International Journal of Research in Agriculture and Forestry
Volume 6, Issue 10, 2019, PP 22-31
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

Interaction Effects of Genotype by Environment and AMMI Stability Analysis of Seed Yield and Agronomic Performance of Faba Bean Genotypes in the Highlands of Oromia Region, Ethiopia

Tekalign Afeta[1*], Bulti Tesso [2] and Dagnachew Lule [3]

[1]Bore Agricultural Research Center Bore, Ethiopia
[2]School of Plant Sciences, Haramaya University, Haramaya, Ethiopia
[3]Oromia Agricultural Research Institute, Finfinnee, Ethiopia

***Corresponding Author:** Tekalign Afeta, Bore Agricultural Research Center, Bore, Ethiopia, Email: tekafeta2009@gmail.com*

ABSTRACT

Analysis of interaction of genotypes with locations and other agro-ecological conditions would help in getting information on adaptability and stability performance of genotypes. This study aimed to evaluate the adaptability and yield stability of faba bean varieties using AMMI (additive main effects and multiplicative interaction) and other ancillary statistics. Thirteen faba bean varieties were evaluated at five locations. The ANOVA for grain yield accounted about 13.50% of the total sum of squares (SS) attributable to the genotypes (G), 53.12% to the environments (E) and importantly 18.31% to G x E interaction effects. The first two multiplicative components of the interaction cumulatively explained 80.45% of total interaction effect. The significant effects of IPCA1 and IPCA2 in the ANOVA indicated that the AMMI model was the best fit for the data set. The scores of the principal interaction components showed high variability for the environments relative to the variety effects. High varietal yield stability was observed across environments. AMMI bi-plot analysis and genotype selection index incorporating the AMMI stability value and yield capacity in a single non-parametric index were useful for discriminating genotypes with superior and stable grain yield. AMMI analysis also allowed for the identification of more favorable environments, leading to the site specific cultivars recommendation.

Keywords: *AMMI model; ASV; GSI; Stability; Vicia faba*

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the most important cool season crops in the highlands of Ethiopia and the country is considered as the secondary center of diversity. *Vicia. faba* has a diploid (2n) chromosome number of 12, meaning that each cell in the plant has 12 chromosomes (6 homologous pairs). Five pairs are acrocentric chromosomes and 1 pair is metacentric (Alghamdi, 2009; Hanelt and Mettin, 1989).

In Ethiopia, faba bean is a food security crop that is predominantly grown in the mid-altitude and highland areas as a multi-purpose crop and leads the pulse category in terms of area and production (CSA, 2016). Faba bean is a major source of dietary protein (Sarah *et al*., 2009), and staple food used in different forms by the majority of small-scale, subsistence farmers in Ethiopia. Besides its contribution to food and nutrition security in the households, it plays an important role in management of soil fertility through crop rotation in cereal production hence contributing to agricultural sustainability (Agegnehu and Fessehaie, 2006; FAOSTAT, 2014). It is also a foreign currency earner for the national economy. Ethiopia is the fourth largest exporting country of faba bean next to France, Australia and United Kingdom (FAOSTAT, 2014).

The faba bean is very cold hardy, but cannot take excessive heat during flowering. As faba beans mature, the lower leaves darken and drop, pods turn black and dry progressively up the stem (Hekneby *et al*., 2006; Singh *et al*., 2013). This annual legume grows best under cool, moist conditions. Hot, dry weather is injurious to the crop, so early planting is important. Faba bean tolerates frost. Rainfall of 650 to 1000 mm per annum evenly distributed is ideal for faba bean (Abdel, 2008; Gasim and Link, 2007).

Medium textured soils are ideally suited for faba bean production. It prefers types of soil with pH ranging from neutral to alkaline (pH of 6.5 to 8.0) (Rajan *et al*., 2012). Since the crop requires a good moisture supply for optimum yields, moderate moisture supply is necessary.

Studying involving large number of genotypes and locations provide useful information on the adaptation and stability of genotypes and also on similarities of locations (Annicchiarico, 1997). Furthermore, Poehlman and Slepper (1996) indicated that yield potential is a complex process which is affected by genotypes, environment and genotype x environment interaction. In addition, measuring a separate expression of each physiological process is not practical. Their different expressions are however, measured in total grain yield. Several statistical methods may be used to analyze and interpret grain yield performance of genotypes x environment interaction. However, Additive Main effects and Multiplicative Interaction (AMMI) model has been found to be more accurate in estimating yield of genotypes with in locations than unadjusted mean (Crossa *et al*., 1990; Zobel *et al*., 1988). Besides, AMMI can treat both the additive main effect and multiplicative interaction component employing the analysis of variance (ANOVA) and Interaction Principal Components (IPCA), respectively. Thus, the objective of this experiment was to identify stable and high yielding varieties grown in multi-environments.

MATERIALS AND METHOD

Description of the study areas

The experiments were conducted at five locations namely Gedo (E1), Bore (E2), Alleyo (E3), Anna Sorra (E4) and Uraga (E5) representing highland agro-ecologies of Oromia region.

