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Genotype and genotype by environment interaction and grain yield stability of medium maturity groups of soybean [*Glycine max* (L.) Merrill] varieties in Western Oromia, Ethiopia

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The objectives of this study were to identify high yielding and stable medium maturity soybean varieties across environment and examine the influence of genotype × environment interaction (GEI) on grain yield of soybean varieties in western Oromia. Seven early soybean varieties were evaluated at five locations (Bako, Gute, Billo, Chewaka and Uke) using randomized complete block design (RCBD) with three replications for two consecutive years (2016 and 2017). Combined analysis of variance showed that grain yield was significantly (P<0.01) affected by environments, genotypes and GEI. The environment, genotype and genotype by environment interaction accounted for 57.4, 20.9 and 19.8% variations, respectively. The first two principal components ($IPCA_1$ and $IPCA_2$) were used to create a two-dimensional genotype and genotype by environment interaction (GGE) biplot and explained 68.9 and 15.6% of the total sums of squares of GEI, respectively. According to the average environment coordination (AEC) views of the GGE-biplot, soybean variety Didhessa and Hawassa-04 were identified as the most stable and high yielding varieties. In addition, Didhessa and Hawassa-04 also showed better stability performance according to AMMI stability value (ASV), genotypic selection index (GSI), Wricke's ecovalence and cultivar superiority measure among the evaluated varieties whereas variety Davis and AFGAT were identified as the least stable and low yielding variety. Therefore, among medium maturing soybean varieties, Didhessa, Hawassa-04 and Cheri were recommended for further production in most soybean growing areas of western Oromia.

Key words: Additive main effects and multiplicative interaction (AMMI), AMMI stability value (ASV), cultivar superiority measure, genotype, genotypic selection index (GSI).

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is a legume native to East Asia perhaps in North and Central China (Laswai et al., 2005) and it is grown for edible bean, oil and protein around the world. Soybean is found in family Fabaceae and species *G. max* (Shurtleff and Aoyagi, 2007). Soybean is one of the most important oil grain legume crops in the world. In the International trade market, soybean ranks number one among the major oil crops with an average protein content of 40% on dry matter basis. It has the highest protein content of all field crops and is the second only to groundnut in terms of oil content (20%) among the food legumes. Dugje et al. (2009) reported that soybean is more protein rich than any of the common vegetable or legume food sources in Africa. Soybean is a promising pulse crop proposed for alleviation of acute shortage of protein and oil worldwide (Mahamood et al., 2009). It is used as a good source of unsaturated fatty acids, minerals (Ca and P) and vitamins A, B, C and D (Alam et al., 2009). Zerihun et al. (2015) indicated that soybean in Ethiopia could be grown between 1300 and 1800 m altitude with annual rain fall of 900 to 1300 mm, an average annual temperature between 20 and 25°C and soil pH of 5.5.

Soybean is classified in different groups such as early, medium and late maturing varieties. A variety is classified to a specific maturity groups according to the length of 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. Therefore, identification of different maturity groups of soybean varieties that fit specific agro-ecologies of western Oromia is an alternative option to boost soybean productivities.

In Ethiopia, soybean is a multipurpose crop, which can be used for a variety of purposes including preparation of different kinds of soybean foods, animal feed, soy milk, raw material for the processing factories like tasty soya, fafa food factories, etc. Currently, there are also factories producing oil from soybean showing increasing importance of soybean in the country. It also counter effects depletion of plant nutrients especially nitrogen in the soil resulting from continuous mono-cropping of cereals, especially maize and sorghum, thereby contributing to increasing soil fertility (Mekonnen and Kaleb, 2014). Its area of production is increasing and according to CSA (2016) report, soybean was produced on about 38,166.04 ha of land and 81241.833 tons produced in 2015/16 main cropping season with the productivity of 2.1 t ha^{-1}; which is low as compared to world average of 2.6 t ha^{-1}. This low yield may be attributed to a combination of several production constraints among which low soil fertility, lack of high yielding varieties, periodic moisture stress, diseases and insect-pests, weeds and poor crop management practices play a major role (Georgis et al., 1990).

