GENOTYPE-ENVIRONMENT INTERACTIONS AND STABILITY PARAMETERS FOR GRAIN YIELD OF FABA BEAN (*Vacia faba L.)* GENOTYPES GROWN IN SOUTH EASTERN ETHIOPIA

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ABSTRACT

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Grain yield of 16 faba bean *(Vacia faba L.*) genotypes tested in a Randomized Complete Block Design (RCBD) with four replications across 12 environments during 2004-2006 growing season of South Eastern Ethiopia was analyzed using parametric stability measures. The objectives were to asses the genotype-environment interactions (GEI), determine stable genotypes, and compare mean yield with the parametric stability parameters. To quantify yield stability seven stability statistics were calculated (ASV, CV_i, S^2xi, Wi^2, σi^2, S^2di and bi). EH 94050-2 and EH 9200-ov 4-2-1 were more stable genotypes which has 7 out of 7 stability statistics used in the study. Moreover, the stability analysis identified genotype EH 94050-2 (genotype 7) and EH 9200-ov 4-2-1(genotype 12) as most stable genotypes and recommended for commercial production in the South East Ethiopia. Highly significant correlations were found among stability parameters implying their closer similarity and effectiveness in detecting stable genotypes and they are equivalent in measuring stability. Hence, any one of these stability parameters could be used to describe genotypes stability.

Key words: Parametric stability, correlation coefficient, yield of faba bean, AMMI analysis

INTRODUCTION

Genetic-environment interactions (GEIs) are great interest when evaluating the stability of breeding plants under different environmental conditions. The reliability of genotype performance across different environmental conditions can be an important consideration in plant breeding. Breeders are primarily concerned with high yielding and stable cultivars as much possible as since cultivar development is a time consuming endeavor. A successfully developed new cultivar should have a stable performance and broad adaptation over a wide range of environments in addition to high yielding potential. Evaluating stability of performance and range of adaptation has become increasingly important for breeding programs. Hence, if cultivars are being selected for a large group of environments, stability and mean yield across all environments are important than yield for specific environments (Piepho, 1996).

Several methods have been proposed to analyze GEI or phenotypic stability (Lin *et al.,* 1986; Becker and Leon 1988; Piepho, 1998; Truberg and Huhn, 2000). This method can be divided into two major groups, univaraite and multivariate stability statistics (Lin *et al*. 1986). Joint regression is the most popular among univaraite methods because of its simplicity of calculation and application (Becker and Leon 1988), where as Additive Main Effect and Multiplicative Interaction (AMMI) is gaining popularity and is currently the main alternative multivariate approach to the joint regression analysis in many breeding programs (Annicchiarico, 1997). Joint regression provides a conceptual model for genotypic stability (Becker and Leon, 1988; Romagosa and Fox, 1993). The GEI from analysis of variance is partitioned into heterogeneity of regression coefficients (bi) and the sum of deviation (ΣS^2di) from regressions. Finlay and Wilkinson (1963) defined a genotype with coefficient of regression equal to zero (bi= 0) as stable while Elberhart and Russell (1966) defined a genotype with bi= 1 to be stable. Most biometricians consider S^2di as stability parameter rather than bi (Elberhart and Russell, 1966; Becker and Leon, 1988). According to the joint regression model, a stable variety is one with a high mean yield, bi=1 and $S^2di=0$ (Elberhart and Russell, 1966). Wricke (1962) suggested using GEI for each genotype as a stability measure, which he termed as ecovalance (Wi^2). Shukla (1972) developed an unbiased estimate using stability variance ($\sigma^2 i$) of genotypes and a method to test the significance of ($\sigma^2 i$) for determining stability of a genotype. Francis and Kannenberg (1978), used the environmental variance ($S^2 i$) and the coefficient of variation (CV_i) to define stable genotype.

However, recent development comprises a multiplicative interaction model, which was first introduced in social science (Crossa, 1990), that was later adapted to the agricultural context as AMMI (Piepho, 1996). This model was considered appropriate if one is inserted in predicting genotypic yields in specific environments (Annicchiarico, 1997). It combines the analysis for the genotype and environment main effect with several graphically represented interactions for principal component analysis (IPCAs) (Crossa, 1990; Abamu and Alluri

1998). Thus, it helps to summarizing the pattern and relationship of genotypes, environment and their interaction (Gauch and Zobel, 1996).