Table1. *Description of the study sites*

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

Sources: *Yazachew and Kassahun, 2011; Geleta, 2015; Demissie, 2016.*

EXPERIMENTAL MATERIALS AND DESIGN

Thirteen faba bean genotypes were laid out in a complete randomized block design with three replications across all locations. The plot size was 1.6 m x 4 m with 4 rows and 10 cm spacing between plants, while the net harvested area was 2.88 m^2. To reduce border effect, data were taken from the central two rows. Weeding and other management practices were done as required. The fertilizer rate 121 kg NPS/ha was used.

Table2. *Description of tested varieties in the experiment*

Variety	Code	Pedigree	Methods of development	Seed size	Year of release	Adaptation area (m.a.s.l)	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-70 x ILB4615	Hybridization	Medium	2008	1800-2800	HARC
Gebelcho	G5	Tesfa x ILB4726	Hybridization	Large	2006	1800-3000	HARC
Tumsa	G6	Tesfa x ILB 4726	Hybridization	Large	2010	2050 - 2800	HARC
Obsie	G7	CS20DK x ILB 4427	Hybridization	Large	2007	1800-3000	HARC
Dosha	G8	Coll 155/00-3	Collection	Medium	2009	1900 - 2800	HARC
Bulga70	G9	Coll 111/77	Collection	Small	1995	2300 - 3000	HARC
Hachalu	G10	EH960091-1	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

Sources: *Crop variety register*

Statistical Analysis

The collected data were subjected to analysis of variance was computed using the SAS program (SAS institute, 2011) versions 9.3. Variance homogeneity was tested and combined analysis of variance was done using the Mixed Linear Model (PROC ANOVA) procedure to partition the total variation into components due to genotype (G), environment (E) and G × E interaction effects. The following model was used for combined ANOVA:

$$Y_{ij} = \mu + G_i + E_j + GE_{ij} + \beta(E)_{jk} + \varepsilon_{ijk} \quad (1)$$

where; μ = the grand mean, G_i = the effect of the ith genotype, E_j = the effect of the jth location, GE_{ij} = the interaction of the ith genotype with the jth location, $\beta(E)_{jk}$ = the effect of the kth replication in the jth location, and ε_{ijk} = the error. The non-additive interaction (GE_{ij}) as defined in the above equation implies that an expected value (Y_{ij}) depends not only on the level of G and E separately, but also on the particular combination of levels of G and E (Crossa, 1990).

Grain yield data was analyzed using Additive Main effect and Multiplicative Interaction (AMMI) model so as to partitions the interaction sum of squares into IPC axes. The AMMI model is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^{N} \lambda_k \alpha_{ik} \gamma_{jk} + \theta_{ij} + \varepsilon_{ij} \quad (2)$$

where, Y_{ij} = the yield of the ith genotype in the jth environment, μ = the grand mean, G_i and E_j= the genotype and environment deviations from the grand mean respectively, λ_k = the eigen value for IPCA analysis axis k, α_{ik} and γ_{jk}= the genotype and environment principal component scores for axis k, the summation handles N number of principal components retained in the model, θ_{ij} = the AMMI residual and ε_{ij} = the error (Zobel *et al*., 1988).

AMMI stability value (ASV): It was calculated in the excel spread sheet using the formula developed by Purchase *et al*. (1997).

$$ASV = \sqrt{\left[\frac{SSIPCA1}{SSIPCA2}(IPCA1\ Score)\right]^2 + [IPCA2\ Score]^2} \quad (3)$$

where, $\frac{SSIPCA\ 1}{SSIPCA\ 2}$ is the weight given to the IPCA value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares.

Genotype selection index (GSI): GSI was also calculated by the formula suggested by Farshadfar *et al*. (2008). GSI was calculated for each genotype which incorporate both mean grain yield and stability index in a single criteria (GSI_i) as:

$$GSI_i = RASV_i + RY_i \quad (4)$$

where, RASV is the rank value of genotypes for AMMI stability value and RY is the rank value of genotypes for grain yield. A genotype with the least GSI is considered as the most stable (Farshadfar, 2008).

Result and Discussion

The combined analysis of variance over locations for grain yield revealed highly significant differences (P≤0.01) due to environments, genotype and genotype x environment interaction.

Table3. *Combined analysis of variance for grain yield (tons ha-1) of 13 faba bean varieties across five locations during the 2017/18 main cropping season*

Sources	DF	SS	MS
Total	194	245.66	
Environments	4	130.50	32.62**
Block(Environments)	10	3.96	0.396
Genotypes	12	33.16	2.76**
G x E Interaction	48	44.97	0.94**
Pooled Error	120	33.07	0.28
Grand mean = 2.70			
CV (%) = 19.46			
R^2 = 86.54			

Key: *** = highly significant at the level of 1% probability, ns = non-significant; DF = degrees of freedom, SS = sums of squares, MS = means of squares and CV = coefficient of variability.*

Agronomic and Yield Performances of Genotypes Across Locations

Days to Flowering and Maturity

Differences in days to flowering of faba bean varieties were observed at Alleyo and Anna Sorra only (Table 4). Among the tested varieties, early flowering was recorded at Gedo (49.38 days) while late flowering was observed at Bore (63.46 days). Similarly, varieties showed early physiological maturity at Gedo

(128.9 days) and Uraga (129.15 days), but matured late at Bore (146.51 days) (Table 4).

