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SOYBEAN (GLYCINE MAX L. MERILL) GENETIC IMPROVEMENT IN ETHIOPIA: A REVIEW

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Abstract

Soybean is an economically important leguminous crop. Genetic improvements of the crop have focused mainly on enhancement of seed and oil yield, development of varieties suited to different cropping systems and locations, and breeding resistant/tolerant varieties for various biotic and abiotic stresses. The concept surrounding genetic improvement of soybean has the potential to impact all aspects of the crop. Resistance to biotic and abiotic factors have a profound impact on production, quality, crop values and profitability. Plant breeders have used conventional breeding techniques for the improvement of these traits in soybean. The conventional breeding process can be greatly accelerated through the application of molecular and genomic approaches. Since the inception of soybean breeding in Ethiopia in the 1950s a remarkable success has been achieved in increasing its yield and developing varieties which fit in the vast agro-ecology of the country. Even though Ethiopia lags behind many nations from the point of view of productivity of the crop considerable achievements were made possible. The overall success in the breeding program of soybean is reviewed in this article.

Keywords: Productivity; Genetic Variability; Adaptability; Stability.

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1. Introduction

Soybean (*Glycine max*) is one of the world's most important legumes in terms of production and trade and has been a dominant oilseed since the 1960s (Smith and Huyser, 1987). The crop is said to have originated in Asia and later introduced into North America, Europe, then into South and Central America (Hymowitz, 2004). Currently, about 50 countries worldwide grow soybean (Boerma and Specht, 2004). The United States of America (USA) accounted for 40 to 45 % of the world's total soybean production in 2003 (Boerma and Specht, 2004). The United States of America and Brazil were the first and second biggest producers of soybean in the world with an output of 73 million metric tons (33 %) and 42 million metric tons (28 %) respectively in 2008.

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Records in 2008-2009 show Nigeria is the largest Africa's soybean producer (39 %), closely followed by South Africa (35 %) while Uganda is the third African producer (14 %). Africa's soybean production cannot match her demand. According to FAO, Africa spent US$ 1 billion in 2004 to import soybean and soy oil (Kolapo, 2011).

Soybean breeding in Ethiopia was started in the 1950s on evaluation of introduced varieties with main emphasis of replacing soybean flour import with locally produced soybean flour and introducing the crop in to the existing crop production system and in the diet of the poor farmers (Hammer and Haraldson, 1975).

In Ethiopia, soybean is grown over wider agro-ecologies especially in low to mid altitude areas (1,300 to 1,700 masl) that have moderate annual rainfall (500-1500mm) and, hence it is exposed to the influence of GEI. Soybean breeding in Ethiopia is characterized by plant introductions, which are being used as the only source of new genes. The introductions were evaluated to identify varieties well adapted to the country, and at the same time to identify potential areas for producing the crop (Amare, 1987). During the five decades of breeding effort in the country, varieties suitable for different areas of production in the country were identified.

Currently the area covered under soybean production is 38072.70 ha with total production in quintal of 864,678.69. The productivity of the crop per hectare remains to be 22.71 (CSA, 2017/18)

1.1. History of Soybean Breeding in Ethiopia

Breeding work on the plant was started in the 1950s and was characterized by plant introduction. The introductions were evaluated to identify suitable varieties adaptable to different environmental conditions of Ethiopia, and at the same time to identify potential areas for soybean production in the country.

According to Hammer and Haraldson (1975) and Amare (1987) the first variety trial was conducted at Jimma College of Agriculture in 1956. Then the variety trials were conducted at Debre Zeit Agricultural Research Center (DZARC) from 1958-1963. The breeding work was discontinued for some time. Thereafter, trials on some introduced varieties from America and Germany were conducted at CADU (Chilalo Agricultural Development Unit) from 1967-1970. In 1971, CADU and ENI (Ethiopian Nutrition Institute) launched a joint introduction program with major objective of replacing imported soybean flour, and inclusion of the crop to the existing farming system and diet of the peasant farmers. The program attempted variety trial with 112 introduced entries from Uganda and 63 entries from FAO in 1971. The joint program also evaluated the materials introduced from West Africa, Indonesia, USA and Japan at different locations in 1972.

