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RESEARCH ARTICLE

GGE bi-plot analysis of multi-environment trial for grain yield stability of faba bean (*Vicia faba* L.) genotypes in the highlands of Oromia region, Ethiopia

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Abstract

Yield of a variety is the most complex trait and influenced by several factors. G x E interaction significantly influenced grain yield of faba bean suggested the presence of differentially adapted faba bean genotypes. Thirteen faba bean genotypes were evaluated at five faba bean growing areas of Oromia highlands during 2017/18 main cropping season with the objective of determining the magnitude and nature of G x E interaction for grain yield of faba bean varieties and to identify stable high yielding variety (s) under wide production for the tested environments and similar agro-ecologies. Combined analysis for grain yield revealed highly significant ($P \leq 0.01$) difference among varieties, locations and variety by location interaction. Walki (3.35 tons ha-1) was the highest yielding variety followed by Tumsa (3.10 tons ha-1), Gebelcho (3.08 tons ha-1) and Dosha (3.00 tons ha-1)with yield advantages of 24.07%, 14.80%, 14.07% and 11.11% compared to the grand mean, respectively. Stability analysis models used in the present study such as regression coefficient (bi) and deviation from regression (S^2di) variance (Wi) ecovalence, coefficient of determination (r^2i), cultivar superiority measure (Pi), stability variance (α^2i) and coefficient of variation revealed that Gebelcho, Shallo and Walki varieties were the most adapted across environment and accompanied with high mean grain yield. Conversely, varieties Holeta-2 and Mosisa were the most unstable. Overall, Dosha and Tumsa had specific adaptation to environments Bore and Alleyo, respectively, Alloshe at Uraga. Walki was also adapted to Gedo and Anna Sorra. Furthermore, Gebelcho Shallo and Walki had general adaptability hence can be recommended for wider production in the tested locations and similar agro-ecologies of the region. Therefore, those varieties were scaled-up as per their adaptability.

Key words: Faba bean, genotypes, GGE bi-plot stability, yield

Introduction

Faba bean (*Vicia faba* L.) a member of the family fabaceae, also known as faba bean, field bean and horse beans, it’s believed to be originated in Mediterranean region or in western or central Asia. It is produced in a wide range of environments around the world.

Faba bean is normally grown as a winter season crop in sub tropical region, with mild winter at high elevation under tropical condition, where the temperature is suitable its generally grown as spring season crop to avoid the period of sever frost (Kay, 1979). It is believed that faba bean was introduced to Ethiopia soon after its domestication around 5000 B.C. (Asfaw *et al.*, 1994). However, its production has not yet spread over compared to the country's potential. It is mainly constrained by lack of improved and stable genotypes suited for different growing ecologies in the country and lack of popularization and market linkages. Faba bean research in the country has been going and managed the release of some improved genotypes tested across environments in Ethiopia. Nevertheless, the national program overlooked the effect of genotype x environment (G x E) interaction and the concept of stability and it capitalizes on genotypes with only good mean performance across a wide array of environments and years.

Generally *Vicia faba* is widely grown as a winter season crop in sub-tropical regions with mild winters and at high elevations (above 1200 m) under tropical conditions, whereas in temperate areas it is generally grown as a spring season crop thus avoiding the period of severe frost .Moreover, the G x E interaction effect is most often, a common phenomenon in a multi-environment yield trail and presents limitations on genotype selection and recommendation for target environments, and hence, must be either exploited by selecting superior genotype for each specific target environment or avoided by selecting widely adapted and stable genotype across wide range of environments (Ceccarelli, 1989). Yield of a variety is the most complex trait and influenced by several factors. While selecting genotype environmental influence should be less. Previous studies in Ethiopia and elsewhere revealed significance presence of genotype x environment interactions in multi-environment yield trial data in faba bean (Gemechu *et al.,* 2002; Gemechu and Musa, 2002; Musa and Gemechu, 2004; Gemechu *et al.,* 2006; Fekadu *et al.,* 2012; Tamene *et al.,* 2015), in soya bean (Asfaw et al., 2009; Fekadu *et al.,* 2009; Tukamuhabwa *et al.,* 2012; Amira *et al.,* 2013; Bueno *et al.,* 2013; Mulugeta *et al.,* 2013), in linseed (Tadele *et al.,* 2017).

