Analysis of Genotype x Environment Interaction in Common Bean (*Phaseolous vulgare* L.) varieties in Lowland Areas of Amhara Region

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Abstract

Identifying Stable varieties with high yield is given special attention under rain-fed conditions in Ethiopia, where there is high Genotype by Environment interactions. Hence, this study was designed to determine the extent of variety by environment interaction and the response of testing environments to most popular common bean varieties in the country. The study was carried out on 15 common bean varieties replicated three times at Kobo, Sirinka, Jari, Chefa, Shewarobit and Koga during 2011 and 2012 in Amhara Region, Ethiopia. A combined analysis of variance, AMMI and GGE biplot model analysis were carres p oua. on,

facilitate variety recommendations in breeding programs. The most recent and important methods of interpreting GE interactions are AMMI multivariate stability methods using Interaction Principal Component (IPC) (Zoble *et al*., 1988) and genotype plus genotype x environment interaction (GGE) analysis (Yan *et al*., 2000).

National and regional variety trials have been carried out in specific localities which could allow developing varieties in different bean growing areas in the country. In presence of genotype by Environmental interaction, yield is less predictable and unlikely interpreted based on genotype (G) and environment (E) means alone (Reza *et al*., 2007; Ebdon and Gauch, 2002). The measured yield of each cultivar in each test environment is a mixture of environment main effect (E), genotype main effect (G) and GE interaction (Yan, 2002). However, several studies showed that the effect of environment on yield has larger than other factors. A study carried out in Dawro zone by Melkasa research center indicates that 50.27% of the interactions were due to environmental effect (Zeleke and Sentayehu, 2017). Zeleke *et al*. (2016) have also showed GEI contributes 15.7% of the total interaction. When varieties are introduced into new environments, genotype x environment interaction (GEI) is expected and in its presence, selection of superior varieties based on means averaged over locations is misleading (Gauch and Zobel, 1997). GEI reflects differences in adaptation and can be exploited by selecting for specific or wide adaptation (Adjei *et al*., 2010).

Despite the above mentioned fact, the extent of interaction of different types of bean varieties to environmental change and their stability have not been studied well, and responses of genotype testing locations have not been well known in the bean breeding program of Amhara Region. Thus, the objectives of this study were to determine the nature of adaptation and interaction level of common bean varieties to environmental change; and to classify common bean testing locations in the region into mega environments.

Material and Methods

The experiment was conducted at six locations, namely Kobo, Sirinka, Jari, Chefa, Shewarobit and Koga; experimental locations of Amhara Agricultural Research Institute, Ethiopia during 2011 and 2012 cropping seasons. Descriptions of each testing sites are indicated in Table 1.

Fifteen common bean varieties were tested in this experiment. The descriptions of the varieties are shown in Table 2. The experiment was laid out in randomized complete block design with three replications. The size of the experimental plot was $6.4m^2$ (1.6m x 4m), with an inter- and intra-row spacing of 0.4m and 0.1m. Planting was carried out from the first week of July up to mid-July. Seeds were hand-drilled in rows and later thinned to 0.1 m between plants. Fertilizer was not applied and weeding and other agronomic practices were done as required.

Table 1: Rainfall, soil type, altitude, latitude and longitude of the testing sites

Locations	Soil type	Global position

	Altitude (m.a.s.l.)	Temp. (min and max in ^{o}C)	Rain fall average (mm)		Latitude	Longitude
Sirinka	1850	13.6-27.3	876	Eutric vertisol	11^{o}08’	39^{o}28’
Kobo	1470	15.8-29.1	637	Eutric fluvisol	12^{o}8’	39^{o}18
Jari	1680	NA	NA	Vertisol	11^{o}21’	39^{o}38’
Chefa	1400	11.6-30.4	850	Vertisol	10^{o}57’	39^{o}47’
Shewarobit	1200	13.1-32.5	928	NA	10^{o}06’	39^{o}53’
Koga	1900	16-20	1589	Nitisol	11^{o}25’	37^{o}17’

Source: Sirinka and Debre Birhan Agricultural Research Centers for altitude, rainfall and soil types; Wikipedia for global position. NA= not-available

