 of which over 95 per cent is produced in Africa. About 85% of total production came from the West African countries, Nigeria alone contributing40% of the total production in Africa. As multipurpose crop (Islam *et al*., 2006) where all parts of the crop are used as nutritious food for human or feed for animals and best fit in drought condition, the crop requires more research and development attention in Ethiopia.

Utilization of lowland pulses

Farmers producing lowland pulses in Ethiopia can use the grain for home consumption, seed for planting, source of income from selling the grain, in kind payment for wages and/or animal feed. Information and trends for common bean (Table 9) and for mung bean (Table 10) are presented below. Information available on utilization of cowpea suggest the crop is mainly used as human food and animal feed (Alemu *et al*., 2016; Beshir *et al*., 2016).

From 2008-2015, on average about 69% of the common bean production is consumed at farm levels, 17% is sold, 12% used for seed and 2% for other uses. While the trend in the share of total production used for seed remained stable, the proportion that went to grain market showed a modest rise from 13% to 22%between 2008 and 2015 (Table 9). The local market share was about 68% common bean market (Mulugetta, 2010).The per capita consumption of common bean ranges from 1kg to 16 kg and some major production regions like SNNPR has higher per capita consumption of 9-16 kg year^{-1} (FAO, 2015) which is comparable with Uganda (Ferris *et al*., 2008).

Mung bean has high potential as commercial crop and more than 70% of the total production in 2014 and 2015 was supplied to the market (Table 10). The data also indicated that there is an increase in the proportion that is consumed and used as seed from 2014 to 2015.

Table 9. Utilizations pattern of common bean

Year	Total production (MT)	Utilization (%)			
		Consumption	Seed	Sales	Others (wage, feed etc.)
2008	329,775	70	12	13	2
2009	362,890	73	12	13	2
2012	463,009	67	12	18	3
2013	258,634	70	12	17	1
2014	311,604	67	11	20	2
2015	380,500	66	10	22	2
Mean	351, 069	69	12	17	2

Note: There is no data for years 2010 and 2011; Source: CSA (2008-2015)

Table 10. Utilizations pattern of mung bean

Year	Total production (ton)	Utilization (%)			
		Consumption	Seed	Sales	Others (wage, feed etc.)
2014	14,068	7.5	10.9	78.7	2.9
2015	27,159	12.0	14.0	70.4	3.6

Source: CSA (2014-2015)

Marketing of lowland pulses

Common bean and mung bean are the two important lowland pulses traded in domestic and international markets. While common bean has a well-established marketing system, mung bean is an emerging commercial product. Cow pea is not as popular in the market and there is no sufficient data on marketing of the crop.

Common bean marketing

Marketing of common bean generally starts with collection of grains from farmers at farm gate, village level or wereda town. Beans produced by farmers are assembled by collectors and supplied to wholesalers who may sell to exporters or who may be exporters themselves. Marketing is dominated by collectors at a grass root levels who are linked to few big wholesalers and/or exporters. The main actors representing the value chain include farmers, assemblers, wholesalers and exporters, retailers and farmer cooperatives. Common bean market chains are relatively short with farmers having various selling outlets.

Farmers have four types of market outlet (fellow farmers, wholesalers, collectors) but the most important pattern seen is a flow of beans from farmers through collectors (handling

85% of sales) to the wholesalers (Katungi *et al.*, 2010). In Ethiopia, the common bean market is fragmented mainly because it is principally produced by smallholders who are located over a wide area and supply low volumes to small traders at different levels. Input suppliers, farmers/producers, traders/retailers, processors and exporters are the main actors in the product flow value chain (Figure 5). These actors operate in a policy framework that promotes market orientation and provides for access to market related information through institutions like Ethiopian Commodity Exchange (ECX). Marketing agents get access to services including finance, transportation, storage and contracts (through ECX) and others which facilitate the marketing activities. EIAR, MoANR, Seed Enterprises and NGOs play key roles in delivery of technologies and information, inputs (fertilizers, seeds) to farmers.

Since the establishment of ECX in 2010, common bean has a relatively well developed marketing system. Government decision to trade the white pea beans exclusively through ECX is a case in point ensuring a fair trade benefiting all marketing actors including producers. Accordingly, prices are determined by the market forces minimizing market information asymmetry and relatively shortening the market channel. In effect, ECX is replacing the role of brokers (who used to have monopoly of price information) in favor of all other actors in the market (Figures 6 (a) and (b)).

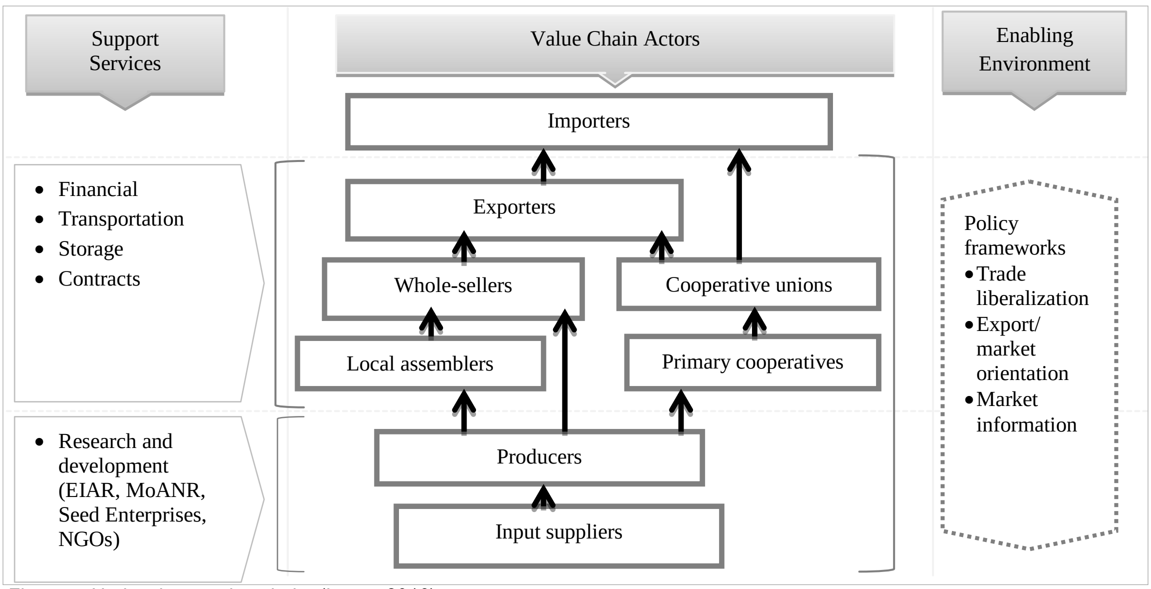
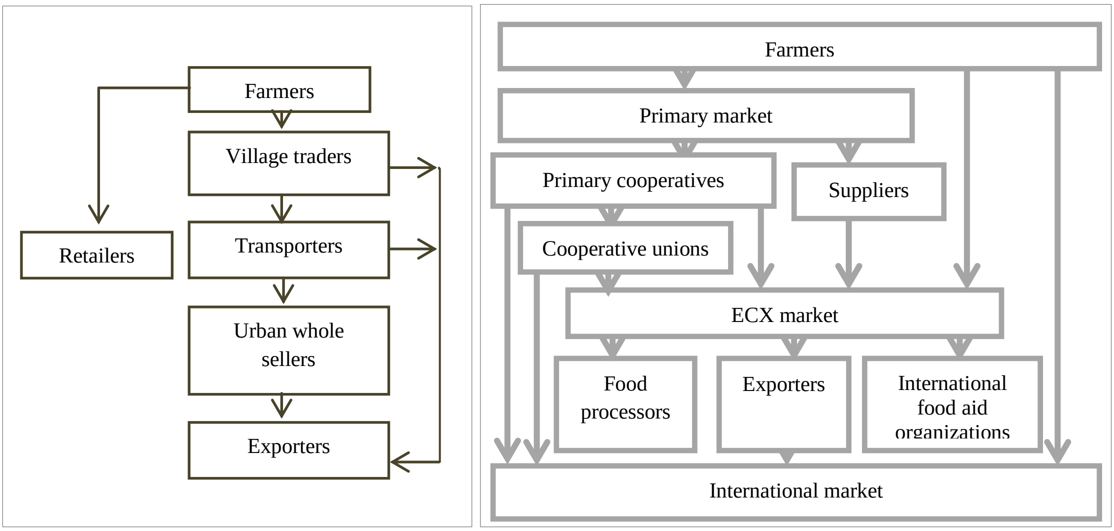


Figure 5. Haricot bean value chain (Lemu, 2016)



(a) Before ECX (b) After ECX

Figure 6.White pea beans marketing channel before and after establishment of ECX; Source: Ferris and Kaganzi (2008); Mulugetta (2010)

The increase in volume of bean export can partly be linked with the emergence of ECX marketing services, improvements in price information and road infrastructure. However, FAO (2015) showed that the ECX system created more transaction and transport costs than the traditional broker systems. As a result, the ECX system created a shift in domestic market signals, from white beans to red beans. Domestic traders are increasingly focusing on red beans which incur less transaction cost than the export type (white beans). The white beans which used to have the largest share of local market for food aid showed a declining trend since 2010. With increasing importance in the export market, the red ones which are often consumed locally and partly exported through ECX can also be expected to eventually assume similar status as the white beans (Ferris and Kaganzi, 2008).

The new white bean trading system has seven market actors and three market places (Mulugetta, 2010). The actors are farmers, suppliers, primary cooperatives, unions, food processors, exporters, international food aid organizations. The market places are primary markets, ECX and the international markets. Farmers have options to supply their beans to any of the three markets of their choice. Primary markets are based at *weredas* in potential production regions and farmers are the only suppliers while primary cooperatives or suppliers are the only buyers from this market. Primary cooperatives can as well supply directly to their cooperative unions, ECX or international market. Suppliers, however, can only supply to the ECX market. Actors who can supply common beans to the international market include farmers, primary cooperatives, cooperative unions, and exporters.

Farmers grow two classes of common bean varieties: canning type primarily grown for export market, and the cooking type primarily grown for food. The former is dominantly produced in Oromia region particularly along the rift valley- by 83% of the farmers; while the latter is primarily grown in the SNNP region, south of Lake Ziway (Katungi *et al*., 2010).Common bean is the third most important export crop (Alemu *et al*., 2010; IFPRI, 2010) contributing about 9.5% of total export value from agriculture (FAOSTAT, 2010) and over 85% of export earnings from pulses (Negash, 2007). Alemu and Seifu (2003) have found common bean as dominant export crop among pulses before and after 1991 and the trend is growing rapidly. The major export was dry white pea beans but recently, the red beans and green beans have emerged in the market.

Ethiopia is among the leading producers and exporters of common bean in Africa. The trend over the last decade also shows that the quantity and value of haricot bean export have been consistently increasing in the country. The export earnings have grown over six times during the last ten years, an increase from 18.5 million in 2006 to 131.7 million US dollar in 2015 (see Table 11). However, its share in the pulse export is declining due to the growth in the export volume and value of other pulse crops like chickpea, faba bean and lentils (Alemu and Seifu, 2003).

Table 11.Volume and value of common bean export (2005/06-2014/15)

Year	Haricot bean produced (t)	Haricot bean exported (t)	Value of export ('000 USD)	Unit price (USD t^{-1})
2005/06	138422	53810	18,497	344
2006/07	222701	66064	31,919	483
2007/08	241418	42735	25,317	592
2008/09	329775	58275	35,523	610
2009/10	362890	80169	44,799	559
2010/11	340280	102267	58,151	569
2011/12	387802	123765	82,223	664
2012/13	463008	183217	122,433	668
2013/14	457412	201812	157,559	781
2014/15	513725	192990	131,794	683

Note: 2005/06 refers to amount produced in 2005 and exported in 2006; USD=US dollar
Source: Ministry of Trade (MoT) (2016)

The overall trend in the last decade shows that there is a consistent increase in common bean value and volume of export (Table11). The average annual percentage change of export value for the period 2006-2014 was 28%and the corresponding figure for the volume and price over the same period was 18% and 9%. The increase in export value is associated with both volume and price, the former being relatively more important. This partly departs from the observation made by FAO (2015), who based on data for 2000-2012 stated prices, instead of volume, as the main driver of the growth of export value. In fact, the price has shown improvement over the last several years; for instance, the average price over 2006-2014 was about USD 595 per tons while the corresponding figure for the period 2011-2014 was USD 673. None the less, the export volume has grown at higher rate suggesting the potential return if the price continues to shift upward.

