Libyan Agriculture Research Center Journal International 3 (4): 195-200, 2012
ISSN 2219-4304

DOI: 10.5829/idosi.larcji.2012.3.4.539

Genotype X Environment Interaction and Stability Analysis of Faba Bean (*Vicia faba* L.) Varieties in North Ethiopia

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Abstract: Faba bean is the second most important pulse crop next to field pea in Wag-himera and Lasta areas. However, its productivity is not more than 500 kg ha^{-1}. Therefore, evaluation of seven nationally released faba bean varieties against the local check was conducted in RCBD with three replications for two consecutive years at three locations (Dahna, Sayida and Lalibela) with the objective of identifying adaptable and high yielding varieties. Thus, based on the results of analysis of variance (ANOVA), AMMI analysis and farmer's selection criteria we recommend varieties Mesay and Gebelecho that gave the respective mean seed yield of about 1956 and 1574 kg ha^{-1} for production in Dahana, Lalibela, Sayida and similar areas.

Key words: AMMI (Additive Main Effects and Multiplicative Interaction) • Analysis of variance (ANOVA) • Genotype by environment interaction (GEI) • Stability

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the major pulse crops grown in the highlands (1800-3000 m.a.s.l.) of Ethiopia. It is believed that the crop was probably brought to Ethiopia from Middle East through Egypt [1] around the 5th millennium B.C. immediately after domestication [2]. Ethiopia is now considered as one of the centers of secondary diversity for faba bean [1]. The crop is grown in several regions of the country with annual rainfall of 700-1000 mm. It is a crop of manifold merits in the economic lives of the farming communities in the highlands of Ethiopia: serves as a source of food and feed with a valuable and cheap source of protein; plays a significant role in soil fertility restoration as a suitable rotation crop that fixes atmospheric nitrogen; and a good source of cash to the farmers and generates foreign currency to the country. Despite its importance, however, the productivity of the crop is far below its potential due to several yield reducing factors. The inherent low-yielding potential of the indigenous cultivars is among the most important production constraints [2, 1]. Moreover, diseases like chocolate spot (*Botrytiss fabae*), rust (*Uromyces viciae-fabae*) and root rot (*Fusarium solani*) and abiotic stresses like water logging are important production constraints [2, 3].

Even though faba bean is the second most important pulse crop next to field pea in Wag-himera and Lasta areas, its productivity, 500 kg ha^{-1} (WADO, unpublished), has been by far lower than the national average,1150 kg ha^{-1} [4]. The indiscriminate use of low yielding local cultivars by the farmers could be one of the most important factors accountable to such low productivity. Therefore, this study was conducted with the objective of identifying adaptable and relatively high yielding varieties for production in the area.

MATERIALS AND METHODS

Description of Testing Locations: This study was conducted at three locations, namely Dahana, Sayida and Lalibela within the altitude of 200 to 2100m above sea level and soil type of relatively light black soil. The testing locations fall in the SM2-5 sub agro-ecology (Table 1).

Experimental Treatments, Management Practices and Data Collection: Seven nationally released varieties and a local check were evaluated in RCBD with three replications at each location in each year (2007 and 2008 *meher* cropping season). The plot size was 2.4m x 4m with the spacing of 40cm and 10cm between row and plants, respectively. Sowing was done in early

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Table 1: Characteristics of the SM2-5 sub agro-ecological zone

Characteristics	SM2-5 (Tepid to cool sub-moist mountain plains)
Physiography	Mountain and plateau
Altitude	1600-2200m above sea level
Soil	The dominant soil types are Eutric, Cambisols, vertic, Luvisols and Vertisols with moderately fertile
Mean annual rainfall (mm)	700-1200
Mean annual PET (mm)	1800-1900
Mean annual temperature (°C)	16-27.5
Length of growing period	3-5.5 months
Rainfall availability (%)	15-35
Drought availability (%)	20-50
Potential	Rainfed crop production on plains and afforestation on mountains

Source: Land Use and Regulatory Department, MOA (1998)

July (1st week of Hamele) with the application of DAP fertilizer at the rate of 100 kg ha^{-1}. Hand weeding was done three times. Data were collected on days to flowering, days to maturity, plant height, number of pods per plant, number of seeds per plant, 100 seeds weight and seed yield. Yield was estimated from a net plot area of 6.4m^2. During the time of maturity in 2008 cropping season, a group of 20-30 farmers evaluated the performance of each variety at Dahana, Sayida and Lalibela. They evaluated the performance of the varieties according to their selection criteria: yield potential, earliness, pod load, pod size, pod length and stand vigor.

