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Full Length Research Paper

Genotype X environment interactions and grain yield stability of haricot bean varieties in Northwest Ethiopia

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Seven haricot bean (*Phaseolus vulgaris* L.) varieties were evaluated in 2000 to 2001 and 2001 to 2002 cropping seasons at three representative locations in northwest Ethiopia. The objective of this study was to evaluate genotype x environment interactions (GEIs) and grain yield stability in multi-environmental trials across wide ecological locations. The trial was laid out in the randomized complete block design with three replications. Combined analysis of variance (ANOVA) and various statistical models that simultaneously combine high yield and stability of performance were applied for evaluation of the effect of GEI, genotype classifications and stability. The ANOVA showed highly significant ($p < 0.01$) grain yield difference among the varieties, environments and variety x environment interactions for grain yield. Atendaba and Roba-1 were found to be widely adaptable and high yielding varieties with mean grain yield levels of 3,109 and 2,382 kg ha^{-1}, respectively. Hence, they are recommended for further use within the northwest region of the country.

Key words: Genotype by environment interactions, grain yield, haricot bean, stability.

INTRODUCTION

Haricot bean (*Phaseolus vulgaris* L.) (2n = 22) is one of the most important and widely cultivated species of Phaseolus in Ethiopia. It plays an important role in human nutrition and market economies of some rural and urban areas of the country. It is widely grown by smallholder farmers and mainly concentrated in the areas of the central rift valley of the country. The other parts of the country also account for a reasonable share for haricot bean production (CSA, 2009). Nevertheless, the production of haricot bean was limited in northwest Ethiopia. As a result, limited efforts were made to promote improved technologies on the crop in this part. Currently, haricot bean is widely cultivated in the region with different cropping systems; sole, intercropping, and double cropping. However, the productivity of the crop is low due to lack of high yielding varieties adapted to diverse agroecological conditions and adaptation of better agronomic practices. The national bean improvement programme has released several improved varieties that can meet local consumption and export purposes. The performance of these varieties has not been evaluated under northwest conditions of Ethiopia.

The differential response of genotypes to changing environmental conditions is known as genotype x environment interaction (GEI). Differential responses of crop varieties to variable environmental conditions limit accurate yield estimates and identification of high yielding stable ones. In order to identify stable genotypes, the GEI can be evaluated using stability statistics that are assignable to each genotype evaluated across a range of environments (Fernandez, 1991). According to Baker (1988) GEI can be defined as the difference between the phenotypic value and the value expected from the

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corresponding genotypic and environmental values. Heinrich et al. (1983) indicated that yield stability of a variety is the ability of a genotype to avoid substantial fluctuations in yield over a range of environments. Stability indices have allowed researchers to identify widely adapted varieties to use in breeding programmes and helped to recommend well-buffered varieties for various agroecological zones (Fufa et al., 2000; Yayeh and Bosland, 2000).

Analysis of variance (ANOVA) procedure is useful for estimating the existence and magnitude of GEI. However, variance components alone do not provide satisfactory explanation of GEI (Domitruk et al., 2001). To this effect, several stability measures were developed by different authors as selection and evaluation criteria. A regression model which was proposed by Eberhart and Russell (1966) is commonly used for interpreting the GEI. The method is based on the regression coefficient and mean square deviation from linear regression and can be used to determine the stability of genotype. The genotype is stable if the regression coefficient is close one and the mean square deviation is close to zero. In the regression method, variety performance and environmental factors were assumed having a strong linear relationship (McLaren and Chaudhary, 1998). Besides, a number of other statistical models were developed and are being used to assist interpretation of GEIs. Finlay and Wilkinson (1963) stated that the regression coefficient of varietal means on environmental means could be used as an indicator for phenotypic stability. Gauch (1992) also proposed the additive main effects and multiplicative interaction (AMMI) model for interpreting the genotype and environment interaction. The AMMI consists of two models, that is, the additive model (the overall mean, genotype mean, and environmental mean), and the multiplicative model (the genotype and environment interaction). The AMMI model does not need an assumption that there is a strong linear relationship between variety performance and environmental factors (McLaren and Chaudhary, 1998). The study was undertaken to evaluate the stability and adaptability of commercial haricot bean varieties in the northwest Ethiopia by using different statistical models.