The annual change in share of volume exported is slow and stagnated at around one third of the total production. IFPRI (2010) indicated a marketed surplus of 13 to 28% with the balance being consumed on-farm. Additional efforts should be made to earn more foreign exchange by shifting from local to export market. One possible strategy could be to promote market oriented commercial production using modern inputs and management practices. Moreover, smallholder farmers need to be integrated into markets and better infrastructure should be developed to reduce transaction costs.

Destination markets of common beans

Annually the marketed surplus of common bean accounts 17% of the total production. The domestic market takes the lion share of the traded surplus followed by export market directed to European, Middle East, African, and Far East countries (Mulugetta, 2010; Abera *et al.*, 2016). Although the domestic market offers premium price for the large mottled beans, the small red beans still dominates in this market. White pea beans are the main products traded in the export market whereas ten per cent are the red beans. The main destination markets for the red beans include Pakistan, United Arab Emirates, Djibouti, East Timor and Yemen. However, the red beans are also illegally traded in Ethio-Kenya border around Moyale (Mulugetta, 2010; Ferris and Kaganzi, 2008).

The major importers of common bean include Sudan, Kenya, Djibouti, South Africa and Egypt (from Africa); Yemen, United Arab Emirates, Saudi Arabia, Israel, and Jordan (Middle East); United Kingdom, Belgium, Bulgaria, Netherlands, Italy, Turkey, Greece and German (from Europe); India, Pakistan (from Asia); and many more countries (Alemu *et al.*, 2010; IFRPI, 2010; Mulugetta, 2010

About 75% of the total export volume in 2009/10 were to Sudan (14%), Yemen (10%), UK (9.2%); India (8.3%), UAE (8%), Kenya (6.3%), Pakistan (6%), South Africa (5.2%), Belgium (4.7%) and the Netherlands (4%) (Mulugetta, 2010). Lemu (2016) indicated that the long-term main destination markets in terms of export value were Yemen (10.7%), Belgium (8%), Greece (7.8%), Russia (7.2%), Czech Republic and Italy (6.4%), Turkey (5.7%), Djibouti (5.4%) and India (4.2%).

Ethiopia has a comparative advantage because of its geographic proximity to markets. For example, from Ethiopia it takes three weeks to reach the European Union market compared to nine weeks from China. Nonetheless, the challenge facing the Ethiopian pulse sector is the market demand for competitive price, product quality and product delivery. Many studies have indicated that high transaction cost is among factors which limit competitiveness in the export market. The presence of many actors and their less defined roles in the pulse value chain as well as the aggregation of production and the dispersed nature of farmers who supply small volumes are few of the important drivers of the transaction costs (FAO, 2015; Katungi *et al*., 2010; Ferris *et al*., 2008).

Mung bean marketing

Mung bean is becoming an important commercial crop in the export market. Both the production and export volume has shown an increasing trend over the past years with some exceptions during 2006-08 (Table 12). Export volume increased by more than tenfold where corresponding export value also rose from less than 2 million to more than 27million USD between 2004 to 2013.The growth in mung bean export has led to the decision to include it as the sixth commodity to be traded in ECX floor in 2014.

Table 12. Green mung bean export during 2004-2013

Year	Export volume (tons)	Export value ('000 USD)	Price (USD/T)
2004	2,310	1,732	749.9
2005	5,667	3,661	646
2006	2,873	1,754	610
2007	1,471	918	624
2008	44	24	550
2009	7,964	10,007	1,256
2010	10,570	10,867	1,028
2011	17,396	16,712	961
2012	22,213	27,034	1,217
2013	22,719	27,822	1,225

Source: MoT (2016)

Mung bean presents great opportunity with its growing export. The annual percentage change of export volume, value and price was constant up to 2008 though a significant shift both in the volume and value of export is observed since 2009 probably associated with corresponding rise in price. Boosting production and marketing of mung bean can be instrumental in harnessing emerging market opportunity thereby diversifying the export commodities of the lowland pulse crops.

Challenges and opportunities in production and marketing lowland pulses

Challenges in production and marketing of common bean

Low varietal replacement practice: The use of newly released improved varieties by farmers is very low where only few old varieties are popular and widely produced. High varietal adoption rates of 83% to 92% were reported in the Central Rift Valley (Katungi *et al.*, 2011; Abebe and Bekele, 2015). But the adoption rate drops to 29%whenonly varieties released after 1989 are considered. High seed prices, non-availability of desired varieties, long distance from the farm to the seed source, poor seed quality and risk aversion are the challenge that constrain cultivation of new bean varieties (Katungi *et al.*, 2010).

Limited access to quality seed: Most common bean farmers use seed from the informal sector such as own saved seed, other farmers or local markets. Farmers are forced to use old varieties and recycled seed because certified seed is neither adequately available nor accessible particularly in remote areas. Besides, farmers have limited access to information about new bean varieties. A sizeable proportion (32-38%) of farmers who cultivated a new bean variety for the first time relied on local information networks (Katungi *et al.*, 2010).

Limited use of improved agronomic practices: Many varieties are on research shelf than in farmers' fields. Use of improved varieties is affected by drought, insect pests and diseases, land shortage, market access, and gender (Abebe and Bekele, 2015; Katungi *et al.*, 2011; IFPRI, 2010; Katungi *et al.*, 2010; Negash, 2007). Declining soil fertility, insect pests and diseases are impediments limiting cultivation of new varieties. Farmers perceive use of purchased inputs like improved seed as uneconomical when the risk of crop failure is high. High population density in the rural areas encourages mono cropping and continuous cultivation of same piece of land with limited soil amendment practices which result in soil nutrient depletion or create better conditions for pests and diseases (IFPRI, 2010).

Drought: Common bean production is substantially vulnerable to drought. Drought induces significant losses in yield. Bean farmers are highly vulnerable to drought with each farmer in Ethiopia expecting to lose on average about 22% of his/her harvest. Actual yield losses in the event of drought is much higher and estimated between 40-60% (Katungi *et al*., 2010).

High transaction costs: High transaction cost in common bean market channels is one of the constraints limiting the competitive-ness of the product. Most producers are smallholder farmers that are scattered in different production areas and cannot be also accessed by motorized vehicles. These farmers depend on pack animals and human labor to transport their surplus produce to primary markets. Assemblers and other market actors often pay high transportation costs to move their purchases to secondary and tertiary markets which become expensive and slow. High operational costs due to high transport costs, inadequate and poorly designed storage facilities, inadequate flow of market information, quantity and quality of supplies are among the sources of high marketing costs (IFPRI, 2010; Katungi *et al*., 2010; Alemu *et al*., 2010; Lemu, 2016).

Complex marketing chain and poor grain quality: The presence of many actors makes the marketing chain of common beans complex which is counter productive on product quality and access to reliable markets. This reduces product quality through excessive handling and limits transmitting demand signal due to the multiple middlemen separating producers and exporters, where farmers are less informed about the quality and demands of the markets. Quality is an important parameter that determines both the price and volume of exports. Most common bean producers are small-scale farmers dispersed over different production areas of the country using different varieties (Alemu *et al*., 2010) where aggregation, storage and transportation are major problems. According to IFPRI (2010), exporters estimate that they reject 10-25% of produce due to quality standards, which reduces profitability of exporters and ultimately prices paid to farmers.

Limited bargaining and risk bearing capacity of farmers: Smallholder farmers have limited bargaining capacity for higher prices due to lack of coordination among them. They miss the opportunity to exploit economies of scale from bulking their individual small produces. Katungi *et al* (2010) reported that traders try to spread the risk among themselves and to the producers in form of lower prices, cheating in weights, payment of commission and manipulation with false information. Although farmers recognize the disadvantages associated with selling through middle men, they continue to do so because it reduces transport cost and provides immediate cash.

Systemic inefficiency associated with cost: The cost of bringing common beans to the international market is quite high with processing and handling cost accounting half of the total cost. Transport costs, impurity losses, processing, handling, and exporters' margin are the main cost components (FAO, 2015). Lack of bulk transportation facilities and poor quality of beans supplied by exporters as well as processing, storage and handling costs are inefficiencies which could be reduced to boost profit margins along the value chain.

Challenges in mung bean, cowpea, pigeon pea and other pulses

The main challenge of mung bean, cowpea, pigeon pea and other lowland pulses is limited attention from research and development where there are few technological options. The improved varieties and agronomic practices are not only few or missing in some cases, but also less popular. The production practices are not developed and promoted enough to reap their benefits both at household and national level.

Opportunities in production and marketing of lowland pulses

One of the opportunities for lowland pulses particularly common bean is the presence of favorable policy environment which encourages market oriented production and provides incentive for farmer based organizations to participate in international market. The existing production potential for lowland pulses and the establishment of ECX could present choices for farmers to link to markets. The experience in common bean marketing through cooperatives and unions can lend opportunity to expand to other lowland crops like mung beans. Moreover, the experience in decentralized seed production and dissemination of common bean which empowered farmers and their organizations in production and marketing of improved seeds alongside the extensive extension service in the country can be an important instrument to unleash the fast flow of technologies. The experiences established in common beans can as well be a reasonable starting point for the other low land pulses.

Given the multiple uses and benefits lowland pulses play an important role in the household and national economy. The GTP II has identified common beans (both white pea bean and red beans) and mung bean among priority export crops. Mung bean, for example included in ECX and this can strengthen the linkage in the value chain.

GTP II has 'building climate resilient economy' as one of its strategic pillars where adaptation to climate change is an important aspect. Lowland pulses like cow pea and pigeon pea fits well the plan. Cowpea which has dual purposes of being food as well as feed, and the ability to resist stressful conditions such as drought can offer the potential to enhance food security while serving as livestock feed. This is very much so for the agro-pastoral system with a relatively moisture stressed areas where both food and feed scarcity present formidable challenge.

The presence of relatively well-established export markets and availability of a range of improved varieties of common beans (developed through strong national research program) and favorable agro-ecological conditions are the opportunities that can be harnessed to boost not only production but also marketing of this commodity. Relating to export market, increasing international demand for common beans and mung beans is a golden opportunity for our farmers to increase production, and for research and development actors to develop and promote technologies that meet such demands.

Improvement in the road infrastructure linking major production areas with market places and progresses in accessing price information (because of expansion in coverage of mobile phones) are also developments which present better opportunities for production and marketing of lowland pulses. Ongoing developments on communication and marketing infrastructure are expected to reduce the transaction cost of marketing lowland pulses thereby provide incentive for increasing the quantity and quality of production.

Conclusions and Recommendation

Lowland pulses, particularly, common bean has been receiving relatively better attention in research and development due to its importance for household consumption and national economy. This resulted in increased production, export earnings and benefits accrued to the farm households. Nonetheless, with increasing competition in the world market and the need to improve the quality of the product and to remain competitive, additional investment in research and development is necessary. Technological options that helps to satisfy the local and international market demand should be developed and access to these technologies should also be improved through better extension and seed delivery services. The necessary inputs and credit services need to be also made available to farmers. The support for farmer based organizations engaged in production and marketing also need to be maintained and strengthened.

Adequate resources should be devoted to the development and promotion of improved technologies of mung bean and cow pea which have been neglected over the last decade. These crops are getting an increasing importance in the world market (mung bean) and food and feed crop (cow pea) particularly in drought prone areas of agro-pastoral farming systems. Technology development efforts should target traits demanded by the producers and the markets. An in-depth value chain analysis is necessary, particularly for mung bean to understand the market and provide support in improving both the input (seed, fertilizer) and output (grain)markets.

Production of low land pulses, particularly common bean is linked with markets. Although there are progresses in access to market information since the introduction of ECX, there is still lack of regular flow of information since all beans are not traded through this route. There is a need to ensure timely and smooth flow of market information and intelligence for the producers and guide their production decisions. Such information is also critical to meet the quality standards of products required by the markets.