A nationally coordinated soybean research was started in 1974 by the then IAR (Institute of Agricultural Research). Before and after the decentralization of agricultural research in 1990s, Awassa Agricultural Research Center (AWARC) of the present SRARI (Southern Regional Agricultural Research Institute) has been coordinating the soybean genetic improvement work nationally. Plant introduction and to some extent selection from introductions were the breeding methods used.

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2. Literature Review

2.1. Breeding objectives and Genotype x Environment Interaction (GEI)

Soybean breeding in the country focuses mainly on seed yield, disease resistance, resistance to shattering and crop maturity for different areas of production. Since late 1990s when the large-scale farmers started producing soybean, more emphasis in breeding soybean has been put on the development of varieties resistant to lodging and suitable for combine harvesting.

Targeting variety selection onto its growing environments is the prime interest of any plant-breeding program. To realize this, breeding programs usually undertake a rigorous genotypes performance evaluation across locations and years mostly at the final stage of variety development process.

In such type of multi-environment trials, the occurrence of genotype x environment interaction (GEI) is inevitable (Ceccarelli et al., 2006). Both biotic and abiotic factors are said to be the main contributors for GEI and yield instability in crops. However, these known factors not fully but can partly explain most of the GEI in multi environment trials (Ferreira et al., 2006).

2.2. Breeding Procedures

Development of varieties superior to the existing ones in yielding ability, disease and insect resistance and other characteristics is an ultimate goal of any breeding program (Singh, 1983). In the development of soybean varieties for commercial production, various stages of trials are followed in the country, some of which are; Nursery-I, Nursery-II, Pre-National Variety Trial, National Variety Trial and Variety Verification Trial.

2.3. Progress in Soybean Genetic Improvement

Identification of Suitable Varieties and Areas of Production

During the last 50 years, a large number of soybean introductions with varying maturity duration were evaluated for adaptation, yield potential and desirable agronomic characters at several locations ranging from 300 to 2,200 m.a.s.l in the country. As a result, varieties suitable for production in the country were recommended or released for general cultivation.

Since the crop is new to the country, identification of areas suitable for production was of primary concern in the process of variety development. The crop can grow at different altitudes ranging from 300 to 2,200 m.a.s.l. Soybean is said to be a medium-altitude crop well adapted to areas located in altitudes ranging from 1300 to 1800 m.a.s.l and receiving annual rainfall of 900 to 1300 mm (Hammer and Haraldson, 1975; Amare, 1987). The crop also does well in some areas as low as 500 m.a.s.l and as high as 1900 m.a.s.l that receive a well distributed average rainfall of 550 to 700 mm throughout the growing period.

The varieties recommended or released are of varying length of maturity and their suitability to different agro ecologies depend on the length of growing period of the growing agro-ecology. The

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soybeans in Ethiopia are classified in to three maturity groups based on the number of days they require to reach physiological maturity (Amare, 1987).

Williams, Crawford, Clark 63k and Awassa-95 are early maturing varieties reaching physiological maturity in 90 to 120 days. The early-maturing varieties are suitable for short rainfall areas, and may also suit for double cropping in long rainfall areas. Davis and Cocker-240 are medium-maturing varieties (requiring 121 to 150 days to reach physiological maturity) and suitable for production in areas with intermediate and long rainfall areas. Belessa-95 and TGX-13-3-2644 are late maturing varieties (requiring more than 150 days to reach physiological maturity) and suitable for production in areas with long growing season.

2.4. Multi Location Yield Trials and Grain Yield

Yield is a complex quantitative character governed by polygenic inheritance. In such traits, the influence of the environment is high, and genotype x environment interaction effect is often highly significant (Poehlman and Sleper, 1995). High seasonal variability of yield is common in pulse crops due to pollination deficiency, water stress, competition from vegetative sinks, and losses due to diseases. The occurrence of such variability makes it difficult to predict ideal genotypes for both maximal yields in favorable seasons and for yield stability under conditions of environmental stress (Williams, 1985). The great expenditure of energy for nitrogen fixation in competition with grain filling is also cited as one factor for reduced yield of pulses as compared to cereals (Simmonds, 1986).

In an experiment conducted at four locations in Ethiopia, Senayit (1993) has reported that seed physical characteristics (thickness, breadth, length and weight) varied significantly among varieties and locations, and the location x variety interaction was also significant.

The report revealed highly significant differences for cooking time and significant differences in the proportion of non-soaked seeds, both among varieties and locations.