Faba bean (*Vacia faba L.*) is one of the major pulses grown in the highlands (1800-3000m asl) of Ethiopia, were the need for chilling temperature is satisfied. This crop is very much important in the South Eastern Ethiopia since it fetches cash for the farming community and also serves as rotational crops which play great role in controlling disease epidemics in areas were cereal monocropping is abundant. Generally, it is a crop of manifold merits in the economic lives of the farming communities of Ethiopia. However, to date, little information is available on this crop and its adaptation pattern, especially under southeastern Ethiopian conditions. Keeping this in view, the present study was conducted to assess the nature and magnitude of G-E interaction, degree of correlation among some stability parameters of grain yield and to identify stable genotypes.

MATERIAL AND METHOD

Sixteen seemingly hopeful genotypes of faba bean *(Vacia faba L.)* obtained from Institute of Biodiversity Conservation (IBC), Holeta Agricultural Research Center (HARC) and Sinana Agricultural Research Center (SARC) were evaluated for 3 consecutive years, 2004-2006 under 4 warmer faba bean production areas of Bale Highlands; Southeastern Ethiopia. Making 12 environments, the locations are *Sinana, Agarfa, Gassera and Adaba* at altitude ranges from 2400-2500m asl. Description of 16 genotypes and 12 environments are given in Table 1. The experimental design was Randomized Completely Block Design (RCBD) with four Replications. The seeding rate was 200 kg ha^{-1} and fertilizer rate was 18/46 N/P_2O_5 Kg ha^{-1}. Each genotype was sown in 4 rows; 4m length with 40cm inter-row spacing; the two central rows per plot were harvested. Harvesting was done by hand. Grain yield was obtained by extrapolating plot grain yields on a hectare basis (kg ha^{-1}).

Table 1. List of studied Environment, Entries, and Origin / Source of entries

Environments	Entries Code	Entry name	Origin/ Source
Sinana 2004	1	Acc. No. 250111	IBC
Agarfa 2004	2	Acc. No. 250207	“
Gassera 2004	3	Acc. No. 250219	“
Adaba 2004	4	Acc. No. 25041	“
Sinana 2005	5	Acc. No. 25042	“
Agarfa 2005	6	Acc. No. 25194	“
Gassera 2005	7	EH 9200-ov 4-2-1	HARC
Adaba 2005	8	EH 92005-ov 3-1	“
Sinana 2006	9	EH 93002-ov 3-39	“
Agarfa 2006	10	EH 94002-ov 4 -1-4	“
Gassera 2006	11	EH 94005 ov 2-3	“
Adaba 2006	12	EH 94050-2	“
	13	Degaga	“
	14	Shalo	SARC
	15	Bulga -70	HARC
	16	Local landraces	L.landraces

IBC= Institute of Biodiversity Conservation; HARC= Holeta Agricultural Research Center and SARC= Sinana Agricultural Research Center.

Statistical analysis

Combined analysis of variance was performed across test environments of location and years. Stability analysis was performed using Mstat-c (Michigan state University 1991) and IRRI stat computer program (Irri stat 2003). AMMI’s stability value (ASV) was calculated as suggested by Purchase (1997). The stability parameters were performed in accordance with Eberthart and Russell’s (1996) the slope value (bi) and deviation from regression (S^2di), Wricke’s (1962) (Wi^2) ecovalance, Shukla’s (1972) stability variance ($\sigma^2 i$), Francis and Kannenberg’s (1978) coefficient of variability (CVi) and environmental stability variance (S^2i) were calculated for each genotypes using spread sheet programs. Spearman’s coefficient of rank correlation was computed for each pair of the possible pair-wise comparison of the stability parameters by Minitab computer software (Minitab, 1996) and the significance of the rank correlation coefficient was tested according to Steel and Torrie (1980).