Numerous statistical methodologies have been proposed and used to analyze and visualize the nature and magnitude of genotype by environment interaction. However, GGE best fits for mega environment analysis (like 'Which-won-where' pattern), genotype evaluation (mean vs stability), and test environment evaluation which provides discriminating power versus representativeness (Yan *et al.,* 2007; Amira *et al.,* 2013) of the test environment. GGE has been recognized and implemented as useful method to analyze and visualize the pattern of genotype x environment interaction in multi environment cultivar evaluation of different crops including faba bean, wheat, maize, soybean, and oilseeds (Yan *et al.,* 2000; Fan *et al.,* 2007; Asfaw *et al.,* 2009; Brar *et al.,* 2010; Jandong *et al.,* 2011; Fekadu *et al.,* 2012; Fentaw *et al.,* 2015).

Hence, the aim of the study was to examine the nature and magnitude of genotype x environment interaction effects on faba bean grain yield and to determine the winning genotype (s) for test environments in the highlands of Oromia region.

Materials and methods

Field experiment was conducted during the 2017/18 main cropping seasons from July to January at five locations representing highland agro-ecologies of Oromia region such as Gedo, Bore, Alleyo, Anna Sorra and Uraga.

Table 1: Altitude, rainfall, soil type, latitude and longitude of the studied locations

Location	Code	Altitude (m.a.s.l)	Rainfall (mm)	Soil type	Global Position	
					Latitude	Longitude
Gedo	E1	2240	1186.4	NA	9^0 02' N	37^0 25' E
Bore	E2	2736	1550	Nitosols	6^0 24' N	38^0 35' E
Alleyo	E3	2692	NA	Nitosols	6^0 19' N	38^0 39' E
Anna Sorra	E4	2451	NA	Nitosols	6^0 10' N	38^0 42' E
Uraga	E5	2385	1204	Slightly Nitosols	6^0 05' N	38^0 35' E

Sources: Geleta, 2015; Demissie, 2016; NA: Not Available.

Thirteen faba bean genotypes were evaluated under rain fed condition. Each plot consisted of four rows of 4 meter length with 40cm inter-row spacing and 10cm between plants; and fertilizer rate 19/38/7 N/P_2O_5/S Kg ha^{-1} was applied at planting time. All pertinent management practices were carried out at all sites following standard recommendation. Harvesting was done by hand. The central two rows were used as net plot for data collection including yield at each test environments.

Table 2: Description of the thirteen faba bean genotypes used in the experiment

Variety	Code	Pedigree	Methods of development	Seed size	Year of release	Adaptation area	Breeder/ Maintainer
Shallo	G1	EH011-22-1	Introduction	Small	2000	2300-2800	SARC
Mosisa	G2	EH99047-1	Introduction	Medium	2013	2300-2800	SARC
Alloshe	G3	EH03043-1	Introduction	Large	2017	2300-2800	SARC
Walki	G4	Bulga-70x ILB4615	Hybridization	Medium	2008	1800-2800	HARC
Gebelcho	G5	Tesfa x ILB4726	Hybridization	Large	2006	1800-2800	HARC
Tumsa	G6	Tesfa x ILB4726	Hybridization	Large	2010	2050-2800	HARC
Obse	G7	CS20DKx ILB4427	Hybridization	Large	2007	1800-3000	HARC
Dosha	G8	Coll 155/00-3	Collection	Medium	2009	1900-2800	HARC
Bulga-70	G9	Coll 111/77	Collection	Small	1995	2300-3000	HARC
Hachalu	G10	EH969991-1	Introduction	Large	2010	1900-2800	HARC
Holeta-2	G11	BP1802-1-2	Introduction	Small	2000	2300-3000	HARC
Gora	G12	EH91026-8-2 x BPL44-1	Hybridization	Large	2012	1900-2800	HARC
Didia	G13	-	Hybridization	Large	2014	1800-2800	HARC

