Yield Stability Analysis of Soybean Varieties (early set) in Western Oromia, Ethiopia

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Abstract

Over the decades, very limited early maturing soybean varieties were developed and released in Ethiopia. This experiment was conducted to identify adaptable, high yielding and stable variety (s) among the released but potential early maturing soybean varieties for Western Oromia. The influences of genotype by environment interaction on grain yield of soybean varieties were also examined. Seven early maturing soybean varieties were evaluated at Bako for two years (2016 and 2017), at Billo and Gute during 2016, and at Chewaka and Uke during 2017 main cropping seasons. Combined analysis of variance showed that grain yield was significantly (P< 0.01) affected by environments, genotypes and their interactions; accounting for 51.1, 35.9 and 12.2% variations, respectively. The first two principal components (IPCA$_1$ and IPCA$_2$) were used to create a two-dimensional Genotype and Genotype by Environment (GGE) biplot and explained 84.49 and 9.1% of the total sums of squares of G x E interaction, respectively. Soybean variety Nyala was identified as the most stable and high yielding genotype in the test environments. In addition, Boshe and Coker-204 also showed better stability & high yield performance, whereas variety Nova was identified as the least stable and low yielding. Therefore, among early set soybean varieties, Nyala, Boshe and Coker-204 were recommended for further demonstration and large scale production in the test environments and similar agro-ecologies of western Oromia.

Keywords: AMMI, Genotype, *Glycine max,* Maturity

Introduction

Soybean [*Glycine max* (L.) Merrill] is one of the most important oil grain legume crops in the world (Laswai *et al.,* 2005). Soybean is rich in nutritional value due to its high protein and oil content as well as aspects of its functional composition, such as is flavones (Liu *et al*., 2017). In Ethiopia, soybean is used for a variety of purposes including preparation of different kinds of soybean foods, animal feed and soy milk (Hailu and Kelemu, 2014). Soybean is classified in different maturity groups such as early, medium and late maturing varieties based on to the length of growing period from planting to maturity. This phenological attribute is determined by two abiotic factors: photoperiod and temperature (Mourtzinis and Conley, 2017), and these factors can dictate the most suitable maturity groups of soybean varieties for a particular geographical

location (Liu *et al*., 2017). Therefore, identification of different maturity soybean varieties that fit specific agro-ecologies of western Oromia is an alternative

To maintain improved agricultural productivity, the development of varieties with high yielding potential is the ultimate goal of plant breeders in a crop improvement program. In the recent years of soybean breeding in Ethiopia, special focuses have been given to develop varieties with improved grain yield, good seed color and size, and resistant to major diseases. In addition to high yielding potential, a successfully developed new cultivar should have a stable performance and broad adaptation over a wide range of environments. However, variation from season to season and from place to place within a shorter distance is among the most important features of the Ethiopian environmental conditions (Tolessa and Gela, 2014). In such cases, genotype by environment (G x E) interaction effect is expected to be greater.

Genotypes exhibit fluctuating yields when grown in different agro-climatic zones. This complicates demonstration of the superiority of particular genotypes. Multi-environment yield trials are crucial to identify adaptable high yielding cultivars and discover sites that best represent the target environment (Tolessa and Gela, 2014; Dabessa *et al*., 2016). Failure of genotypes to respond consistently to variable environmental conditions is attributed to genotype by environment interaction (EI). Knowledge of genotype and genotype by environment interaction (GGE) is advantageous to have cultivar that gives consistently high yield in wider range of environments and to increase efficiency of breeding program and selection of best genotypes.

Genotype and genotype by environment interaction (GGE) biplot allows for assessing the performance of genotypes in the tested environments. Phenotypic variation of genotypes across environments results from environmental and genotypic variations and genotype by environment interaction. Environmental variation is the dominant source of phenotypic variation (Amare and Tamado, 2014; Funga *et al*., 2017). Therefore, multi-environment trials (MET) are required to identify specific and the general adaptability of genotypes. In western Oromia, where this study was conducted, the yields of early maturing soybean varieties were very low due to different biotic and abiotic factors. Therefore, this study was aimed at identifying high yielding and stable early maturing soybean varieties across environments and examining the influence of GEI on grain yield of soybean varieties.