Seed yield data was collected in gram per plot and finally converted to tone per hectare (t ha^{-}). Seed moisture was adjusted to the moisture level of 10%. Homogeneity of variance was explored using barttlets test. After proving the homogeneity of variance, combined analysis of variance over locations, GGE and AMMI analysis for yield data were computed using the Genstat statistical program version 13^{th}. The GGE biplot method as of Yan *et al.* (2000) was employed to understand the existence of Mega-environments and to characterize the test locations. Mega-environment can be defined as a group of locations that consistently share the best set of genotypes over years (Yan and Rajcan, 2002). The biplot was also used for comparing the varieties at different locations and identify the highest yielding genotypes at the different locations.

Table 2: Description of common bean varieties

No.	**Variety**	**Seed color**	**Seed size**	**Adaptation M.asl**	**Year of release**	**Breeder/maintainer**
1	Tabor	Gray	Small	1200-1800	1998/99	ARARC/SARI
2	Hawassa Dume	Red	Small	1200-1800	2008	AWARC/SARI
3	Dimutu	Red	Small	1200-1800	2003	MARC/EIAR
4	Nasir	Red	Small	1200-1800	2003	MARC/EIAR
5	Deme	R.speckled	Large	1200-1800	2008	MARC/EIAR
6	Awash Melka	White	Small	1400-2200	1998/99	MARC/EIAR
7	Roba-1	Gray	Small	1400-2200	1990	MARC/EIAR
8	Zebra	W.speckled	Medium	1400-2200	1998/99	MARC/EIAR
9	Awash-1	White	Small	1400-2200	1990	MARC/EIAR
10	Red Wolaita	Red	Small	1400-1850	1974	MARC/EIAR
11	Bobe red	Red	Medium	1400-1850	2006	MARC/EIAR
12	Wodo	Gray	Large	1450-1850	2003	SRARC/ARARI
13	Lehode	White	Large	1450-1850	2009	SRARC/ARARI
14	Chercher	Red	Medium	1300-1950	2006	HU
15	Haramaya	Cream	Large	1650-2200	2006	HU

ARARC- Areka Agricultural Research Center, AWARC- Hawassa Agricultural Research, HU- Haramaya University, MARC- Melkasa Agricultural Research Center, SRARC- Sirinka Agricultural Research Center, ARARI- Amhara Regional Agricultural Research Institute, EIAR- Ethiopian Institute of Agricultural Research, SARI- South Agricultural Research Institute.

AMMI’s Stability Value (ASV)

AMMI Stability value was calculated after AMMI analysis using the first two IPCA scores. It was calculated using the following formula (Purchase, 1997). AMMI stability value can explore the level of varietal stability.

$$\mathrm{ASV} = \sqrt{\left[\frac{\mathrm{SSIPCA1score}}{\mathrm{SSIPCA2score}} \times \mathrm{SIPCA2scor}\right]^2 + (\mathrm{IPCA2score})^2}$$

Where ASV = AMMI's stability value, SS = sum of squares, IPCA1 = Interaction of principal component analysis one, IPCA2 = Interaction of principal component analysis two.

Results and Discussion

Analysis of variance

Mean yield of each variety in each test location over years is a function of variety main effect, location main effect, year main effect and their interactions (Yan, 2002). Analysis of variance for seed yield revealed significant difference ($p<0.001$) for the main effects of variety (V), location (L), and year (Y) as well as interaction effects of VL, VY, LY and VLY (Table 3). The significance of the VLY interaction and its linear and nonlinear components demonstrated that varieties differed in their responses to environmental variations. The significant interaction of these three entities associated with significant varietal rank change over environments brings potential limitations on selection and recommendation of varieties for target set of environments (Navabi *et al*., 2006). Location x Year x Variety had a larger role to play in determining yield and these can be considered as a relevant entity in common bean variety evaluation. The significane of main effect of variety indicates that there is large variation among the released varieties in yield and the significance of Location x Year effect suggests the need to evaluate common bean genotypes in regional variety trials more than one year for more reliable inference on performance.