Genotypes exhibit fluctuating yields when grown in different environments or agro-climatic zones. This complication demonstrates the superiority of a particular genotype. Multi-environment yield trials are crucial to identify adaptable high yielding cultivars and discover sites that best represent the target environment (Dabessa et al., 2016). It was also reported by Yazici and Bilir (2017). Poor response of genotypes to different environmental condition is the result of genotype and genotype by environment interaction (GGE). The information and understanding of GGE is good to have varieties that gives permanently high yield in wider range of environments and to increase efficiency of breeding program and selection of best genotypes. Knowledge and information of GGE permit for judging the performance of genotypes in evaluated environments. The level of yield variation of genotypes across environments resulted from genotype, environment and genotype by environment interaction (Amare and Tamado, 2014; Funga et al., 2017). Thus, multi-environment trials (MET) are required to identify genotypes that have the specific and the general adaptability in tested environments. In western Oromia, the yield of medium soybean variety is very low due to different biotic and abiotic factors. Therefore, the objectives of this study was to identify high yielding and stable medium maturity soybean varieties across environment and consider the effect of genotype × environment interaction (GEI) on grain yield of soybean varieties.

MATERIALS AND METHODS

Seven medium maturity groups of released soybean varieties (Clark 63k, Davis, Cheri, AFGAT, Didhessa, Hawassa-04 and Wello) were evaluated at six locations for two consecutive years during 2016 and 2017 main cropping season (Table 1). The study sites included Billo and Gute during 2016, Chewaka and Uke during 2017 main season and Bako during 2016 and 2017 (Table 2). The experimental land was ploughed, disked and harrowed by tractor. The first ploughing was done before on-set of rainfall. The plantings were done in mid-June at each location using a randomized complete block design with three replications. Each plot consisted of four rows of 4 m length with 40 and 10 cm spacing between rows and seeds, respectively. The two middle rows were used for data collection and harvested at maturity. Fertilizer was applied at the rate of 100 kg NPS ha^{-1} during planting time. All other management practices were applied as per the recommendations.

Multivariate method, Additive Main Effects and Multiplicative Interaction (AMMI) model was used to assess GEI pattern. AMMI model is expressed as:

$$Y_{ger}=\mu+ag+ße+\sum n\lambda n\gamma gnden+eger+\rho ge \quad (1)$$

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

Variety	Pedigree	Source of materials	Year of release	Adaptation altitude (masl)	RF (mm)	Maturity date
Clark 63k	NI	HwARC/SARI	1981	1000-1700	520-1500	110-120
Davis	NI	HwARC/SARI	1981	1000-1700	400-700	115-125
Cheri	IBP-81EP7	BARC/OARI	2003	1300-1850	900-1300	110-120
Afgat	TGX-1892-10F	HwARC/SARI	2007	520-1800	750-1300	110-120
Didessa	PR-149-81-EP-7-2	BARC/OARI	2008	1200-1900	1000-1200	115-125
Hawassa-04	AGS-7-1	HwARC	2012	1200-1700	500-1300	110-120
Wello	TGX-1895-33F	SARI/ARARI	2012	520-1800	520-1200	115-125

NI: Not indicated.

Table 2. Environments used in the study and their main characteristics.

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

NI: Not indicated.

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 the grand mean, and ße is the deviation environment e; multiplicative parameters: λn is the singular value for IPCA, γgn is the genotype eigenvector for axis n, 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 i^{th} 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):

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

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) a selection index called genotype selection index (GSI) was calculated for each genotype, which incorporates both mean grain yield (RY) and stability index in single criteria (GSI) as (Purchase et al., 2000):

$$GSI = RASV + RY \quad (3)$$

Wricke’s ecovalence (Wi)

Wricke (1962) proposed using the contribution of each genotype to the G×E interaction sum of squares as a stability parameter.

$$Wi = \frac{P}{(P-2)(q-1}\sum_{j=1}^{q}(Xij - \bar{X}.i - \bar{X}.j + \bar{X}..)2 \quad (4)$$

where x_{ij} is the mean performance of genotype i in the j^{th} environment, xi. and x.j are the marginal mean of genotype i and environment j, respectively and x.. is the overall mean. Thus, genotype with a low W_i value are stable.