Materials and Methods

Seven early set soybean varieties (Table 1) were evaluated at six locations for two consecutive years during 2016 and 2017 main cropping

seasons. The study sites included Billo and Gute during 2016, Chewaka and Uke during 2017 and at Bako during 2016 and 2017 main cropping season (Table 2). Each plot consisted of four rows of 4-meter length, with 40 cm and 10 cm spacing between rows and plants, respectively. Fertiliser rate of 100 kg ha^{-1} NPS was applied at planting. All other management practices were applied as routinely used in the study areas.

Table 1 Pedigree, origin, area of adaptation and year of release of soybean varieties used for the study

Variety	Pedigree	Source center	Adaptation Altitude (m.a.s.l)	Year of Release	Maturity (days)
Boshe	(IAC-13-1)	BARC/OARI	1200-1900	2008	100-110
Coker-204	NI	HwARC/SARI	700-1700	1981	100-110
Crawford	NI	HwARC/SARI	1300-1850	1974	90-100
Jalale	AGS-217	BARC/OARI	1300-1850	2003	100-110
Nova	NI	HwARC/SARI	1200-1700	2012	90-100
Nyala	NI	HwARC/SARI	800-1700	1974	100-110
Williams	NI	HwARC/SARI	1000-1700	1974	90-100

NI = not identified

Table 2: The study Environments and their main agro ecological features

Location	Year	Longitude	Latitude	Altitude (m.a.s.l)	RF (mm)	Soil type
Bako	2016 & 2017	37°09'E	09°06'N	1650	1431	Sandy-clay
Gute	2016	E:036^{0}38.196'	N:09^{0}01.061'	1915	NI	Clay
Billo	2016	E:037^{0}00.165'	N:09^{0}54.097'	1645	1500	Reddish brown
Chewaka	2017	036.11703E	09.98285N	1259	NI	Clay loam
Uke	2017	E:036^{0}32..391'	N:09^{0}25.082'	1319	NI	Sandy loam

NI = not identified   RF= Rainfall

Additive Main Effects and Multiplicative Interaction (AMMI) model was used to assess genotype by environment interaction (GEI) pattern. AMMI model is expressed as:

$$Y_{ger} = \mu + ag + \beta e + \sum n\lambda n\gamma gnden + eger + \rho ge \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 1}$$

Where: Yger is the observed yield of genotype (g) in environment (e) for replication (r);

Additive parameters: μ is the grand mean; ag is the deviation of genotype g from mean, ße is the deviation environment e;

Multiplicative parameters: λn is the singular value for IPCA, γgn is the genotype eigenvector for axis n, and den is environment eigenvector; eger is error term and ρge is PCA residual.

Accordingly, genotypes with low magnitude regardless of the sign of interaction principal component analysis scores have general or wider adaptability while genotypes with high magnitude of IPCA scores have specific adaptability (Gauch, 1992; Umma *et al.*, 2014).

AMMI stability value of the ith genotype (ASV) was calculated for each genotype and each environment according to the relative contribution of $IPCA_1$ to $IPCA_2$ to the interaction SS as follows (Purchase *et al*., 2000):

$$ASV_i = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}}[IPCA1_{score}]\right]^2 + [IPCA2_{score}]^2}$$

…………….Equation 2

Where: SS_{IPCA1}/SS_{IPCA2} is the weight given to the $IPCA_1$ value by dividing the $IPCA_1$ sum of squares by the $IPCA_2$ sum of squares.

Based on the rank of mean grain yield of genotypes (RY) across environments and rank of AMMI stability value (RASV), the Genotype Selection Index (GSI) was calculated for each genotype, which incorporate both mean grain yield (RY) and stability I (GSI) (Purchase *et al* 2000).

$$GSI = RASV + RY \text{…………………………………} \text{Equation 3}$$

Genotype plus genotype by environment variation (GGE) was used to assess the performance of genotypes in different environments. The environmental effects were removed from the data and results obtained from the data were used to calculate environment and variety scores and these scores were used to plot the standard principal component bi-plots (Yan and Kang, 2003). Analysis of Variance (ANOVA) and Additive Main Effect and Multiplicative Interaction (AMMI) analysis and GGE bi- plots were performed using Gen Stat 18th edition statistical package (GenStat, 2016).