RESULTS

The result for combined and AMMI analysis of grain yield across locations and years is given in Table 2. Nearly, all the source of variation in the combined analysis were highly significant (P<0.01) except for location-genotype and genotype-location. Out of the total variance, relatively larger variation were obtained from location within year, years and locations accounted for about 37.87%, 29.98% and 8.46% respectively. This variability was mainly due to the distribution of rainfall, which differed greatly across locations and seasons during the experimental years.

The AMMI analysis of variance of grain yield (ton ha^{-1}) of 16 faba bean genotypes tested in 12 environments showed that 88.50% of the total sum of squares was attributable to environment effects, only 4.70% to genotypic effect and 6.90% to GEI effects (Table 2). A large sum of squares of environments indicates that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. The magnitude of the GEI sum of square was 1.46 times larger than that for genotypes, indicating that there were substantial differences in genotype response across environments. The IPCA scores of a genotype in the AMMI analysis were reported by Gauch and Zobel (1996) and Purchase (1997) as indication of the stability of genotypes are across their testing environments (Yau 1995; Purchase 1997).

The average grain yield and their ranks for 16 faba bean genotypes tested across four locations over the three years are presented in Table 3. The highest yield 4.12 t/ha were obtained from genotype 13 at Sinana, while the lowest was 1.92 t/ha from genotype 5 at Adaba. The mean yield across locations over 3 years (Table 3) showed substantial changes in ranks among the genotypes, reflecting the presence of high G-E interactions (Baker 1998).

Similarly, the majority of the tested genotypes (Table 4) were non-significantly different from a unit regression coefficient (bi=1) and had small deviation from regression (S^2di), and thus possessed average stability. Finlay and Wilkinson (1963) and Eberhart and Russell (1966) stated that genotypes with high mean yield, regression coefficient equal to unity (bi=1) and deviation from regression as small as possible ($S^2di=0$) are considered a stable. Accordingly, genotypes 7 and 12 were the most stable genotypes since the regression coefficients almost unity and had one of the lowest deviations from regression and also have above average mean yield. Besides, their Wi^2 and S^2xi were low and they had lower coefficient of variability (CV %) and Shukla stability variance (σi^2) confirming their stability. In contrast, varieties such as 8, 9, and 14 with regression coefficients greater than one were regarded as sensitive for environmental change.

Table 2. The combined analysis of variance and Gollob tests of interaction principal components in AMMI for grain yield (t/ha) of 16faba bean genotypes tested in southeastern Ethiopia, 2004-2006

Source	df	SS	MS	F	Explained (%)
Year	2	384.00	192.00	641.77**	29.98
Location	3	108.42	36.14	120.81**	8.46
Year x Location	6	485.10	80.85	270.24**	37.87
Replication (LY)	36	30.87	0.86	2.86**	2.41
Treatments	15	37.89	2.53	8.44**	2.96
Year x Genotype	30	17.88	0.59	1.99**	1.40
Location x Genotype	45	18.94	0.42	1.40ns	1.48
Year x Location x Genot.	90	36.24	0.40	1.35ns	2.83
Error	540	161.55	0.29		
Total	767	1280.92			
Genotype	15	12.66	0.84		4.70
Environment	11	239.09	21.73		88.50
Genotype x environment	165	18.53	0.11		6.90
AMMI Component 1	25	9.06	0.36	5.35**	48.89
AMMI Component 2	23	2.63	0.11	1.95**	14.14
AMMI Component 3	21	2.41	0.11	2.48**	13.00
AMMI Component 4	19	1.59	8.39	2.27**	8.58
G x E Residual	77	2.84			
Total	191	270.29			

**, ns= highly significant, non-significant at P<0.01 probability level respectively. CV= 15.2%; SS= Sum of squares, MS= Mean square

Table 3. Mean grain yield (t/ha) and rank (R) of 16 faba bean genotypes tested for 3 years per location in Southeastern Ethiopia 2004-2006

