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# Review of Challenges, Opportunities, and Major Achievements of Pulse Crop Breeding in Ethiopia

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## Abstract

Most of the crop breeding programs in Ethiopia are to develop varieties under optimum environments/management although marginal environments/management characterizes the ultimate target population of environments. The success of any agricultural development program largely depends on whether or not appropriate technologies are developed, made available, accepted, and properly used in production. It was recognized long ago that unless and otherwise the realization of these technologies was properly and systematically guided, it would have been difficult for Ethiopia to feed the increasing population. Varietal selection mainly depends on the production environment and is vital to maximizing gains from crop productivity and production efforts done by pulse crop breeding in Ethiopia. Therefore, the objective of this review will focus on the challenges, opportunities, and major achievements of pulse crop research in Ethiopia.

**Keywords:** Varietal selection; Optimum environment

## Introduction

Pulses have the potential to provide important benefits to smallholder farmers (SHFs) as a source of protein and nutrition and as a potential source of income as a cash crop (Kabata et al., 2016). According to FAO (1994), pulses, a subgroup of legumes, are crop plant members of the Leguminosae family (commonly known as the pea family) that produce edible seeds, which are used for human and animal consumption (Brick & Fisher, 2017).

Pulse crops, an essential part of the dietary requirement for most Ethiopians, are grown mostly by private peasant holdings under rainfed conditions. They contribute about 8% to the total daily calorie intake of the Ethiopian diet against 63% of cereals and about 17% of potatoes and other tubers. On the other hand, animal products contribute only 1.9% of the total daily calorie intake. In developed countries, the contribution of cereals to the daily calorie intake is 20% while that of pulses and nuts is about 2.3% against 29.1% of animal products (FAO, 1996). Thus, the pulses (the edible seeds of food legume crops) serve as an important protein supplement in the cereal-based Ethiopian diet. They also form a significant export commodity group and help earn important hard currency for the country (Keneni & Ah, 2006) [1,2].

The great variation in altitude ranging from sea level up to 4500 meters above sea level provides a great variation in climate and soil types which makes the country profitable in agriculture (Rashid et al., 2010; Ruters et al., 2015; Mulugeta et al., 2015). Agriculture contributes about 35.8 percent to the national GDP and about 70 percent of the Ethiopian population is employed in the agriculture sector (World Factbook, 2018) [3].

After cereals pulse are important crops growing in all parts of the country. In the main agricultural areas of Ethiopia, there are two rainy seasons, the main rainy season (Meher) and the Belg season. The main rainy season (Meher) runs from mid-June, July, and August to mid-September and is the main cropping season. Crops cultivated in the Meher season would be harvested between September and February. The second season is Belgian season which covers the months of February to May and has short and moderate rainfall. The harvesting period for Belg season crops is between March and August. The Meher season is the main production season that accounts for over 95% of the national annual crop production (Alemayehu et al., 2011; Broek et al., 2014) [4].

The inherent capacity of pulse crops to fix atmospheric nitrogen and the ability to increase soil fertility and decrease the use of expensive chemical nitrogenous fertilizers make the cultivation of pulses a good fortune for farmers and the environment (Kissinger, 2016; Karanja, 2016; Snapp et al., 2018). Enhanced pulse production can also create opportunities for local value-added processing, stimulate domestic demand, and provide off-farm employment and sources of income for the rural poor, especially women and youth (Anjana, 2016).

Since pulse has high nutritional value reduces rampant malnutrition around the globe and are nutritious seed for a sustainable future FAO and the United Nations have declared the year 2016 as the "International Year of Pulses" (Anjana, 2016; Shivashankar et al., 2016). Improvements in planting techniques could double overall pulse production in future years in Ethiopia (USAID, 2010; Chilot et al., 2010) [5].

The objective of this review will focus on the challenges, opportunities, and major achievements of pulse crop breeding in Ethiopia.

## Literature Review

### Defining pulse crops

The word 'pulse' is derived from the Latin word 'puls' meaning

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pottage, i.e., seeds boiled to make porridge or thick soup. The Food and Agricultural Organization (FAO) of the United Nations has recognized 11 primary pulses, viz. dry beans, which include several species of Phaseolus and Vigna; common beans, Phaseolus vulgaris L.; lima beans, Phaseolus lunatus L.; tepary beans, Phaseolus acutifolius var. latifolius; scarlet runner beans, Phaseolus coccineus; black gram, Vigna mungo L. Hepper; green gram, Vigna radiata L. Wilczek; moth beans, Vigna aconitifolia Jacq Marechal; rice beans, Vigna umbellata Thunb Ohwi and Ohashi and adzuki beans, Vigna angularis Willd Ohwi and Ohashi), dry broad beans (Vicia faba), dry peas (Pisum spp.), dry cowpeas (Vigna unguiculata L. Walp), pigeon peas (Cajanus cajan L. Millspaugh), chick-peas (Cicer arietinum L.), lentils (Lens culinaris Medikus spp. culinaris or Lens esculenta Moench), bambara groundnuts (Vigna subterranea), lupines (Lupinus spp.), common vetch (Vicia stiva) and minor pulses (lablab, Lablab purpureus L. Sweet; jack beans, Canavalia ensiformis, sword beans, Canavalia gladiata, winged beans, Psophocarpus teragonolobus; velvet beans, Mucuna pruriens var. utilis and yam beans, Pachyrrizus erosus) (Sardana, Sharma, & Sheoran, 2010) [6].