When yield trial first started at Jimma College of Agriculture in 1956, it was discouraging as the best yield of 1,100 kg/ha was obtained from cultivar Acadian (Hammer and Haraldson, 1975). In 1980, the overall mean yield of 1,920 kg/ha was obtained from variety trials conducted at different locations in the country. The top three yielding varieties in the 1980 yield trial were TGX-13-3-2644, TGM 260-2-2-2493 and Jupiter. In 1984, a mean yield of 1,722 kg/ha was obtained from a yield trial conducted at six locations with Clark-63k, F-76-8827 and Gail as the three top yielders. The existing files of variety trials reveal that varieties of all maturity duration were tested together up to 1984. When mean of the 1984 yield trial was compared with that of the first variety trial in 1956, there was 71.1% yield advance, which was about 2.6% yield gain every year.

From 1985 onwards, the variety trials were constructed in three groups; early-, medium-, and late-maturity classes.

In 1985, among the varieties tested in early-maturity class, Crawford, Wright and Williams were top yielding varieties with a mean yield of 1,167.3 kg/ha. In 2000 and 2001 the mean yield of three top yielding early varieties were 1,749.9 and 2,098.9 kg/ha, respectively. When it was compared

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with the 1985 mean of top three yielding varieties, there was 64.9% yield gain. In medium- and late-maturity class, yield gain was observed in the first 5 years trials but no yield gain was observed in recent years. This could reveal that either low yielding potential genotypes were evaluated or the erratic rainfall was experienced in the country which hindered the genotypes to express their full yield potential. However, in variety testing procedure, entries are promoted from one stage to the next stage yield testing whenever they are superior to the standard check(s) in yield or other desirable traits. Thus, the latter justification could be true.

Comparisons of the yielding potentials of three maturity classes in different years of trials revealed no wide yield gap among them. However, early- and medium-maturity classes, on an average, expressed relatively better yielding potential. This could be due to the growing periods at many of the variety testing locations favoring early- and medium-maturity sets, and disfavoring late-maturity set even though the varieties in this were higher yielding in areas, where the growing season accommodated them. From the mean yield of the 15-years trials, the breeding program learnt that focus should be given for the development of early- and medium-maturing varieties in majority of the test locations. The program has also looked for late-maturing variety development for areas receiving longer rainfall, especially in the western part of the country.

Table 1: Characteristics of some soybean varieties recommended or released for cultivation in Ethiopia

Characteristics	**Variety**									
	Williams	***Crawford***	***Clark 63k***	***Awassa-95***	***Cocker 240***	***Devis***	***Jalale***	***Cheri***	***Belesa-95***	***TGX-13-3-2644***
Maturity group	Early	Early	Early	Early	Medium	Medium	Medium	Medium	Late	Late
Days to maturity	90-120	90-120	90-120	90-120	121-150	121-150	120-133	135	>150	>150
Growth habit*	D	D	D	D	D	D	-	-	InD	InD
General adaptability	Short rain Fall area	Short rain Fall area	Short Rain fall area	Short Rainfall area	Intermediate and long Rainfall area	Intermediate and long Rainfall area	Intermediate and long rainfall area	Intermediate and long rainfall area	Long rainfall area	Long rainfall area
Grain yield (kg/ha)	15-20	15-20	15-20	17-26	15-25	15-25	16-21	24	17-29	20-25

*D=determinate, InD= indeterminate

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Table 2: The likely areas of adaptation of soybean varieties

Location	**Best performing varieties**
Gojebe (1,250masl)	*Cocker-240*
Jimma (1,750 masl and surrounding)	*Cocker-240, Davis, Clark-63K, TGX-3-3-22644, Awassa-95, Belessa-95,*
Gambella (520 masl)	*Awassa-95, Belessa-95*
Metu (1,605masl)	*Davis, Clark-63K*
Awassa (1,700masl)	*Williams, Clark-63K, Crawford, cocker-240, Davis, Awassa-95*
Arsi negelle (1,960 masl)	*Cocker-240, Clark-63K, Williams, Crawford*
Belle wolayta (1,400masl)	*Clark-63K, Williams*
Arbaminch (1,400masl)	*Cocker-240, Williams*
Bako (1,650masl)	*Cocker-240, Williams, Davis, Belessa-95, TGX-13-3-2644*
Anger gutin (1,400masl)	*Cocker-240, Clark-63K, Williams, Davis*
Deddessa (1,300 masl)	*Cocker-240, Cclark-63K, Williams, davis*
Pawe (1,200masl)	*Belessa-95, TGX-13-3-2644, Awassa-95, Crawford*
Lower Bir shelleko (1,530masl)	*Cocker-240, Clark-63K, Davis, TGX-13-3-2644*
Melka worer (750masl)	*Cocker-240, Clark-63K, Williams*
Zeway/alage (1,649masl)	*Early maturing varieties*
Woldiya (1,900 masl), Bure (2,150masl) and Harbu (1,500 masl)	*Clark-63K, Williams, Davis*