Source: Crop variety register

To generate a biplot that can be used in visual analysis of MET data. GGE biplot best identifies G x E interaction pattern of data and clearly shows which genotype performs best in which environment. The GGE biplot model of *t* principal components is given as follows:

$$\bar{Y}ij - \mu_i - \beta_j = \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$$

where; $\bar{Y}ij$ = the performance of genotype i in environment j, E = the grand mean, α_j = the main effect of environment j, k = the number of principal components (PC); λ_k = singular value of the kth PC; and Y_{ik} and Y_{jk} = the scores of ith genotype and jth environment, respectively for PC $_k$; E_{ij} = the residual associated with genotype i in the environment j. Usually only the first two PCs are used especially if they account for the major portion of the G x E interaction.

Results and discussion

According to the results of combined analysis of variance (Table 3), genotype x environment interaction was highly significant (P<0.01) for grain yield. The application of the biplot for partitioning through GGE biplot analysis showed that PC1 and PC2 accounted for 47.74% and 21.31% of GGE sum of squares, respectively explained in figure (1), a total of 69.05% variation.

Table 3: Combined analysis of variance for grain yield of 13 faba bean genotypes across locations

Sources	DF	Means of square	Means of square	Means of square (%)
Total	194	249.83		
Environments	4	130.93	32.732**	52.41
Block within Environments	10	6.21	0.621*	2.49
Genotypes	12	33.48	2.790**	13.40
Genotype x Environment	48	44.97	0.937**	18.00
Error	120	34.24	0.285	13.71

*,** = significant at the level of 5% and 1% probability, respectively

Table 4: The mean values of grain yield of 13 faba bean varieties at individual environment

Entry	Genotype	Testing Environment					
		Gedo	Bore	Alleyo	Anna Sorra	Uraga	Genotype means
1	Shallo	2.64^{a}	4.34^{a-c}	2.00^{b-e}	1.66^{c-f}	3.72^{a-c}	2.87^{b-e}
2	Mosisa	2.41^{a}	3.12^{c-e}	2.14^{b-d}	0.30^{g}	3.98^{ab}	2.39^{f}
3	Alloshe	2.26^{a}	3.68^{b-d}	2.71^{ab}	1.82^{b-e}	4.29^{a}	2.95^{b-e}
4	Walki	2.94^{a}	4.45^{ab}	2.59^{a-d}	2.92^{a}	3.86^{a-c}	3.35^{a}
5	Gebelcho	2.54^{a}	4.36^{a-c}	2.65^{a-c}	2.08^{a-d}	3.75^{a-c}	3.08^{a-c}
6	Tumsa	2.41^{a}	4.68^{ab}	3.39^{a}	1.26^{d-f}	3.75^{a-c}	3.10^{ab}
7	Obsie	2.46^{a}	4.19^{a-d}	2.50^{b-d}	1.13^{e-g}	2.36^{e}	2.53^{ef}
8	Dosha	1.82^{a}	5.46^{a}	2.61^{a-d}	1.32^{d-f}	3.77^{a-c}	3.00^{a-d}
9	Bulga70	1.71^{a}	2.99^{de}	1.25^{e}	0.92^{fg}	2.98^{de}	1.97^{g}
10	Hachalu	2.19^{a}	3.72^{b-d}	2.08^{b-e}	2.62^{ab}	2.72^{de}	2.67^{c-f}
11	Holeta-2	1.64^{a}	1.83^{e}	1.80^{de}	0.79^{fg}	3.38^{b-d}	1.90^{g}
12	Gora	2.23^{a}	2.91^{de}	2.53^{b-d}	2.22^{a-c}	3.18^{cd}	2.61^{d-f}
13	Didia	2.04^{a}	3.99^{b-d}	1.85^{c-e}	2.07^{a-d}	3.35^{b-d}	2.66^{c-f}
	Environmental means	2.25	3.82	2.32	1.62	3.47	2.70
	CV(%)	31.87	16.77	21.21	31.68	12.50	19.46