Plant Height (cm)

The varieties showed different response for plant height across the tested environments. The tallest plant height was recorded at Uraga (160.27 cm) with a non-significant height of difference between the varieties while the shortest plant height was recorded at Anna Sorra (98.20 cm).

Number of Branches and Productive Branches

Number of branches and productive branches per plant were the highest (1.33, 1.22, respectively) at Bore, but the least (0.14) at Anna Sorra. Dosha produced the highest number of branches and productive branches at Bore, while the variety Mosisa had no branch at Anna Sorra (Table 4).

Number of Pods and Seeds

The mean value for number of pods per plant ranged from 3.30 pods for Mosisa at Anna Sorra to 26.73 pods for Dosha and Walki at Bore; number of seeds per plant was 2.14 seeds for Mosisa at Anna Sorra to 3.39 seeds for Obsie at Bore (Table 4). The highest numbers of pod was recorded at Bore (21.20) while the lowest number of pods recorded at Anna Sorra (7.51), the highest number of seeds per pod was observed at Bore (2.90) and Uraga (2.88) while the lowest numbers of seed was obtained at Gedo (2.55) and Anna Sorra (2.61) without difference between them (Table 4).

Hundred Seed Weight (g)

The mean values of hundred seed weight among varieties were statistically similar. The average hundred seed weight of varieties across locations is 72.21 g. Of all the tested varieties, Gora (96.54g) produced the heaviest seed weight, while Bulga70 resulted numerically the lowest (48.00g) hundred seed weight (Table 5). The result was in line with the report of Tamene and Tadese (2013), variety Gora was released from "EK01024-1-2" as a new variety in 2013 mainly it characterized by a heavier seed than seeds any other faba bean varieties released to date in the country. Likewise, Teame *et al.* (2017) reported similar result. In the tested environments, at Uraga and Alleyo the lowest (68.87g) and highest (78.50g) seed weight were recorded, respectively (Table 4).

Biomass Yield (tons/ha)

In case of biomass yield, varieties Walki, Tumsa, Gebelcho, Alloshe, Dosha, Didia, Hachalu, Gora and Obsie had above average biomass yield (9.05 tons ha^{-1}),while the lower was recorded from Holeta-2, Bulga70, Mosisa and Shallo. The highest biomass yield across locations was recorded by variety Walki (10.68 tons ha^{-1}). Among the tested environments, the lowest and highest biomass production were recorded at Anna Sorra and Uraga with amount of 5.97 tons ha^{-1} and 12.86 tons ha^{-1}, respectively. The probable reasons for low biomass yield at Anna Sorra might be thin and short plants due to poor soil fertility that caused stunted growth. Whereas the possible reason for high biomass at Uraga was the presence of enough soil fertility of the site as a result of the highest plant height was recorded here. As the result expansion of cells and cell divisions were increased, this caused biomass yield increment.

Harvest Index (%)

In terms of harvest index, the mean harvest index value ranged from 0.26 at Anna Sorra to 0.34 at Bore. The mean value of varieties for harvest index ranged from 0.19 for variety Obsie at Anna Sorra to 0.38 for varieties Shallo and Holeta-2 at Bore with statistically similar among varieties (Table 4).

Chocolate Spot Resistance (%)

In terms of disease reaction across the tested environments the most common faba bean foliar disease for chocolate spot (*Botrytis fabae*) was detected in the five locations. The disease severity scores of tested varieties ranged from (36.35 - 58.19%), which showed moderately resistant to moderately susceptible to chocolate spot (Table 5). Chocolate spot disease severity scores of the genotypes across the environments ranged from moderately resistant to moderately susceptible reaction (Musa *et al*., 2008; Tamene *et al*., 2015). According to Nigussie *et al.* (2008), some improved varieties were moderately resistant to moderately susceptible for most faba bean fungal diseases. In the tested environments the occurrence of smallest (16.09%) and highest (63.45%) chocolate spot severity were recorded at Uraga and Anna Sorra, respectively (Table 4). Testing in multi location is the appropriate means to select resistant cultivars to foliar diseases. For the reason, pathogens may vary in their aggressiveness under different environments. Furthermore, physiological races may be different across environments. Hence, the growth, development and physiological status of host genotypes may change across environments.