2.5. Yield in Relation to Reproductive and Vegetative Growth

In soybean, grain yield, as in other crops, is a complex character, which is dependent on a number of variables. To increase its yield, the study of direct and indirect effects of yield and its components provide the basis for its successful breeding program and thus increase of bean yield can be more effectively tackled on the basis of performance of yield components and selection for closely associated traits.

The varieties flowered and matured relatively earlier in low-altitude areas like Abobo, Gambella (520 m.a.s.l) and Pawe (1,200 m.a.s.l) than at high-altitude areas like Awassa (1,700 m.a.s.l). As a result, the varieties classed in medium- and late-maturity groups in high-altitude areas like Awassa and Jimma fell in early group in low-altitude areas like Abobo. This could be due to the environmental conditions of lowland areas characterized by high temperatures that promoted reproduction and early maturity faster, thereby enabling the varieties to reach maturity in less than 120 days. The productive period is almost same in all the maturity groups except a 30 days difference observed between early variety G-2261 and late variety IPB-142-81-EP7. In high-altitude locations like Awassa and Jimma, late-maturing varieties were taller than early ones although height differences were observed even within the same maturity class. In plant height, growth habit duration, it is indeterminate growth habit that favors tallness. But, all the late varieties under the test conditions were of intermediate growth habit hence taller than early- and medium-maturing varieties.

It was also revealed that late-maturing varieties in areas with long rainfall like Bako, Jimma and Pawe gave relatively higher yield. This could be due to prolonged pod-filling period in late-maturing varieties. However, at Abobo, early-maturing varieties gave high yield in reverse

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conditions. This might be because the moisture during the growing season did not support relatively long-duration varieties to fully express their potential.

2.6. Breeding Soybean for South Western Ethiopia

During 1999 to 2002, 11 early-maturing soybean varieties were tested at Bako, Loko and Gute areas. The mean grain yield recorded across years and locations indicated that AGS-217 with mean grain yield of 2,155 kg/ha, was the top-ranking variety. This variety was released in April 2003 by the name Jalale. From the medium-maturity types AGS-65, Tunia and V-1 were found to be the best yielders with a grain yield advantage of 49%, 44% and 50% respectively, over the standard check (Davis). These three varieties were recommended for wider production in western Oromia region. Similarly, 11 late-maturing soybean varieties were tested in a regional variety trial at Bako, Loko and Gute. Among these varieties, IPB-81-EP7 was found to be the best in grain yield and agronomic characters and was released in April 2003 by the name Cheri.

2.7. Adaptation Trials

Eight soybean varieties, including two released (Davis and Clark 63K), one recommended (TGX-13-3-2644), four in pipe line (V-1, IPB-81-EP7, IPB-14281-EP7, and PR-149-66), and one local (Ethio-Yugoslavia), were tested for their adaptability at Ambo, Ijaji, Ano, Bako, Gute, and Bilo Boshe during 2001-02 and 2002-03 seasons (BARC 2002, 2003). The mean grain yield recorded across years and locations indicated that TGX-13-3-2644, PR-149-66 and IPB-14281-EP7 were top performing varieties.

Table 3: Mean seed yield of different soybean varieties tested for two consecutive years at various sites (2001-02 and 2002-03).