The family Fabaceae (earlier known as Leguminosae) comprises more than 600 genera and about 18,000 species of cultivated plants. It is the second largest family after Poaceae (earlier known as Gramineae), in terms of food and vegetable protein source, and fodder. The sub-family Papilionoideae consists of 480 genera and about 12,000 species, of which only a few are cultivated for human nutrition. Endowed with excellent food and fodder qualities, these crops also restore soil fertility by scavenging atmospheric nitrogen, adding organic matter, enhancing phosphorus availability, and improving the physical, chemical, and biological properties of the soil. Hence, they occupy an indispensable position in various cereal-based cropping systems in marginal and sub-marginal lands, where they sustain intensive agriculture and farming systems adopted by small and marginal farmers (Sardana et al., 2010) [7,8].

WHO and FAO (2007) and FAO (2016) defined pulse crops as dry seeds of leguminous plants which are distinguished from leguminous oil seeds by their low-fat content. Dried beans, lentils, chickpeas, and peas are the most commonly known and consumed pulses. Pulses have many shapes and sizes and can be found in different climatic conditions across Sub-Saharan Africa. They are the edible seeds of plants of the legume family (grain legumes) and they have in common that they grow in pods and can be dried and stored for longer periods without refrigeration. Soybean and groundnuts are mostly considered grain legumes, but because they are primarily used for oil extraction, soybeans, and groundnuts are not considered pulses they have the same advantages for human health and environmental sustainability as pulses (Koroma et al., 2016) [9,10].

## Role of classical breeding in the improvement of pulse crops

According to (Nadarajan N, 2010); classical plant breeding uses deliberate interbreeding of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. Thus, classical breeding relies largely on homologous recombination between chromosomes to generate genetic diversity. However, the classical plant breeder may also use in vitro techniques such as embryo rescue or mutagenesis to generate diversity and produce hybrid plants that would not exist in nature [11].

Most of the agronomic traits studied in pulses are polygenic. Variation in polygenic traits is attributed to quantitative trait loci (QTLs). Quantitative traits were studied using a variety of genetic models, and designs including the analysis of mating designs in segregating populations using biometrical techniques. Many times, the detection of several genes for a trait using segregation analysis alone is not efficient because of the differences due to genotype by environment interaction. A modest beginning has been made in the use of molecular markers for precision breeding in pulses. However, the lack of reliable and reproducible high-resolution polymorphic markers and expensive genotyping facilities limited the option for wider application of modern tools in the improvement of pulse crops [12].

## History of pulse crops research in Ethiopia

The success of any agricultural development program largely depends on whether or not appropriate technologies are developed, made available, accepted, and properly used in production. It was recognized long ago that unless and otherwise the realization of these steps was properly and systematically guided, it would have been difficult for Ethiopia to feed the increasing population. The idea of agricultural research in Ethiopia was first conceived after the establishment of the Arsi Rural Development Unit (ARDU) and agricultural colleges like the Alemaya College of Agriculture (now Haramaya University). Research on highland pulses was started by ARDU in the 1950s followed by the Debre Zeit Research Center which was then under Alemaya College of Agriculture (Keneni & Ah, 2006) [13].

The research efforts on crops in general and pulses in particular were strengthened and organized on a multidisciplinary basis with the establishment of the then IAR (now EIAR) in 1966. Research works on the crops between 1972 and 1985 were limited to some locations in disconnected efforts. Since the mid-1980s, however, a wider collaboration between local institutions and CGIAR Centers, particularly ICARDA and ICRISAT, further incorporated different perspectives into the research system (Lakew & Tadesse, 2018) [14].

Currently, the Holetta Agricultural Research Center coordinates national faba bean and field pea research, the Debre Zeit Agricultural Research Center coordinates chickpea and lentil research with the collaboration of some federal and regional research centers, and the Melkassa Agricultural Research Center coordinates land pulse research (Lakew & Tadesse, 2018) [15].