Market facilities like storage which can hedge producers against unexpected drop in price need to be developed. There is a seasonal price fluctuation which is driven by seasonal pattern in the production and marketing of common beans. Common bean production is mainly rain fed and the grain market primarily depends on harvest season. Smoothening the price over the seasons would require improving the storage-an important challenge facing the bean sector.

A continued support is required to strengthen existing and/or new marketing groups (cooperatives, unions) to increase bargaining position which usually compels them to sale their products at cheaper price for collectors at farm gate. Strengthening of marketing groups would also help to supply a higher proportion of total production to the markets. This changes subsistence oriented production by stimulating use of modern inputs and management practices. Integrating farmers with the markets by introducing guidelines and honoring contractual agreements between buyers and sellers would also improve the efficiency of markets.

One of the most important constraints in production of low land pulses, particularly common beans is the use of old improved varieties. Farmers have limited awareness and access to new varieties due to unavailability of this input in the right time and place, especially for farmers in remote areas. Enhancing wider adoption of new bean varieties requires making input or output markets accessible by investments in seed delivery systems and removing household liquidity constraint for seed purchase. Scaling up small pack seed marketing approach enables the creation of awareness and demand for new improved varieties.

Improving access to input and output markets requires strengthening the expansion of the rural road networks which is instrumental in minimizing transaction costs incurred in transportation services. High transaction costs are among important constraints which limit access to modern inputs and outputs markets. Thus, development of infrastructure (road and transport facility, telecommunication) is necessary to reduce marketing/transaction costs which often affect competitiveness in the world market.

There is the need to expand production of lowland pulses to new areas where they have comparative advantage and are becoming important commodities. For example, it is possible to expand common bean to Tigray; mung bean to Oromia, Benishangul Gumz and SNNPR; and cow pea to Oromia, Tigray, SNNP and Gambela. Awell-designed promotion strategy and strong and effective extension service and platforms can bring different actors along the value chain and their interest together.

Acknowledgements

We would like to acknowledge Mr. Solomon Tsega (EIAR Library) for sharing CSA data and Mr. Demeke Nigussie (GIS expert, EIAR) for preparing the GIS maps used in this report.

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Strategies and Innovative Approaches for Food Legumes Seed Delivery in Ethiopia

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Abstract

Seed is the only vehicle in crop technology promotion, adoption and impact enhancement. Legumes play an important role in food and nutritional security of smallholder farmers and sustainability of farming systems in Ethiopia. The national agricultural research systems (NARS) in partnership with the international agricultural research centres (IARCs) have developed several improved varieties and integrated crop management technologies for legume production in the country. Currently about 201 legume varieties have been released by NARS from the federal and regional agricultural research institutes. However, the adoption of improved varieties and agronomic management practices are constrained by lack of information, skills and knowledge and inadequate availability, access and use of inputs by most farmers. The paper reviews the status, challenges and opportunities of the legume seed sector and suggests strategies to enhance seed delivery within the Ethiopian context.

Key words: Food legumes, farmer-based seed production, Ethiopia, scaling, seed delivery

Introduction

Legumes play a significant role in the integrated crop-livestock farming systems and provide multiple benefits to the smallholder farmers in Ethiopia. They are important sources of protein, micro-nutrients and vitamins ensuring food and nutritional security; improve soil fertility and health fixing N from the atmosphere and as break crops for rotation ensuring sustainability of farming systems; increase farm incomes improving rural livelihoods and reducing poverty as cash crops in the domestic and international markets earning foreign currency for the country. Legumes are also known for their low carbon foot print and help in mitigation of climate change. In 2015/16 crop season, both highland and lowland legumes collectively occupied 1.7 million ha (13.24% of crop area) with production of 2.8 million t (10.38% of crop production) at an average productivity of 1.68 t ha^{-1} (CSA, 2016). The main grain legumes produced include faba bean, field pea, chickpea, grasspea, lentil, fenugreek and lupine in the highlands; and haricot bean, soybean and mung bean in the lowlands. CSA has no statistics yet on adzuki bean, *Dekoko* (*Pisum sativum* var. *abyssinicum*), cowpea and pigeon pea production (CSA, 2016).

Table 1 shows substantial area expansion, increase in grain production and progress in crop productivity particularly during the last one and half decade (2001-2016). The overall area expansion for all legumes was 63% with the range from the highest of 198% for haricot bean to the lowest of 20% for faba bean (except soya bean). Similarly, grain production had increased by 171% for all legumes with range from 448% (haricot bean) to 90% (faba bean). The productivity increase was 68% with the range of 133% (highest for soya bean) and 35.4% (the lowest for lupine) followed by faba bean (58%) and grasspea (64%). For some crops productivity is the main source of increase in production compared to area expansion. The minimum productivity increase of grasspea and lupine is understandable given little or no agricultural research on both crops even though they are hardy and low input crops, with better N fixation (Atnaf *et al.,* 2015) and human health benefits (Foyer *et al.*, 2016) and long history in the traditional farming systems of smallholder farmers in the country.

This review examines the achievements made in legume seed system development over the last decades and identifies major challenges constraining the availability and access to seeds of legumes in Ethiopia. The review concludes with opportunities and way forward to enhance the development of legume seed systems in the country.

Table 1. Area, production and productivity changes of legumes in Ethiopia, 2001-2015

	Area in ha (000)			Production in t (000)			Yield t ha^{-1}		
Crop	2001	2016	Increase (%)	2001	2016	Increase (%)	2001	2016	Increase (%)
Faba bean	369.15	443.97	20.3	447.06	848.65	89.8	1.21	1.91	57.8
Field pea	175.22	221.42	26.4	147.27	323.39	119.6	0.84	1.46	73.8
Chickpea	184.80	258.49	39.9	179.82	472.61	162.8	0.97	1.83	87.9
Grass pea	83.52	159.11	90.5	92.34	287.67	211.5	1.11	1.81	63.5
Lentil	60.14	100.69	67.4	38.43	133.93	248.5	0.64	1.33	108.2
Lupine	7.25	16.79	131.6	5.97	18.72	213.6	0.82	1.11	35.4
Fenugreek	15.05	29.84	98.3	10.03	35.65	255.4	0.67	1.19	79.3
Haricot bean	119.88	357.30	198.1	98.67	540.24	447.5	0.82	1.51	83.7
Soya bean	1.77	38.17	2056.5	1.62	81.24	4914.8	0.92	2.13	132.5
Mung bean	-	27.09	-	-	27.16	-	-	1.00	-
Total (legumes)	1016.78	1652.86	62.56	1,021.21	2,769.26	171.2	1.0	1.68	68

Source: CSA (2001 &2016)

State of Food Legumes Research

Agricultural research is crucial to generate new and better crop technologies that address the challenges of food and nutritional security and economic growth and development while maintaining and conserving the natural resource base of the country. The beginning of agricultural research has relatively a long history linked to the establishment of agricultural schools and colleges almost 70 years ago. EIAR (ex IAR/EARO) was later established as a sole public national agricultural research center in 1966. Since 1990s the agricultural research landscape has changed tremendously with the establishment of the regional agricultural research institutes (RARIs).

Institutional Arrangements

In Ethiopia, to date, NARS (National Agricultural Research System) constitute one federal and seven regional public agricultural research institutes (RARIs), 25 public higher learning institutes (HLIs), few private companies and NGOs (https://agriknowledge.org/downloads/1n79h429p). Apart from NARS, legume research is also augmented by the CGIAR centres such as CIAT, ICARDA, ICRISAT and IITA supporting research for development projects of chickpea, lentil, faba bean, beans, grasspea in partnership with the NARS. However, the private sector research on legume crops is very little, if any where they may introduce varieties for testing and release through the public NARS. Effective coordination will avoid duplication of activities and accountability among the Ethiopian NARS at the federal, RARIs and HLIs to facilitate the effort in generating, promoting and delivering new and better agricultural technologies but also the research-extension-farmer linkages. The establishment of NARC in 2014 (Kassa and Alemu, 2017) to undertake overall coordination of agricultural research is expected to address some of these critical issues in the country's national agricultural research system.

In Ethiopia, both cool season (faba bean, field pea, chickpea, lentils and grasspea) and tropical (common bean, pigeon pea, mung bean and soya bean) legumes are grown extensively integrated with cereal crops. Faba bean and field pea are dominant in the barely-livestock farming systems in the highlands; chickpea, lentil and grasspea are common in the wheat-tef based cropping systems in the mid-highlands; and beans (haricot bean, soya bean and mung bean) are dominant in the lowlands where maize and sorghum are the major crops. Almost all grain legume research is coordinated by the federal NARS with few exceptions. Holetta ARC coordinates research on highland legumes such as faba bean, field pea and lupine, Deber Zeit ARC handles chickpea and lentil and Melkasa ARC is responsible for haricot beans. These centres are responsible for development of legume technologies in collaboration with federal and regional ARCs and breeder and pre-basic seed production. However, like cereals, early generation seed production of legumes is constrained by lack of clearly defined roles and responsibility with accountability.

Current Production Constraints of Food Legumes

A considerable number of constraints and challenges were reported in grain legumes along the value-chain from production to utilization in Ethiopia (Atnaf *et al.*, 2015). Compared to cereals, legumes have low investments in crop improvement, management and input use. Grain legumes productivity is far below the potential due to low input use, lack of awareness of improved varieties, limited availability of quality seed, limited use of improved crop management practices, and poor extension services (Atnaf *et al.*, 2015; Kelemework, 2015; Tefera, 2013). Non-availability, high price, and lack of credit facilities have been some of the constraints related to use of inputs such as seeds, fertilizers and agro-chemicals. Poor seed bed preparation and use of marginal land is also identified as production constraints (Abate *et al.*, 2011; IFPRI, 2010). Moreover, weeding is rarely done and little or no fertilizer is applied in legume production.

Weak seed system of grain legumes is often cited as critical constraints to provide quality seed of improved varieties in adequate quantities and price (Abate *et al.*, 2011; Bishaw and Louwaars, 2012; Husmann, 2015; IFPRI, 2010). Poor infrastructure not only exacerbate the quantity and quality of grain legume marketing (IFPRI, 2010) but also hinders the access to inputs and the intensity of technology adoption.

Development of Food Legume Technologies

Variety development and release

The overriding research objectives in grain legumes have been on high grain yield and quality and adaptive traits to diverse production environments in the country (Fikre, 2016). NARS has released 108 highland and 93 lowland legume varieties during the last five decades as shown in Table 2 (MoANR, 2016). All the varieties have been developed for adaptation, productivity, preference and economic traits compared to contemporary standard checks. For example, faba bean varieties tolerant to waterlogging on Vertisols and partially resistant to Orobanche were released for production. Lentil varieties released with resistance to rusts resurrected lentil production in the highlands of Ethiopia.

In terms of varietal releases, haricot bean has the highest (about 1.3 variety per year) followed by field pea (0.8), faba bean (0.7) and chickpea (0.5). However, given variations in total crop area in the country, the number of varietal releases adjusted to per million hectares of crop area is suggested as a useful indicator for comparison (Lantican *et al.*, 2014). Accordingly, the number of varieties released per million ha of cultivated land is the highest for soya bean followed by haricot bean, field pea and lentil owing to the smaller total area under cultivation compared to other legumes.