Table 3: Combined ANOVA on yield of fifteen bean varieties at Kobo, Sirinka, Jari, Chefa Shewarobit and Koga during 2011 and 2012

Source of variation	d.f.	Sum of squares	mean squares	variance ratio	Probability
Total	539	283.68168			
Location (L)	5	34.38099	6.87620	27.85	<.001
Year(Y)	1	7.93264	7.93264	149.00	<.007
L x Y	5	77.90154	15.58031	39.70	<.001
Variety(V)	14	58.81482	4.20106	70.17	<.001
L x V	70	39.55449	0.56506	9.44	<.001
Y x V	14	11.11104	0.79365	13.26	<.001
Y x L x V	70	26.56078	0.37944	6.34	<.001
Residual (error)	336	20.11598	0.05987		

AMMI Analysis

Significant interaction of location x year x variety needs further analysis using AMMI (Guach and Zobel, 1997) or GGE (Yan and Tinker, 2006) to explore the responses of varieties across the environments as well as the nature of the environments. AMMI analysis of variance for seed yield showed the presence of highly significant ($p < 0.01$) differences among varieties for seed yield performance (Table 4). From the total sum of squares, the largest portion was due to environmental effect (42.4%) followed by the interaction effect (27.2%) and the variety effect (20.7%). The large portion of environmental sum of squares indicated greater influence of the environments on seed yield performance of common bean varieties and their larger contribution to the total variation when compared to that of varieties main effects. Similar results were obtained by Zeleke and Sentayehu (2017) and Zeleke *et al*. (2016). Partitioning of the interaction through AMMI model had revealed that IPCA1 to IPCA6 were highly significant ($p < 0.01$). Zobel *et al.* (1988) stated that AMMI with the first two IPCA terms is the best predictive model. IPCA1 and IPCA2 had explained 45.3 and 22.6% of the interaction sum of squares, respectively and together accounted for 67.9% of variation in the interaction. They can predict the seed yield performance variation explained by the interaction. Thus, the overall pattern of varieties by environment interaction was interpreted using AMMI1, AMMI2 and GGE biplot models.

Table 4: Analysis of Variance for AMMI model

Source	Sum of Squares.	Mean sum squares.	% contribution to total	% contribution to interaction
Total	283.68	0.526		
Treatments	256.26	1.432**		
Varieties	58.81	4.201**	20.7	
Environments	120.22	10.929**	42.4	
Block	7.31	0.305**	2.6	
Interactions	77.23	0.501**	27.2	
IPCA 1	34.99	1.458**		45.3
IPCA 2	17.44	0.793**		22.6
IPCA 3	8.17	0.409**		10.6
IPCA 4	6.78	0.377**		8.8
IPCA 5	4.09	0.256**		5.3
IPCA 6	2.29	0.164**		3.0
Residuals	3.46	0.087		
Error	20.12	0.06		

The AMMI model does not quantify and rank varieties according to their trait stability, the ASV measure was proposed by Purchase *et al.* (2000) to cope with this problem. ASV is distance from zero in a two dimensional scatter plot of IPCA1 against IPCA2 scores. Genotypes characterized by mean greater than the grand mean with least ASV is considered as the most stable (Purchase *et al.*, 2000). Conversely, a genotype with high mean performance and large ASV is considered as having specific adaptability to an environment. Accordingly, Tabor and Awash Melka varieties have lower ASV with better yield performance and hence they are widely adaptive varieties. Bobe red and Wodo varieties have high ASV with high yield potential and hence specifically adaptive varieties (Table 5).

Table 5: Mean seed yield, IPCA scores and ASV of 15 common bean varieties

Var. name	Code	SYtha^{-}	IPCA[1]	IPCA[2]	ASV
Tabor	G1	1.933	-0.02871	0.0581	0.0598
Hawassa Dume	G2	1.888	0.39624	0.24106	0.6945
Dimutu	G3	1.427	0.48723	0.35635	0.7555
Nasir	G4	1.53	0.6417	0.31137	1.3586
Deme	G5	0.706	0.12548	-1.08088	1.0810
Awash Melka	G6	1.801	-0.23973	0.53301	0.5438
Roba-1	G7	1.721	0.25014	0.29711	0.3642
Zebra	G8	1.444	0.03764	-0.2633	0.2634
Awash-1	G9	1.367	-0.53653	-0.54906	0.7592
Red wolayita	G10	1.383	0.04817	-0.08896	0.0927
Bobe red	G11	2.018	-1.04536	0.29101	3.7664
Wodo	G12	2.085	-0.85491	0.25459	2.8820
Lehode	G13	1.504	-0.11097	-0.21339	0.2211
Chercher	G14	1.581	0.43303	-0.05758	3.2571
Haramaya	G15	1.526	0.39659	-0.08943	1.7610