Results and Ddiscussion

Combined analysis of variance

There were statistically significant differences (P< 0.01) among soybean varieties, environments and their interaction for grain yield (Table 3). This indicates the presence of genetic variation among the soybean varieties and possibility to select high yielding and stable variety (s); the environments were variable and the responses of soybean varieties across environments are also variable.

Table 3. Combined Analysis of variance for grain yield of early soybean varieties evaluated at across environments

Source of variation	Degree freedom	Mean square
Environments	5	5591561**
Genotypes	6	3280014**
Block within environment	2	90706ns
Interaction	30	223462**
Error	82	21356
CV (%)	8.5	

**= significant at P = 0.01, ns = none significant

Performance of genotypes across environments

Table 4 shows the average mean grain yield of seven soybean varieties evaluated across the test environments. The pooled mean grain yield ranged from 894.5 to 2189.6 kg ha^{-1}. Among all the varieties, the highest grain yield was obtained from Coker-204 variety (2189.6 kg ha^{-1}) followed by Nyala (2008.6 kg ha^{-1}) and Jalale (1708 kg ha^{-1}). However, Nova was the lowest yielder (894.5 kg ha^{-1}). This difference could be due to their genetic potential. Coker-204 was the top ranking genotype at Bako in both years, at Gute and Chewaka. Whereas, Nyala and Boshe ranked first at Billo and Uke, respectively. The difference in yield rank of early set soybean varieties across the test environments revealed high genotype by environment interaction.

Table 4. Mean grain yield (kg ha^{-1}) of seven soybean varieties evaluated at six environments

Varieties	Locations						
	Bako-2016	Bako-2017	Gute	Billo	Chewaka	Uke	Mean
Williams	1870	1471.6	2353.7	1318.3	565.7	1377.1	1542.8
Crawford	2227	1629.9	2389.53	1839.8	957.9	975.7	1669.5
Nyala	2425.4	2390.8	2363.6	2463.2	1089.4	1319.2	2008.6
Nova	1458.4	897.9	7716	915.7	598.6	724.8	894.5
Boshe	2485.5	2546.7	2230.8	2254.8	1096.7	1339.1	1992.3
Coker-204	2655.9	2723.6	2511	2453.2	1472.9	1321.3	2189.6
Jalale (check)	2214.1	2335.9	2080.1	1474.9	969.4	1174	1708.1
LSD (0.05)	206.9	199	188.3	489.5	116.4	191.9	116.4
CV (%)	5.3	5.6	5.04	14.8	6.8	9.2	10.2

AMMI model analysis

AMMI model analysis of variance for grain yield is presented in Table 5. This analysis also revealed presence of highly significant (P< 0.01) differences among soybean varieties for grain yield performance. From the total treatment sum of squares, the largest portion was due to environments main effect (51.1%) followed by varietal main effect (35.9%) and the effect of genotype by environment interaction was 12.2%. A large yield variation explained by environments indicated that the existence of both spatial and temporal diversity in test-environments, with large differences among environmental means causing most of the variation in grain yield. In line with this result, Tolessa and Gela (2014) reported large yield variation of common bean genotypes due to environments. This also indicates the existence of a considerable amount of deferential response among the evaluated soybean varieties to changes in growing environments and the differential discriminating ability of the test environments. The higher percentage of G x E interaction was explained by IPCA-1 (4.8%); followed by IPCA-2 (4.4%) and, therefore, used to plot a two dimensional GGE biplot. Amare and Tamado (2014), and Temesgen *et al.* (2014) suggested the

most accurate model for AMMI could be predicted by using the first two IPCA.

Table 5: ANOVA for grain yield using AMMI mode

Source of variation	DF	Sum of square	Explained SS (%)	Mean square
Total	125	56274352		450195
Treatments	41	54341756		1325409**
Genotypes	6	19680083	35.9	3280014**
Environments	5	27957806	51.1	5591561**
Block	12	386230	0.7	32186[ns]
Interactions	30	6703867	12.2	223462**
IPCA 1	10	2717387	4.8	271739**
IPCA 2	8	2480532	4.4	310067**
Residuals	12	1505948		125496
Error	72	1546366		21477

Key: ns= non- significant, **= significant at 1% and *= significant at 5% probability level. SS= sum of square, DF= degree of freedom.