Lin and Binns cultivar superiority measure

A cultivar-superiority measure was used to calculate stability coefficients for genotype by environment data of each genotype. It is computed as the sum of the squares of the differences between its mean in each environment and the mean of the best genotype there, divided by twice the number of environments (Lin and Binns, 1988).

GGE was used to make judgment about the performance of soybean 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 AMMI analysis and GGE bi-plots were performed using Gen Stat 18th edition statistical package (GenStat, 2016).

Table 3. Combined analysis of variance for grain yield of medium soybean varieties evaluated at six environments in western Oromia.

Source of variation	Degree freedom	Mean square
Environments	5	6389445**
Genotypes	6	1947323**
Block within environment	2	6355^{ns}
Interaction	30	367131**
Error	82	12501
LSD (0.05)	181.6	-
CV (%)	5	-

LSD: Least significant differences, CV: coefficient of variation, **Significant at P = 0.01, ns: non-significant.

RESULTS AND DISCUSSION

Combined ANOVA

There were statistically significant differences (P<0.01) among evaluated soybean varieties, environments and their interaction for seed yield (Table 3). This suggests the existence of genetic variation among the soybean varieties and possibility to select high yielding and stable variety (s), the environments are variable and the differential response of soybean varieties across the testing environments. Dabessa et al. (2016) also reported statistically significant difference among groundnut genotypes, respectively.

Performance of soybean varieties across environments

Figure 1A and B shows the performance of soybean varieties at each environments and average mean seed yield of soybean varieties evaluated across six environments in western Oromia, respectively. The pooled mean grain yield ranged from 1683 to 2720 kg ha^{-1} (Figure 1B). Among all varieties, Davis was the lowest yielder. The highest grain yield was obtained from Hawassa-04 variety (2720 kg ha^{-1}) followed by Didessa (2436 kg ha^{-1}). This differential yield response of soybean varieties could be due to their genetic potential. Hawassa-04 was the top ranking genotype at Bako (2016 and 2017) and Gute, while Clark 63k, Cheri and Didessa gave the highest yield at Billo, Chewaka and Uke, respectively (Figure 1B). The difference in yield response of medium soybean varieties across the test environments were the results of changing genotypes from one area to the other areas, that is, showed high crossover type of genotype by environment interaction. In line with this result, Tolessa and Gela (2014) reported variable yield response of common bean genotypes evaluated across different locations in Ethiopia.

AMMI model analysis

The AMMI model ANOVA for grain yield is shown in Table 4. This analysis also revealed the presence of highly significant (P< 0.01) differences among medium soybean varieties for grain yield performance. From the total treatment, sum of squares, the largest portion was due to environments main effect (57.4%) followed by varieties main effect (20.9%) and the effect of genotype by environment interaction was 19.8%. This suggests the existence of a large amount of inconsistent response among the evaluated soybean varieties to changes in growing environments. Similar result was reported by Dabessa et al. (2016). Considerable percentage of GEI was explained by $IPCA_1$ (8.6%) followed by $IPCA_2$ (6.3%) and therefore used to plot a two dimensional GGE biplot. Amare and Tamado (2014) indicated the most accurate model for AMMI can be forecasted by using the first two IPCA.

In the first four AMMI selection of genotypes, Hawassa-04 took the first position in Bako, Gute and Billo while Didhessa took the second best position in Uke, Bako, Gute and Billo environments (Table 5). Accordingly, Hawassa-04 and Didhessa varieties revealed static stability as compared to other varieties, which is a desirable characteristic for crop production. The relative static performance of Hawassa-04 and Didhessa varieties in different environment is an indication of general adaptability of these varieties. AFGAT and Wello varieties took the first position at Chewaka and Uke showing uniform yield performance in the particular environment (Table 5). The report indicated that the interaction pattern of some locations across crop species is consistent so that they are highly predictable in year to year interaction with genotypes (Ebdon and Gauch, 2002).