Statistical Analysis: Statistical analysis of variance (ANOVA) was done using SAS software and mean differences were tested by using Least Significant Difference (LSD). Homogeneity of error variances was tested prior to combined analysis over location in each year as well as over locations and years. In combined analysis, locations and years were treated as random factors while varieties were fixed [5]. Thus, the pooled error was used to test the effects of locations and years (Random factors). The variety by location by year interaction was tested against the pooled error and it was used as an error term to test the variety by location and varity by year interactions if it was found to be significant. The varieties (fixed factors) were tested against either the variety by year interaction or variety by location interaction if either of these two were found to be significant using the variety by location by year interaction as an error term. The AMMI analysis was done only for seed yield using Crop Stat software programs to test the stability of varieties across the test locations. AMMI's stability value (ASV) was calculated using the following formula, as suggested by Purchase [6].

$$\text{ASV} = \sqrt{\left[\frac{\text{IPCA1 sum of squares}}{\text{IPCA2 sum of squares}}\left(\text{IPCA1 score}\right)\right]^2 + \left(\text{IPCA2 score}\right)^2}$$

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

The varieties Mesay followed by Lalo, Dagm and Gebelcho gave higher mean seed yield (about 1956, 1735, 1588 and 1574 kg ha^{-1}, respectively) than the other varieties (Table 2). The respective seed yield advantage of these varieties over the local check was about 33, 18, 8 and 6%. The performance of these varieties in central highland areas of Ethiopia was reported to be 2000-5000 kg ha^{-1} on research station and 1500-4500 kg ha^{-1} on farmer's field. However, when we see the performance range of the varieties Mesay (1111-2935 kg ha^{-1}), Gebelcho (847-2181 kg ha^{-1}), Cs-20-Dk (1002-2242 kg ha^{-1}), Lalo (1164-2683 kg ha^{-1}) and Degaga (1324-1621 kg ha^{-1}) in our environment it is far below their potentials. This clearly indicates the yield penalty due to moisture deficit stress environments in Wag-himra and Lasta areas.

As indicated in Table 3, mean hundred seed weight of Gebelecho in the three locations was the highest (about 52-77g), being closely followed by Moti having mean hundred seed weight of about 51-73g. These two varieties were not significantly different in seed size while they had significantly the highest ($p<0.05$) seed size than other varieties, which had mean hundred seed weight of about 30-47g. Mesay, the highest yielding variety had mean

Table 2: Mean seed yield (kg ha^{-1}) of faba bean varieties across three locations and two years

	2007			2008			
Variety	Dahana	Lalibela	Sayida	Dahana	Lalibela	Sayida	Over all mean
Cs-20-Dk	1666.20^{3}	2241.70	1002.10	1589.20^{3}	1065.10	1716.20^{1}	1546.75
Moti	1249.50	1193.39	1333.30	1663.00^{2}	1050.50	1618.90^{3}	1351.44
Gebelcho	1658.40	2180.50	1709.10^{2}	1285.30	1765.50	847.40	1574.36
Mesay	1960.00^{1}	2934.60^{1}	1111.40	1944.00^{1}	2089.40^{3}	1694.80^{2}	1955.71
Dagme	1271.70	2267.20^{2}	987.10	1004.90	2591.70^{2}	1404.70	1587.88
Lalo	1315.10	2246.90^{3}	1709.50^{1}	1288.70	2682.80^{1}	1164.30	1734.56
Degaga	1325.50	1620.70	1617.30^{3}	1485.60	1431.90	1432.80	1485.63
Local	1723.80^{2}	1928.40	967.30	1050.50	1994.40	1132.60	1466.15
Mean	1521.29	2076.66	1304.64	1413.91	1833.91	1376.46	
LSD(0.05)	249.59	674.77	246.32	371.50	249.43	328.18	
CV%	9.37	9.90	10.78	15.00	7.77	13.61	

$^{*1, 2, 3}$, Rank of varieties at each location

Table 3: Mean hundred seed weight (g) of faba bean varieties for each location as averaged over two years

Varieties	Dahana	Lalibela	Sayida
Cs-20-Dk	44.90^{B}	46.85^{C}	47.32^{BC}
Moti	72.50^{A}	71.48^{B}	51.28^{BA}
Gebelcho	71.07^{A}	77.07^{A}	52.07^{A}
Mesay	46.87^{B}	46.68^{C}	41.10^{D}
Dagme	32.83^{C}	30.08^{ED}	40.42^{DE}
Lalo	30.67^{C}	29.50^{E}	32.32^{F}
Degaga	47.25^{B}	45.48^{C}	44.50^{DC}
Local	34.00^{C}	32.08^{D}	35.82^{FE}
Mean	47.51	47.40	43.10
LSD(0.05)	3.80	2.16	4.63
CV%	6.77	3.86	9.09

hundred seed weight of about 41-47g, being in the group of the second best varieties in terms of seed size. Mean hundred seed weight of the local variety (about 32-36g) was higher than that of Lalo, which had the lowest weight (about 30-32g).