Grain Yield (tons/ha)

The significant interaction effect suggests that grain yield of varieties varied across the tested environments. Thus, the highest mean grain yield was exhibited by the variety Walki (3.35 tons ha^{-1}) followed by Tumsa, Gebelcho and Dosha with mean grain yield of 3.10 tons ha^{-1}, 3.08 tons ha^{-1} and 3.00 tons ha^{-1}, respectively, above the average while the two varieties with lowest mean grain yield were Holeta-2 (1.90 tons ha^{-1}) and Bulga70 (1.97 tons ha^{-1}) without significant difference between them. Six varieties 75.61% and seven varieties 24.39% had mean grain yields above and below the grand mean, respectively. The change in yield performance with environments among genotypes was also reported by Tamene *et al*. (2015) in faba bean, Getachew *et al*. (2015) in chickpea. Among the locations, the grain yield varied from 1.62 tons ha^{-1} for Anna Sorra to 3.83 tons ha^{-1} for Bore. The mean grain yield averaged over environments and varieties was 2.70 tons ha^{-1} (Table 6). A large yield variation between environments indicated that the environments were diverse, whereby some of environments were favorable for faba bean genotypes to produce high yield.

Table4. *Mean values of yield related traits and chocolate spot resistance in each testing environments during the 2017/18 main cropping season*

Location	Traits										
	PH (cm)	DF	DM	NBPP	NPOBPP	NPOPP	NSPPO	HSW(g)	BY (t ha^{1})	HI	Ch.spt (%)
Gedo	111.58^{c}	49.38^{e}	128.97^{d}	0.65^{c}	0.44^{c}	10.86^{c}	2.55^{c}	72.74^{b}	7.30^{c}	0.31^{b}	49.80^{c}
Bore	118.72^{b}	63.46^{a}	146.51^{a}	1.33^{a}	1.22^{a}	21.20^{a}	2.90^{a}	71.23^{bc}	11.50^{b}	0.34^{a}	46.63^{c}
Alleyo	104.50^{d}	60.38^{b}	142.41^{b}	0.32^{d}	0.25^{d}	10.12^{c}	2.71^{b}	78.50^{a}	7.60^{c}	0.31^{b}	55.14^{b}
Anna Sorra	98.20^{e}	58.00^{c}	139.77^{c}	0.14^{e}	0.14^{e}	7.51^{d}	2.61^{c}	69.74^{bc}	5.97^{d}	0.26^{c}	63.45^{a}
Uraga	160.27^{a}	55.02^{d}	129.15^{d}	0.99^{b}	0.77^{b}	15.47^{b}	2.88^{a}	68.87^{c}	12.86^{a}	0.27^{c}	16.09^{d}
GM	118.65	57.25	137.36	0.69	0.56	13.03	2.73	72.22	9.05	0.30	46.22
CV(%)	9.65	1.90	0.78	20.74	22.43	20.58	6.23	8.87	28.33	16.90	24.39

Key: *GM = grand mean, CV = coefficient of variability, PH = plant height, DF = days to flowering, DM= days to maturity, NBPP = number of branches per plant, NPOBPP = number of podded branches per plant, NPOPP= number of pods per plant, HSW = hundred seed weight, BY= biomass yield, HI = harvest index and Ch.spot = chocolate spot. Values with the same letter in a column are not significantly different.*

Table 5. *Mean values for hundred seed weight (g), biomass yield (tons ha-1) and chocolate spot severity (%)of thirteen faba bean varieties across five tested locations during the 2017/18 main cropping season*

No.	Variety	HSW (g)	BY (tons ha^{-1})	Chocolate Spot (%)
1	Shallo	64.48	8.86	48.83
2	Mosisa	60.20	7.31	54.32
3	Alloshe	72.15	9.82	46.06
4	Walki	67.94	10.68	38.30
5	Gebelcho	85.13	10.14	37.52
6	Tumsa	78.56	10.62	36.35
7	Obsie	79.12	9.23	58.19
8	Dosha	73.22	9.59	45.54
9	Bulga70	48.00	7.18	50.74
10	Hachalu	77.28	9.43	46.78
11	Holeta-2	58.26	6.14	48.03
12	Gora	96.54	9.14	42.40
13	Didia	77.91	9.44	47.81
GM		72.21	9.05	46.22
CV(%)		8.87	28.33	24.39

Key: *GM = grand means, CV = coefficient of variation. HSW = hundred seed weight and BY = biomass yield. Values with the same letters in a column are not significantly different.*

Table6. *Mean values of grain yield (tons ha-1) of 13 faba bean varieties at each environment during the 2017/18 main cropping season*

No	Variety	Test Environments					GM	Rank
		Gedo	Bore	Alleyo	Anna Sorra	Uraga		
1	Shallo	2.64	4.34^{b}	2.00^{b-e}	1.66^{c-f}	3.72^{a-c}	2.87^{b-e}	6