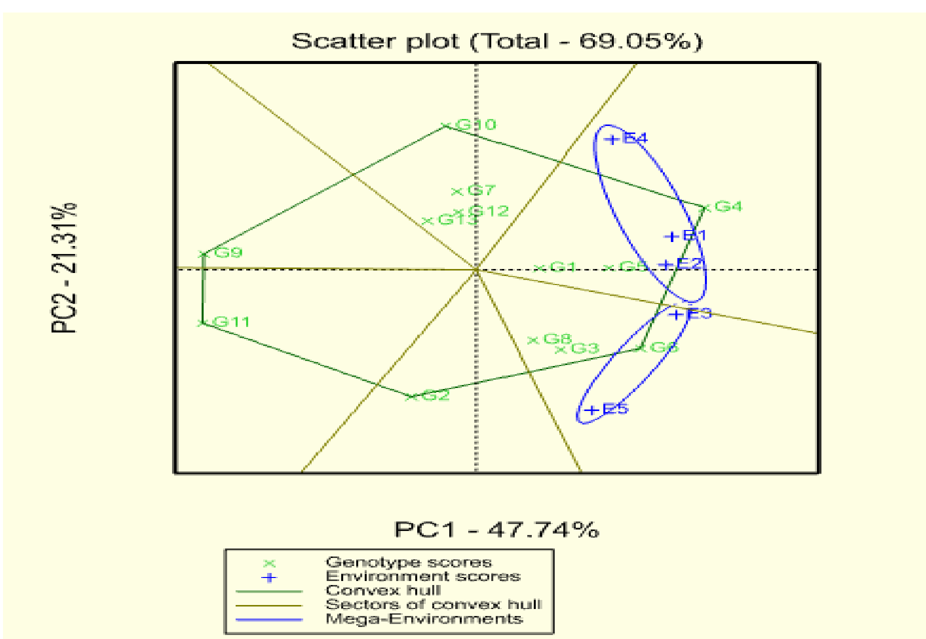
Values with the same letters in a column are not significantly different

This revealed that there was a differential yield performance among faba bean genotypes across testing environments due to the presence of G x E interaction. Large positive PC1 scores for genotypes indicate that those genotypes had higher average yield and PC2 scores near zero indicate that those genotypes were more stable (Yan *et al*., 2000; Yan, 2001). Accordingly, genotypes G4 (Walki), G5 (Gebelcho) and G6 (Tumsa) were high yielding genotypes (Fig. 1). On the other hand, genotypes G9 (Bulga70) and G11 (Holeta-2) were with large negative PC1 scores and they were low yielding genotypes. However, among those genotypes, Shallo and Gebelcho were stable high yielding and should be considered for recommendation.

'Which-Won-Where' pattern and mega-environment identification

Visualization of the "which-won-where" pattern of MET data is important for studying the possible existence of different mega-environments in a region (Yan *et al*., 2000; Yan *et al*., 2001). Many researchers find this use of a biplot intriguing, as it graphically addresses important concepts such as crossover G x E interaction, mega-environment differentiation, specific adaptation, etc. The five environments fell into two sectors with different winner genotypes and the bi-plot showed that six vertex genotypes, G4, G6, G2, G11, G9 and G10. From winner genotypes only G4 (Walki) and G6 (Tumsa) were high yielding in favorable environments. Therefore, GGE bi plot identified the current test locations could be grouped into two different faba bean growing mega-environments. The first environment containing the highest yielding environment (E2) in Bore area with a vertex and the highest in yield genotype Walki; the second environment containing the second highest yielding environment (E5) in Uraga area with winner and the second in yield performance genotype Tumsa (Fig. 1).