Varieties had significantly different ($p<0.05$) number of pods per plant (data not shown): Gebelecho was the least (about 7-10) and Lalo was the highest (15-19), being closely followed by Degaga having about 13-16 pods per plant. The highest yielding variety, Mesay, had about 8-14 pods per plant. There was no appreciable difference among varieties in number of seeds per pod; almost all varieties had 3 seeds per pod but the local variety had about 2 in few instances. There was no big difference among varieties in terms of earliness at maturity (data not shown): the only big difference between the latest maturing Gebelecho and the earliest maturing local variety was about 5 days and that was at Dahana; otherwise, the difference among varieties in other locations was at most about 2 days.

The results of statistical analyses being as indicated above, farmers also evaluated the performance of the varieties based on yield potential, pod load, pod size, earliness, pod length and stand vigor in the year 2008. Thus, the selected varieties were: Moti and Dagaga at Dahana; Gebelcho, Mesay and Cs-20-Dk at Sayida; and Gebelcho, Cs-20-Dk and Lalo at Lalibela.

The overall combined analysis of variance over three locations and two years revealed significance difference among locations and years for all characters considered. The varieties showed significant difference for all the characters except number of pods per plant, number of seed per pod and seed yield. Conversely, the variety by location interaction and variety by year interaction was non-significant for all the characters except a significant varity by year interaction for number of seeds per pod. The variety by year by location interaction was significant for all characters considered except plant height (Table 4). This indicated that the tested varieties showed inconsistence performance over locations and over seasons for most of the characters studied. Therefore, this necessitates the use of AMMI analysis to test the stability of the varieties.

Table 4: Mean square (MS) values of seed yield and agronomic characters of Faba bean varieties for the combined analysis of variance over locations (Dahana, Lalibela and Sayida) and years (2007 & 2008)

Source	df	Days to flowering	Days to maturity	Plant height	No. pods plant^{-1}	No. seeds pod^{-1}	100 seeds weight	Seed yield (kg ha^{-1})
L	2	162.97**	1530.51**	11569.84**	262.31**	0.58**	303.62**	5055065.14**
Y	1	98.34**	132.25**	2096.88**	426.77**	0.15**	105.40**	309811.27**
V	7	30.27*	16.13*	480.83**	130.20^{NS}	0.35^{NS}	3353.72**	616788.74^{NS}
YxL	2	2110.67**	342.27**	8974.62**	474.38**	1.22**	352.26**	298766.84**
V*x*L	14	5.37^{NS}	6.00^{NS}	173.69^{NS}	22.01^{NS}	0.08^{NS}	266.91^{NS}	697127.55^{NS}
V*x*Y	7	4.09^{NS}	9.65^{NS}	100.77^{NS}	38.78^{NS}	0.17**	85.39^{NS}	233209.62^{NS}
V*x*Y*x*L	14	10.73**	4.72**	198.07^{NS}	50.31**	0.05**	124.81**	429419.82**
Error	84	1.20	1.96	120.41	8.98	0.14	9.68	30460.24

L= Location, Y= Year, V= Variety, Y x L = Year by location interaction, V x L = Variety by location interaction, V x Y= Variety by year interaction, V x Y x L=Variety by year by location interaction, **,* Significant at 1% and 5% respectively; NS= Non-significant.

Table 5: Additive main effects and multiplicative interaction (AMMI) analysis of variance for seed yield of the varieties across environments

Source	df	SS	MS	Explained (%)
Environments	5	11020250.00	2204050.00**	29.95
Reps within Env.	12	1498624.00	124885.33**	4.07
Genotypes	7	4316993.75	616713.39^{NS}	11.73
Gen. x Env.	35	17406472.00	497327.77**	47.30
IPCA 1	11	9902158.93	900196.27**	56.89
IPCA 2	9	4591921.84	510213.54**	26.38
Residual	84	2558654.00	30460.17	
Total	143	36800993.75		

Grand mean=1587.79; CV= 10.99; R-square =0.93; NS = non significant; ** = significant at p < 0. 01

The AMMI analysis of variance (Table 5) for seed yield of 8 varieties evaluated at 6 environments (combinations of two years by three locations) showed that 29.95% and 11.73% of the total variation was attributed to the respective environmental and genotypic main effects; and 47.30% was due to genotype by environment interaction (GEI). Significant MS of environment indicate that the environments were diverse, with large difference among environmental means causing most of the variation in seed yield. The first interaction principal component axis (IPCA1) captured 56.89% of the interaction sum of squares. Similarly, the second interaction principal component axis (IPCA2) explained a further 26.38% of the GEI sum of squares. The mean square for IPCA1 and IPCA2 were significant at p< 0.01 and cumulatively contributed to 83.27% of the total GEI.

