Association of Stability Parameters and Yield Stability of Sesame (*Sesamum indicum* L.) Genotypes in Western Ethiopia

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Abstract:Information on phenotypic stability is useful for the selection of crop varieties as well as for designing appropriate breeding strategies. The present study was designed to determine the stability of sesame genotypes for seed yield and to elucidate interrelationships among the stability parameters and their associations with mean seed yield. Ten sesame genotypes were tested in four locations in 2011 and 2012 crop seasons using a randomized block design, with three replications. Nine statistical methods were used to determine seed yield stability of the sesame genotypes. The results of the various statistical analyses showed significant variations in seed yield due to genotype, location, and genotype x location interaction. Mean and cultivar superiority performance (Pi) showed high correlation with yield. Cultivar superiority measure (Pi) was significantly associated with S1 and S2. The positive correlation between Wricke and Shukla was perfect and the two procedures are equivalent for ranking purposes. Hence, either Wricke or Shukla can be used. Nassar & Hühn's absolute rank difference (S1) and variance of ranks (S2) were correlated positively and highly significantly ($r = 0.99^{**}$), hence either of them can be used. The correlations among the stability parameters S^2di, Wi, σ^2_i, ASV, S1 and S2 were positive and significant. Two genotypes, viz., EW002 and BG006, have been identified as stable with high mean seed yield and could be recommended for western Ethiopia. It could be concluded that both seed yield and stability should be considered simultaneously to exploit the useful effect of G x E interaction and using non-parametric stability measurements as an alternative to parametric stability measurements is important.

Keywords: Genotype; G x E Interaction; Sesame; Stability; Yield

1. Introduction

Sesame (*Sesamum indicums* L.) is an important oilseed crop grown for local consumption and export in Ethiopia, and it ranks first in area of production and as export crop among oilseed crops grown in the country (CSA, 2015). Ethiopia is among the world's top five producers of sesame and the third largest world exporter of the crop (Wijnands *et al*., 2011). Sesame production is increasing from year to year, which is mainly driven by increasingly high export market demand and availability of suitable agro-ecologies (Zerihun, 2012).

The national average seed yield of sesame in Ethiopia is 0.73 tons ha^{-1} (CSA, 2014), which is very low as compared to the productivity of sesame in such counties like China (1.3 tons ha^{-1}) (FAOSTAT, 2013). This low productivity of sesame is attributed to limited number of adaptable varieties with tolerance to biotic (e.g. bacterial blight) and abiotic factors (Dagnachew *et al*., 2011; Zerihun, 2012). Given the fact that western Ethiopia is one of the potential areas for sesame production (FAO, 2015), the demand for adaptable improved varieties of the crop is very high. All the nationally released varieties of sesame were evaluated for yield performance in western Ethiopia in 2004; however, all were out yielded by a local variety (Dagnachew *et al*., 2011).

For this reason, sesame breeding for western part of Ethiopia was started in 2005 at Bako Agricultural Research Center of the Oromia Agricultural Research Institute. To date, three varieties have been released and some elite breeding lines have been selected for the target agro-ecology. However, the genotypes have been selected based on their mean seed yield per hectare, with little or no reference to the stability of genotypes for seed yield across environments. Information on genotype by environmental interaction and stability is required as a basis for a sound breeding program to serve as a decision tool in releasing improved varieties and deciding the adaptation domain of such varieties (Yan, 2011). Past studies (Zenebe and Hussein, 2009; Hagos and Fetien, 2011; Fiseha *et al*., 2014; Mekonnen *et al.,* 2015) on genotype by environment interaction of sesame have not included western Ethiopia, where biotic factors such as bacterial blight exacerbates genotype by environment interaction and limit stability of varietal performance across different environments. Another issue is the presence of several parametric and non-parametric models for the statistical methods of stability analysis and absence of single method that can adequately explain stability of genotype performance across target environments (Kilic *et al*., 2010). The importance of comparing several models of stability analysis have been reported in Ethiopia for other

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oilseed crops like Ethiopian mustard (Kassa, 2002; Tsige, 2002), linseed (Adugna and Labuschagne, 2002; Adane, 2008), soybean (Fekadu *et al.*, 2009), linseed and niger seed varieties (Abeya *et al.*, 2014).