MATERIALS AND METHODS

The study was conducted for two successive years (2000 to 2001 and 2001 to 2002) at three locations: Fenote Selam, Zema and Addis Zemen. These sites represented the different haricot bean growing ecologies of the northwest part of the country. Seven haricot bean varieties (Melkie, Mexican-142, Atendaba, Awash-1, Besh Besh, Brown Speckled and Roba-1), released for central and southern parts of the country, were used in the present study. Planting of the varieties was done in early June using Randomized Complete Block Design with three replications at each site under rain fed conditions. Each variety was planted in six rows of 6 m row length and the central four competitive rows were harvested for grain yield measurement. A spacing of 60 cm between plots and 40 cm between rows were used in a plot size of 14.4 m^{-2}. The seeding rate was 80 kg ha^{-1}. The recommended fertilizers were manually incorporated into the soil at planting.

Statistical analysis

Analysis of variance (ANOVA) was conducted for each location to assess variation within varieties. Data were also subjected to combined analysis of variance to test the presence of GEIs. Test of homogeneity of the error variance for combined analysis was carried out by using quick test method – by taking the ratio of the largest mean square error to the smallest mean square error in each location as suggested by Gomez and Gomez (1984). Linear regression coefficient (b), deviation from the regression (s^2d), coefficient of determination (R^2) and mean grain yield were used to estimate the stability of each variety by using Agrobase software (Agrobase, 2001). Besides, regression model (Eberhart and Russell, 1966), cultivar performance measure (Lin and Binns, 1988), ecovalence (Wricke, 1962; Wricke, 1966), stability variance (Shukla, 1972), and rank variance (S1) and difference (S2) (Nassar and Huhn, 1987) and additive main effects and multiplicative interaction (AMMI) (Gauch, 1992) models were used for the present study.

Regression model

Eberhart and Russel (1966) developed a regression model of stability. The model proposed that the regression of each variety on a given environmental condition and a function of the squared deviations from regression would provide more useful estimates of yield stability parameters. It was used to calculate the regression coefficient (b_i), deviation from regression (Sd_i^2) and coefficient of determination (R_i^2).

Cultivar performance measure

According to superiority measure of Lin and Binns (1988) the distance mean square between the cultivar's response and the maximum response over locations were the major parameters in identifying more superior cultivars. The smaller the mean square the more superior the new cultivar is. The cultivar performance measure was estimated based on the following formula:

$$P_i = \sum_{j=1}^{q} \frac{(X_{ij} - M_j)^2}{2q}$$

Where P_i is the superiority measure, X_{ij} is the yield of the *i*th genotype grown in the *j*th location; M_j is the maximum yield in the *j*th location.

Wricke's ecovalence

Ecovalence (W_i^2) model suggested by Wricke (1962, 1966) was used to measure the contribution of a given genotype in the GEI. The model was calculated by

$$\sum_{j=1}^{q} (X_{ij} - X_{i.} - X_{.j} - X_{..})^2$$

Where X_{ij} is the mean yield of the *i* genotype in the *j* environment, $X_{i.}$ is the mean of the genotype *i* in all environments, $X_{.j}$ is the mean

Table 1. Mean grain yield (kg ha^{-1}) of seven haricot bean varieties tested at six environments.

Variety	Environments[ǂ]						
	FS00/01	ZM00/01	AZ00/01	FS01/02	ZM01/02	AZ01/02	Mean
Melkie	2,695	457	522	2,412	1,449	1,454	1,498
Mexican-142	1,179	1,768	1,149	1,483	1,440	3,385	1,734
Atendaba	3,772	3,097	1,366	2,951	2,733	4,737	3,109
Awash-1	2,756	1,197	719	929	1,325	2,626	1,592
Besh Besh	2,698	1,508	921	1,077	1,949	3,861	2,003
Brown peckled	1,915	736	674	2,683	1,987	2,082	1,680
Roba-1	2,930	2,050	917	1,918	2,243	4,235	2,382
Mean	2,563	1,545	895	1,922	1,875	3,197	1,999

[ǂ]FS00/01= Fenote Selam in 2000/01; ZM00/01= Zema in 2000/01; AZ00/01= Addis Zemen in 2000/01; FS01/02= Fenote Selam in 2001/02; ZM01/02= Zema in 2001/02; AZ01/02= Addis Zemen in 2001/02.

of all genotypes in j environments and $X_{..}$ is the mean of all genotypes in all environments.

Stability variance

According to the stability variance of Shukla (1972) the stability statistic is calculated in the following formula:

$$\sigma_i^2 = \frac{g}{2(g-1)(e-1)}\sum_{j=1}^{q}(X_{ij} - X_{i.} - X_{.j} + X_{..})^2 + (\frac{SS(GXE)}{2(g-1)(e-1)})$$

Where σ_i^2 is the stability variance; X_{ij} is the mean yield of the i genotype in the j environment; $X_{i.}$ is the mean of genotype i in all environments; $X_{.j}$ is the mean of all genotypes in j environment; and X is the overall mean of genotypes in all environments.