AMMI biplot analysis

AMMI biplot graph with X-axis plotting $IPCA_1$ and Y-axis plotting $IPCA_2$ scores illustrate stability and adaptability of soybean varieties to tested environments (Fig. 1). The more the IPCA scores approaches to zero, the more stable or adapted the genotypes is over all the test environments. The variation of seed yield for each variety was significant at different environments. Jalale and Nyala varieties were specifically adapted to high yielding environments (Fig. 1). Considering the $IPCA_1$ score, Nova, Crawford and Williams were the most unstable varieties and also adapted to low yielding environments. Boshe and Coker-204 were more stable in comparison to other varieties. Boshe and Coker-204 varieties were near to zero IPCA by which it were shown to have higher stability for seed yield than other soybean varieties (Fig. 1). Coker-204 had highest seed yield followed by Boshe variety. Boshe, Coker-204 and Jalale varieties had higher GEI at environments of Bako. It has been reported that the varieties that have the lowest IPCA score in AMMI biplot are an indication of the stability or adaptation over environments (Dolinassou *et al.*, 2016). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted is a genotypes to certain environments.
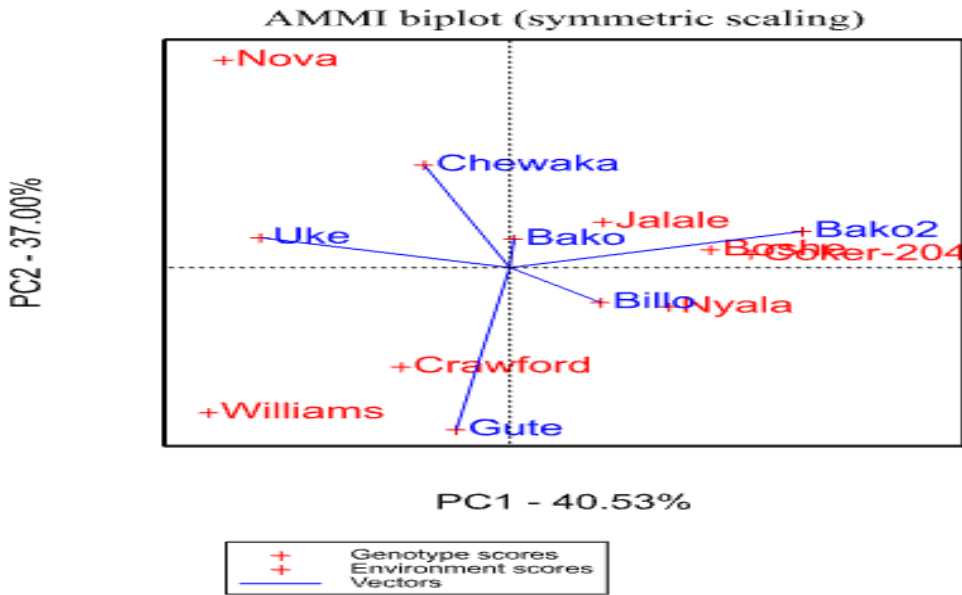
Fig 1. Biplot of interaction principal component axis (IPCA$_1$) against interaction principal component axis (IPCA$_2$) of early set soybean varieties evaluated across six environments in Western Oromia.

AMMI stability value and genotype selection index

The IPCA$_1$ and IPCA$_2$ scores for each variety and also the AMMI Stability Value (ASV) with its ranking for seven early set soybean varieties are presented in Table 6. A genotype/ variety with least ASV score is the most stable (Purchase *et al*., 2000). Accordingly, Boshe, Jalale and Crawford were the most stable. On the other hand, Williams, Nyala and Nova varieties were the most unstable. This measure is essential in order to quantify and rank of varieties according to their seed yield stability. Genotype with the smallest Genotype Selection Index (GSI) value is considered as the most stable with high seed yield (Farshadfar, 2008; Dabessa *et al*., 2016). Based on the GSI result, the most desirable variety for selection of both stability and high seed yield were Boshe and Coker-204 (Table 6), which was in line with the result of AMMI and GGE biplot.