The present study, therefore, was designed with the objectives (1) to analyze the stability of sesame genotypes for seed yield across target environments in western Ethiopia, and (2) to study the interrelationships among the stability parameters and their associations with mean seed yield.

2. Materials and Methods

2.1. Plant Materials

The experimental materials for the present study comprised of two released varieties viz., Obsa and Dicho, seven elite breeding lines and a local check, Wama (Table 1). These genotypes were selected among the different landraces collected from Western Ethiopia based on their relative yield performance and disease resistance by Bako Agricultural Research Center. The local check was mostly grown by farmers in the Wama Valley. All the test genotypes are white seeded, having high market demand.

Table 1. List of genotypes used for the study and their silent feature.

No.	Genotype	Collection zone	Altitude (masl)	DM	PH	BP	CPP	YPP	BB
1	EW002	East Wellega	1470	124	140	9	143	17	R
2	BG006	Benshangul-Gumuz	1000	123	138	7	141	16	R
3	EW023- 2	East Wellega	1580	125	142	5	109	12	MR
4	EW003-1	Horo-GuduruWellega	1400	122	145	7	141	17	R
5	EW0011-4	East Wellega	1384	124	140	8	124	14	R
6	EW008-1	East Wellega	1402	121	137	7	138	16	MS
7	EW011-2	East Wellega	1342	124	139	7	144	16	R
8	Obsa	Horo-GuduruWellega	1395	119	135	7	125	14	R
9	Dicho	East Wellega	1460	120	140	8	130	16	MR
10	Wama	East Wellega	1430	121	137	6	131	15	MR

R = resistant, MR = moderately resistant, MS = moderately susceptible.

2.2. Experimental Sites and Experimental Procedures

The ten sesame genotypes were grown in four locations in 2011 and 2012 crop seasons (Table 2). The locations represent major sesame growing agro-ecologies for sesame production in western Ethiopia. The two locations namely Angar and Uke are found in the Angar and Didessa Valley, about 50 km apart from each other. Wama is found in the valley of Wama, while Bako is found in the Gibe basin. The four locations are also used as a testing site for sesame breeding by Bako Agricultural Research Center.

The genotypes were planted in the mid June each year at each location in randomized complete block design, with three replications. The seeds were drilled in each row at seeding rate of 5 kg ha^{-1} in plot consisting of 6 rows with spacing of 40 cm. A fertilizer rate of 46 kg N ha^{-1} was applied at planting. Twenty days after planting, thinning was done to 10 cm spacing between plants. Four times hand weeding was done at two weeks interval, starting fifteen days after planting. The genotypes were harvested on the second week of October each year. Seed yield per plot of the middle four rows were taken and used to estimate and report yield kg ha^{-1}.

Table 2.Description of experimental sites.

No	Location	Latitude	Longitude	Altitude m.a.s.l.
1	Angar	09^0 32’ N	036^0 37’ E	1355
2	Uke	09^0 22’N	036^0 31’E	1383
3	Wama	08^0 58’N	036^0 48’ E	1436
4	Bako	09^0 04’ N	037^0 02’E	1597

2.3. Statistical Analysis

Bartlett’s test (Steel and Torrie, 1980) indicated heterogeneity of error variance for seed yield in each of four locations for two years and then the data was log transformed to proceed further for pooled analysis. Analysis of variance was conducted using Eberhart and Russell (1966) and Additive Main effects and Multiplicative Interaction (AMMI) (Zobel *et al.*, 1988) to test the presence of significant influence of genotype x environment interaction on seed yield of sesame genotypes. The AMMI analysis was performed using Genestat 15th Edition.