GEN.CODE	SINANA	R	AGARFA	R	GASSERA	R	ADABA	R
1	2.84	11	3.25	4	2.45	13	2.02	14
2	2.63	13	2.87	14	2.48	12	2.24	11
3	2.48	16	3.10	7	2.41	14	2.17	13
4	2.48	15	2.65	16	2.50	10	2.22	12
5	2.56	14	3.01	12	2.50	11	1.97	16
6	2.77	12	2.93	13	2.37	15	1.98	15
7	3.47	4	3.19	5	2.90	1	2.83	2
8	3.66	3	3.27	3	2.72	4	2.58	8
9	2.92	10	3.49	1	2.71	5	2.60	7
10	3.11	9	2.70	15	2.54	9	2.27	10
11	3.29	7	3.05	9	2.70	6	2.67	6
12	3.27	8	3.10	8	2.74	3	2.78	5
13	4.12	1	3.33	2	2.89	2	2.79	4
14	3.84	2	3.03	11	2.61	7	3.13	1
15	3.37	6	3.17	6	2.56	8	2.82	3
16	3.45	5	3.04	10	2.33	16	2.31	9
Mean	3.14		3.07		2.59		2.46	

Table 4. Summary of overall mean yield (t/ha), joint regression, Additive Main effects and Multiplicative Interaction (AMMI) and other stability parameters and their rank (R) orders for 16 faba bean genotypes tested in 12 environments in the South Eastern Ethiopia, 2004- 2006

	Yield		AMMI model				Joint regression				Other parameters							
G.C	t/ha[a]	R	IPCA1	IPCA2	ASV[c]	R	bi[b]	R	S^2di[c]	R	W_i^2[c]	R	SX_i^2[c]	R	CV_i[c]	σi^2[c]	R	F
1	2.64	11	-0.437	0.43	1.14	12	1.019	2	0.15	13	1.46	13	1.54	11	47.05	31.68	13	1
2	2.55	12	-0.431	-0.191	0.88	7	0.866	12	0.07	2	0.98	9	1.08	1	40.76	21.21	9	6
3	2.54	13	-0.715	-0.042	1.33	15	0.88	11	0.16	14	1.85	14	1.20	3	43.11	40.19	14	1
4	2.46	8	-0.377	-0.467	1.11	11	0.885	10	0.09	8	1.06	10	1.14	2	43.39	22.95	10	4
5	2.51	15	-0.492	0.0548	0.92	9	0.929	9	0.09	9	0.96	8	1.25	4	44.66	20.77	8	6
6	2.51	14	-0.236	0.412	0.88	8	0.953	7	0.06	2	0.61	3	1.29	6	45.13	13.13	3	5
7	3.10	3	-0.046	-0.378	0.71	5	0.996	4	0.08	6	0.79	5	1.42	9	38.46	17.06	7	7
8	3.06	4	0.485	0.4156	1.19	13	1.149	16	0.11	12	1.42	12	1.89	15	45.01	30.81	12	1
9	2.93	8	-0.073	0.3916	0.74	6	1.145	15	0.09	10	1.20	11	1.86	14	46.62	26.01	11	2
10	2.66	10	0.167	0.166	0.44	2	0.994	5	0.09	11	0.85	7	1.42	10	44.85	18.37	7	6
11	2.93	7	0.151	0.016	0.28	1	0.968	6	0.06	3	0.57	2	1.32	7	39.30	12.26	2	7
12	2.97	6	0.030	-0.251	0.47	3	1.003	1	0.03	1	0.29	1	1.39	8	39.70	6.15	1	7
13	3.28	1	0.674	0.1891	1.30	14	1.105	3	0.17	15	1.86	15	1.81	13	41.03	40.41	15	2
14	3.15	2	0.899	-0.361	1.80	16	1.121	14	0.28	16	3.07	16	1.97	16	44.49	66.81	16	1
15	2.98	5	0.058	-0.508	0.95	10	0.939	8	0.07	5	0.77	4	1.26	5	37.73	16.62	4	6
16	2.78	9	0.343	0.117	0.67	4	1.047	13	0.08	7	0.80	6	1.56	12	44.85	17.28	6	5
Mean	2.82				0.93		1.00		0.11		1.16		1.46		42.88	25.11		

[a]printed values in bold are higher than the mean; [b]printed values in bold are not significantly different from unity at $P < 0.05$; cultivars with values in bold are considered stable; [c]printed values in bold are lower than the mean; cultivars with lower values than the mean for six stability parameters are regarded as stable; G.C.= Genotype code as listed in Table 1; R=Rank; ASV= AMMI stability value; *bi* = regression coefficient, S^2di = deviation from regression (Eberhart and Russell 1966), Sx^2i = environmental variance, *CV* = coefficient of variation (Francis and Kannenberg 1978), σi^2 = Shukla stability variance (Shukla 1972), Wi^2 = ecovalence (Wricke 1962), *F* = frequency of the number of stability parameters over all of stability parameters for each genotype, if a genotype had seven values of *F*, it could be considered stable.