Table 6. AMMI stability value, genotype selection index and ranks based on grain yield of seven soybean varieties evaluated at six locations in Western Oromia

Varieties	Yield	ASV	RY	RASV	GSI
Boshe	1992.27	13.92	3	2	5
Coker-20	2189.64	28.09	1	4	5
Crawford	1669.47	12.19	5	1	6
Jalale	1708.06	25.02	4	3	7
Nova	894.5	34.04	7	5	12
Nyala	2008.6	43.69	2	6	8
Williams	1542.82	45.69	6	7	13

Where, ASV = AMMI stability value, RY = Rank of yield, RASV = Rank of AMMI stability value and GSI = Genotype selection index

GGE biplot analysis

In GGE biplot (Fig. 2), $IPCA_1$ and $IPCA_2$ explained 84.49 and 9.1%, respectively, of soybean varieties by environment interaction and made a total of 94.1%. Other studies conducted on groundnut by Amare and Tamado (2014) and white lupines by Atnaf *et al.* (2017) explained an interaction of 81.8 and 63.4%, respectively, extracted from $IPCA_1$ and $IPCA_2$. An ideal genotype is defined as genotype which having the greatest $IPCA_1$ score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Fig. 2). A genotype is more desirable if it is located closer to the ideal genotype. Thus, using the ideal genotype as the center, concentric circles were drawn to help visualize the distance between each genotype and the ideal genotype. Therefore, the ranking based on the genotype-focused scaling assumes that stability and mean yield are equally important. In this study, Nyala, Coker-204 and Boshe varieties which fell closest to the ideal genotype were identified as the most desirable genotypes as compared to the rest of the tested soybean varieties (Fig 2). Supportive results were reported by Dabessa *et al.* (2016) for groundnut.
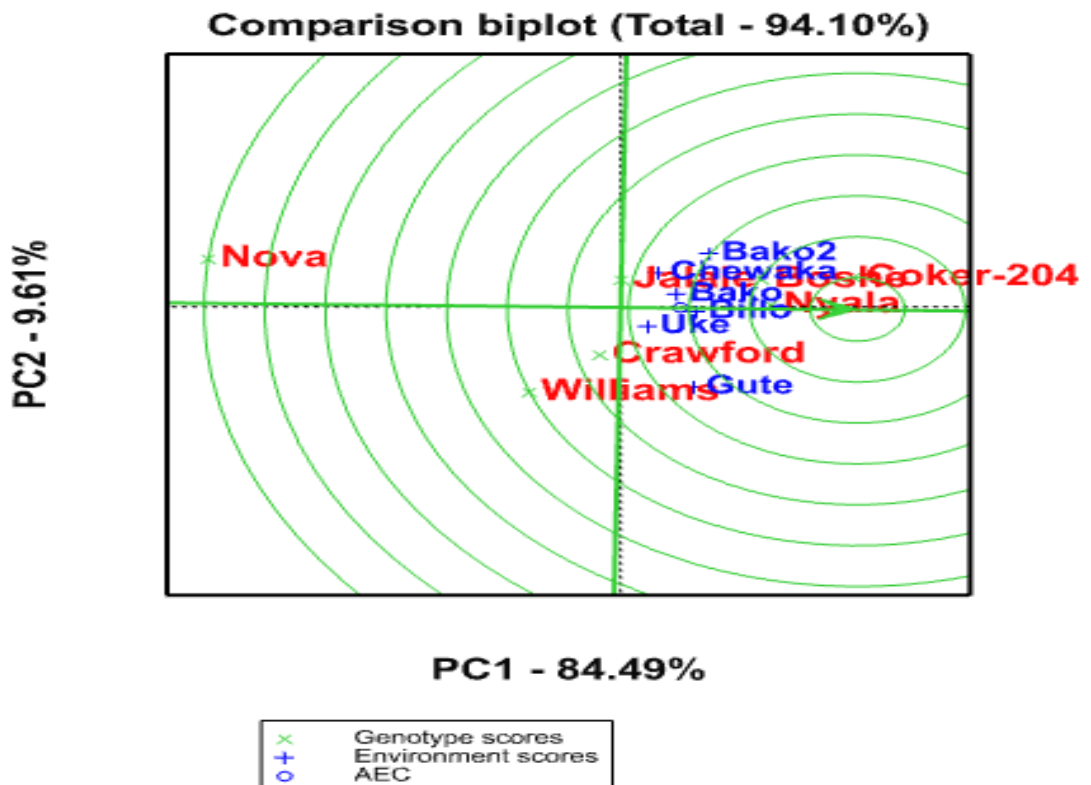