The statistical models used to estimate various stability parameters were Joint linear regression model (bi) and (S^2di) (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966), Wricke’secovalence (Wi) (Wricke, 1962), Shukla’s stability variance (σ^2) (Shukla, 1972), Lin and Binns cultivar superiority measure (Pi), (Lin and Binns, 1988) and Nassar and Hühn’s non-parametric measure of stability (Nassar and Huhn, 1987). For these stability measures statistical analyses were conducted using Agrobase Generation II (Agromix, 2008). In addition, the AMMI Stability Value

(ASV) was also used. It was computed as proposed by Purchase (1997) as follows:

AMMI Stability Value (ASV)

$$(\mathrm{ASV}) = \sqrt{\left[\frac{\mathrm{SSIPCA\ 1}}{\mathrm{SSIPC\ 2}}\mathrm{IPCA1score}\right]^2 + (\mathrm{IPCA2\ score})^2}$$

Where SS = sum of squares, IPCA1= Interaction principal component analysis axis one, IPCA2 = Interaction principal component analysis axis two. Spearman's coefficient of rank correlation was computed for each pair of the possible pair-wise comparison of the stability parameters by SAS 2002 statistical software.

3. Results

3.1. Analysis of Variance

The analysis of variance for the regression model for sesame seed is presented in Table 3. The results show that the variations among the genotypes and for G x E interaction (GEI) were significant. Further decomposition of the sum of squares due to environments and genotype x environment into environments (linear), genotype x environment (linear) and the pooled deviations from the regression model revealed that environment (linear) and pooled deviation were highly significant for seed yield; but G x E (linear) was non-significant.

Table 3. Analysis of variance from Eberhart and Russel's Model for seed yield of 10 sesame genotypes tested in eight environments in western Ethiopia.

Source of variation	DF	SS	MS
Genotypes	9	0.330	0.037**
Environment + (Geno x Env.)	70	1.701	0.024*
Environment (linear)	1	0.785	0.785**
Genotypes x Env. (linear)	9	0.180	0.020ns
Pooled deviation	60	0.736	0.012**
EW002	6	0.024	0.004
BG006	6	0.027	0.005*
EW023- 2	6	0.079	0.013**
EW003-1	6	0.132	0.022**
EW0011-4	6	0.028	0.005*
EW008-1	6	0.143	0.024**
EW011-2	6	0.140	0.023**
Obsa	6	0.055	0.009**
Dicho	6	0.058	0.010**
Wama	6	0.049	0.008**
Pooled error	160	0.247	0.002

, and ns, significant at $P < 0.05$, $P < 0.01$ and non significant, respectively. DF = degree of freedom, SS = sum of squares, MS = sum of squares, Geno x Env = genotype by environment interaction, Genotypes x Env. (Linear) = genotypes by environment interaction linear.*

The mean squares from AMMI analysis of variance indicated significant variations among the genotypes, the environments and their interaction for seed yield (Table 4). The GEI is highly significant (P<0.01), accounting for 47% of the sum of squares (nearly twice that of the genotypes). The GEI was partitioned into two interaction principal component axes (IPCA). The IPCA 1 score was highly significant, explaining 60.78% of the variability due to GEI. The IPCA 2 was significant, accounting for 26.16 % of the variability. As indicated by Sarwar*et al.* (2010), the highly significant differences in GEI under different models strongly justified the need for stability analysis.

Table 4. AMMI analysis of variance for seed yield of 10 sesame genotypes tested in eight environments in western Ethiopia in 2011 and 2012.

Sources of variation	DF	Sum of squares	Mean squares	Sum of square Explained % Total	% G x E
Treatment	39	3.525	0.090***		
Genotype	9	0.892	0.099***	25.00	
Environment	3	0.983	0.327***	28.00	
Rep within E	8	0.082	0.010ns		
G x E	27	1.655	0.061***	47.00	
IPCA 1	11	1.006	0.097***		60.78
IPCA 2	9	0.433	0.048***		26.16
Residuals	7	0.151	0.021		
Error	192	3.138	0.016		
Total	239	6.745	0.028		

