Genotype by Environment Interaction and Seed Yield Stability of Soybean Cultivars in Eastern Amhara, Ethiopia

Tesfaye Teshome DEMISSEW[1]* ZenebeATLAW[1] Gebremedhin BAHRE[2] Abebe MISGANAW[3] Eshete WUDU[3] Seyoum ASEFIE[3]
1. Departement of Plant Sciences, Mersa College of Agriculture, Woldia University, Mersa, Ethiopia
2. Departement of Plant Sciences, College of Agriculture and Environmental Science, Adigrat University, Adigrat, Ethiopia
3Sirinka Agricultural Research Center, Woldia, Ethiopia
Present address of corresponding author: Email: gere.bahre @gmail.com

Abstract
Soybean is a crop of growing importance in Ethiopia. However, its production and productivity are affected by a limited access to improved cultivars in many areas. Hence, the performance of eight nationally released cultivars were evaluated for seed yield, seed protein and oil contents in Eastern Amhara area. The experiments were conducted for two consecutive years under rain fed condition at three locations using randomized complete block design with three replications. Analysis of varianceindicated that the tested cultivars showed inconsistent performance over locations and years. Additive Main Effect and Multiplicative Interaction [AMMI] analysis showed that 64.66%, 7.46% and 13.43% of the total variation was attributed to the respective environmental, genotypic and genotype by environment interaction effects. AMMI Stability Value and Genotype Selection Index were used to select stable cultivars with high seed protein or oil content, respectively for areas where seed protein or oil content is the primary production objective.
Keywords: AMMI, seed protein, seed oil
DOI: 10.7176/JBAH/13-16-01
Publication date: September 30th 2023

INTRODUCTION

Soybean {*Glycine max* [L.] Merr.}, [$2n = 2x = 40$] was domesticated in the eleventh century B.C. in northeastern China (Hymowitz and Shurtleff 2005)**and** first introduced to Ethiopia in the 1950s (Asfaw et al. 2003). Soybean seed is unique for its high protein and oil contents, which are estimated to amount about 40% and 20% respectively (Singh et al. 1998). Soybean covers 6% of the world's arable land and is the most important grain legume in the world in terms of its large international market(McFarlane and O'Connor 2014). Soybean protein is also an important source of livestock feed (Nedumaran et al. 2013). Furthermore, soybean is the most important oil seed crop in terms of annual production and the second most important source of vegetable oil in the world (Sharma et al. 2012).

Currently, soybean covers about 38072.70 hectares [ha] of land and 86467.87 tons of soybean is produced per annum with an average productivity of 2.27 tons per hectare in Ethiopia (CSA 2018). Its growing importance in the country is demonstrated by the large increment in the area of annual production from 1,027 ha in 2004 to 38,072.70 ha in 2017 under private peasant holdings (CSA 2004, 2018). Soybean has also been an important export product with an increasing trend in the volume of exported soybean seed since 2004. The trade deficit between the imported and exported soybean, which is estimated to be 138 million Kg, shows that there is a consistently increasing demand in the domestic market. The increase in the numbers of poultry farmers and foreign investors entering soy products processing are consistent with projections which also indicate increases in soybean demand in the coming years (Hailu and Kelemu 2014).

However, the current average national soybean productivity, which is estimated to be 1.06 ton/ha during the past few years, is very low as compared to the potential which can rise up to 4 ton/ha using improved cultivars(Hailu and Kelemu 2014). Although soybean production and breeding have been conducted since the 1950's in Ethiopia (Asfaw et al. 2003), wider dissemination and production of the crop is not achieved yet. The main limitations in this regard include lack of awareness of farmers on how to use soybean, lack of systematic popularization, and limited use of improved cultivars(Hailu and Kelemu 2014).