2	Mosisa	2.41	3.12^{c-e}	2.14^{b-d}	0.30^{g}	3.98^{ab}	2.39^{f}	11
3	Alloshe	2.26	3.68^{b-e}	2.71^{ab}	1.82^{b-e}	4.29^{a}	2.95^{b-e}	5
4	Walki	2.94	4.45^{ab}	2.59^{a-d}	2.92^{a}	3.86^{a-c}	3.35^{a}	1
5	Gebelcho	2.54	4.36^{b}	2.65^{a-c}	2.08^{a-d}	3.75^{a-c}	3.08^{a-c}	3
6	Tumsa	2.41	4.68^{ab}	3.39^{a}	1.26^{d-f}	3.75^{a-c}	3.10^{ab}	2
7	Obsie	2.46	4.19^{bc}	2.50^{b-d}	1.13^{e-g}	2.36^{e}	2.53^{ef}	10
8	Dosha	1.82	5.46^{a}	2.61^{a-d}	1.32^{d-f}	3.77^{a-c}	3.00^{a-d}	4
9	Bulga70	1.71	2.99^{de}	1.25^{e}	0.92^{fg}	2.98^{de}	1.97^{g}	12
10	Hachalu	2.19	3.72^{b-e}	2.08^{b-e}	2.62^{ab}	2.72^{de}	2.67^{c-f}	7
11	Holeta-2	1.64	1.83^{f}	1.80^{de}	0.79^{fg}	3.38^{b-d}	1.90^{g}	13
12	Gora	2.23	2.90^{ef}	2.53^{b-d}	2.22^{a-c}	3.18^{cd}	2.61^{d-f}	9
13	Didia	2.04	3.99^{b-d}	1.85^{c-e}	2.07^{a-d}	3.35^{b-d}	2.66^{c-f}	8
EM		2.25	3.83	2.32	1.62	3.47	2.70	
CV(%)		31.87	16.77	21.21	31.68	12.50	19.46	

GM = genotypic means, EM = environmental means, CV = coefficient of variation. Values with the same letters ina column are not significantly different.

Adaptability and Stability Analysis of AMMI Model for Grain Yield

The ANOVA for grain yield using the AMMI model accounted about 13.50% of the total sum of squares (SS) attributable to the genotypes (G), 53.12% to the environments (E) and importantly 18.31% to G x E interaction effects (Table 7). A large total variation due to E indicated the overwhelming influence that environments have on the yield performance of faba bean varieties. Similar results were reported for soybean (Asrat *et al.*, 2009), field pea (Tamene *et al.*, 2013), cowpea (Nunes *et al.*, 2014) and durum wheat (Shitaye, 2015; Temesgen *et al.*, 2015). Likewise, Yan and Kang (2003) also reported environment as the predominant source of variation. In the current study, the largest variation in yield explained by environments indicated the presence of different environments that can be grouped into mega-environments. The small proportion of SS due to G indicated that the diversity among the genotypes were not very high. Moreover, this study revealed that the magnitude of the G x E interaction sum of squares was 1.36 times larger than that for genotypes indicating sizeable differences in varietal response across environments. This is associated with a significant genotypic rank change over environments. This result is consistent with that of a previous study of faba bean (Mulusew *et al.*, 2008) in Ethiopia and chickpea (Farshadfar *et al.*, 2013) in Iran.

The multiplicative component of AMMI further revealed that the highly significant ($P \leq 0.01$) G x E interaction were decomposed into PCA; the first IPCA explained 43.37% and the second IPCA additionally explained 37.08%, the first two IPCA totally 80.45% of the G x E interaction variation. Haynes *et al*. (1998); Yan and Kang (2003) reported that if the percentage of the first two principal components would explain more than 50% of the total variation, the biplot would be a good alternative to study the genotype by environment interaction. The only first and second interaction principal components (IPCA) were highly significant (Table 7). Zobel *et al*. (1988) stated AMMI with two interaction principal component axes was the best predictive model for cross validation of the yield variation explained by the G x E interaction, which is in line with the previous findings reported by Bahrami *et al*. (2009); Asrat *et al*. (2009); Mohammad *et al*. (2011); Hintsa and Fetien (2013); Tamene *et al*. (2013); Mulusew *et al*. (2014); Shitaye (2015).

The third and fourth interaction principal component axis captured mostly noise (residual) and therefore did not help to predict validation observations. Thus, the interaction of the thirteen varieties of faba bean with five environments was best predicted by first two interaction principal components and environments that easily visualized with the aid of a biplot. This result confirms that the previous findings of (Asrat *et al.*, 2009; Mohammad *et al.*, 2011; Tamene *et al.*, 2013; Mulusew *et al.*, 2014; Shitaye, 2015).

Table7. *AMMI analysis of variance for grain yield of 13 faba bean varieties evaluated at five environments*

Sources	DF	SS	MS	Total variation explained (%)	GxE explained (%)	GxE cumulative (%)
Total	194	245.66				
Environments	4	130.50	32.62**	53.12		
Rep.(Environment)	10	3.96	0.396	1.61		

Genotypes	12	33.16	2.76**	13.50		
G x E Interaction	48	44.96	0.94**	18.31		
IPCA1	15	19.50	1.30**		43.37	
IPCA2	13	16.67	1.28**		37.08	80.45
IPCA3	11	5.50	0.50^{ns}		12.23	
IPCA4	9	3.29	0.37^{ns}		7.32	
Pooled Error	120	33.07	0.28			

Key: *** = significant at the level of P≤0.01 probability; ns = non significant.*