****, significant at P = 0.001. DF = degree of freedom, Rep within E = replication within environments, G x E = genotype by environment interaction, IPCA 1 and IPCA 2 = interaction principal component axis one and two, respectively.*

3.2. Stability Analyses

The overall ranking and values of the ten sesame genotypes for stability are presented in Table 5. Based on cultivar superiority performance (Pi), S^2di, S1 and S2 genotype EW002 was found to be the most stable genotype with best mean seed yield. Genotype BG006 was ranked the 2nd stable genotype by bi, S^2di, Wi and σ^2i, although ranking third in terms of its mean seed yield. This same genotype ranked the first stable one by ASV. Genotype EW011-4 was ranked first according to bi, wi, $\boldsymbol{\sigma}^2i$ and ranked as the second stable genotypes by S1, S2 and ASV. However, this genotype was associated with low mean seed yield. Genotype EW023-2 was the most unstable genotype for its seed yield with low mean seed yield followed by genotype EW011-2.

Table 5. Mean yield (kg ha-1), various stability measurements and their ranking order of 10 sesame genotypes evaluated in western Ethiopia in 2011 and 2012.

Genotype	Mean	R	Pi	R	Bi	R	S^2di	R	(Wi)	R	(σ^2_i)	R	S(1)	R	S(2)	R	ASV	R
EW002	881	1	0.010	1	1.57	8	0.003	1	0.045	3	0.021	3	2.107	1	3.109	1	0.27	3
BG006	750	3	0.011	3	0.90	2	0.003	2	0.029	2	0.010	2	3.179	4	6.109	4	0.09	1
EW023 -2	556	10	0.045	10	0.48	6	0.012	7	0.101	6	0.049	6	4.357	10	12.438	10	0.47	8
EW003-1	735	4	0.020	4	0.43	7	0.021	8	0.157	10	0.079	10	3.357	5	6.938	5	0.47	7
EW0011-4	608	9	0.032	7	0.91	1	0.003	3	0.028	1	0.010	1	2.893	2	5.234	2	0.17	2
EW008-1	625	8	0.038	8	0.71	3	0.022	10	o.150	8	0.075	8	4.071	8	10.000	7	0.46	6
EW011-2	710	5	0.030	6	1.36	4	0.022	9	0.150	9	0.075	9	4.214	9	11.000	9	0.65	10
Obsa	846	2	0.011	2	0.42	9	0.008	5	0.081	5	0.038	5	3.179	3	6.109	3	0.40	5
Dicho	704	6	0.028	5	1.38	5	0.008	6	0.070	4	0.032	4	4.036	6	9.984	6	0.33	4
Wama	645	7	0.038	9	1.82	10	0.007	4	0.102	7	0.049	7	4.036	7	10.109	8	0.52	9

Note: R = rank; Pi = Linn and Binn's (1988) cultivar superiority measures; bi = regression coefficient; S2di = Eberhart& Russell's (1966) deviation from regression parameter; Wi = Wricke's (1962) ecovalence; (σ2i) = Shukla's (1972) stability variance with no covariates; (S1) and (S2) Nassar and Hühn's (1987) absolute rank difference; ASV = AMMI absolute value.

3.3. Correlation of Stability Parameters

Spearman's coefficient of rank correlation between seed yield and the stability parameters as well as between each of the parameters is presented in Table 6. Mean seed yield and Pi were highly significantly correlated (r = 0.94**). Mean seed yield was generally quite poorly correlated with the rest of the parameters. Cultivar superiority measure (Pi) was significantly associated with S1 (r = 0.75**) and S2 (r = 0.75**). This stability measure has also positive non significant association with S^2di, Wi, σ^2i and ASV. Regression coefficient (bi) showed positive non significant rank association with Wi, σ^2_i, S2 and ASV. Eberhart and Russell (1966) deviation from regression showed highly significant correlation with Wi (r = 0.81**), σ^2i (r = 0.81**) and S1 (r = 0.75**) and significant with S2 (r = 0.68*) and ASV (r = 0.67*).