Fig 1. Which-Won-Where view of GGE bi-plot for grain yield of 13 faba bean varieties evaluated across 5 environments. Environment, E1 (Gedo), E2 (Bore), E3 (Alleyo), E4 (Anna Sorra), E5 (Uraga); Genotype, G1 (Shallo), G2 (Mosisa), G3 (Alloshe), G4 (Walki), G5 (Gebelcho), G6 (Tumsa), G7 (Obsie), G8 (Dosha), G9 (Bulga70), G10 (Hachalu), G11 (Holeta-2), G12 (Gora) and G13 (Didia)



Mean performance and stability of genotypes

The Average-Environment Axis (AEA) or Average-Tester-Axis (ATA) is the line that passes through the average environment and the biplot origin (Yan, 2002). A test environment with a small angle with the AEA is more representative than other environments (Yan, 2002; Asnake *et al*., 2013). In the Figure 2 the average tester coordinate (ATC X-axis) or the performance line passes through the biplot origin with an arrow indicating the positive end of the axis. The ATC Y-axis or the stability axis passes the plot origin with double arrow head and is perpendicular to the ATC X-axis. The average yield of the genotypes is estimated by the projections of their markers to the ATC X-axis. Accordingly, genotypes G4 (Walki) and G6 (Tumsa) had the highest mean yield, while genotypes G9 (Bulga70) and G11 (Holeta-2) had the poorest mean yield. Mean yields of the genotypes were in the following order: G4 > G6 > G5 > G3 > G8 > G1. The performance of genotypes Walki and Tumsa were the most variable (least stable), whereas genotypes G5 (Gebelcho) and G1 (Shallo) were highly stable with high and medium grain yield respectively.

Evaluation of genotypes based on the ideal genotype

The GGE bi-plot analysis of grain yield of faba bean genotypes based on genotype-focused scaling comparison was presented in Fig. 3. An ideal genotype has the highest mean grain yield and is stable across environments (Farshadfar *et al.,* 2012). The ideal genotype is located in the first concentric circle in the biplot. Desirable genotypes are those located close to the ideal genotype. Thus, starting from the middle concentric circle pointed with arrow concentric circles was drawn to help visualize the distance between genotypes and the ideal genotype (Yan and Tinker, 2006). The ideal genotype can be used as a benchmark for selection. Genotypes that are far away from the ideal genotype can be rejected in early breeding cycles while genotypes that are close to it can be considered in further tests (Yan and Kang, 2003). Placed near to the first concentric circle, genotype G4 (Walki) was used as benchmarks for evaluation of faba bean genotypes. This results, confirm those by Mulugeta and Dessalegn (2014), who found an ideal genotype of potato in the first concentric circle. G6 (Tumsa), G8 (Dosha) and G3 (Alloshe) were located near the ideal genotype, thus being desirable genotypes. This suggesting that their potential for specific adaptability with better grain yield performances. On the other hand, undesirable genotypes were those very distant from the first concentric circle, namely, G9 (Bulga70) and G11 (Holeta-2) (Fig. 3).

Discriminating and representativeness of the test environments

GGE biplot discriminating ability and representativeness is an important measure of the testing environments. The concentric circles on the biplot help to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and is a measure of the discriminating ability of the environments (Yan and Tinker, 2006).

A test environment that has a smaller angle with the AEA is more representative than other test environments (Naroui *et al.*, 2013). Thus, in this study among all the five environments, E2 (Bore) had the longest vector from the biplot origin indicating it was the most powerful to discriminate varieties and the representative as it had a smaller angle with the AEA; which was able to provide unbiased information about the performance of the tested varieties.