In Ethiopia, soybean is considered as a lowland pulse crop of sub-humid regions (Dejene 1979) with three recognized maturity groups,i.e. early, medium and late maturing(Amare 1987). Soybean is well adapted to clayey soils and areas located in altitudes ranging from 1300 to 1900 meters above sea level where there is a good combination of temperature and rainfall (Hammar and Haraldson 1975). Accordingly, the agro-ecological conditions of many areas of Eastern Amhara are potentially suitable for soybean production.

Even though data on the area coverage and productivity of soybean is not available for the Amhara region, 34041.20 ton of soybean was produced in 2017, which constitutes 39.37% of the national production (CSA 2018). Despite the potentially suitable agro ecological conditions of many areas in Eastern Amhara including Habru, Tehuledere and Chefa districts, soybean production and productivity is very low (CSA 2018).The fact that there is only one soybean variety released nationally for production in the area so far indicates that the supply of improved cultivars is also low in Eastern Amhara (MoARD 2011). Thus, this study was conducted to evaluate the performance of early maturing soybean cultivars in terms of seed yield, seed protein and oil contents and to identify cultivars with relative seed yield stability.

MATERIALS AND METHODS

Experimental Sites and Materials

The experiment was conducted in three locations: Mersa [Habru district], Jari [Tehuledere district] and Woledi [Chefa district] for two consecutive years in 2015 and 2016 main crop seasons [June -December] under rain fed condition [Table 1]. Eight early maturing cultivars of soybean nationally released for commercial production in Ethiopia were used in this study. The cultivars were obtained from Hawassa, Bako, Pawe and Sirinka Agricultural Research Centers.

Experimental Design and Data Collection

A randomized complete block design with three replications was used for the experiment. Each plot consisted of 5 rows each 4 m long. The inter-row and within row spacings were 0.60 m and 0.1 m respectively. The distances between plots and blocks were 0.80 m and 1.50 m, respectively. Fertilizer was applied during planting in the form of Diamonium Phosphate [DAP] at the recommended rate of 18 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5. All other field management practices were carried out as recommended and as needed.

The three middle rows were used for the collection of all the data. Ten plants were randomly selected for the data which require samples. Data was collected on plant height [m], the number of primary branches, the number of pods per plant, the number of seeds per pod, days to flowering, days to physiological maturity, biomass yield [Kg/ha], hundred seed weight [g] and seed yield [kg/ha]. Seed filling period and harvest index were calculated. The protein and oil contents [%] of the seed were determined using the respective appropriate methods.

Statistical Analysis

All measured parameters were subjected to analysis of variance [ANOVA] using Statistical Analysis System [SAS] version 9.2. Mean comparison was carried out using Duncan's Multiple Range Test [DMRT] to compare treatment means. Preliminary combined ANOVA over years and locations was conducted according to the procedure given by Petersen (1994).Homogeneity of error variances was tested using the procedure given by Gomez and Gomez (1984).However, only separate ANOVA for the three sites and two years were conducted as the error variances were heterogeneous.

Additive main effect and multiplicative interaction [AMMI] analysis was done using Genestat software program version 18 to test the seed yield stability of cultivars across the test locations. AMMI's stability value [ASV] was computed using the formula suggested by Purchase et al. (2013) as follows:

$$\text{ASV} = \sqrt{\left\{\frac{\text{IPCA1 sum of squares [IPCA1 score]}}{\text{IPCA2 sum of squares}}\right\}^2 + [\text{IPCA2 score}]^2}$$

Where ASV = AMMI's stability value, IPCA1 = interaction of principal component analysis one, IPCA2 = interaction of principal component analysis two.Genotype Selection Index [GSI] was calculated for each variety using the formula suggested by Farshadfar (2008)as:$\text{GSI} = \text{RASV} + \text{RY}$ where RY= the rank of mean seedyield of the variety across environments and RASV= the rank of AMMI stability value for the variety.