Table 2. Number of grain legume varieties released in Ethiopia: 1973-2015

Crops	Number of released varieties	Year of first release (variety)	Varieties released in 2015
Highland grain legumes			
Faba bean	31	1977 (CS-20-DK)	Ashebeka, Hashenge
Field pea	35	1979 (FP DZ)	Bursa
Dekoko	2	2015 (Raya 1, Raya 2)	Raya1, Raya 2
Chickpea (Desi)	12	1974 (DZ-10-11, DZ-10-4)	
Chickpea (Kabuli)	11	1999 (Arerti, Shasho)	
Lentil	11	1984 (Checole)	Jiru
Grass pea	1	2005 (Wasie)	
Fenugreek	3	2005 (Chala)	
Lupine*	2	2014 (Vitabor, Sanabor)	
Sub-total	**108**		
Lowland grain legumes			
Haricot bean	57	1973 (Mexican 142)	Ado, Tafach
Soybean	25	<1981 (Crawford, Williams)	Gazale, Pawe 01, Pawe 02
Mung bean	4	2008 (Borda)	
Adzuki bean	1	2015 (Erimo)	Erimo
Cowpea	6	2001 (Bekur)	
Sub-total	**93**		
Total	**201**		

Source: MoAN (crop variety register, issue no 19; 2016Addis Ababa Ethiopia); *Forage crops

Development of integrated crop management technologies

Improved crop varieties should be accompanied by an integrated crop management (ICM) practices to achieve maximum and economic yield. Detailed production package for faba bean, field pea, chickpea, lentil, haricot bean, and soybean were published in Amharic by EIAR (2007) on seed bed preparation; sowing rate, method, and time; irrigation management; weed and disease management; and field and storage insect pest management. However, production packages for grasspea were not specific and there were none for lupine, pigeonpea, fenugreek and mung bean in this guide.

The EIAR report (africasoilhealth. cabi.org/wpcms/wp-content/.../330-EIAR-Biofertlizer-manual.pdf), indicated commercially available rhizobia inoculants for faba bean, field pea, chickpea, soybean, lentil, haricot bean, and cowpea; and the opportunity for better products from the on-going research (Argaw *et al.*, 2015; Mnalku *et al.*, 2009). A study on native rhizobial strains compared to commercial EAL-029 and control showed that inoculation improved grain yield of chickpea in range of 17-42% over the control across locations and chickpea varieties (Alemu, 2016). Strain ICRE-03 and ICRE-05 significantly improved chickpea grain yield by 15.5% and 21.4%, respectively, over EAL-029 at Debre Ziet but no significant difference at Wolayta Sodo. This result implies the potential to develop location specific alternative rhizobial strains to EAL-029 depending on economies of scale and capacity.

Rhizobia inoculants technology is 10 times cheaper compared to 50 kg ha^{-1} application of Urea fertilizer for production of grain legumes (africasoilhealth.cabi.org/wpcms/wp-content/.../330-EIAR-Biofertlizer-manual.pdf). The continuous use of rhizobia inoculants can help improve the soil fertility for subsequent crops and is useful for Ethiopian soils where 85% are reported to have low levels of N. The preliminary study on inoculation method by phosphorus application rates on productivity of soybean suggested that soybean needs application of 20 kg P ha^{-1} when produced without *Bradyrhizohium* inoculation, and no fertilization is required under inoculated condition on Acrisols in south western Ethiopia (Kenea, 2011). However, this result needs further validation across years and locations to reach a conclusive recommendation.

Fikre (2016) reported that legumes-cereals rotation saves 30% of N fertilizer need for the next crop. Such findings are useful to integrate grain legumes with cereals which demand high and expensive fertilizer application for smallholder farmers who may not afford high and rising input costs.

Faba bean gall disease (*Olpidium viciae)* has become the single most important yield limiting threat since 2010 and has reached epidemic levels in Amhara and Tigray Regional States (Abebe *et al.*, 2014; Hailemariam *et al.*, 2016; Hailu *et al.*, 2014). Bitew and Tigabie (2016) reported integrated approaches reduced disease incidence and severity which resulted in improved productivity. Integration of three sprays (at seedling, flowering and podding stages) of Baylaton WP 25 (Triadimefon 250 g kg^{-1}) at the rate of 0.7 kg ha^{-1} with relatively tolerant varieties and improved cultural practices (sowing time, crop rotation, soil fertility) was recommended. Improved varieties were relatively tolerant because of their vigorous early growth than local varieties; and cultural practices which enhances early vigorous growth also contributed to the relative disease tolerance.

The research to control the parasitic weed has enabled to reintroduce faba bean production in previously abandoned hot spot areas of Amhara and Tigray regions of Ethiopia. The ICARDA and NARS cooperative research program (www.mktplace.org/site/images/documents/ID524FinalRep ort.pdf) revealed that integrating partially resistant cultivar *Hashenge* (Abebe *et al.*, 2015) and one to two sprays of sub-lethal glyphosate at flowering stages were found to be effective in managing Orobanche (*O. crenata*) in faba bean and increased grain yield up to 3 t ha^{-1}. Faba bean and lentil genotypes were also identified for further evaluation and release of partially resistant varieties. The integrated faba bean gall disease management and integrated parasitic weed management have been aggressively promoted and being scaled up/out since 2015 by ICARDA in collaboration with NARS and district Offices of Agriculture through USAID funded project.

There are many recent crop management studies which need to be validated and integrated in useable forms for promotion and scaling to reach smallholder farmers producing highland and lowland grain legumes.

Adoption and Performance of Food Legume Technologies

Agricultural research and technological improvements are crucial to increase agricultural productivity to meet demand for food and nutritional security and improve farmers livelihoods and thereby reduce rural poverty. However, these innovations must meet farmers' needs, minimize their risks and ensure predicted income to justify adoption.

Varietal adoption

Several adoption studies of grain legumes have found significant adoption rates of improved varieties and associated technologies such as fertilizers and herbicides among small-scale farmers in Ethiopia. Bishaw and Atilaw (2016) summarized grain legume adoption in Ethiopia, ranging from 44% for bean to 2% for field pea. Yirga and Alemu (2016) reported adoption rates of improved varieties of chickpea, faba bean and lentil was 19.4%, 15.6%, and 11%, respectively. Alemu and Bishaw (2017) however reported that old varieties tend to dominate faba bean varietal adoption. Farmers' knowledge and perception of existing improved varieties, household wealth (land and livestock) and availability of active labor force are major determinants for adoption of improved technologies (Asfaw *et al.*, 2011). Significant variation in adoption however was found between geographic regions and high and low potential areas across the country.

Among crop technology adopters, it was most frequently found that annual gross income of a household positively and significantly influenced crop technology adoption; thus, higher income resulting in a greater adoption of technologies. The impact of adopting new chickpea varieties on household welfare is reported from Ethiopia (Verkaart *et al.*, 2017).

Yield gaps

In Ethiopia, the major outstanding and persistent reason for yield gap is the low adoption of improved technologies by smallholder farmers (Asfaw *et al.*, 2011). Many extension approaches including the recent 'model farmers approach' have been tried for scaling up and out of improved technologies to increase production and productivity (Tefera *et al.*, 2016) but the study also found that the productivity and adoption of the technologies and practices by smallholder farmers remains low. The overwhelming number of farmers across four regions (Amhara, Oromia, SNNP, and Tigray) responded that seed unavailability was the first major factor that hinders use and adoption of improved varieties. On the other hand the major constraint for pesticide use is high cost and unavailability. In most study regions, famers practiced hand weeding instead of herbicide. A recent review of agricultural research and extension linkages by Kassa & Alemu (2017) also reported that many farmers are not aware of the existence of technologies developed by research because of limited capacity of actors responsible for technology multiplication and delivery systems. Partial adoption and sub-optimal application of technological packages by smallholder farmers are also another factor limiting productivity.

Productivity gaps of improved varieties on-station and on-farm conditions are indicated in the crop variety register which is published annually to register and notify the agro-ecological adaptation and the merits of newly released varieties. The national average yield of each crop across different varieties, management practices and agro-ecologies are also reported annually based on the sample survey of the Central Statistical Agency. Figure 1 summarized from these sources, showed that the productivity gaps between potential yield, achieved yield and national average yield by smallholder farmers is very huge.

A combination of genetic improvement coupled with best agronomic management practices has improved grain legumes productivity reaching 3 to 5 tonnes ha^{-1} in favourable agro-ecologies (Fikre, 2016), while the national average grain yield is still 1.64 tonnes ha^{-1} in 2015/16 cropping season (Figure 1). This shows that there is huge potential to bridge the yield gap by making available and accessible improved legume technologies to smallholder farmers.

State of Food Legume Seed Delivery

In Ethiopia, the organized seed sector is now operating for almost close to four decades. It went through several structural and organizational changes although its overall performance has shown mixed results particularly for grain legumes.

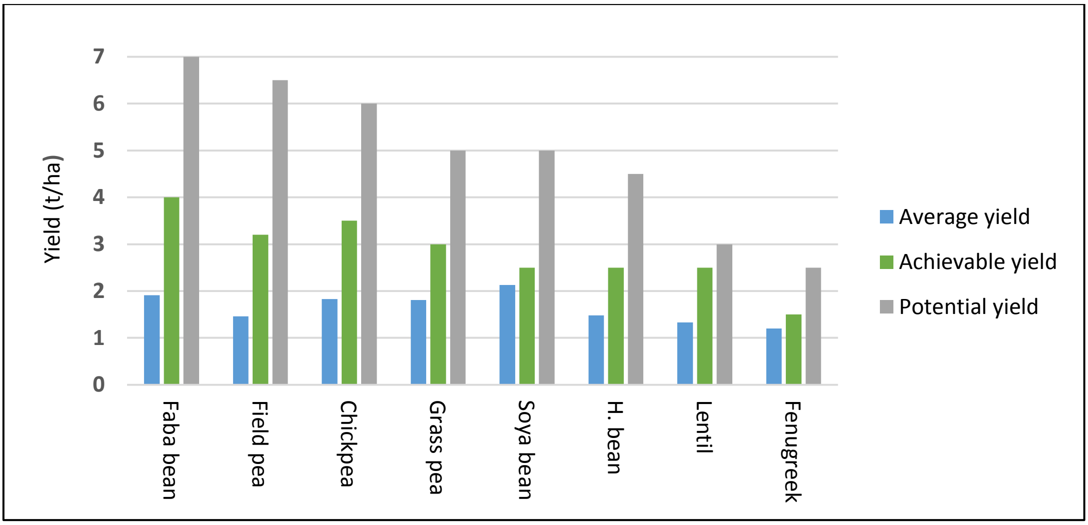

Figure 1. Potential, achievable and national average yield of grain legumes in Ethiopia; Source: Fikre (2016); CSA (2016)

Institutional Arrangements

Currently, a mix of large public seed enterprises (one federal and 4 regional); several small to medium domestic private seed companies (35); and a wide range of licensed or non-licensed semi-informal (intermediate) farmer-based seed production supported by NARS, NGOs or projects are operating in the country (Bishaw and Atilaw, 2016). Most of the domestic private companies started as private farms where seed is not a core business, thus lack the knowledge and experience in managing a seed enterprise. Among 22 seed companies who are members of the Ethiopian Seed Association (ESA, 2015) only seven include legumes as part of their product portfolio (one is a forage legume). From another 13 seed companies with no company or product profile, four PSEs are known to be involved in seed production of at least one or more legumes. A multinational seed company, Pioneer Hi-bred Ethiopia, and a pan African company Seed Co are involved in maize hybrid seed only. In general, reliable data on seed producers and suppliers and their performance in terms of the quantity and quality of seed produced and distributed and the geographic location of their operation is limited. In the next section we will present the performance and experiences of the formal, semi-formal (intermediate) and informal sectors in legume seed delivery.

Performance of Formal Seed Sector

The Ethiopian formal seed sector is still dominated by the public enterprises and mostly engaged in cereal seed delivery particularly wheat and maize (Bishaw and Atilaw, 2016; Bishaw and Louwaars, 2012). From the outset, however, legumes specifically haricot bean and to a lesser extent soya bean have been part of formal seed delivery by the ESE, the sole public seed producer and supplier in the country until the 1990s (Bishaw and Atilaw, 2016; Bishaw *et al.,* 2008). Most of the common bean and soya bean seed produced were used as part of rotation crops for the state farms, the major contractual maize and sorghum seed producers for ESE. Gradually faba bean, field pea, chickpea and lentil seed production came into picture, but remain insignificant due to mechanization problems and as rapeseed is primarily used for rotation by state farms instead of legumes in the highlands.

Haricot bean seed supply is more consistent over the years compared to other legumes. It is difficult to get reliable and credible data from literature as seed production often mixed up with seed distribution and may not also include all legume crops. In some instances, recycled certified seed by farmers are reported as certified seed 2, contrary to standard protocols of seed certification, which inflate the formal sector performance. However, data compiled from different sources on legume seed demand, supply and distribution is presented in Figure 2. In recent years, there is escalation in seed demand for legumes although there is no significant change in actual seed supply. These figures showed that seed demand for legumes did not yet cross the 25,000 tonnes and the seed supply did not exceed 15,000 tonnes per year. More importantly, a closer look into the disaggregated formal seed sector delivery data revealed that, quite often few and relatively old legume varieties are produced and distributed.