The Lowland part of Ethiopia is characterized by high temperatures and insufficient, erratic, and unreliable rainfall during the growing period. Further, in these lowland parts of the country, the growing season is also short. Therefore, crops which can adapt to these climatic conditions are indispensable. Among the suitable crops that fit these conditions are lowland pulses. The most important lowland grain legumes that grow in most parts of the country include common bean /haricot beans (Phaseolus vulgaris L), cowpea (Vigna unguiculata (L.) Walp.), pigeon pea (Cajanus cajan (L) Millsp.) and mung bean (Vigna radiata (L.) Wilczek) [16]. Although lowland pulses research was started in the country around the late 1960s, nationally coordinated research was started in the then Nazareth, now Melkassa Agricultural Research Center in the early 1970s. Since then, several lowland pulses have been introduced and evaluated across years and locations throughout the country for adaptation and productivity. However, among these lowland pulses the national lowland pulse selected the common bean as a priority crop and has been engaged in technology generation and promotion (Lakew & Tadesse, 2018) [17].

## Pulse crop production in Ethiopia

The suitability of soil and climate conditions of the country for pulse crop cultivation makes Ethiopia a huge supplier of dry pulse crops in the international arena (GAIN, 2018). Twelve pulse species are grown in the country. Faba bean (Vicia faba L.), field pea (Pisum sativum L.), chickpea (Cicer arietinum L.), lentil (Lens cultivars Medik.), grass pea (Lathyrus sativus L.), fenugreek (Trigonella foenum-graecum L.) and lupine (Lupinus albus L.) are categorized as highland pulses and grown in the cooler highlands of Ethiopia. Whereas, haricot beans (Phaseolus vulgaris L.), soya beans (Glycine max L.), cowpea (Vigna unguiculata L.), pigeon peas (Cajanus cajan L.), and mung beans are predominantly grown in the warmer and low land parts of the country (Chilot et al., 2010; Karanja,2016; CSA,2018) [18].

Chickpeas, grass peas, and lentils are primarily grown on dark soils on residual moisture, in west and north Shewa zones of Oromiya; north and south Gonder, south Wollo, north Shewa, east and west Gojam Zones of Amhara; Goro zones of SNNPR; and the east Tigray zone. Faba beans and field peas, on the other hand, are grown during the main season on both red and black soils primarily in Amhara, Tigray, Oromiya, and SNNPR regional states. Haricot beans are concentrated in the relatively dry and warmer parts of the country mainly along the Rift Valley. Production of haricot beans is also expanding in the SNNP region, Gambella, and BenshangulGumuz regional states (Chilot et al., 2010) [19].

Ethiopia is one of the top ten producers of total pulses in the world, the second largest producer of fava beans after China, the fifth or sixth largest producer of chickpeas, and the second largest producer of pulses in the common market for eastern and southern African countries (COMESA region) following Sudan. Sudan and Ethiopia have 32% and 22% share of the total COMESA pulses production (USAID, 2010). In Ethiopia, pulses are the third largest export crop behind coffee and oil seed (Boere et al., 2015). The pulse industry has developed significantly with little intervention, but there exists a great potential to increase the production and impact of pulses through proactive and targeted support [20]. Ethiopia could expand its foreign market presence by at least doubling its current exports through increased production levels. Smallholder income could also be increased by at least 40-70 percent per hectare of pulses planted through greater pulse productivity (with better inputs and sound agronomic practices), in other words, there is an opportunity to stabilize and increase supply by improving production up to the full potential which would meet domestic demands, helping to ensure food security (IFPRI, 2010) [21].

The productivity gap of pulse crops can be minimized through the utilization of improved technology to enhance smallholder farmer's income and their food security. The current productivity of pulse crops falls significantly below the demonstrated potential. For example, current average chickpea yields are 20.6 quintals per hectare (CAS, 2018) which is below the demonstrated potential (29 quintals per hectare) if accompanied by the appropriate inputs (Rashid et al., 2010). According to Schneider and Anderson (2010) in Ethiopia with improved verities it is possible to produce 14-50 quintals of lentils per hectare on research fields and 9-30 quintals per hectare on farmers' fields and 40-60 quintals of peas per hectare on research fields. But as that of CSA (2018) agricultural sample survey report the national average productivity of lentils and field peas are 14.71 and 16.71 quintals per hectare on smallholder farmer's fields, respectively [22,23].

However, Ethiopia is considered the leading commercial producer and exporter of common beans (haricot beans) in Africa. Katungi et al (2011) explained most Ethiopian farmers had expanded their farm area under common bean but the use of fertilizer and improved varieties was still low. The same study revealed that the average land allocated to common bean in a cropping season among the smaller farmers (landholding less than one hectare) was 0.34 ha, which is about 33% of the total land under crops in season. On the other hand, larger farmers (with more than one hectare of landholding) allocated an average of 1.2 ha, about 36% of the crop area, to common beans [24].