SYtha^{-} = seed yield tone per hectare; ASV = AMMI stability value

The results of AMMI biplot analysis for seed yield performance of varieties are presented in Figures 1 and 2. The relative magnitude and direction of varieties along the abscissa and ordinate axis in AMMI 1 biplot is important to understand the response pattern of varieties across locations and to differentiate high yielding and stable varieties (Samonte *et al.*, 2005). Tabor and Awash Melka varieties placed relatively close to abscissa line in AMMI 1 and yielded greater than the overall mean were widely adapted to all environments. Wodo and Bobe red were found far to the right side on AMMI 1 biplot indicating that they are high yielding varieties. However, they have high negative IPCA 1 scores and hence are unstable. Most of the environments, except Chefa 2011, Shewarobit 2012 and Koga 2011 have low IPCA 1 scores and hence interact less with the varieties.

In AMMI 2 biplot, the distances from the biplot origin indicates the amount of interaction showed by varieties by environments. Varieties located near the biplot origin are less responsive to environmental changes than varieties far from the origin; and they are widely adaptable to all environments (Voltas *et al*., 2002). In AMMI 2 biplot, varieties Wodo, Bobe red, Awash 1 and Deme found furthest away from the biplot origin. Figure 2 showed high interactive behaviors either positively or negatively whereas Tabor and Awash Melka placed relatively close to the biplot origin express less interaction and widely adapted to all environments. Environments like Shewarobit 2012, Chefa 2011, Koga 2011 and Koga 2012, have longer vectors and interact and discriminate the differences among varieties more than other environments with shorter vectors. Environments with shorter vector length are less interactive and provided little information about the differences among the varieties' seed yield performances as reported by Yan (2002).