Most grain legumes are strictly self-pollinated except faba bean with partial cross pollination where significant out-crossing is expected from adjacent fields, if farmers are growing different varieties. For grain legumes which are self-pollinated, farmers can retain and use the certified seed once they access the improved variety with little loss on purity and identity, if they follow proper agronomic practices. Farmers are not required to replace the legume seed every year unless a hybrid seed technology is available like in pigeon pea. In Turkey, for example a three-year seed replacement rate (SRR) is used for chickpea and lentil. Therefore, applying the rule of thumb of SRR, farmers may be required to replace seed of faba bean every 2-3 years and for other self-pollinated legumes every 4-5 years.

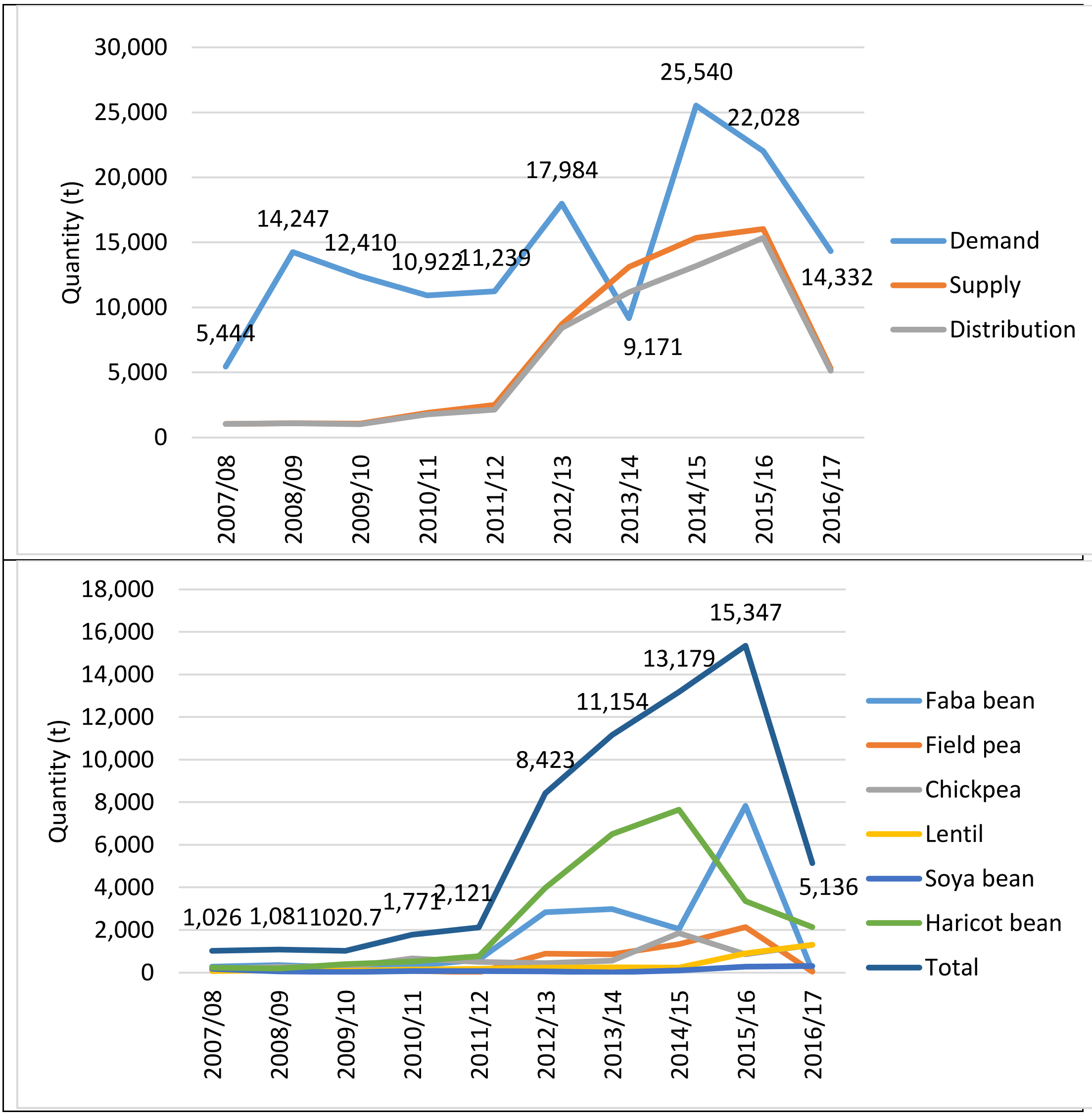

Figure 2. Performance of legume seed sector: a) Seed demand, supply and distribution (top); and b) Seed distribution (bottom)

Analysis of more realistic crop wise legume seed demand and supply based on area under cultivation and average SRR of 33% (every 3 years) for faba bean and 25% (every 4 years) for other legumes is proposed as presented in Table 3. During 2016/17 crop season, ten legume crops were planted on 1,549,912 ha and based on average seed rate (which may vary with seed size) will potentially require an estimated 214,475 tonnes of seed for planting an entire legume area in the country. However, considering the realistic SRR, the amount of certified seed required would be 60,747 tonnes whereas only 5,136 tonnes of certified seed were supplied by the formal sector, which is 8.5% of certified seed required (based on SRR of 25%) or 2.4% of potential seed required for all legumes in the country. The certified seed supplied based on SRR varies from 61% for lentil to 0.2% for faba bean but the long-term trend is erratic and remain below 5% for all legumes compared to the potential seed requirement.

Understanding the realistic demand and developing a road map for legume seed supply will help to sharpen the focus and allocate resources in promoting new varieties and improving the quantity of seed supplied with quality and yield enhancing treatments such as rhizobia inoculants.

Table 3. Amount of legume seed required and supplied in 2016/17 crop season

Crop	Area (ha)	Average seed rate (t)	Potential seed required (t)	SRR (years)	Certified seed required (t)	CS supplied (t)	% of CS required	% of potential seed required
Faba bean	427,697	0.2	85,539	3	28,513	60	0.2	0.1
Field pea	212,531	0.15	31,880	4	7,970	35	0.4	0.1
Chickpea	225,608	0.1	22,561	4	5,640	1,302	23.1	5.8
Lentil	113,685	0.075	8,526	4	2,132	1,299	60.9	15.2
H. bean	290,202	0.1	29,020	4	7,255	2,130	29.4	7.3
Soya bean	36,636	0.08	2,931	4	733	311	42.4	10.6
Grass pea	151,269	0.08	12,101	4	3,025	-	-	-
Mung bean	37,774	0.5	18,887	4	4,722	-	-	-
Lupine	19,908	0.1	1,991	4	498	-	-	-
Fenugreek	34,603	0.03	1,038	4	260	-	-	-
Total	1,549,912		214,475		60,747	5,136	8.5	2.4

Note: Area is based on CSA data (CSA, 2017); CS=certified seed

In 2016/17 crop season, eight cereal crops were planted on 10,219,444 ha and grown by about 16,326,448 smallholder farmers, each farmer cultivating on average about 0.626 ha. Cereals covered 81.27% of the cultivated area and produced by 93.61% of the farming population. In contrast, during the same year, ten legume crops were planted on 1,549,912 ha and produced by about 9,062,008 smallholder farmers, each farmer cultivating on average 0.171 ha.

Legumes occupied 12.33% of the total cultivated area and produced by 51.96% of farming population. A close observation on the population dependent on farming showed that a substantial number of farmers (over 50%) are dependent on legumes as in cereals, though area wise it seems to be significantly low.

Hence, legumes should get the attention they deserve in the development planning given their importance in the livelihoods of smallholder farmers in ensuring food and nutritional security, farming systems sustainability and other environmental and health benefits.

Performance of Farmer-based Seed Production

Experiences in Ethiopia or elsewhere showed that the formal seed system, the public or private sector, were unable to make seed of improved grain legume varieties available and accessible in sufficient quantity, quality and affordable price to smallholder farmers. The formal sector lacks the incentive to participate in the grain legumes seed delivery due to lack of reliable demand and small size of seed markets. Most reviews reported that the formal legume seed delivery showed reaching less than 10% of the farming communities (CARE, 2011; CSA, 2011). Therefore, efforts have been made to make use of a variety of farmer-based seed production initiatives for seed delivery which is semi-formal or informal. Farmer-based seed production is one of the innovative strategies by which legume seed could be produced and become available and accessible to smallholder farmers in a relatively affordable price.

Farmer-based seed enterprises (FBSEs) are not a new concept to Ethiopia. Sahlu *et al.* (2008) summarized the experiences, achievements, constraints and the typology of FBSEs in the country. FBSEs are diverse form of enterprises and sit at the intersection between formal and informal sectors with some similarities to the formal or the informal sectors based on product profile, organizational structure and operations. However, reviews from Ethiopia (Sahlu *et al.*, 2008) and elsewhere in Africa and Asia (Ojiewo *et al.*, 2015) seem to suggest lack of common framework in defining what constitute the FBSEs and the variation that exist among the practitioners. In Ethiopia, seed producer cooperatives (SPCs) emerge as *force de majeure* of farmer-based seed production and recognized as an intermediate sector (ATA,2015) where they all play an important role in seed delivery filling the seed demand gap of the formal sector. Some SPCs, evolved from farmer research groups established for adaptive research, participatory variety selection, pre-extension technology demonstration or pre-scaling up/out activities by NARS while others were established by public seed enterprises for contractual seed production or by NGOs and projects for local seed production. Hence, SPCs are not homogeneous entities and as diverse as their origin and vary in terms of structure, membership, governance, legality, crops, capital, capacity, facilities, geographic coverage and more.

The Agricultural Transformation Agency has recently started organizing and legalizing the formation of seed unions. According to Sisay (2017) about 327 SPCs are engaged in seed production and marketing and about two legally registered seed unions are operating in the country in 2016. The introduction of Quality Declared Seed (QDS) scheme provided an ample opportunity and space for the SPCs to engage in seed delivery. The following section presents some of farmer-based seed production experiences from NARS and development practitioners in Ethiopia.

Experiences of NARS in Ethiopia

Ethiopian NARS has initiated the farmer research groups (FRGs) as part of adaptive research or for pre-extension technology demonstration and pre-scaling-up/out of research results to reach farmers. Some of the FRGs were overtime transformed into farmer seed producer's associations. The EIAR affiliated agricultural research centers particularly Debre Zeit and Melkassa ARC have played a significant role in dissemination of chickpea and lentil and common bean technologies in central, north western, eastern and southern Ethiopia. Debre Zeit ARC (1998-2002) and the EIAR (2009-2010) managed to disseminate seed of improved chickpea varieties to cover an area of 4021.4 ha with the participation of 10462 smallholder farmers distributing about 518.8 tonnes of seed in Amhara, Oromia, SNNPR, and Tigray regions (Eshete *et al.*, 2015). Similarly, the achievement for lentil was 1557.25 ha with the participation of 3905 smallholder farmers who received about 120 tonnes of seed during the same period. Similar approaches and experiences of informal seed production and pre-scaling-up/out activities by NARS were reported for faba bean, chickpea, lentil and haricot bean (Teklewold *et al.*, 2012).

The framework for scaling crop technologies using seed as entry point was implemented for three consecutive years (2009-2011), spearheaded by EIAR in collaboration with RARIs, MoA and local administration to mitigate technology and seed gaps (http://edr.eiar.gov.et:8080/xmlui/handle/123456789/2147). It was integrated approach combining technology, seed systems, knowledge and information and development.

Experiences of ISSD-Ethiopia

The Integrated Seed Sector Development (ISSD)-Ethiopia Project introduced the concept of local seed business (LSB) where through scoping studies farmer research groups, farmer extension groups or cooperatives were identified, organized and trained to become licensed seed producer cooperatives (SPCs) in four regional states (Amhara, Oromia, SNNPR and Tigray) of Ethiopia. Moreover, the SPCs, have been supported in organization and management of seed production, seed marketing, business and finance and linked to input and service providers.