AMMI biplot analysis

AMMI biplot graph (Figure 2) with X-axis plotting $IPCA_1$

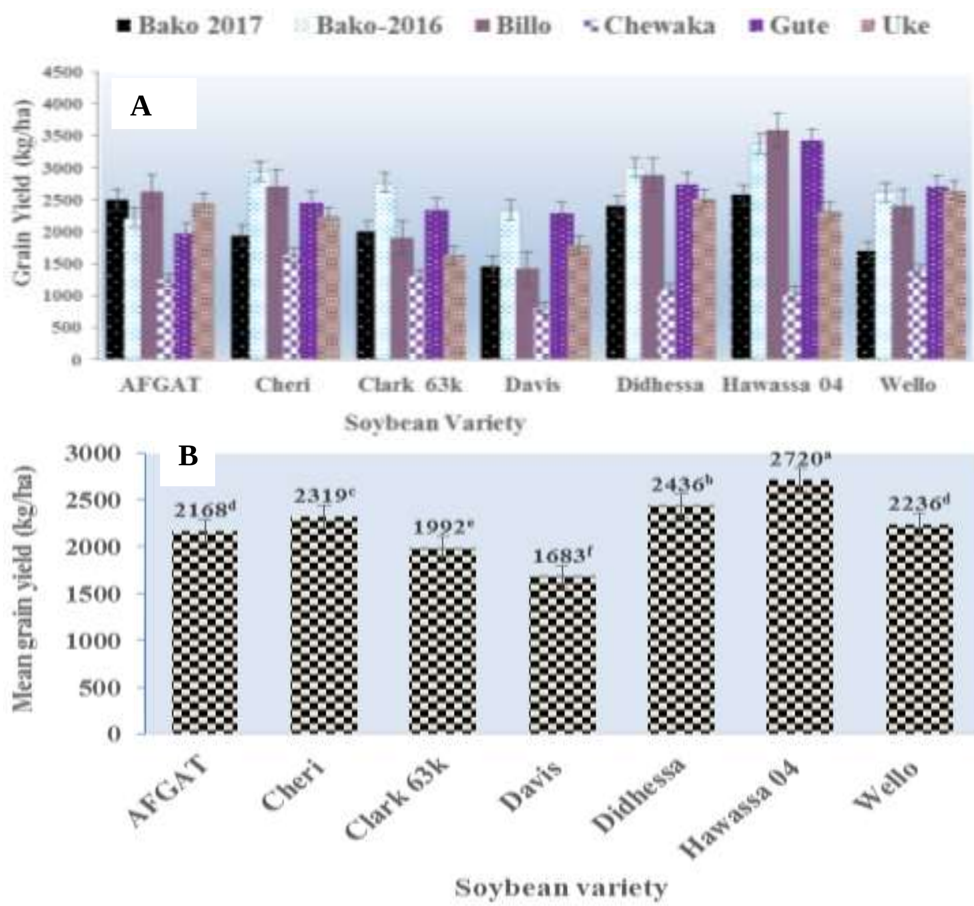

Figure 1. Performance of (A) medium maturity groups of soybean varieties at each environments, (B) mean performance of soybean varieties across environments. Bars followed by same letters are not significantly different from each other at LSD (0.05).

Table 4. Partitioning of the explained sum of square (SS) and mean square (MS) from AMMI analysis for grain yield of seven soybean varieties.

Source of variation	DF	Sum of square	Explained SS (%)	Mean square
Total	125	55682927	-	445463
Treatments	41	54645104	-	1332807**
Genotypes	6	11683938	20.9	1947323**
Environments	5	31947226	57.4	6389445**
Block	12	251654	0.45	20971
Interactions	30	11013940	19.8	367131**
IPCA 1	10	4760206	8.6	476021**
IPCA 2	8	3486895	6.3	435862**
Residuals	12	2766840	-	230570
Error	72	786169	-	10919

ns: Non-significant, **significant at 1% and *significant at 5% probability level. SS: Sum of square, DF: degree of freedom.

and Y-axis plotting $IPCA_2$ scores illustrate stability, adaptability and high yielding of soybean varieties to the testing environments. It has been reported that the $IPCA_1$ scores of a genotypes in AMMI analysis are an indication

Table 5. First four AMMI selections per environment.