Additive main effects and multiplicative interaction (AMMI)

The AMMI model was used to evaluate the significance and magnitude of GEI effect on grain yield and determine the best performing varieties (Gauch, 1992). It utilizes the standard two ANOVA and principal component analysis (PCA) to identify any pattern in the data. The AMMI model is:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \sum_N \lambda_n \gamma_{in} \delta_{jn} + \rho_{ij} \varepsilon_{ijk}$$

Where Y_{ij} is the observed mean yield of genotype i in environment j, μ is the grand mean, α_i is the genotype main effect, β_j is the environment main effect, λ_n is the eigen value of the interaction PCA (IPCA), n, γ_{in} and δ_{jn} are the genotype and environment scores for the IPCA axis, n, ρ_{ij} is the interaction residual, N is the number of IPCA retained in the model, and ε_{ijk} is the random error term.

RESULTS AND DISCUSSION

Analysis of variance

A separate ANOVA was computed for each location and the mean grain yield of the varieties is presented in Table 1. The highest mean grain yield of 4,737 kg ha^{-1} was recorded from Atendaba at Addis Zemen in 2001/02 and the least (457 kg ha^{-1}) from Melkie at Zema in 2000/ 2001. On average, the highest (3,197 kg ha^{-1}) and the lowest (895 kg ha^{-1}) environment mean grain yield were observed at Addis Zemen in 2001/02 and 2000/01, respectively. The mean grain yield of varieties across environments ranged from 1,498 kg ha^{-1} for Melkie to 3,109 kg ha^{-1} for Atendaba with the grand mean grain yield of 1,999 kg ha^{-1}. Atendaba was the top ranking variety in all environments. Combined ANOVA was conducted to determine the effect of the genotype, environment and their interaction on grain yield of the seven haricot bean varieties (Tables 2 and 3). There was significant ($p < 0.01$) GEI indicating the differential response of the tested varieties to change in environments. Similarly, the interaction of genotypes by locations was highly significant for grain yield and showed the relative response of the varieties grown at each location was different. The genotype effects also were significant ($p < 0.01$).

Regression model

Regression coefficient (b), deviation from regression (S^2d) and coefficient of determination (R^2) values of the seven tested varieties are presented in Table 4. Regression coefficient values of the varieties ranged between 0.637 for Brown Speckled and 1.3597 for Roba-1. The highest yielding varieties (Atendaba, Roba-1 and Besh Besh) had the regression coefficient values of above unity ($b > 1.0$) indicating their responsiveness to more favorable environments. On the other hand, varieties such as Melkie, Mexican-142 and Brown speckled had mean grain yield below the overall mean grain yield and had the regression coefficient values below unity ($b < 1.0$) showing their adaptation to poor environmental conditions. The variety Awash-1 had a regression coefficient value close to unity ($b = 1.0$) would have an average adaptation with all environments.

Table 2. Results of combined analysis of variance of grain yield of seven haricot bean varieties tested in six environments.

Source of variation	df	Mean square	F-value
Genotype (G)	6	6095875.10	15.99**
Year (Y)	1	13646711.98	35.79**
Location (L)	2	3393652.89	8.90**
GY	6	542267.97	1.42
GL	12	1170110.28	3.07**
GYL	12	1431722.92	3.75**
Rep/YL	12	1004529.68	2.63**
Error	72	381349.05	
Total	125		

Coefficient of variation (CV) = 30.91%. ** = Significant at 0.01 probability level.

Table 3. Stability analysis for grain yield in seven haricot bean genotypes tested in six environments.

Source of variation	df	Mean square
Genotype (G)	6	1968740.39**
Environment (E) + G x E	35	961094.92
E (Linear)	1	
G x E (Linear)	6	347312.77
Pooled deviations	28	327106.52
Residual	84	156250.29
Total	125	

** = Significant at 0.01 probability level. Grand mean = 19.99 qt/ha. R^2 = 0.73.

Atendaba and Roba-1 had low deviation from regression and their coefficients of determination (R^2) were 92 and 95%, respectively. The rest of five varieties showed high deviation from regression with R^2 values between 32 to 85%. Hence, they are considered as unstable varieties.

Cultivar performance measure

The measure of cultivar general superiority for cultivar x location data is defined as the distance mean square between the cultivar's response and the maximum response averaged over locations. The estimated values for the cultivar performance measure are given in Table 5. Varieties with the lowest P_i values are considered the most stable. Accordingly, the cultivar performance measure of the tested varieties showed that Atendaba had the smallest value and was the most stable variety, whereas Melkie was the least stable one.