During 2009-2015, about 273 SPCs were organized and supported to engage in seed business in potential Agricultural Growth Program (AGP) districts, moisture stress areas in Productive Safety Net Project (PSNP) districts and in non-AGP and non-PSNP districts (Table 4). Among these, 98 SPCs have been engaged in grain legume seed production.

Table 4. Number of SPCs established and engaged in legume seed production in 2015

Region	AGP		PSNP		Non AGP/PSNP		Total	
	Total	Legumes	Total	Legumes	Total	Legumes	Total	Legumes
Amhara	16	8	16	6	40	4	72	18
Oromia	30	22	43	28	46	12	119	62
SNNPR	7	0	19	2	8	7	34	9
Tigray	4	1	7	8	37	0	48	9
Total	57	31	85	44	131	23	273	98

Note: The number of SPCs may increase with expected increase in AGP districts in 2016

Table 5 shows region, crop and year wise distribution of grain legume seed production. The SPCs in Oromia region were involved in seed production of more grain legumes followed by those in Amhara and Tigray regions. SPCs in SNNPR are primarily focus on haricot bean seed production. Chickpea and faba bean were mostly produced in Amhara and Oromia regions, while haricot bean is produced in Oromia and SNNPR (Table 5). Seed production of fenugreek, groundnut and soybean is in Oromia only. Legume seed production increased from 743 tonnes in 2012 to more than three times to 2301 tonnes in 2015. A total of 8676.1 tonnes of seed of different legume crops was produced over the five-year period. About 42.2% of legume seed production was of chickpea followed by lentil (22.4%), haricot bean (14.5%) and faba bean (12.2%) during 2012-15 crop season.

Table 5. Grain legumes seed production by SPCs during 2012-2015

Region	Crop	Quantity of seed produced (t)				Total
		2012	2013	2014	2015	
Amhara	Faba bean	0	42.0	24.0	24.5	90.5
	Field pea	0	0	6.0	0	6.0
	Chickpea	58.6	160.0	57.8	68.5	344.9
	Lentil	75.0	31.3	0	0	106.3
	Sub-total	133.6	233.3	87.8	93.0	547.7
Oromia	Faba bean	96.6	308.4	315.2	131.5	851.7
	Field pea	54.4	114.9	95.3	63.5	328.1
	Chickpea	152.0	851.0	952.5	1327.7	3283.2
	Lentil	37.5	743.0	451.1	605.2	1836.8
	Haricot bean	13.5	23.9	241.3	1.9	280.6
	Soybean	0	40.0	59.3	7.0	106.3
	Groundnut[1]	52.1	93.8	90.6	57.3	293.8
	Fenugreek	0	0	0	13.9	13.9
	Sub-total	406.1	2175.0	2205.3	2208.0	6994.4
SNNPR	Faba bean			9.8		9.8
	Haricot bean	201.8	234.9	538.3	0	975.0
	Sub-total	201.8	234.9	548.1	0	984.8
Tigray	Faba bean	0.8	61.9	43.8	0	106.5
	Field pea	0.7	3.3	2.4	0	6.4
	Chickpea	0	17.0	19.3	0	36.3
	Sub-total	0.8	61.9	43.8	0	106.5
	Total	743.0	2725.4	2906.7	2301.0	8676.1

Note: [1]Ground nut is classified as oil crop in Ethiopia

Experiences with CGIAR Centers

Apart from supporting agricultural research in developing improved grain legumes varieties, CGIAR centers such as ICARDA, ICRISAT and CIAT are involved in scaling out activities of their mandate crops using a combination of formal, intermediate or informal approaches. CIAT and ICRISAT implemented Tropical Legume (TL) projects funded by Bill and Melinda Gates Foundation (BMGF). ICARDA has recently involved in scaling faba bean and chickpea technologies in strengthening the seed sector.

Chickpea seed delivery with ICRISAT

Abate *et al.* (2012) summarized the achievements on chickpea and common bean under TL projects supported by the BMGF during 2007-2011 across a wide range of activities including among them a variety of seed delivery approaches employed to reach farmers. Working with broad range of partners, the project was able to produce 175 t of basic seed and 7780 t of quality declared seed through decentralized production and reaching 464,831 farmers (during phase 1) for common bean whereas 234 t of EGS and 3353 t of certified seed was produced for chickpea reaching a wide of small farmers directly or as spillovers.

Under successive TL project, ICRISAT in partnership with EIAR was able to produce and distribute quality seed of chickpea working with seed producer cooperatives particularly in Eastern Shoa Zone. The project was able to disseminate new improved chickpea technologies (Table 6). It should be noted that however, once again seed of few and relatively old varieties dominated the intermediate sector as in formal sector where the top three varieties (over 12-15 years) captured 81, 10 and 7% of chickpea seed supply, respectively.

Table 6. Community based chickpea seed produced under TL projects in Ethiopia

	Amount of certified/quality seed produced (t)								
Variety	2008	2009	2010	2011	2012	2013	2014	2015	Total
Arerti (2000*)	500	859	1192	1283	1714	1900	2620	1726	11794
Shasho (2000*)	88.5	129.6	120.8	186	239.6	217	396.7	54.1	1432.3
Habru (2004*)	38	69.4	66	111	148.1	194.9	233	208.6	1069
Ejere (2005*)	1.5	2	2.5	6.2	6.7	9.3	6.4	78.6	113.2
Monino (2009*)				2.6	3.3	4.5	8.8	65	84.2
Teji (2005*)	1.5	2	2.5	6.1	4.9	6.8	6.4		30.2
Natoli (2007)				1.7	2.3	2.8	4.4	4.2	15.4
Kutaye (2005)	1			3.6	5.2	3.8	6.8	1.6	22
Chefe (2004*)	0.5	2.5	3	4		5			15
Mariye (1985)	0.2	0.3	0	3	1.8	1.3	2.9		9.5
Minjar (2010)						1.8	4.4	1.7	7.9
Teketay (2013)								6.6	6.6
Dalota (2013)								8.2	8.2
Akuri (2011*)								3	3
Mastewal (2006)								1.5	1.5
Total	631.2	1065	1387	1608	2126	2347	3290	2159	14612

Note: *Kabuli chickpea

Common bean seed delivery with CIAT

Several common bean varieties that are potentially suitable for a wide range of ecologies of Ethiopia were released through partnership between Ethiopian NARS (EIAR and RARIs) CIAT and Pan African Bean Research Alliance (PABRA). However, availability and access to seed of new improved varieties remain a major constraint for adoption. According to Tumsa *et al*. (2015), using community seed production, the Ethiopian National Bean Research Program in partnership with a broader range of organizations managed to increase access to seed of market demanded varieties from less than 20% to about 68% across major common bean growing areas during 2004-2011. During the same period, the area under beans production was also increased by 44.3% while the yield was increased by more than two folds. However, it is difficult to ascertain and attribute all these achievements ignoring the role of partnerships with the formal sector. The work on haricot bean is addressed elsewhere in this proceeding and hence not included to avoid duplication.

Faba bean and chickpea seed delivery with ICARDA

Since 2015, ICARDA has been implementing two USAID funded projects with the overall goal of increasing the productivity and production of faba bean[1] and chickpea[2] as well as improving the livelihoods of smallholder farmers. It has been involved in scaling out improved varieties and integrated crop management technologies to reach new potential areas for legume production and most farmers to compliment the limited performance of the formal seed sector. Anchored on ICARDA's experience in deploying rust resistant wheat varieties in Ethiopia and elsewhere (Bishaw *et al*., 2016) these projects aimed at strengthening some of the key components of the seed value chain working with a broad range of partners and stakeholders from federal (1) and regional (12) NARS; federal (1) and regional (3) PSEs; zonal and district Bureaus of Agriculture (BoA) and extension offices. In 2016, the project was operating in 62 districts for faba bean and 47 districts for chickpea across four regional states which are major producers of these legume crops including AGP, PSNP, non-AGP and non PSNP districts. These projects undertook massive demonstration and popularization of improved varieties and integrated crop management technologies to create awareness and demand among farmers; accelerated early generation seed production (including off-season) to produce sufficient amount of breeder, pre-basic and basic seed with NARS and

[1]Deployment of malt barley and faba bean varieties and technologies for sustainable food and nutritional security and market opportunities in the highlands of Ethiopia

[2]Better livelihoods for small holder farmers through knowledge-based technology interventions in the highlands of Ethiopia: Increasing the productivity of chickpea in wheat-based cropping system

certified seed production through formal public or private sectors; and small seed pack distribution for on-farm seed production by mobilizing existing or newly established seed producers cooperatives or farmer groups; and capacity development of project partners and stakeholders including farmers in providing facilities for NARS and seed producers and training to upgrade knowledge and skills. The project is unique in demonstrating and distributing rhizobia inoculants of faba bean and chickpea in partnership with the private sector (Menagesha Biotech Industry PLC).

A combination of formal, intermediate and informal sectors was used in multiplying the crop technologies for scaling out involving a broad range of partners and stakeholders (Figure 3). NARS are implementing partners and are responsible for technology generation, demonstration and multiplication of early generation seed (EGS) as well as technical support for on-farm seed production and facilitation of linkages with district BoA. NARS are responsible for early generation seed including basic seed with SPCs and make available the seed for further multiplication to certified or quality seed. Public seed enterprises (PSEs), having access to basic seed, are responsible for certified seed production and marketing by themselves. SPCs produce certified seed or quality seed, respectively, and market it formally or sell or exchange locally. BoAs facilitate demonstrate-ions, organize field days and mobilize and provide technical support to SPCs or farmer groups and implement the ‘revolving seed fund’ scheme. The regional seed laboratories inspect and ensure the quality of seed produced to be marketed as certified seed through formal sector or through direct marketing or exchange by seed producers.

Farmers who are members of existing SPCs or newly identified and organized farmer groups are provided with seed of improved varieties and enter a contractual agreement with BoA to produce and market all the seed and return in kind the amount of seed received through the support of the projects under the ‘seed revolving scheme’. The cooperatives or farmer groups will produce the seed under the technical support of NARS and supervision of BoA. The seed produced is inspected and certified through the regional seed laboratories and marketed through different channels. Farmers, after returning the revolving seed and retaining part of the seed for their own use, are free to market the seed collectively through the seed unions to public or private seed suppliers, on-going development projects or sell directly to farmers on cash or through lateral farmer to farmer exchange. About 37 licensed and seven newly formed non-licensed SPCs were involved in faba bean and/or chickpea seed production across four regions. The BoA will recover and use the ‘revolving seed fund’ and provide to other group of new farmers who did not access the technology as part of scaling out improved crop varieties.

NARS were able to produce 78.7 t of breeder seed, 268.54 t of pre-basic seed and 805.91 t of basic seed during 2015 and 2016. These include 38.75 t of breeder seed, 102.97 t of pre-basic seed and 306.67 t of basic seed of faba bean and 39.95 t of breeder seed, 165.57 t of pre-basic seed and 499.24 t of basic seed of chickpea. NARS produce part of the basic seed with SPCs to have sufficient quantity of early generation seed. NARS also supplied part of the pre-basic/basic seed to public or private sector for further multiplication and marketing through their own channels.

The amount of certified seed/quality seed produced through SPCs during 2015-16 is presented in Table 7. The project was able to produce collectively 3386.45 t of certified seed/quality seed of faba bean and chickpea which is sufficient to plant 28,224.2 ha and directly benefitting about 154,331 households. About 1316.1 t of faba bean seed was produced which would cover 7,520.54 ha of land, directly benefiting 60,650 farm households in Amhara, Oromia, SNNP and Tigray Regional States. Similarly, 2070.35t of certified/quality seed of chickpea was produced which would cover 20,703.5 ha of land, directly benefiting 93,681 farm households (Table 7) in Amhara, Oromia and Tigray Regional States. The coverage will be more than two folds as more seed will be injected by the projects in 2017. This show case that availability and access of improved technologies such as seed could be enhanced if concerted efforts continue and complemented by affirmative policy supports.