The association between genotypes and environments can be clearly seen by plotting both the genotypes and the environments on the same graph. Those genotypes and environments located at the right side of the grand mean are considered to be high yielding genotypes and environments while their corresponding located at the left side of the grand mean are low yielding once. The IPCA scores of genotypes in the AMMI analysis are an indication of the stability of adaptation over environments [7,8].The greater the IPCA scores, the more specific adapted is a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotype is over all the environments sampled.

The most stable genotype based on IPCA1 scores were Mesay (d) and Gebelcho (c). The genotypes Mesay (d) and Lalo (f) were high yielding genotypes located at the right side of the grand mean while all the rest of the varieties were low yielding one's which are located on left side of the grand mean. Lalo (f) was unstable genotype adapted to high yielding environments (Lalibela). Conversely, the genotypes Moti (b), Cs-20-Dk (a), Dagme (e) and Degaga (g) were unstable and adapted to low yielding environments of Dahana and Sayida (Figure 1).

IPCA2 scores also play a significant role (26.38%) in explaining genotype by environment interaction. Thus, the IPCA1 scores were plotted against IPCA2 scores to further explore adaptation (Figure 2). Gebelcho (c) was the most stable in addition the local (h) was stable to a lesser extent when plotted on the IPCA1 and IPCA2 scores. The varieties Dagm (e) and Lalo (f) for Lalibela area; varieties Moti (b) and Degaga (g) for Dahana area and the variety Cs-20-DK for Sayida area were specifically adapted genotypes for each location. Farmers also selected all of these varieties except Dagm during their performance evaluation in 2008 cropping season. This clearly indicates the importance of farmer's evaluation in our variety selection activities.

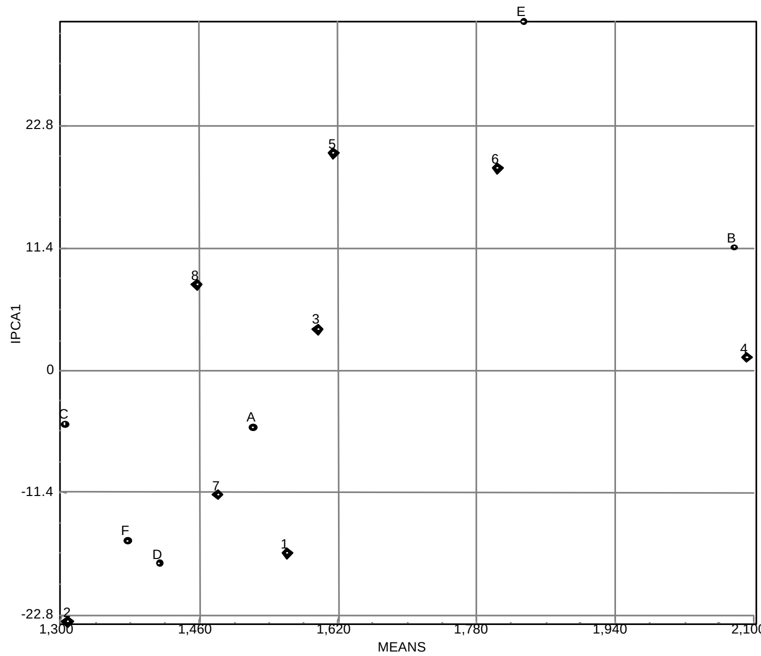

Fig. 1: AMMI biplot of main effects and interactions for seed yield. Where, 1= Cs-20-Dk; 2= Moti; 3= Gebelcho; 4=Mesay; 5= Dagme; 6=Lalo; 7=Degaga; 8=Local; A=Dahana 2007; B=Lalibela 2007; C=Sayida 2007; D=Dahana 2008; E=Lalibela 2008 and F=Sayida 2008.