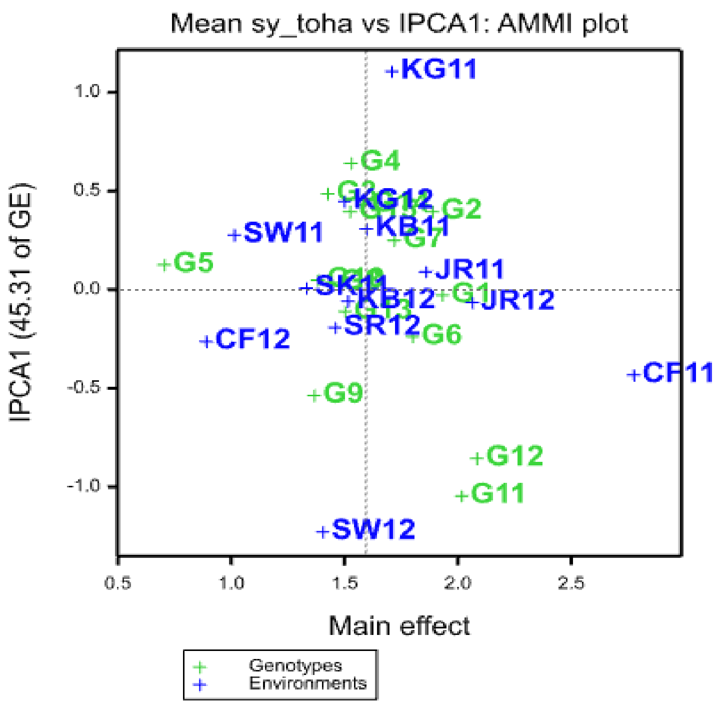

Figure 1: AMMI drawn IPCA 1 vs Yield

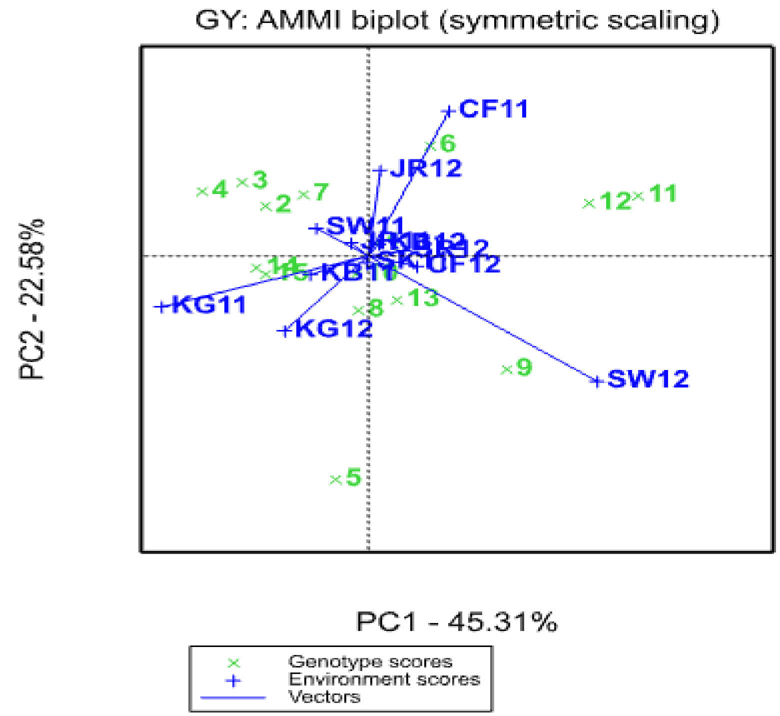

Figure 2: AMMI biplot drawn IPCA 2 vs IPCA 1

KG11= Koga 2011, SW11= Shewarobit 2011, CF11= Chefa 2011, JR11= Jari 2011, SR11= Sirinka 2011, KB11= Kobo 2011, KG12= Koga 2012, SW12= Shewarobit 2012, CF12= Chefa 2012, JR12= Jari 2012, SR12= Sirinka 2012, KB12= Kobo 2012: G1= Tabor, G2= Hawassa Dume, G3= Dimitu, G4= Nasir, G5= Deme, G6= Awash Melka, G7= Roba-1, G8= Zebra, G9= Awash-1, G10= Red Wolayita, G11= Bobe Red, G12= Wodo, G13= Lehode, G14= Chercher, G15=Haramaya

GGE Analysis

GGE biplot consisted of an irregular polygon formed by connecting vertex varieties and a set of lines drawn from the biplot origin and intersecting the sides of the polygon at right angles (Tamene and Tadesse, 2014). In this study, the vertex varieties are Bobe red, Wodo, Hawassa dume, Nasir, Deme and Awash-1. As indicated in Figure 3 the GGE biplot classified the environment markers into three sectors (three mega-environments). Koga 2012, Kobo 2011 and Shewarobit 2011 were grouped into the first mega-environment while Koga 2011 found in the second mega environment. The remaining eight environments were grouped into the third mega-environment. Koga, Kobo and Shewarobit showed inconsistency across years indicating that no single variety performed over years on these locations. Environments within the same sector of the polygon are assumed to share the same winner varieties (Tamene and Tadesse, 2014). Accordingly, varieties Bobe red and Wodo were winner in mega-environment: Chefa, Sirinka and Jari over years. These varieties were released primarily for these locations after they have been tested in regional variety trial for more than two years. However, as mentioned before, it is difficult to single out specific variety for Koga, Kobo and Shewarobit as these locations have inconsistent response across years.