In summary, the review of both formal and informal sectors showed that the performance did not reach the desired level of legume seed delivery. From the case studies of NARS, ISSD and CGIAR, the SPCs have made significant contribution to legume seed delivery compared to the public seed enterprises or private seed companies. They were able to introduce improved varieties and produce and distribute quality seed at relatively lower cost serving as a bridge between formal and informal sectors. Given initial public support in seed business development, SPCs can grow into viable local seed business, serving seed supply of crops that are not adequately handled by public or private sector. However, the anarchic situation of farmer-based seed production we observe today need to be streamlined not to undermine the development of the nascent legume seed sector.

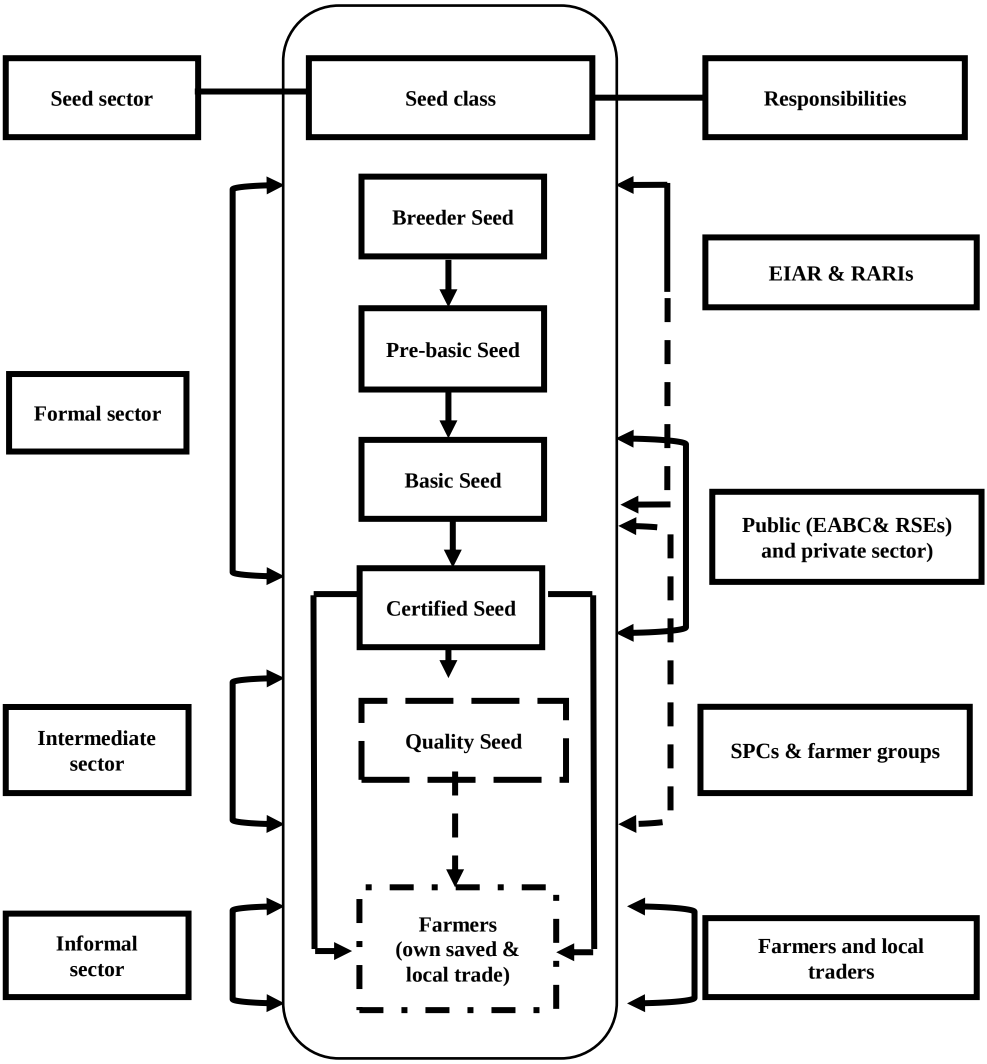

Figure 3. Approaches in seed multiplication for scaling out faba bean and chickpea technologies by ICARDA

Table 7. Faba bean and chickpea certified/quality seed produced and distributed during 2015-16

Region	Crop	2015	2016	Total	Area planted (ha)	Farmers reached (no.)
Amhara	Faba bean	39.0	296.87	335.87	1916.4	15455
	Chickpea	431.0	728.85	1159.85	11598.5	52482
	Sub-total	470.0	1025.72	1495.72	13514.9	67937
Oromia	Faba bean	288.1	588.43	876.53	5008.7	40393
	Chickpea	176.4	602.0	778.4	7784	35222
	Sub-total	464.5	1190.43	1654.93	12792.7	75615
Tigray	Faba bean		104.2	104.2	595.4	4802
	Chickpea	1079.5	241.5	132.1	1321	5978
	Sub-total	107.95	128.35	236.3	1916.4	10780
	Total	1042.45	2344.5	3386.95	28224	154332

Source: ICARDA project reports (2015 and 2016)

Are there Lessons from Developed and Developing Countries?

In developed countries, like Australia and Canada, cool season food legumes such as chickpea and lentil are recent introduction for diversifying the cereal dominated agricultural production systems. Both countries became successful chickpea and lentil producers and competitors in global grain legume markets. According to Gareau *et al.* (2000) in countries like Australia and Canada, and members of European Union (e.g. France) producer associations gather levies from farmers to support research and seed delivery through public-private partnership.

On the other hand, traditional legume producers and exporters became net importers (e.g. Morocco, Turkey, etc.) and less competitors in global markets due to decline in area for legume production, low productivity, marketing and pricing. Some countries like Algeria, Egypt and Tunisia are trying to revive grain legume production through government programs. In Turkey, area and production of chickpea and lentil reached the highest level with cereal-fallow replacement program during 1982-1991 targeting about 1.4 million ha in the Central Anatolia and Transitional Zones of the country. However, grain legume area and production showed sharp decline after the program due to marketing and pricing issues. Currently Turkey is paying subsidies both to the seed producers and seed user farmers to boost domestic grain legume production (Keser, 2016).

Legume production appears to be susceptible to domestic and international markets, leading to volatility in acreage, production and price. India, a major producer, consumer and importer of grain legumes, initiated a national drive for self-sufficiency and boost domestic production to meet the rising demands. The government introduced a minimum support prices to stabilize the acreage, production and prices and related policies to encourage the cultivation of legumes in the country (Subramanian, 2016). Such policies may boost and stabilize grain legume production in Ethiopia too.

Byerlee and White (2000) attributed the success and rapid expansion in soybean production to investments in research, wide-scale extension programs, supporting producer prices, encouraging the agro-processing industry and export markets. Similar efforts may be needed for other legumes in developing countries. Some of the characteristic of legume production and seed delivery in developed and developing countries are presented in Table 8.

Table 8. Legume production in developed and developing economics

Developed Economies	Developing Economies
Legumes introduced as part of crop diversification program	Legumes are part of traditional farming systems
Market-oriented and/or export-led commercial legume production	Subsistence agriculture with focus for domestic production
Strong public-private sector partnership supporting the legume sector (e.g. Australia)	Inconsistent government support for the legume sector (e.g. Turkey)
Private sector and farmers play leading role in seed production and marketing	Private sector lacks the capital and willingness to invest in seed sector
Government will match funds from the private sector to support grain legume research (e.g. Australia)	Introduce minimum support price for grain legumes to boost domestic production (e.g. India)

Source: Bishaw *et al. (*2008)

Strategies for Food Legume Seed Delivery

Bishaw *et al.* (2008) reviewed the major policy, regulatory, technical, institutional, organizational and socio-economic constraints for the development of an effective and efficient legume seed industry in Central and West Asia and North Africa (CWANA) region including Ethiopia. Some of these issues are still relevant today and applies to the national seed sector in general (Bishaw and Atilaw, 2016) and legume seed sector (Bishaw and Pandey, 2016) in Ethiopia. Some of these and other options which are relevant today are presented and discussed in more depth below.

Demand Driven Agricultural Research for Legumes

NARS have played a major role in developing improved technologies with significant contribution to the growth in productivity and production of legumes. Despite impressive achievements over the last five decades of agricultural research there are emerging challenges such as climate change and its ramifications i.e. emerging threats of new pests, increasing temperature, frequent droughts, etc with serious consequences on the agricultural sector (Bishaw and Atilaw, 2016). A ten-year research strategy for pulse crops have been prepared on the occasion of the International Year of Pulses in 2016 to provide future direction in research for development (Sivasankar *et al.*, 2016) which is relevant to Ethiopia too. There is also a legume research strategy developed by EIAR for the next 15 years (2016-2030).

Development of diverse varieties

Grain legumes as diverse as they are also produced in diverse farming systems and agro-ecologies and have multiples uses as nutritious food for human consumption, valuable feed for livestock or break crop for cereal rotation enhancing soil fertility and health or cash crop for domestic or international markets. Farmers require niche varieties that are suitable to their farming systems and production environments (e.g. early or short maturing varieties for late planting), grain quality attributes for consumer preferences (e.g. colour, taste, cooking time) and export markets for certain grain quality attributes (e.g. seed colour, seed size) for premium prices in international markets. Tolessa *et al.* (2015) found a dramatic progress in breeding for seed size while increase in yield is more modest for faba bean during the last 33 years of crop improvement in Ethiopia. Legumes are exposed to suite of abiotic (drought, heat) and biotic stresses (ascochyta blight, fusarium wilt complex, rusts (lentil) and insect pests (African ball worm)]. There are also emerging challenges such as Orobanche and gall diseases in faba bean where resistance varieties are not yet available.

NARS should develop varieties with these specific traits employing both conventional or modern genomic tools to meet the demand of different seed value chain actors to boost legume production and create demand for inputs while confronting the emerging challenges of climate change. Moreover, legumes are inherently low yielders and breaking the yield barrier is of paramount importance through use of modern breeding tools.

Bridging yield gaps

Legume yields vary greatly across farmer' fields and regions due to biophysical, agronomic and other factors as shown elsewhere in this chapter. Legume productivity has shown an increase from 1.0 t ha^{-1} in 2001 to 1.68 t ha^{-1} in 2016, an average increase of 4.5% per year (Table 1). For selected legume crops, the average potential yield is about 4.94 t ha^{-1} compared to the achieved yield of 2.84 t ha^{-1} and national yield of 1.64 t ha^{-1} (Figure 1). Average legume productive-ity reached about 33% of the potential yield though it varies from crop to crop, ranging from the highest of 44% for lentil to the lowest of 23% for field pea. Average yield increases for legumes have not kept pace with cereal crops in Ethiopia or elsewhere. Low productivity due to lack of niche varieties and use of appropriate agronomic practices led farmers switching to mono-cropping or abandoning legume production in certain regions of the country. An integrated crop management is the best option to overcome the current level of low productivity, but farmers often adopt technologies partially which expose the crop to low yields. A concerted effort should be made to take advantage of the opportunities that exist and develop and promote simple but effective and specific integrated crop management technologies to realize the attainable yield within the context of the farming systems and production environments.

Development of hybrid varieties

Ethiopian farmers have demonstrated their strong demand for seed and their strong willingness to pay for hybrid technology. Adoption of hybrid maize varieties and seed is a clear testimony for the emergence and development of the private sector. In India, a pioneering work in hybrid technology development for pigeon pea has attracted the interest of the public and private seed companies and the government. Similar opportunities should be explored for other legumes to attract the seed industry although the potential for greater yield improvement is unclear (Sivasankar *et al.*, 2016).

Research on value addition

Legumes are potential crops for value additions. NARS can play an important role in value addition technologies for the diversification of legume products and to increase farmers' income and better livelihoods. Sivasankar *et al.* (2016) suggested the food industries can offer new niche markets for pulse crops, especially where commercially viable uses can be found for all pulse fractions. Experiences elsewhere show that agricultural transformation and rural industrialization can be achieved through agricultural clusters linking production with the agro-industry. Can the legume exporters and the agro-processing industries play a role in the promotion of legumes in Ethiopia? Such changes are yet to be seen as the transformation of agro-industries may take off in the coming years.