2000-01							2001-02					
Variety	**Bako**	**Gute**	**Loko**	**Anno**	**Ijaji**	**Ambo**	**Anno**	**Bako**	**Gute**	**Ijaji**	**Billo Boshe**	**Mean**
Davis	1,341	1,470	469	1,013	1,734	724	844	1,802	2,364	1,068	677	1,228
V-1	1,659	1.461	590	852	1,897	1,032	1,303	2,442	2,675	950	1,080	1,449
TGX-13-3-2644	2,017	1,689	504	1,799	2,137	1,346	2,018	2,570	2,169	1,059	1,137	1,677
IPB-81-EP7	2,308	1,532	799	1,831	1,545	1,150	1,683	1,988	2,393	883	718	1,530
Clark 63k	918	1,247	451	904	1,230	994	711	1,562	1,981	1,029	446	1,043
RR-149-66	2,392	1,748	521	2,134	1,962	1,075	1,615	2,041	2,029	787	579	1,535
IPB-14281-EP7	2,766	1,550	903	1,740	1,738	1,003	1,694	1,633	1,649	651	228	1,414
Ethio-Yugoslavia	2,051	1,698	677	1,551	1,719	1,057	1,612	1,962	2,249	894	936	1,492
Mean	1,932	1,549	614	1,478	1,745	1,048	1,435	2,000	2,189	915	725	

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2.8. Breeding soybean for Eastern Ethiopia

36 genotypes were evaluated and ranked for growth characters, pod load, vigor and disease reaction at Hirna, western Hararghe. High variation was recorded in grain yield (1.3 to 2.6 t/ha) and 100-seed weight (1 to 6 g). Based on field performance, 20 genotypes were selected and are advanced to variety trial.

2.9. Breeding Soybean for Southern Ethiopia

Study on Genotype x environment interaction (GE) and stability of twenty soybean genotypes was conducted for grain yield, oil and crude protein content at six environments in 2007. F81-7636-4, SR-4-3, AFGAT, IPB-144-81(p), Nova, V1-1, Protana-2, AGS-115-1, Clark-63k, TGX-297-6f-1, AGS-162, Crawford, Braxton, Awassa-95, Hardee-1, G-9945, Davis, Williams, AGS-234 and Cocker-240 were used for the study.

Three genotypes that had medium yield performance, IPB-144-81(p), Braxton and Awassa-95, were identified as stable genotypes for grain yield. The three top yielding genotypes, AGS-115-1, TGX-297-6f-1 and AGS-162, were found unstable and can be recommended for narrow adaptation to Gofa, Areka and Inseno, areas respectively. Haddee-1 and Braxton were genotypes with high oil content and showed stable performance across the environments.

TGX-297-6f-1 had high oil content but unstable with specific adaptation to Bonga. Clarck-63k had the highest crude protein content and also very stable one. IPB-144-81(p) and Afgat had high crude protein content but very unstable and specifically adapted to Areka area.

Table 4: Description of the experimental sites

Locations	**Altitude (masl)**	**Annual rainfall(mm)**	**Mean annual temperature (^{0}C)**	**Soil texture**	**Zone**
Awassa	1700	1046.3	20.1	Clay loam	Sidama
Areka	1710	1385.7	20.3	Silt clay loam	Wolayta
Gofa	1250	1301.3	23.4	Sandy clay loam	Gamo Gofa
Inseno	1650	NA	NA	clay	Gurage
Bonga	1700	1597.2	19.5	clay	Kafa

Table 5: Mean grain yield of soybean genotypes tested across six environments

F81-7636-4	2017.2	1087.9	467.5	3493.6	2385.6	1377.0	1804.8
SR-4-3	2331.8	737.1	1569.0	2972.4	1881.9	1721.5	1868.9
AFGAT	3493.1	894.0	882.1	3669.5	1782.7	2530.4	2208.6
IPB-144-81(p)	2362.0	1322.7	1259.0	3737.5	3041.5	1952.4	2279.2
Nova	1607.6	817.3	1407.9	2381.4	1944.6	911.3	1511.7
V1-1	1971.5	934.4	1281.0	2567.2	1797.9	1458.4	1668.4
Protona-2	2530.4	1366.9	1161.7	3284.4	2224.8	2497.4	2177.6
AGS-115-1	3375.6	911.7	1736.9	3770.8	3157.9	2173.0	2521.0
Clark-63k	1729.0	1213.1	303.5	2867.8	2079.6	2268.0	1743.5
TGX-297-6f-1	2754.3	1075.8	2414.6	3708.3	2215.8	1797.1	2327.7
AGS-162	2397.1	1279.6	1542.9	3814.6	3369.8	1508.8	2318.8
Crawford	2166.1	1397.3	484.6	2682.5	2232.9	2103.4	1844.5