Environment	Mean yield (kg ha^{-1})	Genotype rank			
		1	2	3	4
Chewaka	1209	Wello	Cheri	AFGAT	Didhessa
Uke	2224	AFGAT	Didhessa	Cheri	Hawassa-04
Bako-2016	2754	Hawassa-04	Didhessa	Cheri	Wello
Bako 2017	2081	Hawassa-04	AFGAT	Didhessa	Cheri
Gute	2559	Hawassa-04	Didhessa	Cheri	Wello
Billo	2505	Hawassa-04	Didhessa	AFGAT	Cheri

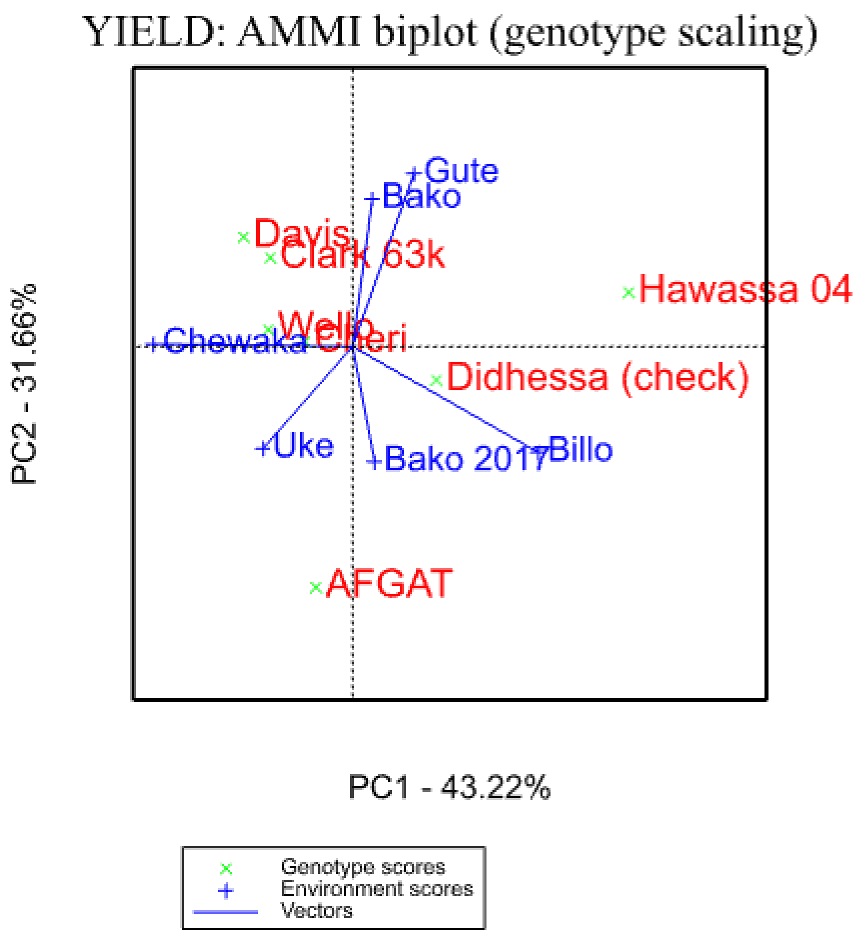

Figure 2. AMMI biplot showing "which won where" and stable soybean varieties evaluated at six environments in western Oromia.

of the stability or adaptation over environments (Alberts, 2004). It is further stated that the greater the IPCA scores, negative or positive, the more specific adapted is a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotypes is over all the environments sampled. According to AMMI biplot, Environments Bako and Gute relatively showed high IPCA scores and contributed largely to GEI. Bako and Gute environments were conducive for best performing soybean varieties. Environments Chewaka and Uke are the low yielding environment for most of the varieties (Figure 2). Varieties

Table 6. AMMI stability value, genotype selection index and ranks based on grain yield of seven medium soybean varieties evaluated at six locations during 2016 and 2017 seasons.