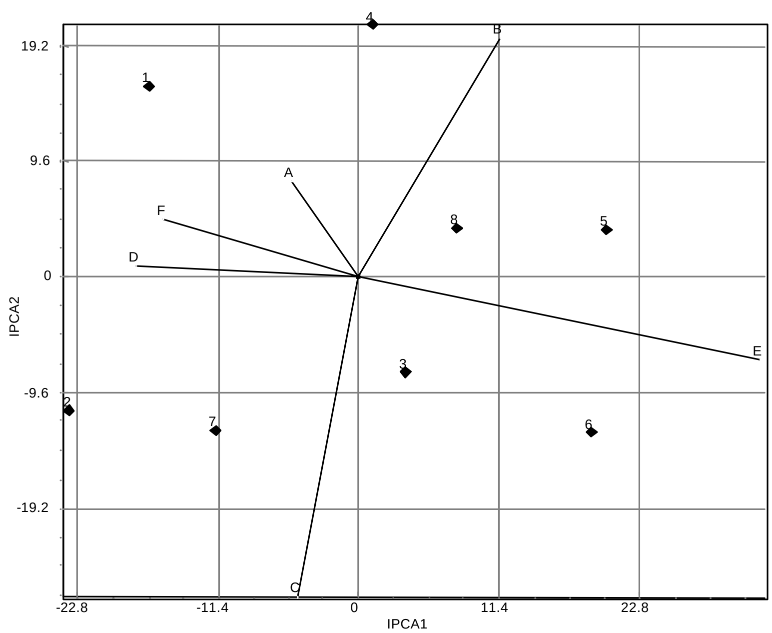

Fig. 2: Interaction biplot for the AMMI2 model. Where, 1= Cs-20-Dk; 2= Moti; 3= Gebelcho; 4=Mesay; 5= Dagme; 6=Lalo; 7=Degaga; 8=Local; A=Dahana 2007; B=Lalibela 2007; C=Sayida 2007; D=Dahana 2008; E=Lalibela 2008 and F=Sayida 2008.

The AMMI model shows patterns and relationships of genotypes and environments successfully. The varieties best adapted to all of the environments were Mesay (d) and Gebelcho (c) inclining to favorable environment. However, the rest of the varieties were unstable genotypes adapted to either high yielding environment or low yielding environments. This can be justified by the typical feature of moisture stressed areas

Table 6: IPCA1 score, IPCA2 score and AMMI Stability Value (ASV) of faba bean varieties tested across three locations and two cropping seasons

Variety	IPCA1	IPCA2	AMMI Stability value (ASV)
Cs-20-Dk	-17.03	15.82	39.99
Moti	-23.47	-11.06	51.80
Gebelcho	3.82	-7.95	11.45
Mesay	1.22	20.94	21.11
Dagme	20.16	3.91	43.66
Lalo	18.88	-12.93	42.72
Degaga	-11.55	-12.79	28.00
Local	7.97	4.05	17.65

which is characterized by fluctuation of climatic factors over seasons and wide variation among localities. This is in agreement with Alberts, [7] who reported that factors such as rainfall, temperature, soil and pest incidence can result in conditions unique to each year-location combination and that the genotypes respond differently to these conditions. Considering the environments Dahana & Sayida were low yielding environments while Lalibela was high yielding. This was as expected because from our experience we know that Lalibela area is better in rainfall amount as well as in soil fertility.

AMMI Stability Value (ASV) based on the AMMI model's IPCA1 and IPCA2 scores for each genotype was also computed [6] and presented in Table 6. ASV is the distance from the coordinate point to the origin in a two dimensional scattergram of IPCA1 scores against IPCA2 scores. The larger the IPCA scores, either negative or positive, the more specifically adapted genotype is to a certain enivironments; the smaller the IPCA scores, the more stable the genotype is to the over all environments studied. Thus, based on ASV the varieties Gebelcho, Local Check and Mesay that scored the lowest AVS were the most stable over the environments. However, the varieties Lalo, Dagm and Moti, which had the highest ASVs, were unstable varieties over the testing environments (Table 6).

CONCLUSION

The combined analysis of variance over three locations and two years reveled that there was siginificant variety by year by location interaction for most of the characters, indicating that the tested varieties showed inconsistence performance over locations and years. Mesay and Gebelecho varieties were selected by AMMI analysis for they are higher yielding and relatively stable performance across locations and years. Gebelecho was positively selected by farmers in all test locations, while Mesay was selected in one location. Therefore, Mesay, in addition to Gebelecho, was selected for its merits on variety diversification, its highest mean seed yield across locations and years and its bigger seed size than the local variety. Seed size of Gebelecho was by far bigger than that of Mesay. Thus, Gebelecho and Mesay varieties are recommended for production in Dahana, Lalibela, Sayida and similar areas.

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