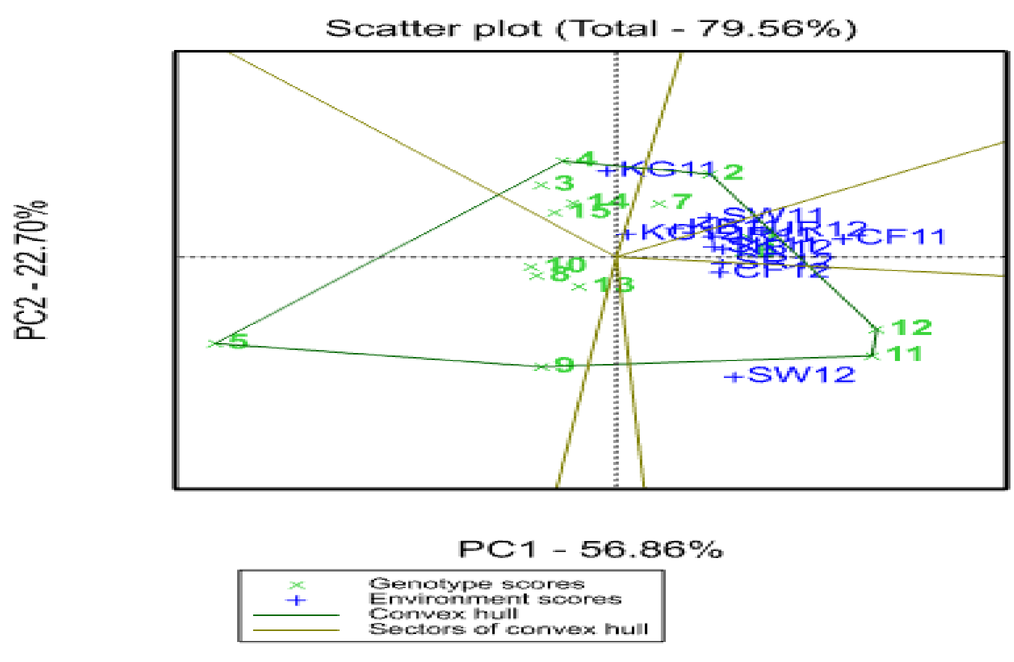

Figure 3: Environmental clustering and which-won-where "view of the GGE biplot"

KG11= Koga 2011, SW11= Shewarobit 2011, CF11= Chefa 2011, JR11= Jari 2011, SR11= Sirinka 2011, KB11= Kobo 2011, KG12= Koga 2012, SW12= Shewarobit 2012, CF12= Chefa 2012, JR12= Jari 2012, SR12= Sirinka 2012, KB12= Kobo 2012: G1= Tabor, G2= Hawassa Dume, G3= Dimitu, G4= Nasir, G5=

Deme, G6= Awash Melka, G7= Roba-1, G8= Zebra, G9= Awash-1, G10= Red Wolayita, G11= Bobe Red, G12= Wodo, G13= Lehode, G14= Chercher, G15=Haramaya

Mega environment classification

One of the purposes of this study is to identify test environments that effectively identify superior genotypes for a mega-environment. The result of the present study shows the existence of complex mega-locations involved in crossover interactions that are not repeatable over years. This requires distinct test sites to select varieties that are superior across the whole region (Yan and Rajcan, 2002). Testing cost can be reduced and efficiency improved by using a minimum set of test locations. Identification and removal of non-informative and redundant test locations must be based on multiyear data. Yan and Tinker (2006) mentioned that on a biplot display, the cosine angle between vectors lines connecting the locations marker to biplot origin approximates their correlation in ranking of the varieties; and the vector length, which is proportional to the standard deviation within the respective environments, estimates the discriminable of the locations. In Figure 4 Sirinka, Jari and Chefa were highly correlated in their ranking of the varieties so that according to Yan and Tinker (2006) these locations produced similar information about the varieties. As the pattern is repeatable across years, conducting regional variety trial at Sirinka, Jari and Chefa is redundant. Chefa is highly correlated with other locations found in the same mega-environment and its longer vector length is considered more representative and discriminative environment as explained by Yan and Tinker (2006); hence it can represent Sirinka and Jari in regional variety trials. These locations represent major bean production areas in Eastern Amhara region.

Kobo has short vector length in both years and it was less informative for the varieties tested. According to Tamene and Tadesse (2014) such type of environments could be considered as less important in variety trials. Koga and Shewarobit have low correlation with the other environment and also have inconsistence response to the varieties across years hence used for culling unstable genotypes in preliminary yield trials. These locations can be used specially for testing genotypes at early stage of an experiment to extrapolate large amount of testing materials with different nature.