Variety	Yield	ASV	RY	RASV	GSI
AFGAT	2167.6	29.08	5	5	10
Cheri	2318.9	9.20	3	2	5
Clark-63k	1991.9	24.46	6	4	10
Davis	1683.4	3.31	7	1	8
Didhessa (check)	2436.3	40.62	2	6	8
Hawassa-04	2719.6	21.39	1	3	4
Wello	2236.3	42.62	4	7	11

ASV: AMMI stability value, RY: rank of yield, RASV: rank of AMMI stability value, GSI: genotype selection index.

Table 7. Stability analysis of Cultivar superiority index, static stability and wrikles ecovalence values of medium soybean varieties evaluated in western Oromia.

Variety	Cultivar superiority	Rank	Wricke's Eco valence	Rank
AFGAT	382694	5	864972	6
Cheri	207273	3	230634	2
Clark-63k	489342	6	466509	5
Davis	813077	7	420541	4
Didhessa	121320	2	158038	1
Hawassa-04	38822	1	1120645	7
Wello	282916	4	409974	3

Davis, Clark 63k and Wello were intended to low yielding environment (Figure 2). Based on the IPCA score, AFGAT and Davis were not stable varieties and as well performed under low yielding environments. Dhidhessa variety revealed more static performance across environments in comparison to other soybean varieties. Varieties Wello and Cheri were adapted to low yielding environments and also relatively stable (Figure 2). Dhidhessa and Hawaassa-04 varieties have relatively lower IPCA by which they proved to have best grain yield stability than other varieties (Figure 2). Hawassa-04 variety had the highest grain yield followed by Dhidhessa variety. Similar results were also reported by Temesgen et al. (2014) on linseed and Niger seed in Western Ethiopia.

AMMI stability value and genotype selection index

Analysis of AMMI stability value (ASV) and genotype selection index (GSI) with their ranking for seven soybean varieties are shown in Table 6. According to ASV result, genotype with least ASV value is the most stable (Purchase et al., 2000). Accordingly, Hawassa-04, Didhessa and Cheri were the most stable, but Clark-63k and Davis showed dynamic stability. This method is vital to measure and rank varieties based on seed yield stability. The summation of rank of ASV and rank of yield are used to calculate GSI. The genotype with least GSI is considered as the most stable with high grain yield (Dabessa et al., 2016). According to GSI, the best variety for choice of high seed yield and general adaptation was Hawassa-04, Cheri and Didhessa, respectively.

Stability analysis using Wricke's ecovalence (wi) and cultivar superiority measure

Stability in performance of soybean varieties across environments using Wricke's ecovalence (Wi) was performed for grain yield. The result showed that Dhidhessa and Cheri were comparatively stable as their contribution to the G×E interaction sum of squares was least (Table 7). On the other hand, AFGAT and Hawassa-04 were unstable in grain yield performance because these genotypes had relatively the highest Wricke's ecovalence (Wi). In line with this result, Gurmu et al. (2009) reported a significant Wricke's ecovalence of twenty soybean genotypes in Southern Ethiopia. According to Lin and Binns (1988) for cultivar superiority measure analysis, the genotype with low or small cultivar superiority measure value is considered to be more