According to the CSA (2018), agricultural sample survey report in the main cropping season (Meher) of 2017/2018 about 8.32million smallholder farmers cultivated 1.60 million hectares of land (12.61% of the total cultivated land) with pulse crops, from which about 29.80 million quintals of pulses (9.73% of the total harvested grain crop) was harvested. The amount produced is second next to cereal crops. Faba beans, haricot beans, chickpeas, and field peas take the first four largest proportions, which are about 9.21, 5.20, 4.99, and 3.68 million quintals, respectively. Amhara, Oromia, SNNPR, and Tigray regions are the first four leading regions in producing pulses crops in the country. The total cultivated area under pulses in Amhara, Oromia, SNNPR, and Tigray regions is 0.68 (42.40%); 0.62(39.91%); 0.24(14.75%) and 0.037(2.33%) million hectares of land, respectively. Considering the volume of production these four regions, Oromia, Amhara, SNNPR and Tigray regions take the largest percentage proportions which are 43.7; 39.47; 13.31, and 1.19, respectively. Amhara and Oromia regions alone produce 83.17 percent of pulse crops. Fig summarizes the trend of land size cultivated with pulse crops for the last eleven years [25].

During the last eleven years, the Oromia region has been the largest producer of fava beans, field peas, and haricot beans whereas the Amhara region is the leading region to produce chickpeas, lentils, and fenugreek. Next to the Oromia region, SNNPR is the largest producer of haricot beans.

Area coverage has increased by 5.34% between the cropping year 2007/2008 and 2017/2018 with an annual growth rate of 0.95% (Figure 1). Pulses production by volume has increased from 17.83 million quintals to 29.79 million quintals with annual increment of 6.86% for the same duration (Figure 2). Total pulses productivity, which is volume of production per unit area, has been increased from 11.75 quintals per hectare to 18.63 quintals per hectare that is 58.55% increment (Figures 3 and 4).

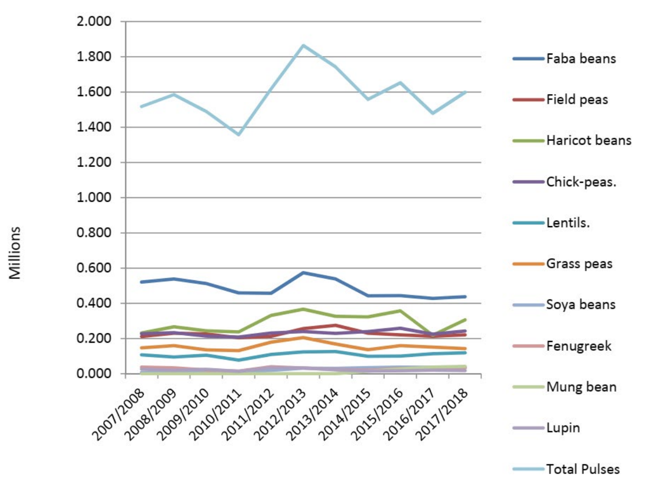


**Figure 1:** Trends of land size cultivated with different pulse crops in Ethiopia (in million hectares) production year of (2007/2008 - 2017/2018).

Source: CSA (Central Statistical Authority of Ethiopia) agricultural sample survey reports (2008-2018)

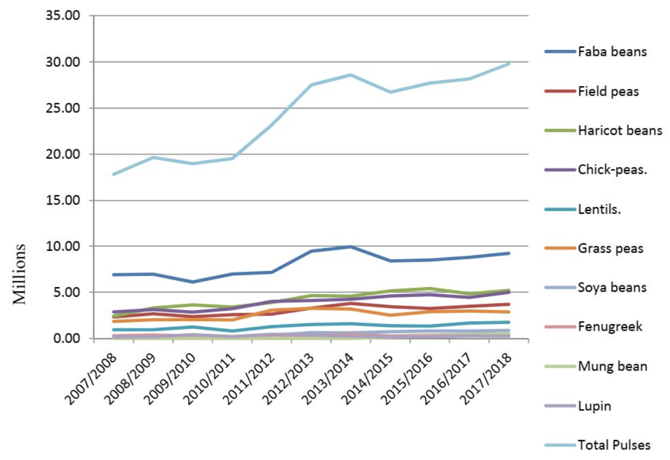


**Figure 2:** The volume of production trend (in million quintals) of different pulses crops in Ethiopia, in the production year (2007/2008 - 2017/2018).

Source: CSA (Central Statistical Authority of Ethiopia) agricultural sample survey reports (2008-2018).