Strengthening the Food Legume Seed Sector

To date, both formal (public and private) and informal sectors including alternative and innovative approaches (intermediate) are used in legume seed delivery. Despite progresses made in the past few years, the review of their performance clearly demonstrated that the legume seed delivery is yet not at the desired level in ensuring the availability, access and use of seed of desired varieties and serving most of the farming communities.

Institutionalization of EGS production

EGS remain a major bottleneck in commercialization of improved legume varieties leading to long time lag between variety development and use by farmers. Four principal issues are important for streamlining EGS production by the federal and the regional NARS: institutional framework and capacity for EGS production, adequate planning for EGS production, decentralization of EGS production, and adequate quality assurance (Bishaw and Atilaw, 2016; Atilaw *et al.*, 2017). There is no clear institutional arrangement for organizing EGS production for public-bred varieties which is very much an ad hoc arrangement and inconsistent in terms of varieties, seed classes and amount of seed produced. NARS should take the lead in commercializing their varieties investing sufficient resources in promotion and production of EGS. Such arrangements may require the establishment of seed units to undertake this responsibility which will work as a commercial wing of NARS. Production planning for seed is a four-year cycle starting from breeder seed to certified seed where adequate consultation is required at the national level among the seed value chain actors as the varieties are moved from research centres to farmers' fields. NARS may also need to formally decentralize EGS production to regional agricultural research institutes or centres for varieties with regional interest to ease the pressure on their capacity to produce EGS due to shortage of sufficient land. Variety maintenance and seed quality assurance are some of the areas that need to be strengthened to overcome the current problem of varietal purity and seed quality to build the confidence of both the seed suppliers and the seed users.

Apart from the strategy document on seed sector developed by ATA, an independent study on EGS was commissioned by ATA and financed by Scaling Seeds and Technologies Partnerships-Alliance for a Green Revolution in Africa (SSTP-AGRA). The study identified priority crops and EGS production archetypes, among which chickpea and haricot bean were included. Although both crops fall within the category of low demand for improved seed and low profit margin for producer, thus public-sector dependent for EGS production, the feasibility analysis of haricot bean showed that EGS production can be outsourced to the private sector while the public sector can produce certified seed. However, for a meaningful change of the current impasse, an action–oriented program should be developed and implemented instead of on the shelf-studies with no practical value, no further follow-up and execution of the recommendations.

A new approach and a drastic departure from the current stalemate on EGS production could be to create a mechanism to provide incentives for NARS where they have the authority to give exclusive rights for public or private seed companies for commercialization of their varieties within the context of revised breeders' rights proclamation in the country. In Turkey, for example, public varieties are equally protected as private varieties, and the royalty payment is shared between NARS and the breeders incentivizing the public breeding program.

Commercialization of public 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. Currently, the public seed sector, represented by one federal (Ethiopian Agricultural Business Corporation ex ESE) and three regional PSEs (Amhara, Oromia and South) and wheat and maize seed delivery continue to dominate the formal sector. EABC is reorganized with the new business model where, the corporation is intended to provide agricultural inputs (seeds, fertilizers) and services (mechanization) which may improve logistical and operational efficiency.

From the outset, PSEs are inherently lack commercial orientation and operation and focus on social services to meet government targets. Low productivity, high production costs, uncertain seed markets and farmers' willingness to pay are some of the factors affecting the legume seed delivery. A study by DGDA (2012) showed that expansion in production of legumes such as chickpea, lentil and haricot bean would lend ESE profitable and financially sustainable while contributing to the national agricultural and rural development program of the country which is a positive outcome. PSEs should grapple with the paradox of financial sustainability and social services to the farming communities where they need to make strategic decisions in their seed operations.

Among legumes handled by the formal sector, haricot bean is the only crop with sizeable and regular seed supply though the amount remains low compared to national seed requirement and other cereal crops. The analysis of legume seed sales showed that PSEs are producing seed of few and also yet very old legume varieties. Focusing on promotion and seed production of newly released varieties with better yield and productivity would help them to offset high production costs and increase profitability by introducing legumes in their production plan. Small seed packs may also be used as marketing strategy since the landholdings are very small compared to cereals.

Participation of private seed sector

The Ethiopian national seed policy encourages that the private sector to play greater role in seed delivery. Despite policy pronouncements, the private sector remains weak in a primarily public sector dominated seed industry where there is lack of clear and practical incentives targeted to the seed sector. Moreover, given the technical constraints and lack of incentives the absence of private sector involvement in legume seed delivery is not surprising. As stated elsewhere only few members of ESA include legumes in their product portfolio dealing with legumes. How such modest beginning could be encouraged, motivated and supported to diversify and expand their operation in legume seed delivery is yet to be seen. Gareau *et al.* (2000) reported how public-private partnership drives legume production and seed delivery in countries like Australia and Canada and European Union.

Support to seed producer cooperatives

Empirical evidence from Ethiopia and elsewhere in Africa and Asia indicates that legume seed delivery will remain in the hands of smallholder farmers at least in the coming decade or so (Neate and Guei, 2011; Bishaw and Pandey, 2016). The diversity of farmer-based seed production approaches and lack of common framework (different contexts) however, bring into forefront the criteria to measure their performance in terms of technical feasibility, economic profitability and long-term sustainability, particularly in the absence of some external support. It is critical to distinguish between SPCs, where seed is a core business where the full responsibility of seed production and marketing lies within their remit and those which are organized for different purposes such as out-growers for PSEs or for conservation of genetic resources or others for the social wellbeing of the member farmers.

Bishaw and van Gastel (2008) outlined the framework and critical steps for establishing and operating business-oriented VBSEs (village-based seed enterprises) and demonstrated their performance in terms of their technical feasibility and economic profitability (Srinivas *et al.,* 2010) which ensures long-term sustainability. The VBSEs can eventually be transformed into small-medium enterprises (SMEs) as they grow, diversify and expand their operations (Samadi and Aziz, 2015), if from the outset these enterprises are provided with appropriate facilities, technical support, access to finance and markets, linked to formal sector institution, have established enterprise governance, and mentored for sufficient number of years. Moreover, diversification of product portfolio and operations beyond their immediate vicinity would enhance their performance and thus their sustainability. In Ethiopia, market orientation (customer and supplier orientation and inter-functional coordination) along with marketing activities are expected to contribute to better performance of SPCs (Sisay, 2017). Under Ethiopian context, SPCs emerged as *force de majeure* and most effective seed delivery partners where they need to be promoted and supported for gradual evolution into the SMEs. The introduction of QDS provided greater opportunity for meaningful contribution of SPCs to seed delivery particularly of legume crops in terms of choice of seed quality and access to seed certification.

Undertaking seed market research

In Ethiopia, seed marketing is one of the critical challenges of the national seed sector, be it formal, intermediate or informal sector, leaving aside local seed exchange and trade among farmers. The centralized production planning, seed demand assessment, seed marketing, and seed pricing are lots to be desired (Bishaw and Atilaw, 2016; DGDA, 2012). It stifles competition and innovation among seed producers and suppliers. There is a general lack of reliable data on seed market– be it in terms of potential market demand (crop area and its agro-ecological characteristics like drought incidence), effective market demand (varietal use and seed renewal rates) and supply (seed volumes produced/traded).

Legume seed production should be informed and guided by the seed market and seed pricing by farmers' willingness to pay for seed of improved varieties. Legumes are inherently low yielders with high seed rates and low average yields of less than 2 tonnes ha^{-1}which impacted heavily on seed delivery due to high seed to grain price ratio. The DGDA (2012) study showed that while expansion of chickpea, lentil and haricot bean production will be profitable for ESE, the production of faba bean, field pea and soya bean appear problematic and incurring losses as the seed is priced below their production costs. The study suggested for ESE to undertake market research to accurately understand and forecast demand estimates and market size and farmers' willingness to pay for seeds of all crops (including legumes) and decide on production mix where profits from some crops finance the production of other crops.

Under Ethiopian context, commercial seed production is at least a four-year cycle from breeder to certified seed where accurate production planning is critical to achieve annual targets. Creating a national forum of seed value chain actors including NARS, seed suppliers and policy makers would be more effective and practical to overcome the key constraints of seed sector including marketing rather an ambitious plan of GTP targets which remain un-fulfilled as seen from previous experiences. The federal and regional state institutions such as MoANR, BoANR, NARC and ESA have a major role to play in this endeavour.

Enabling Policy Environment

The policy environment can be a major driver for legume production and seed delivery and should take diversity into account by avoiding a uniform approach to all crops, given legume-specific challenges.

Creating functional legume value chains

A functional food legume sector is critical to attract farmers and private sector investments in seed delivery. According to National Agricultural Research Council (NARC), among legumes chickpea and haricot bean are identified as priority crops of commercial interest whereas faba bean and lentil as food security crops. In Ethiopia, the Agricultural Commercial-ization Clusters (ACC) project within the national agricultural transformation agenda aimed at providing a strategic platform to drive greater integration across priority value chains. Such farmer-ago-industry linkage through ACC may pave the way for contract farming and will be an opportunity for future expansion and uptake of agricultural inputs including seeds by the farming communities that can improve the production and productivity of legume crops. These plans are yet to put into practice to bring about desired changes.

Product segmentation

Currently, there is no grain legume grading system, hence no market signals are transmitted from end-users to producers and hence a dysfunctional legume value chains. Farmers lack the incentives for quality products since they receive no premium prices in primary markets. Abate (2012) reported the presence of grades and standards for common bean where a similar effort is underway for other legumes in Ethiopia. It is stated that introducing standards can reduce price risks and encourage adoption of improved varieties. Moreover, lower quality and high domestic prices emanating from low productivity and high production costs render legume production less competitive in domestic and export markets.

Seed policy and regulatory framework

The Ethiopian Government has identified improving the efficiency of the seed system as the most effective means of meeting the Sustainable Development Goals. In GTP II, it is 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 (Bishaw and Atilaw, 2016). Concrete steps are required to translate the policy direction into practical action if we need to support the entry of the private sector and diversify the seed industry.

Conclusion

There is a tremendous yield gap on research stations and on-farmersfields despite the avaiability of improved legume technologies with high yield potential. Lack of information, knowledge and skills and poor acess to technologies are some of the limiting factors. For legume seed delivery some of the crtical limiting factors are but not limited to the following:

i. Insuffcient investment in agricultural research and development of the grain legumes despite their importance in the farming systesms and multiple uses compared to food security cereal crops
ii. Lack of awareness of legume varieties and integrated crop management practicies due to insufficient demonstration or popularization by NARS and agricultural extension services
iii. Limited availability and access to EGS (breeder, pre-basic and basic seed) from NARS where priroity is given to major crops due to limited resources
iv. Limited interest from both the public and the private sector in certified seed production and marketing, contrary to empirical evidence, excusing themeselves with lack of reliable seed demand, small seed market and low profit margins
v. Lack of enabling policy environment for the input and output markets where grain legumes receive little attention compared to food security cereal crops

Hence, detailed value chain analysis to identify the gaps and propose solutions based on an integrated seed system development to create functional linkages between demand for grain and demand for seed of improved varieties is critical.

In Ethiopia, given the diversity of the legume crops, farming systems and agro-ecologies, there will be no one solution for legume seed delivery where a mix of formal, intermediate or informal sector need to operate side by side at least for the decades to come. However, the performance of the legume sector clearly demonstrated where SPCs emerge as *force de majeure* in seed delivery. Apart from commercialization of the public sector and incentivizing the private sector to engage in legume seed delivery, SPCs deserve a well targeted support and promotion. Strengthening the technical and financial capacity, business-orientation and management, improving enterprise governance, improving business skills and knowledge of its members and leaders is one of the best options for legume seed delivery in the years ahead. SPCs need to be nurtured and mentored leading to the development of the nascent legume seed sector.

The recent strategy developed by ATA is believed to provide the road map in transforming the Ethiopian seed industry. Translating the strategy into actions by allocating sufficient resources is critical whose success is dependent on adequate ownership, coordination, and accountability of partners and stakeholders at all levels which is equally relevant to the development of the legume seed sector.

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Ethiopian Journal of Crop Science

Special Issue Volume 6
Number 3
October, 2018
ISSN 2072-8506

Price: 50 Birr