# 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).

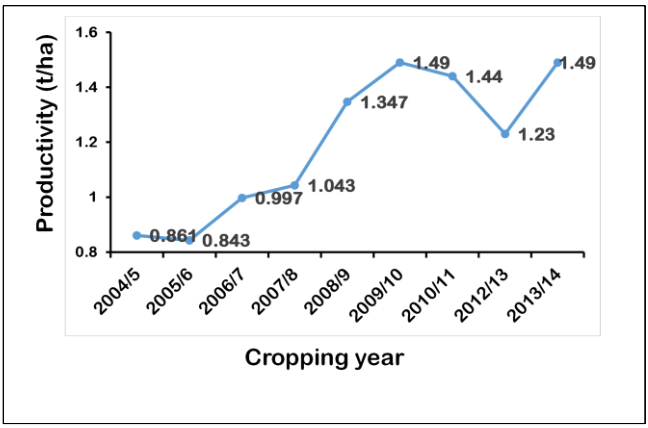


**Figure 1:** Common bean productivity per hectare for the period 2004/5 to 2013/14 (Source: modified from CSA, 2004 to 2015)

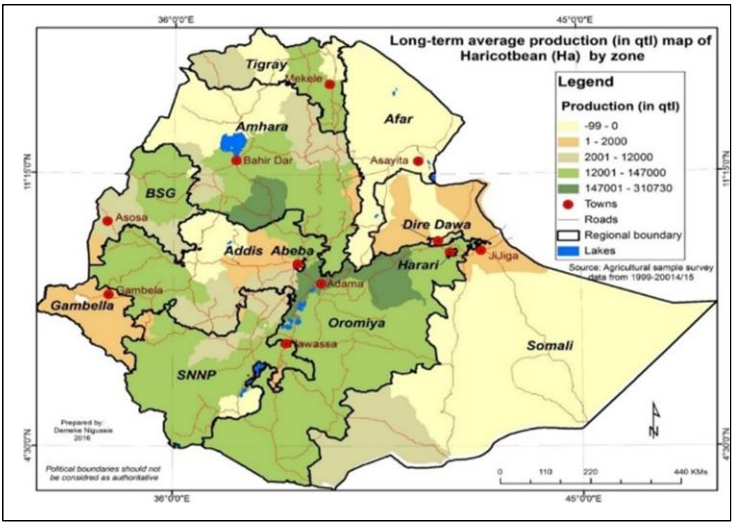


Figure 2: Geographic distribution of common bean production in Ethiopia
(Source: Nigusse, 2016)

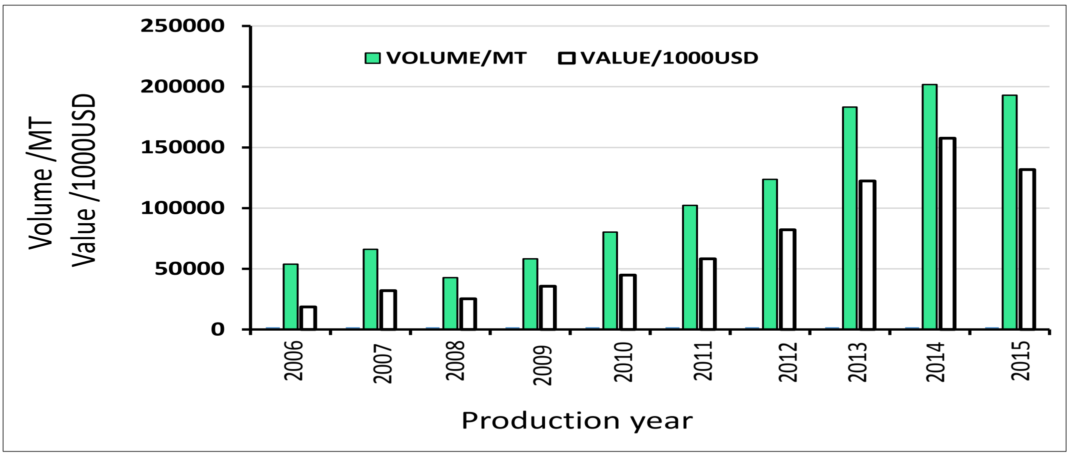


Figure 3.Common bean export for the period 2006 to 2015 (Source: Ministry of Trade, 2016).

## 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.

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