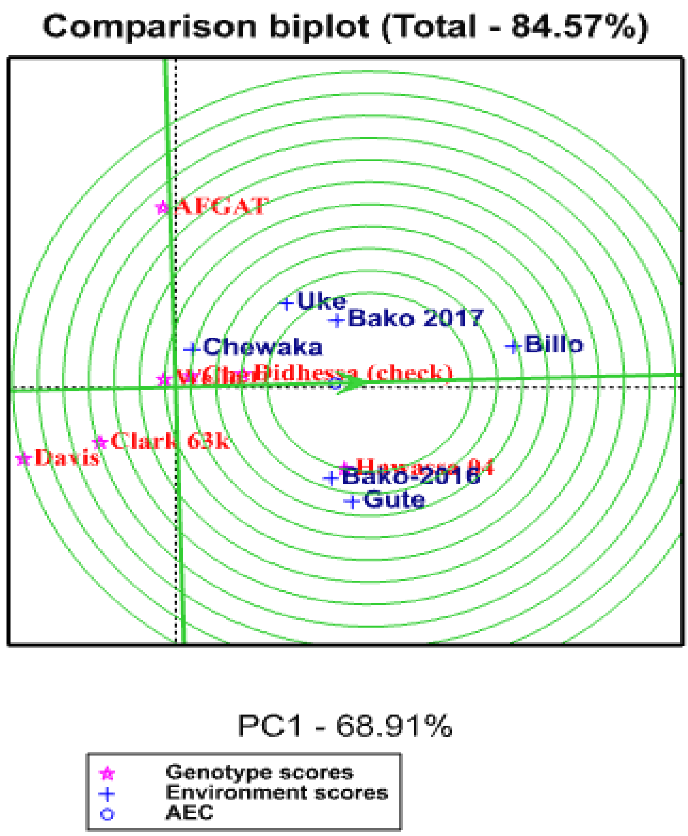

Figure 3. GGE bi-plot based on genotype-focused scaling for comparison of medium soybean varieties for their seed yield potential and stability.

stable. Among studied medium soybean varieties, Hawassa-04 and Didhessa had the smallest cultivar superiority measure values, which showed their best yield performance and seed yield stability (Table 7).

GGE biplot analysis

In GGE biplot (Figure 3), $IPCA_1$ and $IPCA_2$ explained 68.9 and 15.6%, respectively, of soybean varieties by environment interaction and made a total of 84.57%. The 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 have the greatest IPCA1 score (mean performance) and with zero GEI, as represented by an arrow pointing to it (Figure 3). 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, Didhessa and Hawassa-04 varieties which fell closest to the ideal genotype was identified as the most desirable varieties as compared to the rest of the tested soybean varieties (Figure 3). Similarly, Dabessa et al. (2016) identified ideal genotype based on the genotype-focused scaling assumes that stability and high mean yield of studied genotypes.

Ideal test environment is an environment which has more power to discriminate genotypes in terms of the genotypic main effect as well as able to represent the overall environments. But such type of environment may not exist in real conditions. Therefore, by assuming a small circle which is located in the center of concentric circles and an arrow pointing on it as ideal environment (Figure 4), it is possible to identify desirable environments which are found closer to the ideal environment (Yan and Rajcan, 2002). Hence, among the testing environments, Billo, which fell near to this ideal environment were identified as the best desirable testing environments in terms of being the most representative of the overall

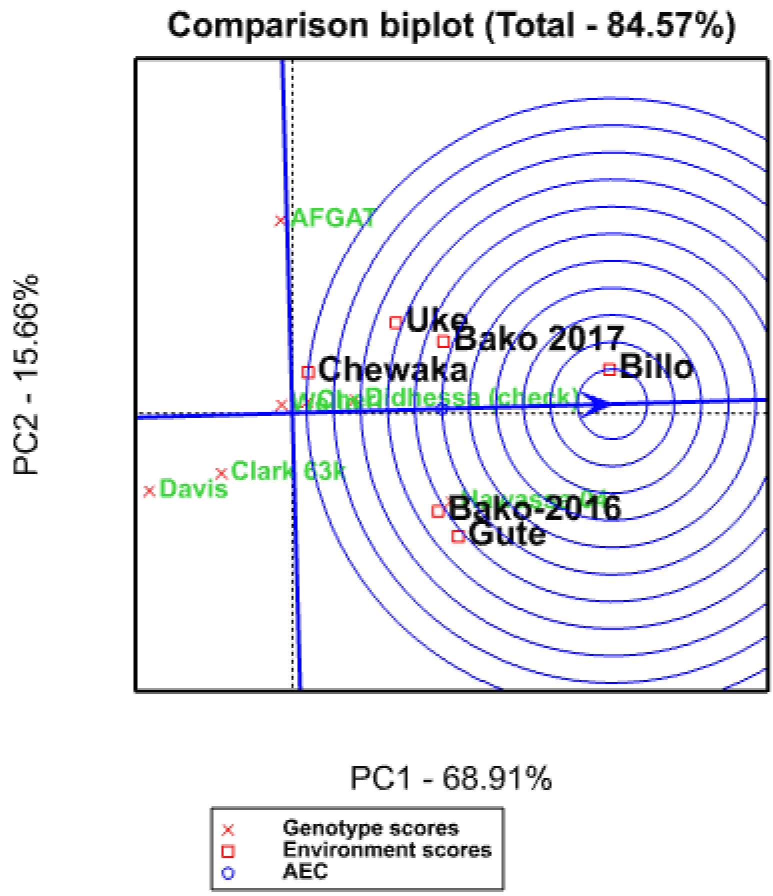

Figure 4. GGE-biplot based on environment-focused scaling for comparison the environments with the ideal environment. PC stands for principal component.

environments and powerful to discriminate soybean varieties.