Fig 2: GGE-biplot based on genotype-focused scaling

Discriminating ability and representativeness of the environments

An environment is more desirable and discriminating when located closer to the centre circle or to an ideal environment (Naroui *et al.*, 2013). A test environment with a small angle with the AEA is more representative than other environments (Yan and Rajcan, 2003). Therefore, in the present study, Bako and Billo locations were identified as relatively the most discriminating environment as compared to Chewaka, Gute and Uke (Fig. 3). Thus, Bako and Billo were identified as the most conducive environments for soybean production. Both discriminating ability and representativeness view of the GGE biplot are the most important measures of testing environment, which provide not only valuable but also unbiased information about the tested genotypes (Yan and Kang, 2003). Yan and Tinker (2006) also reported that the length of environmental vector is directly proportional to the standard deviation within the respective environments and help to know the discriminating ability of this target environment i.e. an environment with long environmental vector has high discriminating ability and vice versa.
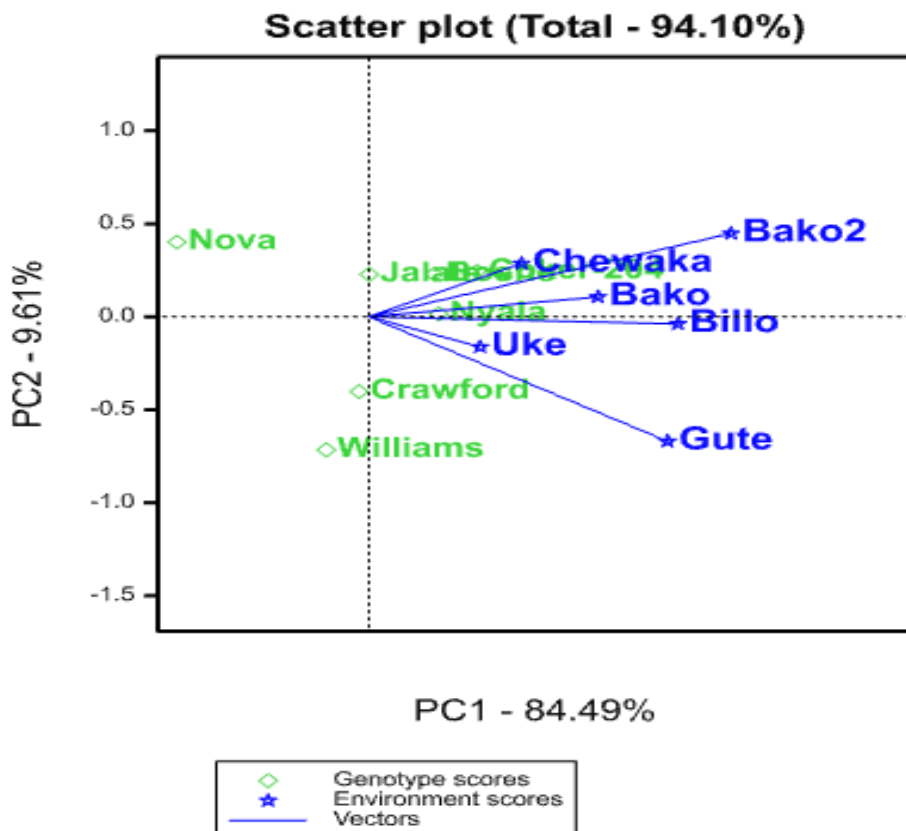

Fig 3. The vector view of GGE biplot which shows the interrelation ships among the test environments in Ethiopia

Conclusion

Combined analysis of variance indicated that grain yield performances of the tested varieties were highly influenced by environment, varieties and GEI. This indicated that a particular variety does not exhibit uniform performance under different environmental conditions or different varieties may respond differently to a specific environment. The varieties and environment main effects and genotype-by-environment interaction effect were highly significant for early set soybean varieties. The environment contributed most to the variability in grain yield. Varieties Nyala, Boshe and Coker-204 were close to the ideal genotype and can thus be used as bench marks for the evaluation of early set soybean genotypes in western Oromia. Considering simultaneously mean yield and stability, Boshe and Coker-204 were the best early maturing soybean varieties that fit in the study areas.

Acknowledgements

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