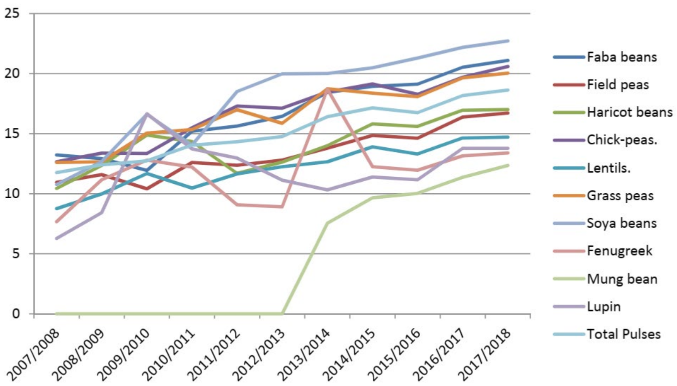


**Figure 3:** Trends of productivity (quintals per hectare) of different pulses crops in Ethiopia, in cropping year (2007/2008 – 2017/2018).

Source: CSA (Central Statistical Authority of Ethiopia) agricultural sample survey reports (2008-2018).

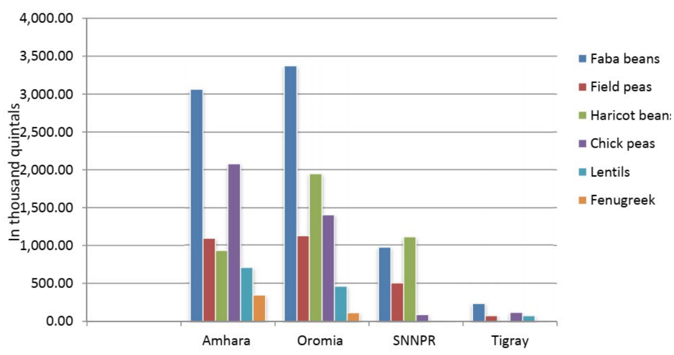


**Figure 4:** Top four pulse-producing regions' average volume of production (in 000 quintals) during the last eleven years.

Source: CSA (Central Statistical Authority of Ethiopia) agricultural sample survey reports (2008-2018).

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## Challenges in Pulse Crop Breeding in Ethiopia

### Mismatch between selection and target production environments

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

Consideration of varietal selection vis-à-vis actual target production environment is vital to maximizing gains from breeding efforts. The tradition across most of the breeding programs in Ethiopia is to develop varieties under optimum environments/management even though marginal environments/management characterize the ultimate target production environments. Even though tangible scientific evidence from the Ethiopian context is scanty, the complaint that the varietal generation processes in developing countries do not take into consideration the target production systems (Hawtin et al., 1988) should be considered seriously. Farmers have to afford to take up the whole production package along with the varieties. However, the majority of the resource-poor farmers may not afford to apply optimum agronomic practices and the cost of production inputs [26].

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

Where marginal situations dominate, breeders must recognize the unique situations and fit varieties to the bio-physical and socio-economic needs. Contrary to breeding for optimal situations, the process in which cultivars are adapted to fit the prevailing growth environment is encouraged instead of the environment being altered to fit the cultivars (Wallace and Yan, 1998). Fitting the growing period of the crop genotypes to the probable period of availability of the limiting resource under different scenarios through genetic manipulation is essential. For terminal moisture stress, for instance, developing crop cultivars for earliness or cultivars that can complete their lifecycle before the onset of terminal moisture stress could be one option. One may also think of cultivars with modest demand that do not exhaust the available moisture at the early stage of development but that can fairly distribute throughout their lifecycle. Cultivars that can continue growing and yield only residual moisture at a later stage could also be considered under the same scenario [27].

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

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

The appearance of new threats like parasitic weeds, Orobanche crenata, and fava bean gall at the top of existing ones in the northern part of the country coupled with the absence of readymade varieties that overcome the negative effects of these newly emerged threats and lack of prior experience of dealing with these threats is becoming a serious concern. Lack of parental sources of resistance/tolerance to Orobanche, insects (field and storage) and faba bean gall resulted in limited crop protection technologies including post-harvest technologies. Abscission of flower buds and immature pods in faba bean particularly when the crop is grown under sub-optimal conditions for reasons that are not yet clearly determined by research is another serious challenge (Keneni et al., 2016.

### Competition from cereals

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

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

It is expected that the genetic potential of improved pulse production technologies developed so far may not be exhaustively exploited as in some cereals even after a countrywide popularization of improved production packages that proved the superiority of the improved technologies over the old-age practices. This could be attributed to the low priority given by public extension to pulses, the least priority farmers give to food legumes in general in terms of land and input allocation, and relatively poor crop management and protection practices provided to pulses by the farmers as compared to cereals (Keneni et al., 2016).