RESULTS AND DISCUSSION

The mean seed yields of the tested cultivars at the three locations over two years are presented in Table 3. The variety Wello gave the highest seed yield, both in 2015 and 2016 at Mersa. The variety Boshe gave the highest seed yield at Jari and Chefa in 2015. The variety Afgat gave the highest seed yield at Jari in 2016. The variety Wello, followed by Afgat and Gizo gave the highest mean seed yield averaged over the three study locations and two years. However, only the variety Wello was close to its yield potential reported in Ministry of Agriculture and Rural Development [MoARD] (MoARD 2010,MoARD 2011,MoARD 2012). This may be due to the unusual late onset of the main cropping season rainfall in 2015 and the fact that Wello is released for the area as compared to the other cultivars. It may also indicate the yield penalty due to the relatively erratic rain fall in a shorter rainy season which is characteristic to Eastern Amhara.

The highest mean seed protein content was recorded from the variety Afgat followed by Wollo and Gizo. Similarly, the highest seed protein contents at all the environments were recorded from these cultivars [Table 4] which are also the highest mean seed yielders [Table 3]. The highest mean seed oil content as well as at the three test locations during the two years was recorded from the variety Hawassa 04 followed by Boshe and Nova [Table 5]. These cultivars are not among the highest seed yielders. These results allude to the strong inverse relationship between seed protein and oil content in soybean(Simpson and Wilcox 1983).

Separate analysis of variance revealed that biomass yield showed significant difference [$P \leq 0.05$] among cultivars at all the environments except Jari in 2015. Harvest index also showed significant difference at all locations in 2016 and at Jari in 2015. The number of pods per plant showed highly significant difference [$P \leq 0.01$] among cultivars at Mersa in both 2015 and 2016 seasons as well as at Jari in 2016. The number of seeds per pod also showed significant difference [$P \leq 0.05$] among cultivars at Mersa in 2015 and at Jari in both years [Data not shown]. These results are in agreement with previous reports(Gurmu et al. 2009).

It was not possible to compute combined ANOVA as error variances were heterogenous and the nature of the data wouldn't allow data transformation as a remedy. However, combined ANOVA computed with its limitations according to the suggestion by Petersen (1994) indicated that the variety by year by location interaction was highly significant [$P \leq 0.01$] for all the characters, except harvest index which was significant at $P \leq 0.05$[Data not shown].This indicates that the tested cultivars showed inconsistent performance over locations and years. Hence, AMMI analysis was conducted to test the stability of evaluated cultivars. The variety Nova was not included into the AMMI analysis as no seed yield was obtained in one of the environments.

The AMMI analysis of variance [Table 6] for the seed yield of the seven cultivars evaluated at the six environments showed that 64.66% and 7.46% of the total variation was attributed to the respective environmental and genotypic main effects and 13.43% was due to genotype by environment interaction [GEI]. In agreement with previous findings (Krisnawati and Adie 2018),significant mean square of environment indicates that the environments were diverse, with large differences among environmental means causing most of the variation in seed yield. The first interaction principal component axis [IPCA1] captured 78.02% of the interaction sum of squares. The second interaction principal component axis [IPCA2] explained a further 11.96% of the GEI sum of squares. The mean square for IPCA1 was significant at $P \leq 0.01$, while the mean square for IPCA2 was insignificant [Table 6]. Both IPCA1 and IPCA2 cumulatively contributed to 89.98% of the total GEI. This is in agreement with previous reports (Alene and Bezabih 2012,Kadhem and Baktash 2016)where the first two interaction principal component axes in AMMI explained a large proportion of the interaction sum of squares.

The most stable cultivars based on IPCA1 scores were Gishama [G7], Wegayen [G2] and Hawassa04 [G6] [Figure 1]. The cultivarsWello [G4], Afgat [G3] and Gizo [G5] were unstable and high yielding cultivars located at the right side of the grand mean, while all the rest of the cultivars were low yielding which are located on the left side of the grand mean. These relatively unstable cultivars were adapted to high yielding environments of Chefa [E3 and E6] in both years as well as Mersa [E4] and Jari [E5] in the better season of 2016. Boshe [G1] was unstable and adapted to low yielding environments of Mersa in the year 2015. This result is consistent to the erratic and irregular rainfall in the 2015 main cropping season, particularly at Mersa and Jari.The role of IPCA2 scores in explaining genotype by environment interaction [11.96%] was not significant. Thus, the plot of IPCA1scores versus IPCA2 scores contributes little to further explore adaptation [Figure 2]. However, such plot confirmed that the variety Gishama [g] was the most stable variety followed by the cultivars Gizo [e] and Wello [d].