Discriminating ability and representativeness of environments

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, that is, an environment with long environmental vector has high discriminating ability and vice versa. Thus, as shown in Figure 5, the test location (Billo and Gute) were identified as the most discriminating environment as compared to Bako and Uke that were identified as the least discriminating testing environments. Among the testing environments, Chewaka was identified as the least discriminating environment.

Conclusion

Despite its potential and market demand, production of soybean is not yet popularized among farmers in Western Ethiopia. These could be attributed to the lack of information on the effect of genotype, predictable and unpredictable environmental variations and their interaction on yield. Thus, seven medium soybean varieties were tested at six locations under rain fed conditions in western Oromia to determine the effect of genotype, environment, and their interaction and to identify stable ones in yield performance. The environment contributed most to the variability in grain yield. Genotypes Didhessa and Hawassa-04 were close

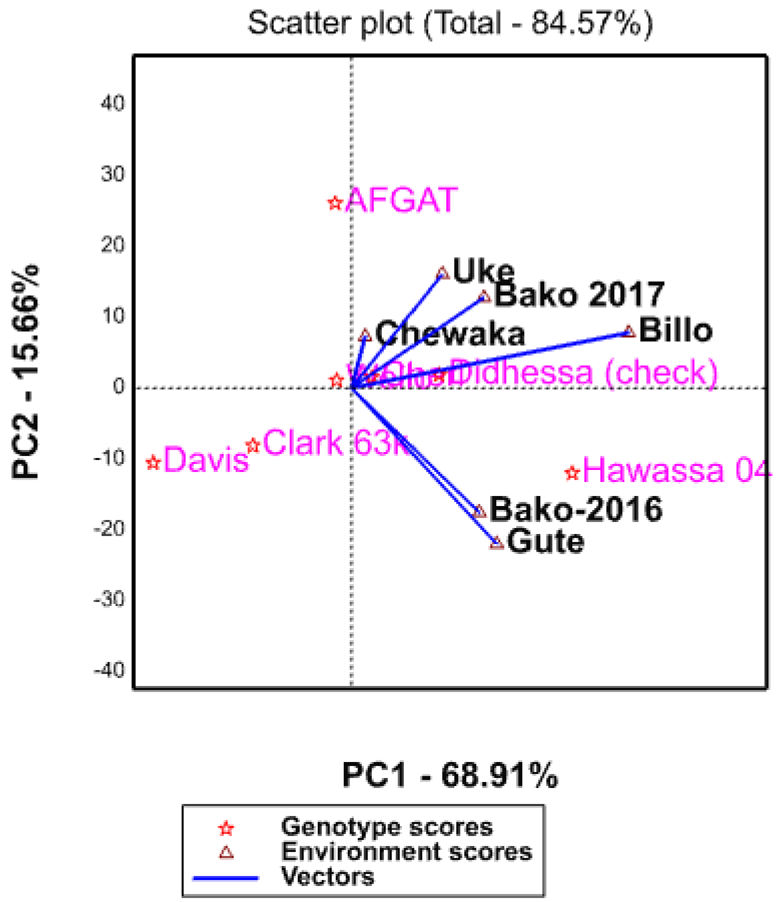

Figure 5. The vector view of GGE biplot which shows the interrelation ships among the test environments and their discriminating ability.

to the ideal genotype and can thus be used as benchmarks for the evaluation of medium maturity groups of soybean genotypes in the western Oromia. Considering simultaneously mean yield and stability, Didhessa and Hawassa-04 were the best soybean varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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