### Lack of capacity to serve multi-dimensional interests

The big challenge to highland food legume breeders is the difficulty of serving multi-dimensional interests with the limited financial, technical, and material resources they have at their disposal. In addition to the diversity of local needs emanating from the physical environments, farming systems, and consumers ‘preferences, export qualities and standards may deserve at least an equal level of priority as breeding objectives. The generation of technologies conducive to mechanization (unlike cereals) stagnated in its early infancy mainly because of the indeterminate behavior and low priority given to legumes (Lakew & Tadesse, 2018).

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

### Lack of effective technology multiplication and supply system

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

## Opportunities of Pulse Research in Ethiopia

### Availability of technologies

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

### Successes of Prior Scaling Up Activities

A series of knowledge dissemination, producer's training, and scaling up of technologies resulted in steadily increasing productivity and made farmers aware of the importance of improved technologies for various crops. It is believed that more technologies will be released from research and the demand for additional technologies is expected to increase because more farmers will realize the benefits of using improved technologies. Recently, there has been a nationwide scaling-up of value crop production technologies which is already underway that paved the way for more technologies to come and more scaling-up plans to be initiated (Lakew & Tadesse, 2018)

### Risks of cereal-cereal monoculture

This is a time when risks of cereal-cereal monoculture in some potential production areas are already considered a national threat both at technical and policy levels. Failures of some wheat varieties almost immediately after release due to their susceptibility to the major diseases have already been encountered in Ethiopia and a number of them have shortly been put obsolete. The whole process of this genetic vulnerability is believed, at least in part, to have been aggravated by cereal-cereal monoculture which resulted in an excessive buildup of disease inoculums particularly in areas like Arsi and Bale. Pulses, being the best crops for rotation with cereals, are important not only in soil fertility restoration but also as "break" crops to pests and weeds (Lakew & Tadesse, 2018).

### Increasing demand for pulses in local and export Markets

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

### Conducive policy environment

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

## Major Achievements of Pulse Crop Breeding in Ethiopia

### Development of basic genetic information

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

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

### Varietal development

No question improved seed is a prime background source input through which other component technologies are transferred to farmers. Sources of genetic variation for genetic improvement of these crops in Ethiopia include germplasm collections from important production complexes of the country, introduction and acquisition of genetic materials from international sources like ICARDA and ICRISAT, and crossing of selected parents from all sources. Some were received at their earlier filial generations to select better-performing segregants under the Ethiopian conditions. Most of the landrace collections utilized in the breeding programs were either received from the Institute of Biodiversity or through target collections by breeders in collaboration with the Institute of Biodiversity (Lakew & Tadesse, 2018).

The creation of genetic variation is followed by the identification and isolation of plants having the desired combinations of characters in their progeny. In the screening nurseries, the selected genotypes are evaluated for good pod setting, early flowering and maturing, disease tolerance/resistance, and qualities such as seed size and color. Introductions, collections, and segregants from hybridization are usually grown either with artificial inoculations of the virulent isolates of foliar diseases, on sick plots for root rot diseases, or in the hotspot areas for other biotic and abiotic stresses depending on the situation. Insects may also be mass-reared on bulk seeds of susceptible cultivars and used for artificial infestation. Pedigree and bulk methods are mostly employed at the selection stages (Keneni et al., 2016).

The appropriateness of varieties for release in terms of performance consistency across a range of physical environments is confirmed by the multi-location evaluation of varieties with some collaborating research centers under the federal and regional research institutes and universities representing different agroecologies of the country. It is obvious that if a variety developed for better agronomic behavior by breeders is unacceptable to farmers for some other reasons and is not adopted at the end of the day, all the resources invested in the development of that variety would be wasted. It is very important, therefore, that farmers are involved in the selection and testing processes. To this end, variety evaluation usually involves farmers at a certain level of variety evaluation schemes as part of the regular procedure where it was learned that farmers (male and female) and researchers have their own unique and common selection criteria (Keneni et al., 2002). The participation of the farmers in the process of variety evaluation is, therefore, essential in that selection criteria overlooked by researchers might be addressed when the farmers are involved from the early stage. This is expected to hasten the dissemination of the released varieties, as farmers are the end users. When selection is made for varieties to be finally verified and released, emphasis is given to genotypes that have superior performances and stability over the most recently released variety as a check.

Estimation of genetic progress from a breeding program enables to monitoring of the periodic advancement in the genetic gain of traits of interest. Studies on genetic progress from breeding efforts in Ethiopia on faba bean (Temesgen et al. 2015), chickpea (Keneni et al., 2012), field pea (Legese, 2011), and lentil (Bogale et al., 2015) confirmed the existence of reasonable levels of yield gain with tremendous improvement in seed size (of faba bean and chickpea) over the last decades. Temesgen et al. (2015) reported the average cumulative genetic gain over 33 years of faba bean breeding to be 290 kg ha-1 for grain yield, 266.3 g per 1000 seeds for seed size, and-8.9% for chocolate spot severity.