AMMI Stability Value based on theIPCA1 and IPCA2 scores of the AMMI model was computed for each variety using the formula suggested by Purchase et al. (2013) [Table 7]. Accordingly, the cultivarsGishama, Wegayen and Hawassa04 which had smaller ASV scores are stable cultivars, while thecultivarsBoshe, Afgat, and Welloare unstable. Stability of cultivars is a very important attribute given the seasonal variability of Eastern Amhara. Alene and Bezabih (2012) reported similar results in faba bean where high yielder cultivars were relatively unstable, and some yield inferiority was tolerated to recommend a stable variety for production.

Since the most stable genotypes may not necessarily be the highest yielders, previous authors stressed the need for using a selection criteria which integrates both yield and stability (Bavandpori et al. 2015,Kadhem and Baktash 2016).Therefore, Genotype Selection Index was computed for each variety [Table 7] using the rank of ASV and the rank of mean seed yield according to the formula given in Farshadfar (2008). The cultivars with smaller GSI values are more stable and higher yielders. Accordingly, GSI selected Gishama and Wello as the most stable cultivars followed by Hawassa04 and Gizo, whereas, Afgat, Wegayen, and Boshe are relatively unstable cultivars.

The variety Wello followed by Afgat and Gizo gave higher mean seed yield at the three test locations during the two years. These three cultivars also produced higher seed protein though the highest mean seed protein content was recorded from Afgat. However, both ASV and GSI selected Gishama as the most stable variety. Genotype Selection Index selected Gishamaalong with Welloas the most stable cultivars even though AMMI analysis showed that Wello is unstable. The highest seed oil content at each environment and the highest mean seed oil content were recorded from the variety Hawassa 04 followed by Boshe and Nova. However, Nova gave low seed yield while Hawassa 04 was selected as one of the relatively stable cultivars by both ASV and GSI. Thus, the variety Gishama is recommended for promotion and popularization as an alternative to the relatively unstable recommended variety,Wello in Mersa, Jari, Chefa and similar areas where the seed protein content is the primary production objective. The Variety Hawassa04 is recommended for promotion and popularization in Mersa, Jari, Chefa and similar areas where the seed oil content is the primary production objective.

ACKNOWLEDGEMENT
The authors thank Woldia University for funding the research. Woldia University, Sirinka Agricultural Research Center and Amhara Agricultural Research Institute are acknowledged for providing land and technical support during the experiments. The authors would like to thank Hawassa, Bako, Pawe and Sirinka Agricultural Research Centers for provision of the seeds of the soybean cultivars used in the experiments.

REFERENCES
Alene, T & Bezabih, A (2012) Genotype x environment interaction and stability analysis of faba bean (vicia faba l.) varieties in north ethiopia. **Libyan Agric. Res. Cen. J. Intl 3:** 195-200.

Amare, B (1987) Progress and future prospect in soybean research in ethiopia. **Proceedings of the 19th National Crop Improvement Conference. Addis Ababa, Ethiopia, 22-26 April 1987, Institute of Agricultural Research.:** 252-265.

Asfaw, A, Tesfaye, A, Alamire, S & Atnaf, M. Soybean genetic improvement in ethiopia. **Kemal Ali, Gemechu Keneni, Seid Ahmed, Malhotra Rajendra, Beniwal Surendra, Makkkouk Khaled and Halila, MH (eds) Food and forage legumes of Ethiopia: progress and prospects. Proceedings of the workshop on food and forage legumes**, 2003. 22-26.