According to the IPCA 1 scores, genotype 12 was the most stable genotype, followed by 7, 15 and 9. On the other hand, when IPCA 2 is considered, this stability order had a different picture. According to IPCA 2 scores, genotype 11 was the most stable genotype followed by 3,5 and 16. This means that the two IPCAs have different values and meanings. Therefore, the other better option is, to calculate ASV using a principle of the Pythagoras theorem and to get estimated values between IPCA 1 and IPCA 2 scores. ASV was reported to produce a balanced measurement between the two IPCA scores (Purchase, 1997; Adugna and Labuschagne, 2002).

Summary of the joint regression, AMMI and other stability parameters such as Francis and Kannenberg's (1978) coefficient of variability (CV%), Wricke (1962), ecovalance (Wi^2), environmental stability variance (S^2xi) and Shukla stability variance (1972) (σi^2) were also analyzed for comparison (Table 4). Nearly, all of them identified genotype 12 as the most stable genotype. It had low CV_i, S^2xi, Wi^2, σi^2, S^2di and bi value closer to unity. Similarly, genotype 11 and 7 was identified as the next most stable genotype than the remaining ones.

Spearman's coefficient of rank correlation was computed among all the stability parameters (Table 5). Highly significant ($P<0.01$) rank correlation between Wi^2 and ASV ($r=0.818$) was observed. The same held true between bi and Wi^2 ($r=0.644$). Similarly, high significant rank correlation ($P<0.01$) was found between S^2di and Wi^2 ($r= 0.949$). Shukla's stability parameters (σi^2) were significantly correlated with ASV ($r=0.818$), Wi^2 ($r=0.989$), bi ($r=0.644$) and with S^2di ($r=0.949$). Similarly, Alberts (2004) reported high rank correlations between S^2di and σi^2; Wi^2, S^2di and ASV, CV, bi, ASV and Wi^2 and this implies their strong relationship in detecting the stable genotype. In general, AMMI, joint regression, Wricke (Wi^2), S^2xi and Shukla's (σi^2) were found to be useful in assessing the stability of faba bean (*Vacia faba L.)* genotypes under the studied environments of South East Ethiopia. Although, AMMI was found to be more informative in depicting the adaptive response of the genotypes (Purchase, 1997), the joint regression analysis also remains a good option.

Table 5. Spearman's coefficient of rank correlation for seven genotype-environment (G-E) stability parameters of 16 faba bean genotypes evaluated in 12 environments in Ethiopia, 2004-2006.

	ASV	Wi^2	S^2xi	CV_i	b_i	S^2di
Wi^2	0.818**					
Sxi	0.130	0.356				
CV_i	0.155	0.369	0.404			
b_i	0.593*	0.644**	0.187	0.141		
S^2di	0.771**	0.949**	0.438	0.369	0.518*	
σi^2	0.818**	0.989**	0.356	0.369	0.644**	0.949**

**,*= Highly significant, significant correlation at t=0.01 respectively; ASV= AMMI stability value; bi = regression coefficient, S^2di = deviation from regression (Eberhart and Russell 1966),Sx^2i= environmental variance, CV_i = coefficient of variation (Francis and Kannenberg 1978),σi^2 = Shukla stability variance (Shukla 1972), Wi^2 = ecovalance (Wricke 1962).

DISCUSSION

Successful variety of faba bean needs to be adapted to a broad range of environmental conditions in South Eastern Ethiopia in order to ensure their yield stability and economic profitability. Farmers are most interested in variety that produce consistent yields under their growing conditions and breeders also want to fulfill these needs. Hence, information on G-E interaction and stability is of paramount importance for faba bean breeders and farmers under a set of environments.