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Braxton	2726.1	1137.1	965.4	3469.8	2390.0	1533.5	2037.0
Awassa-95	2307.8	757.9	1069.2	3367.7	2731.9	1537.9	1962.1
Hardee-1	2527.6	1124.2	1657.5	3726.0	2493.5	1415.3	2157.4
G-9945	2397.3	716.9	1056.7	2682.7	3426.7	2172.1	2075.4
Davis	2322.6	1056.7	1185.2	3182.5	1794.6	2019.1	1926.8
Williams	2251.9	746.3	709.6	2538.5	2913.8	1811.1	1828.5
AGS-234	2842.0	1095.4	982.7	3557.3	1576.5	1339.3	1898.9
Cocker-240	1754.7	901.0	739.4	2489.2	2399.4	2357.7	1773.6

Table 6: Mean grain yield (kg/ha) of soybean varieties evaluated at different location from 1999 to 2001

variety	**Maturity**	**Location**					
		Awassa	**Jimma**	**Bako**	**Pawe**	**Abobo**	**Mean**
PR-149-6	late	1319.3	2865.8	2865.8(2)	2273.6(2)	1227.2(2)	2110.3
PR-138-8	Late	1431.1	2304.8	2073.1(2)	2021.9(2)	1250.8(2)	1816.3
IPB-142-81-EP$_7$	Late	1106.3	2518.5	2253.4(2)	1909(2)	1358.4(2)	1829.3
TGX-13-3-2644	Late	1293.8	2205.8	1900.9(2)	1774.3(2)	1500.5(2)	1735.1
PR-160-6	Medium	1270.8	-	1771.1	1337.7(1)	1687.4(1)	1516.6
Tunia	Medium	1222.8	-	1777.6(1)	1000.4(1)	1765(1)	1441.5
Cocker-240	Medium	1210.1	-	1134.1(1)	1209.6(1)	1593.0(1)	1286.7
Davis	Medium	1136.8	-	1251.7(1)	1409.8(1)	1592.5(1)	1347.7
G-2261	Early	1458.1	1912.5	1993.6(1)	1757.2(1)	3999.5(1)	2224.2
Sable	Early	1274.9	2064.8	2143.2(1)	1989.7(1)	2048.2(1)	1904.2
Williams	Early	1189.8	1076.5	1320.9(1)	1679.7(1)	2094.6(1)	1472.3
crawford	Early	1433.7	1741.3	1643.1(1)	1741.6(1)	2505.5(1)	1813.0

3. Conclusions

Soybean can play a significant role in Ethiopian agriculture. It has great yield potential, wide range of adaptability, high nutritional value for both food and feed, and a great importance in cropping systems. Breeding work on the crop mainly concentrated on evaluation of introductions to identify suitable varieties well adapted to the country. As a result of rigorous evaluation of the introductions, more than six varieties were recommended or released for general cultivation in the country. Areas suitable for soybean cultivation were also identified. However, the total area of soybean production under peasant holdings in the country is only1769.47 ha, which is very low as compared to other pulse crops (CSA, 2002). The varieties released are also not popular among small holder farmers. Hence, attention should be given to include the crop in existing cropping system and diet of peasant farmers using adaptive and mini-kit trials (trials conducted on-stations and on farmers' fields in larger plots). If the crop is included in the existing cropping system, it may serve as a cheap and a rich source of quality protein for poor people who have less access to animal protein.

Since soybean is an exotic crop and of recent introduction in the country, there is not enough diversity to effectively run a sustainable genetic improvement program. There has been limited introduction in recent years, which is the only source of new genes for soybean improvement. Therefore, a hybridization program has to be initiated to generate new genetic variability.

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The soybean in Ethiopia is classed in three groups: early, medium and late. The results of the three maturity classes in variety trials revealed that early- and medium-maturing varieties have potential for Ethiopia. They have potential in short and intermediate rainfall areas and are suitable for multiple-cropping systems in long rainfall areas. Thus, the soybean breeding program in the country should focus on the development of early- and medium-maturing varieties, as a short term strategy. Besides, the breeding program should also plan for development of late-maturing varieties, which have great potential in the longer rainfall areas.

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