Bavandpori, F, Ahmadi, J & Hossaini, S (2015) Yield stability analysis of bread wheat lines using ammi model. **Agricultural Communications 3:** 8-15.

Csa (2004) Agricutural sample survey 2003/04: Report on land utilization [private peasant holdings, meher season]. **Statistcal bulletin 302 V. IV Addis Ababa, Ethiopia**.

Csa (2018) Agricutural sample survey 2017/18: Report on area and production of major crops [private peasant holdings, meher season]. **V.1. Statistcal bulletin 586. Addis Ababa, Ethiopia**.

Dejene, M (1979) Pulse crops in ethiopia: Paper submitted to the symposium of grain legume production in east africa. **Addis Ababa University, College of Agriculture, Department of Plant Science.**

Farshadfar, E (2008) Incorporation of ammi stability value and grain yield in a single non-parametric index (gsi) in bread wheat. **Pak J Biol Sci 11:** 1791-6.

Gomez, KA & Gomez, AA (1984) **Statistical procedures for agricultural research**, John Wiley & Sons. Page

Gurmu, F, Mohammed, H & Alemaw, G (2009) Genotype x environment interactions and stability of soybean for grain yield and nutrition quality. **African Crop Science Journal 17**.

Hailu, M & Kelemu, K (2014) Trends in soy bean trade in ethiopia. **Research Journal of Agriculture and Environmental Management 3:** 477-484.

Hammar, O & Haraldson, L (1975) Introduction of soybeans in ethiopia. **INTSOY Ser Int Soybean Program**.

Hymowitz, T & Shurtleff, WR (2005) Debunking soybean myths and legends in the historical and popular literature. **Crop Science 45:** 473-476.

Kadhem, F & Baktash, F (2016) Ammi analysis of adaptability and yield stability of promising lines of bread wheat (triticum aestavum l.). **The Iraqi Journal of Agricultural Science 47:** 35-43.

Krisnawati, A & Adie, MM (2018). Genotype by environment interaction and yield stability of soybean genotypes. **Indonesian Journal of Agricultural Science 19:** 25-32.

Mcfarlane, I & O'connor, E (2014). World soybean trade: Growth and sustainability. **Modern Economy 5:** 580-588.

Moard (2010). Ministry of agriculture and rural development crop variety development department: Crop variety register. . **Issue number 13. Addis Ababa, Ethiopia.**

Moard (2011). Ministry of agriculture and rural development crop variety development department: Crop variety register. **Issue number 14. Addis Ababa, Ethiopia.**

Moard (2012). Ministry of agriculture and rural development crop variety development department: Crop variety register. . **Issue number 15. Addis Ababa, Ethiopia.**

Nedumaran, S, Abinaya, P, Shraavya, B, Rao, P & Bantilan, M (2013). Grain legumes production, consumption and trade trends in developing countries-an assessment and synthesis, socioeconomics discussion paper series number 3.

Petersen, RG (1994). **Agricultural field experiments: Design and analysis**, CRC Press. Page

Purchase, JL, Hatting, H & Van Deventer, CS (2013). Genotype × environment interaction of winter wheat (triticum aestivum l.) in south africa: Ii. Stability analysis of yield performance. **South African Journal of Plant and Soil 17:** 101-107.

Sharma, M, Gupta, S & Mondal, A (2012). Production and trade of major world oil crops. **Technological innovations in major world oil crops, volume 1**. Springer: 1-15.

Simpson, A & Wilcox, J (1983). Genetic and phenotypic associations of agronomic characteristics in four high protein soybean populations 1. **Crop Science 23:** 1077-1081.

Singh, RJ, Kollipara, KP & Hymowitz, T (1998). The genomes of glycine canescens fj herm, and g-tomentella hayata of western australia and their phylogenetic relationships in the genus glycine willd. **Genome 41:** 669-

679.