Keneni et al. (2011) reported that genetic progress from chickpea breeding resulted in an annual rate of genetic progress of 21 g/five plants for grain yield in 15 years and a corresponding gain in seed size of 141 g per 1000 seeds during the same period. Bekele et al. (2014) later reported that the genetic progress for grain yield was 32 kg ha-1year-1(for Desi type) and 23.986 kg ha-1year-1(for Kabuli type) over the last 40 years, whereas progress in seed size was 0.302 g 100 seeds-1 year-1for Desi and 0.821g 100 seeds-1 year-1for Kabuli. These studies clearly showed that, through fava bean and chickpea breeding efforts in Ethiopia during the last decades, better genetic progress was obtained both in seed size and grain yield but the former was better improved than the latter (Keneni et al., 2012; Bekele et al., 2014; Temesgen et al. 2015). Legese (2011) reported that genetic progress for grain yield of 22.23 kg ha-1 year-1 was obtained from over 31 years of field pea breeding. Similarly, Bogale et al., (2015) also studied genetic progresses from breeding lentil during the last 30 years and found an average rate of genetic gain of 27.82 kg ha-1year-1 at Debre Zeit and 18.02 kg ha-1 year-1 at Enewari (Table 1).

## Crop management and protection practices

Good varieties alone cannot lead to potential yields beyond a certain limit from suboptimal crop management and protection practices. It is generally believed that future productivity is most likely to increase from the integration of a mutually beneficial set of crop varieties that efficiently and effectively exploit the best of crop management and protection practices to be provided by the producers. It is also believed that a technical breakthrough in highland pulse crop production can partly be achieved through the temporal and spatial intensification of crop production. System sustainability, multi-disciplinary approaches, and the participation of relevant stakeholders, particularly farmers, in the technology generation and dissemination process, should be encouraged (Lakew & Tadesse, 2018).

Appropriate fertilizer and seed rates, planting time, and plant population densities have been developed for the major production areas. Strains of Rhizobium for faba bean, chickpea, field pea, and lentil were found effective in N fixation and are promising for commercial production (Bejiga, 2004). The desired plant population is roughly 350,000 plants ha-1 for faba bean, 300,000 ha-1 plants for chickpea, and 1,000,000 plants for field peas and lentils. The weed flora associated with fava bean, chickpea, field pea, and lentil has been identified and yield losses due to weed competition have been estimated. Critical weed-free periods, optimum periods, and frequency of hand weeding

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

**Table 1:** Faba bean, chickpea, field pea, and lentil varieties developed by the EIAR research centers.

and weed control using chemical methods have been developed and recommended for major weeds. The major diseases and insects in the major production areas of faba bean, chickpea, field pea, and lentil have also been identified. Improved varieties with different levels of resistance to the diseases have been developed and chemical control measures not only for the diseases but also for the major insect pests have been recommended (Tables 2, 3 and 4).

## Technology scaling-up

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

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

## Socio-economic studies

It is obvious that if a technology developed for boosting agricultural productivity is not adopted at the end of the day by farmers, all the resources invested in the development of that technology would be

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

**Table 2:** Agronomic practices recommended for faba bean, chickpea, field pea, and lentil.

| Crop | Major insects | Control methods (examples) |
|---|---|---|
| Faba bean | African bollworm (*Helicoverpa armigera*) | • Single spray with Cypermethrin at the rate of 150ga.i. $ha^{-1}$ when infestation starts<br>• Endosulfan 39% EC 2 l $ha^{-1}$ |
| | Bean Bruchids (*Callosobruchus chinensis*) | • Actellic (2% dust) 50 g 100 $kg^{-1}$ of seed<br>• Application of Primiphos-methyl at the rate of 40g100$kg^{-1}$ (6-8 ppm) |
| Chickpea | African bollworm (*Helicoverpa armigera*) | • Single spray with Cypermethrin at the rate of 150ga.i. $ha^{-1}$ when infestation starts<br>• Endosulfan 39% EC 2 l $ha^{-1}$ |
| | Cutworm (*Agrotis* spp.) | • Apronstar 42 WS 250 g 100 $kg^{-1}$ of seed |
| | Bean bruchids (*Callosobruchus chinensis*) | • Actellic (2% dust) 50 g 100 $kg^{-1}$ of seed<br>• Application of Primiphos-methyl at the rate of 40 g 100 $kg^{-1}$ (6-8 ppm) |
| Field pea | Green pea aphid (*Acyrthosiphon pisum*) | • Spraying Primor 50%WP at the rate of 0.5 kg a.i. $ha^{-1}$ when 35% of the plants are infested |
| | African bollworm (*Helicoverpa armigera*) | • Single spray with Cypermethrin at the rate of 150g a.i. $ha^{-1}$when infestation starts<br>• Endosulfan 39% EC 2 l $ha^{-1}$ |
| | Bruchid (*Bruchus pisorum*) | • Fumigation with aluminum phosphide at the rate of 1-3 tablets per ton<br>• Pyrethrum flowers applied at 1% W/W ratio<br>• Field spray with Cyperimethrin at the rate of 40 a.i. $ha^{-1}$ or endosulfan at 350 g ai $ha^{-1}$<br>• Actellic (2% dust) 50 g 100 $kg^{-1}$ of seed |
| Lentil | Pea aphid (*Acrythosiphon pisum*) | • Spraying Primor 50% WP at the rate of 0.5 kg a.i. $ha^{-1}$ when 35% of the plants are infested<br>• Actelic dust 50 g 100 $kg^{-1}$ of seed |
| | African bollworm (*Helocoverpa armigera*) | • Single spray with Cypermethrin at the rate of 150ga.i. $ha^{-1}$ when infestation starts<br>• Endosulfan 39% EC 2 l $ha^{-1}$ |
| | Bruchids (*Callosobruchus chinensis*) | • Actellic (2% dust) 50 g 100 $kg^{-1}$ of seed<br>• Application of Primiphos-methyl at the rate of 40 g 100 $kg^{-1}$ (6-8 ppm) |