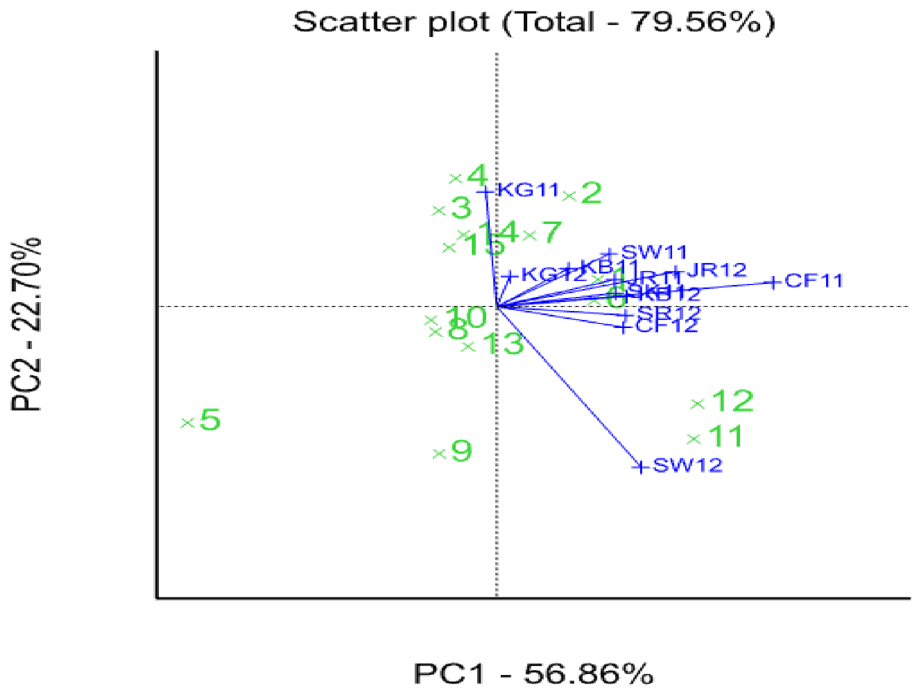

Figure 4: "Relations among test locations in terms of discriminating power vs. Representativeness" views of the GGE biplot

Key:

KG11= Koga 2011, SW11= Shewarobit 2011, CF11= Chefa 2011, JR11= Jari 2011, SR11= Sirinka 2011, KB11= Kobo 2011, KG12= Koga 2012, SW12= Shewarobit 2012, CF12= Chefa 2012, JR12= Jari 2012, SR12= Sirinka 2012, KB12= Kobo 2012: G1= Tabor, G2= Hawassa Dume, G3= Dimitu, G4= Nasir, G5= Deme, G6= Awash Melka, G7= Roba-1, G8= Zebra, G9= Awash-1, G10= Red Wolayita, G11= Bobe Red, G12= Wodo, G13= Lehode, G14= Chercher, G15=Haramaya

Variety evaluation

An ideal variety should have both high mean performance and high stability across mega-environments (Yan *et al*., 2007). Figure 5 showed the mean vs. stability of GGE biplot and its function is exactly similar to AMMI 1 biplot. The arrow on the biplot axis of the Average Environmental Coordinate (AEC) abscissa points in the direction of higher mean performance of the varieties (Yan, 2011) and, consequently ranks the varieties with respect to mean performance. Moreover, AEC abscissa approximates the varieties contributions to variety main effect. The AEC ordinate approximates the varieties' contribution to GE interaction which is the measure of their stability or instability (Yan, 2011). Thus, variety Awash Melka followed by Tabor was stable variety as it was located almost near to the AEC abscissa with high seed yield than the other varieties. This indicates that their rank were highly consistent across environments. As previously mentioned, ASV value showed similar result indicating that both Awash Melka and Tabor are relatively stable than the other varieties. Hence, in areas like Kobo, Shewarobit and Koga where there is inconsistency in response as mentioned earlier, Awash Melka and Tabor are ideal varieties. In contrast, variety Bobe Red and Wodo were the least stable varieties with high mean seed yield value. However, the GGE biplot indicated that variety Bobe red and Wodo can be potential varieties in Mega-environment where Chefa is found.