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Fig 2: GGE ranking bi-plot shows means performance and stability of thirteen faba bean varieties. Environment, E1 (Gedo), E2 (Bore), E3 (Alleyo), E4 (Anna Sorra), E5 (Uraga), Variety, G1 (Shallo), G2 (Mosisa), G3 (Alloshe), G4 (Walki), G5 (Gebelcho), G6 (Tumsa), G7 (Obsie), G8 (Dosha), G9 (Bulga70, G10 (Hachalu), G11 (Holeta-2), G12 (Gora) and G13 (Didia)

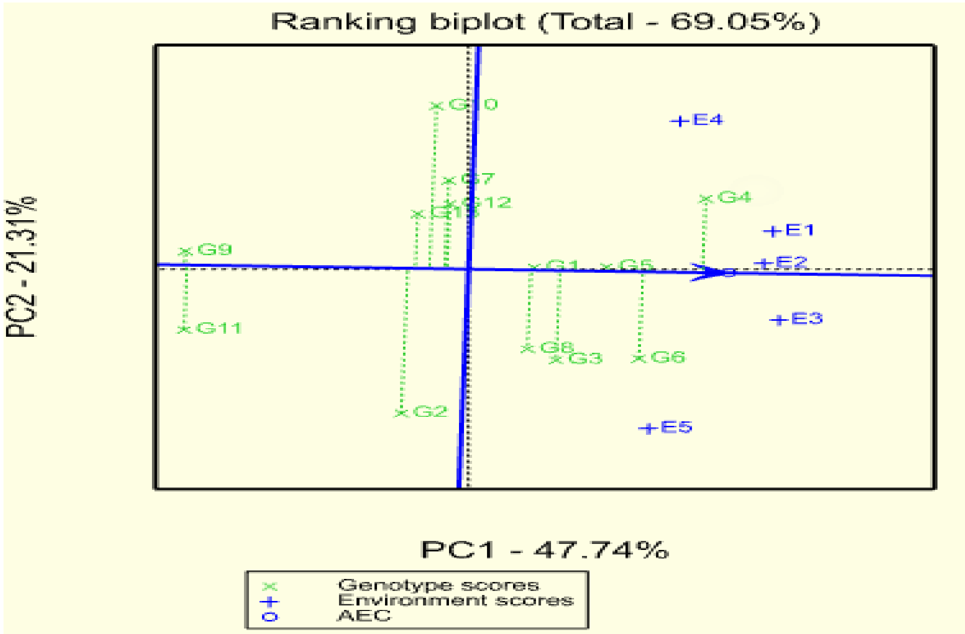
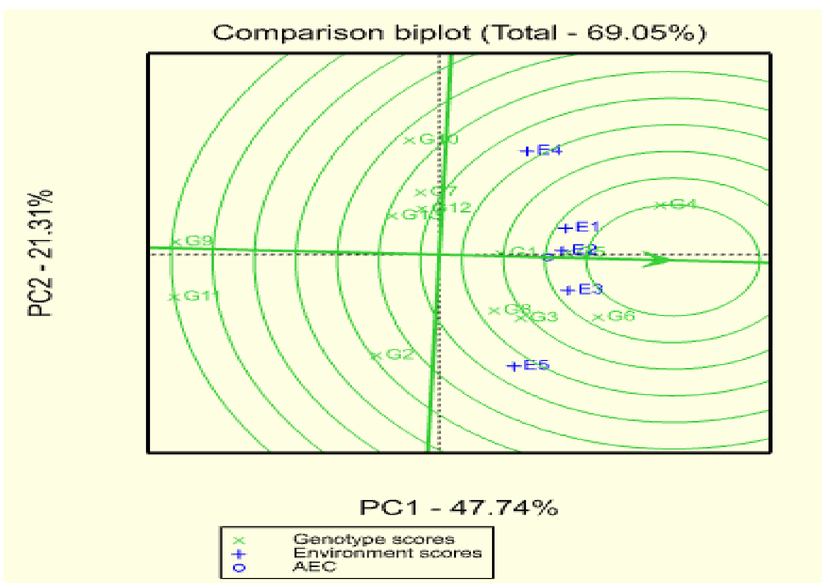