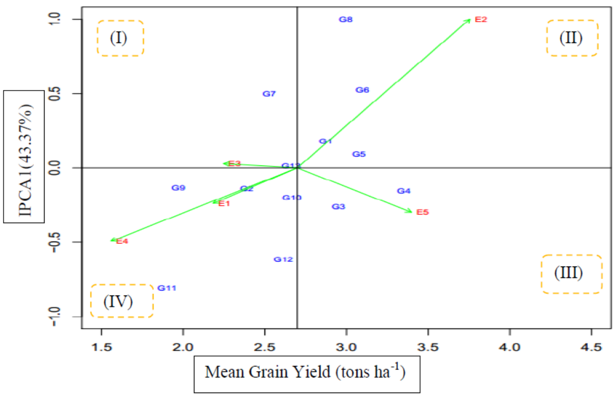
AMMI 1 Bi-Plot

The six varieties; G4 (Walki), G6 (Tumsa), G5 (Gebelcho), G8 (Dosha), G3 (Alloshe) and G1 (Shallo) were relatively had higher grain yield than the other varieties and located to the right side of the grand mean (Figure 1). The two varieties; G11 (Holeta-2) and G9 (Bulga70) were the lowest varieties and located to the left of the perpendicular line, in which they were far apart from the origin. Holeta-2 was interactive variety with unstable performance across testing environments. The two varieties; Gebelcho and Shallo were stable nearly place to the origin (horizontal line). Among the test environments, it is clear that there is variability observed ranging from the lower yielding environment in quadrant I and IV to the high yielding environment in quadrant II and III. Generally, E4 (Anna Sorra) was categorized under the least low yielding unfavorable faba bean environment as compared to the two low yielding environments (Gedo and Alleyo), while E2 (Bore) and E5 (Uraga) were high yielding favorable environments for the tested materials (Figure 1).

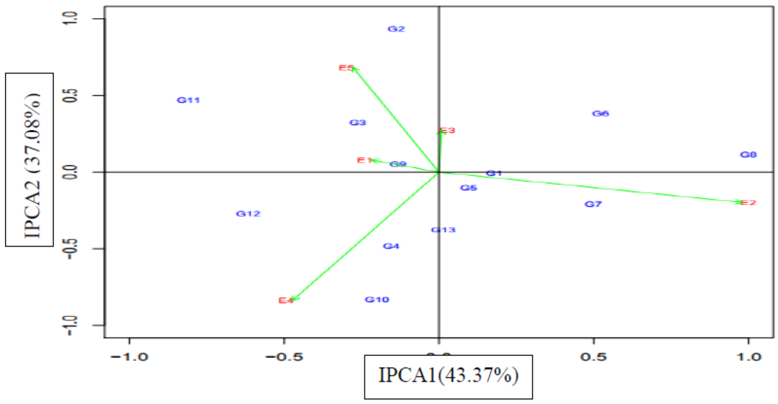
AMMI 2 Bi-Plot

In case of the AMMI2 biplot from below graph, genotypes which occur close to each other are have similar yielding performance across all testing environments, while those genotypes which far apart may differ in mean yield or show a different pattern of response over the environments. Accordingly, varieties G5 (Gebelcho) and G1 (Shallo) which occur close to each other in the AMMI2 biplot (Figure 2) had similar performance to all environments. Genotypes that are close to environment indicate their better adaptation to that particular environment. Here, Dosha and Mosisa were showed specifically adapted to favorable environments, as they are close to environments E2 (Bore) and E5 (Uraga), respectively (Figure 2). Besides to the above in the AMMI1 biplot, genotypes which occur nearer to the origin are less sensitive to environmental changes where as those genotypes which occur distant from the origin are sensitive to environmental change and have large interaction. Hence, varieties Gebelcho, Shallo and Bulga70 were close to the origin and have good responses among the changed environmental conditions, which indicating their minimum contribution to the total G x E interaction variance and are considered as stable varieties. Whereas, varieties G2 (Mosisa), G10 (Hachalu) and G11 (Holeta-2) were distant from the origin and have considerable contribution to the G x E interaction variance and unstable.

However, with respect to the testing environments, E2 (Bore) and E4 (Anna Sorra) were scattered far from the origin indicating that these environments contribute higher amount of variation to the total G x E interaction. Particularly, Bore was the most discriminating environment. On the contrary, E1 (Gedo) and E3 (Alleyo) were located close to the origin indicating lower contribution to the G x E interaction variance and least discriminating environments.