**Table 3:** Major insects of faba bean, chickpea, field pea, and lentil.

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

**Table 4:** Major diseases of faba bean, chickpea, field pea, and lentil in Ethiopia.

wasted. Despite previous investments in research, some socio-economic problems challenged the adoption of improved technologies as reviewed elsewhere (Elias, 2006; Fasil and Kiflu, 2006; Legesse and Adam, 2006). The major ones include the insufficient supply of improved seeds, limited ability to afford production inputs by the farmers, lack of skill and competence among farmers, competition from other staple crops receiving favorable policy support, and market-associated problems (Gezahegn and Dawit, 2006). The low understanding of farmers regarding the profits they are making with each crop and the monetary and non-monetary values of pulses. Experiences showed that technology adoption particularly of legumes follows a step-by-step pattern where components of the same package may be adopted separately at different times, resulting in low productivity of the component technology because of a lack of synergy among the components (Keneni et al., 2006). Nevertheless, the situation is currently changing as the Ethiopian government is now taking significant steps to encourage the production of grain legumes as "high-value" crops and market prices are improving [28].

## Summary and Conclusions

The inherent capacity of pulse crops to fix atmospheric nitrogen and the ability to increase soil fertility and decrease the use of expensive chemical nitrogenous fertilizers make the cultivation of pulses a good fortune for farmers and the environment.

Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background.

The success of any agricultural development program largely depends on whether or not appropriate technologies are developed, made available, accepted, and properly used in production.

A modest beginning has been made in the use of molecular markers for precision breeding in pulses.

The tradition across most of the breeding programs in Ethiopia is to develop varieties under optimum environments/management although marginal environments/management characterizes the ultimate target production environments.

The research efforts on crops in general and pulses in particular were strengthened and organized on a multidisciplinary basis with the establishment of the then IAR (now EIAR) in 1966.

Major challenges of pulse crop breeding in Ethiopia that have been identified were a mismatch between selection and target production environments, the appearance of new threats and lack of sources of resistance/tolerance, competition from cereals, lack of capacity to serve multi-dimensional interests, and lack of effective technology multiplication and supply system.

Major opportunities for pulse crop breeding in Ethiopia were the availability of technologies, successes of prior scaling-up activities, risks of cereal-cereal Monoculture, increasing demand for pulses in local and export markets, and a conducive Policy environment.

Tremendous achievements have been gained so far in pulse crop breeding with the disciplines of basic genetic information generation, varietal development, crop management and protection practices, technology scaling-up, and socio-economic studies.

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

Building capacities and capabilities of the coordinating and collaborating research centers through different sorts of technical, material, and financial backstopping holds good promise for sustainably generating need-based options of technologies, making them available to farmers, and ensuring proper promotion and application in production.

Efforts should be made to ensure that the research and development process will continue autonomously to bring benefits rapidly to a large number of people through enhanced involvement of collaborative research centers by decentralization of the research process and seed system.

Broadening genetic basis in the source germplasm to enable the creation of options of technological packages and use of modern and cutting-edge science also needs adequate investment in capacity and capability building.

There is a further need to encourage multi-disciplinary approaches, system sustainability with temporal and spatial intensification, and the participation of relevant stakeholders including farmers, in the technology generation, multiplication, promotion, and proper application in production. In conclusion, a holistic approach where each discipline and research for development partners including donors complement/supplement each other is essential.

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