Fig 3: GGE bi-plot based on genotype-focused scaling for comparison of faba bean varieties for their yield potential and stability. Environment, E1 (Gedo), E2 (Bore), E3 (Alleyo), E4 (Anna Sorra), E5 (Uraga); Variety, G1 (Shallo), G2 (Mosisa), G3 (Alloshe), G4 (Walki), G5 (Gebelcho), G6 (Tumsa), G7 (Obsie), G8 (Dosha), G9 (Bulga70, G10 (Hachalu), G11 (Holeta-2), G12 (Gora) and G13 (Didia)



In addition, E1 (Gedo) had the smallest angle with the AEA indicating it was the most representative of the test environments for grain yield, but it was less discriminating power (Fig. 6). E5 (Uraga) had the shortest vector from the biplot origin indicating it was the least discriminating and least representative testing site, as it had largest angle with the AEA. However, E4 (Anna Sorra) although discriminating of the varieties, but it was less representative (Fig. 6). Test locations that are both discriminating and representative like Bore are good test environments for selecting generally adaptable varieties. Environments such as Anna Sorra which was discriminating but non-representative are recommended for selecting specifically adapted genotypes. Test environments that are consistently non-discriminating provide little information on the genotypes and, therefore, should not be used as test environments (Yan and Tinker, 2006). However, removal of non-informative and redundant test location requires multi-year data (Yan *et al.*, 2007). The angles between all the five environments were acute (< 90^o) indicating positive correlations among them for grain yield. This suggests that the same information could be obtained about the genotypes from these environments which are closely associated, thus fewer test environments could be used to reduce costs. An 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 (Yan and Tinker, 2006). Ideal test environment, which is the center of the concentric circles. It is a point on the AEA in the positive direction (most representative) with a very long vectors from the origin are most discriminating. Hence, among the testing environments E2 (Bore), which fell in the center of the concentric circles was therefore, the most desirable testing environment in terms of being the most discriminating and representative of the test environments (Fig. 7).

Fig. 6: The discriminating power and representativeness view of the GGE bi-plot to show relationship among five testing environments. Environment, E1 (Gedo), E2 (Bore), E3 (Alleyo), E4 (Anna Sorra) and E5 (Uraga)