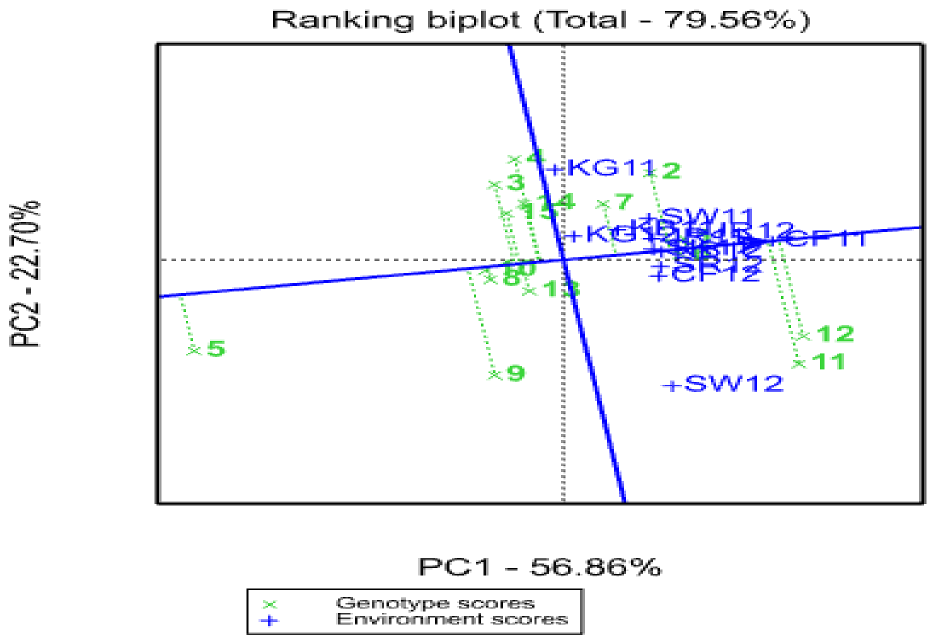

Figure 5: "Mean vs. Stability" view of the GGE biplot

KG11= Koga 2011, SW11= Shewarobit 2011, CF11= Chefa 2011, JR11= Jari 2011, SR11= Sirinka 2011, KB11= Kobo 2011, KG12= Koga 2012, SW12= Shewarobit 2012, CF12= Chefa 2012, JR12= Jari 2012, SR12= Sirinka 2012, KB12= Kobo 2012: G1= Tabor, G2= Hawassa Dume, G3= Dimitu, G4= Nasir, G5= Deme, G6= Awash Melka, G7= Roba-1, G8= Zebra, G9= Awash-1, G10= Red Wolayita, G11= Bobe Red, G12= Wodo, G13= Lehode, G14= Chercher, G15=Haramaya

Conclusion

AMMI and GGE are the most recent and effective models to interpret the adaptation pattern of varieties and the response of multi-environmental sites. The significant contribution of interaction to the total variation in the AMMI model showed the variation of varietal ranking across location as well as the different responses of testing locations. Based on AMMI 1, AMMI 2 and AMMI stability value varieties Awash Melka and Tabor were found widely adaptive varieties. Bobe red and Wodo were the highest yielder and the most unstable varieties. They are specifically adaptive varieties. Moreover, GGE biplot identified Awash Melka and Tabor varieties found desirable for majority of the test environments while Bobe red and Wodo are specifically adapted to Sirinka, Jari and Chefa. Both in the AMMI and GGE biplot, the majority of the testing environments fall in the first quadrant indicating that they are potential for common bean production. Sirinka, Jari and Chefa have showed consistent response to the varieties across years and found in one mega-environment. Chefa with longer vector length and high correlation with the other locations within the same mega-environment can be representative to discriminate genotypes in variety trials. Thus, Chefa can be used in place of Sirinka and Jari. Kobo has short vector length from the biplot origin in both years and it was found non-informative in the variety trial. Therefore Kobo could be considered as less important for varietal trial. Koga and Shewarobit were found to be unpredictable environments so they could be used for culling unstable genotype and for testing genotypes at early stage of an experiment.

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