Wricke's procedure of stability statistic showed highly significant and positive association with (σ^2_i) (r = 1.00*) and ASV (r = 0.85**) as well as significant with S1 (r = 0.65*) and S2 (r = 0.64*) Shukla's (1972) highly positively and significantly correlated with ASV (r = 0.85**) and significantly with S2 (r = 0.64*) and S2 (r = 0.64*). Nassar and Hühn's (1987) absolute rank difference (S1) and variance of ranks positive significantly associated with all the stability measures, except with mean seed yield and bi. The correlation of these two stability measures with mean seed yield is positive but not significant. The AMMI stability value was positively associated with all other stability parameters.

Table 6. Rank correlation between stability parameters for 10 sesame genotypes evaluated in western Ethiopia (2011 and 2012).

	Mean	Pi	Bi	S^2di	Wi	σ^2_i	S(1)	S(2)
Mean								
Pi	0.94**							
bi	-0.36	-0.15						
S^2di	0.39	0.45	-0.10					
Wi	0.09	0.30	0.33	0.81**				
σ^2_i	0.09	0.30	0.33	0.81**	1.00**			
S(1)	0.58	0.75**	-0.03	0.75**	0.65*	0.64**		
S(2)	0.58	0.75**	0.05	0.68*	0.64*	0.64*	0.99**	
ASV	0.30	0.53	0.43	0.67*	0.85**	0.85**	0.77**	0.81**

** Significant at 0.05 and ** significant 0.01 probability level; Pi = Lin &Binns's (1988) cultivar superiority performance, bi = regression coefficient, S^2di = Eberhart& Russell's (1966) deviation from regression parameter, Wi = Wricke's (1962) ecovalence, (σ^2_i) = Shukla's (1972) stability variance, S1 &2 = Nassar&Hühn's (1987) absolute rank difference and variance of ranks and ASV = AMMI stability value.*

4. Discussion

Data from multi-location trials help researchers to estimate yield stability more accurately and understand the interaction of yield with environments. In present study, seed yield was affected by GEI, accounting for 47% of the total, and it was far greater than that for genotype (25%) and environment (28%), indicating that there were substantial differences in genotypic responses across environments. The significant variation of genotypes and GEI suggests that genotypes exhibited different performance in the four testing locations, which can be due to their different genetic makeup, the variation due to the environments or both. Hagos and Fetien (2011) reported the highest share of sum of squares (73.1%) for environments. Thus, effective interpretation and utilization of a multi-environment trial data set remains a major challenge to researchers in making selection decisions in crop variety evaluation (Mortazavians and Azizi-nia, 2014).

The highly significant linearity for environment implies that the assumption for the differences among the linear response to environment is valid. The non-significance of G x E (linear) effect indicated that the behavior of the genotypes for seed yield is unpredictable over environments. The significance of pooled deviation from regression showed that the presence of non linearity for seed yield. As a result, the performance of different varieties fluctuated significantly from their respective linear path of response to environments.

The use of stability analysis other than the ANOVA and yield ranking would enhance prediction of cultivar choice for a target environment. The stability parameters that have been used in this study quantified the stability of genotypes with respect to mean seed yield, stability and the best combination of them. Both yield and stability of performance should be considered simultaneously to exploit the useful effect of GEI and to make selection of the genotypes more precise and refined (Farshadfar *et al.*, 2012). Most of the stability parameters used in this study were closely related in sorting out the relative stability of the evaluated genotypes. Though, some deviations were also observed.

Study on the association among stability statistics is essential to make any recommendations of a crop variety (Karimzadeh *et al.*, 2013). In the present study, rank correlation of mean seed yield was highly significantly with Pi. The highly significant correlation of mean seed yield with Pi indicates that selection for yield would change yield stability by increasing Pi, leading to the for development of genotypes that are especially adapted to environments with optimal growing conditions. In agreement with this result, Pourdad (2011) also observed strong positive rank correlation of mean seed yield with Pi in safflower. A very serious concern in any breeding program is the possibility of rejecting a potentially useful cultivar whose mean may not be high but that shows good adaptability to a relatively narrow niche of environments, or accepting a cultivar whose mean may be high but that shows considerable variation over certain locations. Lin and Binns (1991) recommended the Pi measure to overcome this negative aspect of stability analysis.