The highly significant differences ($P<0.01$) of the combined analysis across locations and years indicate the fluctuation of genotypes in their responses to the different environments. There are also tremendous changes in yield ranks of the genotypes across locations. Pham and Kang (1988) indicated that a G-E interaction minimizes the usefulness of genotypes by confounding their yield performance. Thus, it is important to study in depth the yield levels, adaptation patterns and stability of genotypes in multiplication trials. Becker and Leon (1988) also indicated that assessment of stability across many sites and years could increase both reliability and heritability of important traits.

The partitioning of variance components revealed that both predictable environment (location) and unpredictable environment (year) were important source of variation (Table 2). When G-E interaction is due to variation in predictable environmental factors, faba bean breeders can have the alternatives of either developing specific variety for different environments (location, soil types, management system etc.), or broadly adapted variety that can perform well under variable conditions. However, when G-E interaction results from variation in unpredictable environmental factors, such as year to year variation in rain fall distribution, as in the case, in this study, the breeder need to develop stable varieties that can perform reasonably well under a range of conditions. Such breeding strategies can assist the farmers in risk avoidance. Ceccarelli (1994) and Piepho (1998) indicated that farmers perceive yield stability as the most important socio-economic aim to minimize crop failure, especially in marginal environments.

As mentioned above the joint regression analysis revealed that genotypes 7 and 12 were stable in yield and such stable performance is a desirable attributes of cultivars, particularly countries such as Ethiopia, where environmental variations are very high and unpredictable (MOA,1998). Breeding efforts for such environments should give more emphasis to develop widely adapted genotypes such as genotypes 7 and 12. Similarly, breeding for specific localities need to be encouraged using the existing sub-centers and, of course, with in the available resources since the latter is more expensive than the former. Romagosa and Fox (1993) indicate that the common breeding strategy for variable environments is generally to develop widely adapted varieties by testing over a rage of diverse conditions covering representative samples of special and temporal variations.

Among the joint regression stability measures, S^2di was largely used to rank the relative stability of cultivars (Becker and Leon, 1988). The indication was that bi could be used to describe the general response to the goodness of environmental conditions, where as, S^2di actually measures the yield stability. However, AMMI, S^2di, Wi^2, σi^2 and S^2xi were generally found to be important in determining the comparative stability of the faba bean genotypes tested (Table 4). This fact also reflected by spearman's rank correlation that displayed significant correlations among these stability parameters (Table 5). Since AMMI combines analysis of variance and principal component analysis in one model (Yau, 1995; Purchase, 1997), it was found useful in describing both the G-E interaction and stability analysis. In general, most of stability parameters identified that genotype 12 as the most stable. As result, genotype 12 is recommended for commercial release in Ethiopia. It also possessed other desirable agronomic characteristics, such as early maturing, number of seed per pod, pod per plant and tolerant to diseases. A stable variety that performs reasonable well under a range of conditions is essential for unpredictable environments, such as that of Ethiopia. For better description and prediction, however, the environmental variable have to adequately measured and analyzed along with the data of genotypes, and thus, future research should focus on these areas. Crossa (1990) emphasized that greater attention must be paid in collecting, analyzing and interpreting the environmental and physiological variables to characterize the genotypes and the geographical regions in order to manage and further explain the G-E interactions. Similarly, Basford and Cooper (1998) also stressed the need to understand environmental characters and reliability of G-E interactions as key issues in cultivar development programme.

Finally, the following major findings can be summarized from this study:

I. Genotype 12 and 7 was found to be the most stable genotype and is thus recommended for commercial release in South East Ethiopia.

II. AMMI, S^2di, Wi^2, S^2xi,CVi, bi and σi^2 were found to be useful in detecting the phenotypic stability of the genotypes studied;

III. The significant G-E interactions and the changes in the rank of genotypes across environments suggests a breeding strategy of specifically adapted genotypes in homogenously grouped environments, and

IV. Whenever, new varieties are proposed for commercial release, information on G-E interactions and stability, clearly indicating their specific and/ or general adaptations needs to be available to the users.

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