Key: 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(Haleta-2), G12(Gora) and G13(Didia). Figure 1. AMMI1 biplot of IPCA1 against mean yield of 13 faba bean varieties tested at five environments



***Key:** 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(Haleta-2), G12(Gora) and G13(Didia). Figure 2. AMMI2 biplot interaction of IPCA1 and IPCA2 Scores of 13 faba bean varieties across five environments*

The IPCA scores of genotypes in the AMMI analysis indicate the stability or adaptation over environments (Gauch and Zobel, 1996; Purchase, 1997; Alberts, 2004). The greater the IPCA1 scores, negative or positive, (as it is a relative value), the genotype is specifically adapted to certain environments with IPCA1 scores of the same sign. However, the genotype with high mean performance and with large value of IPCA1 score are consider as having specific adaptability to the environments. By considering the IPCA1 scores alone, varieties Dosha and Tumsa were unstable genotypes which specifically adapted to higher yielding environments with average grain yield above the grand mean yield. Although this result indicated inconsistent yield performance across locations, it demonstrated site specific adaptability for those varieties (Dagnachew *et al.*, 2014). Whereas varieties Gora, Obsie and Holeta-2 were also unstable but adapted to lower yielding environments with average grain yield below the grand mean (Table 9). Genotypic stability is crucial in addition to grain yield (Naroui *et al.*, 2013). Conversely, variety Didia with below grand mean yield, also showed IPCA1 very close to zero (0.03), indicating consistence in yield performance across locations.

According to the AMMI model, the genotypes which are characterized by means greater than grand mean and the IPCA1 score nearly zero are considered as generally adaptable to wider environment. Since variety Gebelcho had high mean grain yield along with the IPCA1 score closer to zero, it was less influenced by the environmental fluctuations and could be considered as stable variety, which had general adaptation over all the testing environments (Table 9). AMMI analysis was also conducted and the stability of genotypes was predicted on the basis of mean performance and the magnitude of IPCA1 scores in soybean (Zobel *et al.*, 1988), maize and wheat (Crossa *et al.*, 1990) and chickpea (Mahnaz *et al.*, 2013).

Similar signs of IPCA1 score for both the genotype and the environment indicate positive interaction and thus higher yield of the genotype at that particular environment. Accordingly, Dosha and Tumsa among the varieties, and Bore and Alleyo from the environments had similar negative sign of IPCA1 score. Hence, these varieties could be specifically adapted to both locations respectively. Similarly, Walki and Alloshe were suited to commercial production in Gedo and Uraga, respectively (Tables 8 and 9).

Table8. *Mean yield response and estimates of first two IPCA scores in respect of five environments*

Environment	Code	EN. Mean (t ha^{-1})	IPCA1Score	IPCA2 Score
Anna Sorra	E4	1.624	0.66826	-1.13273
Alleyo	E3	2.317	-0.03790	0.36916
Bore	E2	3.825	-1.35496	-0.26885
Gedo	E1	2.254	0.32231	0.10820
Uraga	E5	3.467	0.40229	0.92422

Grand mean		2.70		

Key: *EN mean = environmental mean and IPCA = interaction principal component axis*

AMMI Stability Value (ASV)

In ASV method, the genotype with least ASV score is the most stable. However, stability needs to be considered in combination with yield (Farshadfar, 2008). Thus, varieties Walki and Tumsa had higher grain yield but with high ASV were identified as best varieties to validate for yield performance and specific adaptability. In this study, AMMI stability value distinguished varieties Gebelcho and Shallo as the best stable varieties within good yield performances (Table 9). Odewale *et al*., 2013 reported that two out of the five coconut genotypes grown across nine environments in southern Nigeria showed smaller ASV and thus better stability. Farshadfar (2008) noted three out of the 20 bread wheat genotypes evaluated gave smaller ASV and higher grain yield than the grand mean and thus better relative stability.

Genotype Selection Index (GSI)

Simultaneous consideration of grain yield and ASV in single nonparametric index is needed. Nevertheless, stable genotypes would not inevitably provide the best yield performance and hence identifying genotypes with high grain yield coupled with consistent stability across growing environments has paramount importance. In this regard, genotype selection index was utilized to further identify stable genotypes with better yield performance. Therefore, based on the GSI, Gebelcho, Walki and Shallo were considered as the best three most stable varieties with high grain yield. Whereas, varieties Holeta-2, Gora and Mosisa were unstable (Table 9). This result was consistent with Biru *et al*. (2017) on Chickpea.

Table9. *AMMI stability value, Genotype selection index, yield rank and principal component axis*

Variety	Means (t ha^{-1})	Rank	IPCA1 scores	IPCA2 scores	ASV	Rank	GSI	Rank
Alloshe	2.95	5	0.25127	0.30987	0.427	5	10	4
Bulga70	1.97	12	0.12693	0.05171	0.157	2	14	6
Didia	2.66	8	-0.01332	-0.35947	0.360	4	12	5
Dosha	3.00	4	0.96047	0.10822	1.129	13	17	7
Gebelcho	3.08	3	0.09247	-0.09924	0.147	1	4	1
Gora	2.61	9	0.59202	-0.25854	0.739	9	18	8
Hachalu	2.67	7	0.19264	-0.80020	0.831	10	17	7
Holeta-2	1.90	13	0.77634	0.45046	1.014	12	25	10
Mosisa	2.39	11	0.13175	0.89917	0.912	11	22	9
Obsie	2.53	10	-0.47841	-0.20029	0.594	7	17	7
Shallo	2.87	6	0.17213	-0.00531	0.201	3	9	3
Tumsa	3.10	2	-0.50132	0.36695	0.692	8	10	4
Walki	3.35	1	0.14717	-0.46333	0.494	6	7	2