Table 1. Description of the study areas

SNo.	Parameters	Locations		
		Habru[†] /Mersa‡/	**Tehuledere /Jari/**	**Chefa /Woledi/**
1	Location	11°40′N 39°40′E	11°21′N39°38′E	10°50′N39°48′E
2	Altitude	1570m	1680 m	1470m
3	Mean annual max. Temperature	28.5 °C	25.6°C	29°C
4	Mean annual min. Temperature	15 °C	11.2°C	18°C
5	Mean annual rainfall	875 mm	1204.6mm	930.8mm
6	Soil	Cambisol	Cambisol	Vertisol

[†]District, ‡Specific experimental location
Abbreviations: N, north; E, east; m, meter; °C, degree Celsius; mm, millimeter

Table 3. Seed yield [kgha^{-1}] of soybean cultivars across three locations and two years

Variety	2015			2016			Overall mean
	Mersa	Jari	Chefa	Mersa	Jari	Chefa	
Boshe	875.9[a]	603.4a	2260.9a	969.6cd	1331.0b	1590.9bc	1271.9
Nova	704.4[a]	165.1b	2012.1a	892.8d	No yield	1289.3c	1012.74
Wegayen	1050.9[a]	339.5ab	1797.3a	1299.8c	1458.2ab	1234.7c	1196.7
Afgat	861.7[a]	321.7ab	1870.5a	2459.0a	2286.9a	2013.2ab	1635.5
Wello	1084.6[a]	523.4ab	2136.0a	2496.3a	2174.7a	2492.8a	1818.0
Gizo	586.9[a]	393.0ab	1961.4a	2190.5a	1937.1ab	1830.1bc	1483.2
Hawassa04	1082.4[a]	259.8ab	2219.9a	1271.0c	1548.3ab	2009.3ab	1398.4
Gishama	856.3[a]	389.7ab	2111.6a	1648.8b	1288.5b	1813.0bc	1351.3
Mean	887.87	374.46	2046.2	1653.48	1717.80	1784.16	
CV	37.12	57.63	20.69	11.17	24.95	17.37	
R^2	45.43	44.07	26.46	95.03	61.80	72.76	

Different superscripts letters in the same row indicate significant differences [p≤0.05].
† mean of five environments
Abbreviations: CV, Coefficient of variation; R^2, Coefficient of determination

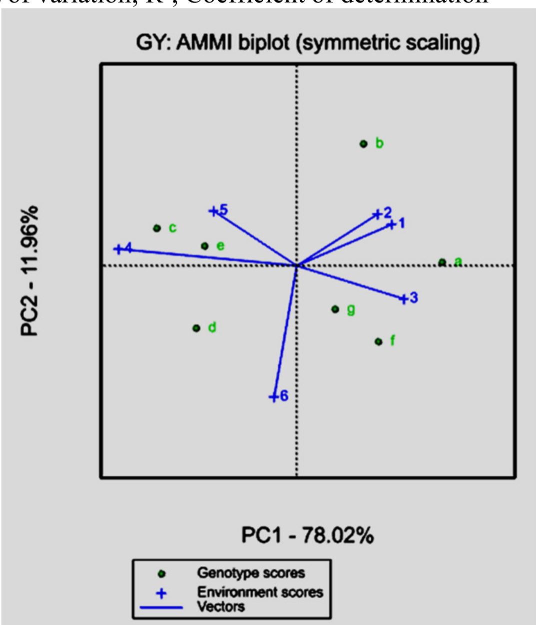

Figure 2. Interaction biplot for the AMMI2 model for seed yield of soybean.
E1, Mersa in 2015; E2, Jari in 2015; E3, Chefa in 2015; E4, Mersa in 2016; E5, Jari in 2016; E6, Chefa in 2016; G1, Boshe; G2, Wegayen; G3, Afgat; G4, Wello; G5, Gizo; G6, Hawassa04; G7, Gishama; GY, seed yield; PC1 and 2, Principal component axes one and two