Ecovalence (Wrick's approach)

This method suggests that the genotype with lower ecovalence values had greater contribution to total GE sums of square (SS). On the other hand, the lower the ecovalence value of a variety, the smaller its fluctuations from the experimental mean under different environments and thus it has a smaller share in the interactions SS. The variety with the least ecovalence may be considered as more stable and the variety with a high ecovalence has poor stability. According to this method Roba-1, Awash-1 and Atendaba were the most stable varieties (Table 5).

Stability variance – No covariate (Shukla's approach)

In this method, the values are estimates of a variety's variance across environments. According to this method varieties with lowest σ_i^2 values are considered more stable. Hence, Roba-1, Awash-1 and Atendaba were the most stable varieties. Varieties such as Melkie, Brown speckled and Mexican-142 had relatively higher values indicating lower stability (Table 5). These types of measures are useful to breeders and agronomists because they can pinpoint contributions of individual genotypes in a test to total GEI (Danyali et al., 2012).

Table 4. Stability statistics of the seven haricot bean varieties tested in six environments.

Varieties	Regression coefficient (b)	Deviation from regression (s^2d)	Coefficient of determination (R^2)%
Melkie	0.6589	0.478	32
Mexican-142	0.7345	0.375	49
Atendaba	1.3477	0.194	92
Awash-1	0.9761	0.251	79
Besh Besh	1.2861	0.268	85
Brown speckled	0.6370	0.388	40
Roba-1	1.3597	0.156	95

Table 5. Cultivar superiority measure, ecovalence, stability-variance (no covariate and location mean as covariate), and rank variance (S1) and rank difference (S2) for seven haricot bean varieties tested in six environments.

Variety	Cultivar superiority measure	Ecovalence	Stability variance		S1	S2
			No covariate	Location mean as covariate		
Melkie	1796899	3291555	2540049	2836361	3.067	5.899
Mexican-142	1182722	2025798	1476813	1661241	3.067	5.222
Atendaba	0	868772	504911	277052	2.467	3.583
Awash-1	1299214	807005	453027	616467	2.000	2.333
Besh Besh	730620	1179487	765912	734529	2.533	3.667
Brown speckled	1431743	2344995	1741938	1790551	2.800	5.000
Roba-1	297100	725224	384348	97906	1.800	1.806

Stability variance with location mean as covariate

Stability analysis was also done using mean of each environment as covariate for better comparison among different varieties across environments. According to this method varieties with lowest values of stability variance with location mean as covariate are considered as the most stable varieties. Therefore, Roba-1 was the most stable variety, whereas Melkie, Brown speckled and Mexican-142 had showed the highest values implying their unstable performance across the testing environments (Table 5).

Rank variance (S1) and difference (S2)

This is a non-parametric test and is based on the ranks of genotypes across environments giving equal weight to each location or environment. The varieties with fewer changes in rank are considered more stable. S1 estimates are the variances of the ranks for each genotype across environments and S2 estimates are the means of the absolute rank differences of each genotype across environments. In both estimates, smaller values indicate greater stability of a variety compared to the average stability. Accordingly, varieties Roba-1 and Awash-1 were the most stable varieties, whereas Melkie and Mexican-142 were the least stable ones (Table 5).

Additive main effects and multiplicative interaction (AMMI) analysis

This model has been regarded as a powerful analytical tool while dealing with large GEI data sets (Gauch, 1992). AMMI model provided the relative magnitude and importance of the effects of GEI and its interaction terms related with genotype and environmental effects. The model suggests that a genotype with IPCA (interaction principal component analysis) value close to zero shows general adaptation to the tested environments. A large genotypic IPCA score reflects more specific adaptation to environments with IPCA scores of the same sign. Table 6 showed that there were highly significant variation ($p < 0.01$) among genotypes, environments, genotype x environment interactions and IPCA1 and significant variation ($p < 0.05$) for IPCA2. IPCA1 and IPCA2 explained 65.42 and 22% of the GEI sum of squares, respectively. The varieties Melkie and Brown Speckled showed the highest IPCA1 scores indicating that these genotypes are sensitive to changes in environments (Figure 1). On the other hand, Awash-1 had the lowest

Table 6. ANOVA of AMMI for grain yield of seven haricot bean varieties across six environments.