Key: *ASV = AMMI stability value, GSI = genotype selection index, IPCA= interaction principal component axis*

Conclusion

The study has indicated that the AMMI model can summarize the pattern and relationship of genotypes and environments. AMMI1 biplot identified Anna Sorra, Gedo and Alleyo as unfavorable environments, whereas Bore and Uraga were the two high yielding and highly favorable testing sites for faba bean grain yield. Among varieties, Gebelcho, Walki and Shallo were close to the origin (horizontal line) are less sensitive to environmental changes and are considered as stable varieties. Based on the AMMI Stability Value (ASV), IPCAs and mean grain yield, Gebelcho and Shallo were selected as the best two varieties. The result of Genotypes Selection Index (GSI) analysis was showed that the most stable varieties with high grain yield were Gebelcho and Walki varieties. Hence, Gebelcho variety was identified as the best and was recommended for production in the study area and similar agro ecologies of the region.

Acknowledgement

We would like to thank Oromia Agricultural Research Institute and Agricultural Growth Program (AGP-II) project for their financial support. We also wish to thank Bore Agricultural Research center (BOARC) and Bako Agricultural Research Center (BARC) for facilitating the land for the field trials. Also grateful gratitude go to team members of Pulse and Oil crops of research at BOARC and BARC

REFERENCES

[1] Abdel Lyi . 2008. Effect of seed size and plant spacing on yield and yield components of Faba bean (*Vicia fava* L.). *Res. J Agric. Biolog. Sci*. 4:146-148.

[2] Agegnehu, G., and R. Fessehaie. 2006. Response of faba bean to phosphate fertilizer and weed control on nitosols of Ethiopian highlands. *Italian Journal of Agronomy* 2:281-290.

[3] Alghamdi SS. 2009. Heterosis and combining ability in a diallel cross of 8 faba bean (*Vicia faba* L.) genotypes. *Asian J. Crop Sci*. 1(2):66-76.

[4] Annicchiarico, P. 1997. Joint regression versus AMMI analysis of genotype x environment interaction for cereals in Italy. *Euphytica* 94: 53-62.

[5] Crossa J, Gauch HG, Zobel RW. 1990. Additive main effect and multiplicative interaction analysis of two maize cultivar trials. *Crop Science* 30: 493-500.

[6] Crossa, J. 1990. Statistical analysis of multi location trials. *Advanced Agro*nomy, 44: 55-86.

[7] CSA. 2016. Report on area and production of crops. Central Statistics Agency agricultural sample survey for 2016/2017 Addis Ababa, Ethiopia.

[8] FAOSTAT. 2014. Data base. Available at: http://faostat3.fao.org/faostat-gateway.

[9] Gasim S, Link W. 2007. Agronomic performance and the effect of soil fertilization on German winter faba bean. *J. Central Eur. Agric*. 8:121-127.

[10] Hanelt P and Mettin D. 1989. Biosystematics of the genus *Vicia* L. (*Leguminocaea*). *Annu. Rev. Ecol. Syst*. 20:199–223.

[11] Hekneby M, Antolin MC, anchez-Diaz SM. 2006. Frost resistance and biochemical changes during cold acclimation in different annual legumes. *Environ. Exp. Bot*. 55:305–314.

[12] Kalia, P. and Sood, S. 2004. Genetic variation and association analyses for pod yield and other agronomic and quality characters in an Indian Himalayan collection of broad bean (*Vicia faba* L.). *SABRAO Journal of Breeding and Genetics*, 36: 55-61.

[13] Poehlman JM, Slepper DA. 1996. Breeding Field Crops (4th edition). Iowa State University Press. Ames, Iowa.

[14] Rajan K, Singh AK, Pandey AK. 2012. Faba bean soils and there management for higher productivity. *In*: Faba Bean (*Vicia faba* L.): A potential leguminous crop of India (Eds. Singh and Bhatt). ICAR, RC for ER, Patna, pp. 205-212.

[15] Sarah, A.E., A.B. Hassan, and E.E. Babiker. 2009. Nutritional Evaluation of cooked Faba bean (*Vicia faba* L.) and white bean (*Phaseolus vulgaris* L.) cultivars. *Australian Journal of Basic and Applied Sciences* 3:2484-2490.

[16] SAS Institute. 2011. SAS/STAT user's guide. SAS Institute Inc., Cary, North Carolina, U.S.A. Available at: http://support.sas.com/kb/42/384.html.

[17] Zobel, R. W., Wright, M. J., and Gauch, G. 1988. Statistical analysis of a yield trial. *Agronomy Journal* 80: 388-393.

Citation: *Tekalign Afeta, Bulti Tesso and Dagnachew Lule "Interaction Effects of Genotype by Environment and AMMI Stability Analysis of Seed Yield and Agronomic Performance of Faba Bean Genotypes in the Highlands of Oromia Region, Ethiopia", International Journal of Research in Agriculture and Forestry, 6(10), 2019, pp 22-31.*