Rank correlation of bi with mean seed yield was negative but no significant. On the other hand, Mekonnen *et al.* (2015) observed significant and positive correlation between mean seed yield and bi. The rank correlation between regression coefficient (bi) and deviation from regression (S^2di) was negative but not significant. This is in harmony with the reports by Mekonnen *et al.* (2015). However, Elfadl *et al.* (2012) for seed yield in sunflower and Mirza *et al.* (2013) for seed yield and branches per plant in sesame reported highly significant correlation of bi with S^2di.

Positive and significant rank correlation of S^2di with Wi, S1, S2 and ASV in the present study implies that S^2di and these parameters could be used independently. Similarly, Mekonnen *et al.* (2015) reported significant rank correlation of S^2di with ASV in sesame for seed yield. In the present study, the correlation between Wi and σ^2i was perfect (r = 1.0**), indicating that the two procedures are equivalent for ranking purposes and either of them can be used. This is in agreement with the results of Schoeman (2003) and Mashayekh *et al.*, (2014), who reported significant and positive association of Wi with σ^2i in sunflower.

The present study showed that Nassar and Hühn's absolute rank difference S1 and variance of ranks S2 were positively correlated (r = 0.99**) with each other, indicating that they were similar for classifying genotypes according to their stability under different environmental conditions. This suggests that the two statistics can be used alternatively to assess stability. Similarly, Balalić *et al.* (2011) reported in sunflower that these two non-parametric measures of stability parameters were nearly perfectly correlated. Mortazavians and Azizi-Nia (2014) also observed significant and positive association of S1 with S2 in canola. The two non-parametric stability measures S1 and S2 were positively significantly correlated with Pi, S^2di, Wi, σ^2i and ASV, suggesting that non-parametric stability measurements seem to be useful alternatives to parametric measurements. In other words, this non-parametric stability measures can complement the parametric stability measures used in this study.

In this study, AMMI stability value (ASV) was highly significantly correlated with Wi, σ^2i, S^2di, S1 and S2. In line with present result, Elfadl *et al.* (2012) also reported significant and positive rank association of ASV with S^2di for seed yield in sunflower. The association among S^2di, Wi, σ^2i, ASV, S1 and S2 was significant, which revealed that the parameters were similar in sorting sesame genotypes for stability. These results demonstrated that ranks of stability for genotype could be determined from any of these methods as they were in agreement and that these parameters can be used as alternatives to one another.

5. Conclusions

In conclusion, this study has emphasized that the effect of GEI was high, accounting to 47% of the total variation for sesame seed yield. The mean seed yield and cultivar superiority performance (Pi) showed significant rank correlation. In turn cultivar superiority measure has also showed significant rank association with S1 and S2. The Wricke and Shukla stability parameters showed perfect correlation, which indicates that either of the two procedures can be used for purposes ranking genotypes. Similarly, Nassar & Hühn's absolute rank difference (S1) and variance of ranks (S2) had near to perfect correlation suggesting that the two parameters can be used alternatively to assess stability. The two non-parametric stability measures (S1 and S2) were significantly and positively rank correlated with Pi, S^2di, Wi, σ2i and ASV. This showed that non-parametric stability measures seem to be useful either to use as alternative or to complement the parametric stability measure. The rank correlation among S^2di, Wi, σ2i, ASV, S1 and S2 being positive and significant, indicated that the parameters were similar in assessing the stability of sesame genotypes. Two genotypes namely EW002 and BG006 were identified as stable genotype with high mean seed yield and recommended for western Ethiopia. The result of this study showed that considering more than one stability parameter is important to recommend stable genotype, with high mean seed yield to exploit the useful effect of GEI. It is also important to use the parametric and non-parametric stability measures jointly since results obtained from the two groups of stability measures can complement each other.

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