Source of variation	df	SS	MS	F value	Explained % of GEI
Total	125	175727366.3			
Replications (E)	12	11827054.2	985587.8		
Environments (E)	5	67186389.4	13437277.9	13.63**	
Genotypes (G)	6	35437326.9	5906221.2	5.25**	
GEI	30	33728577.2	1124285.9	2.94**	
IPCA1	10	22065592.0	2206559.2	5.77**	65.42
IPCA2	8	7419778.8	927472.4	2.42*	22.00
IPCA3	6	2954818.4	492469.7	1.29^{ns}	8.76
IPCA4	4	1225785.6	306446.4	0.80^{ns}	3.63
IPCA5	2	62602.4	31301.2	0.08^{ns}	0.19
Residual	72	27548018.6	382611.4		

CV=30.93; R^2= 0.84. **,* Significant at the 0.01 and 0.05 probability levels, respectively; ^{ns}= non significant; df= degree of freedom; SS= sum of square; MS= mean sum of square; CV= coefficient of variation; R^2= coefficient of determination.

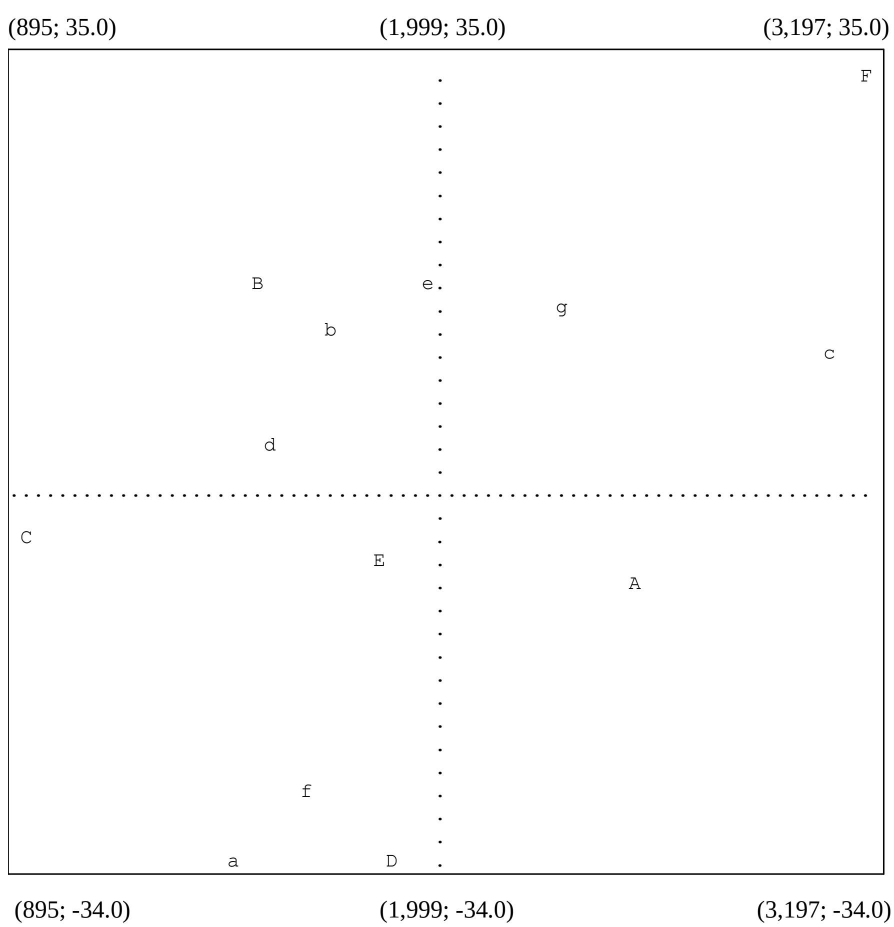

Figure 1. Biplot with abscissa (x-axis) plotting mean grain yield from 895 kg ha^{-1} to 3,197 kg ha^{-1} and with ordinate (Y-axis) plotting IPCA1 scores from -34.0 to 35.0; Genotypes plotted as a, b, c, ... and environments as A, B, C... arieties: a = Melkie, b = Mexican-142, c = Atendaba, d = Awash-1, e = Besh Besh, f = Brown Speckled, and g = Roba-1; Environments: A= FS00/01, B = ZM00/01, C = AZ00/01, D = FS01/02, E = ZM01/02, and F = AZ01/02.

IPCA1 score but below average grain yield. The varieties Atendaba and Roba-1 had mean grain yield above general mean grain yield and relatively lower IPCA1 scores revealing that they are widely adaptable and stable varieties especially in relatively favorable environments.

Conclusion

Results of all tested statistical models in this study had identified Atendaba and Roba-1 as the two best performing and stable varieties. Therefore, it is reasonable to recommend these varieties for further production in the region. Moreover, results recommend the importance of using different statistical models in evaluating the performance of varieties across environments.

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