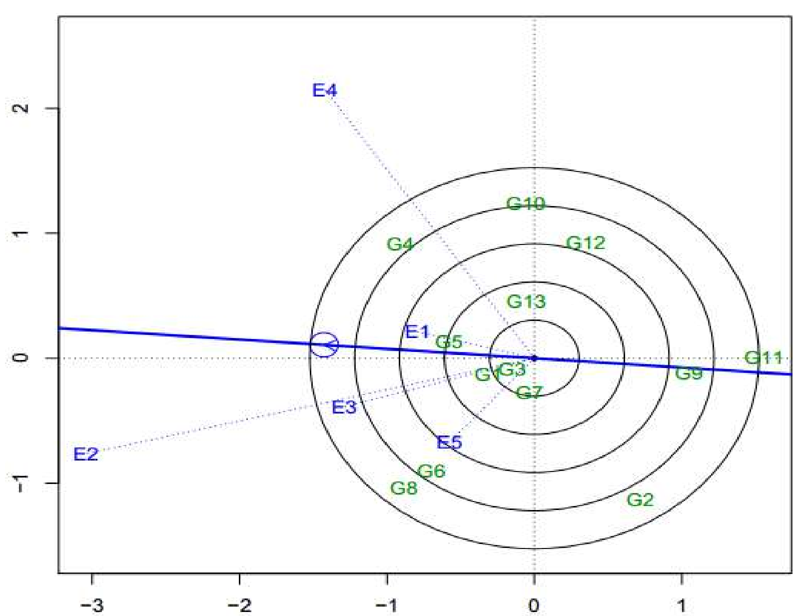
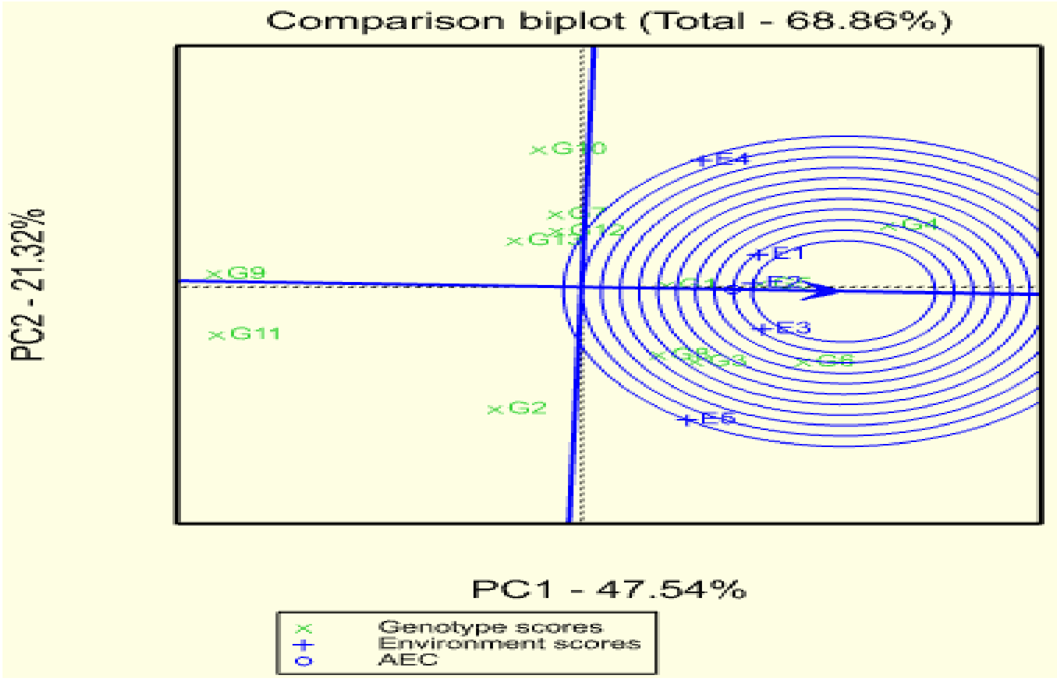


Fig 7: GGE bi-plot based on environment-focused scaling for comparison of testing environments. Environment, E1 (Gedo), E2 (Bore), E3 (Alleyo), E4 (Anna Sorra), E5 (Uraga) and variety G1 (Shallo), G2 (Mosisa), G3 (Alloshe), G4 (Walki), G5 (Gebelcho), G6 (Tumsa), G7 (Obsie), G8 (Dosha), G9 (Bulga70, G10 (Hachalu), G11 (Holeta-2), G12 (Gora) and G13 (Didia)



Conclusion

The combined analysis of variance for grain yield showed that highly significance difference among the environments, genotype and genotype x environment interaction for faba bean genotypes studied in the highlands of the country. The environments have different impact on the yield potential of the genotypes while the genotypes have different performance in the testing environments so that they showed rank difference. Genotype Walki was fell to the first concentric circle and can thus be used as benchmarks for the evaluation of faba bean genotypes in the future breeding program. Genotypes, Gebelcho and Tumsa were located on the next consecutive concentric circle, these regarded as the most desirable varieties. Besides, mean yield and stability, genotypes Gebelcho and Shallo were had wider adaptability. Nearest to the first concentric circle, environment Bore was the ideal environment; therefore, it should be regarded as the most discriminating and representative environment to select widely adapted varieties.

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