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USE OF PARAMETRIC STABILITY STATISTICS TO EVALUATE SOME BARLEY GENOTYPES

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ABSTRACT

The current study aimed at assessing twelve genotypes of barley in a randomized complete blocks design with 3 replications across 8 environments (the combinations of 2 years x 2 locations x 2 sowing dates) during 2008/2009-2009/2010 seasons in Egypt. Significant differences were observed among barley genotypes for heading date, grain filling , number of spike/m^2, spike length , thousand grain weight and grain yield (ardab/fed). Combined analysis of variance of grain yield of twelve genotypes tested in eight environments showed highly significant ($p<0.01$) differences between the genotypes, between environments and for GEI, of all traits under study, suggesting differential response of genotypes across testing environments and the validity of stability analysis. Several biometrical methods are available for analysis of G-E interaction and yield stability. To quantify yield stability, six parametric stability statistics were calculated (b_i, S^2_{di}, R_i^2, W_i^2, S^2i and CV_i). According to the stability parameters, for grain yield of barley genotypes, the results revealed that genotypes Giza 123, Giza 129, Giza 127, G4, G2, G6 and G8 were more stable genotypes for 7, 7, 7, 5, 4, 4 and 4 out of all 7 stability statistics used, respectively. Thus, these genotypes would be considered to be more stable than others for these statistics. This implies therefore that there genotypes are of low contribution to the genotypic by environment interaction. These genotypes may be utilized as donor parents of stability in barley improvement programme, and could be recommended to be as commercial stable high yielding cultivars. Highly significant rank correlations coefficient were found among S^2_{di}, W^2_i and R_i^2 implying their close similarity and effectiveness in detecting stable genotypes and they are equivalent in measuring stability. Hence any one of these parameters could be used to describe genotypes stability. Our results showed that high-yielding genotypes can differ in yield stability, and suggest that yield stability and high grain yield are not mutually exclusive.

Key words: ***Barley, Grain yield, Parametric stability statistics, Genotype by environment interaction, Spearman's rank correlations.***

INTRODUCTION

Barley (*Hordeum distichon* L. and *Hordeum vulgare* L.) has a long history of use as human food and animal feed, of health benefits and malting and brewing in many countries around the world (Malcolmson *et al* 2005).

Barley is the staple food for a large part of the world population. In Egypt, it is grown in 75 479 thousand hectares with an average grain yield of 1.97 ton / ha and total production of 149 238 thousand tons (FAO 2009). This producturty is far below that of most countries of the world like Canada (3.36 ton / ha), Spain (3.25 ton / ha) and Ukraine (3.03 ton/ha) (FAO 2009).

The production of barley can be increased either by bringing more area under cultivation or by increasing yield per unit area. Currently, it is nearly impossible to increase area under barley crop due to competition with other crops and because of restricted supply of irrigation water etc. Therefore, the only alternative left is to increase it's per feddan yield by better crop management techniques and introducing high yielding varieties along with resistance against environmental stresses.

Genotype x environment interactions (GEI) are of major importance because they provide information about the effects of different environments on cultivar performance and play a key role for assessment of performance stability of the breeding materials. Numerous methods have been developed to determine the stability of a genotype. Finlay and Wilkinson (1963) first described stability as the linear relationship of the yield of genotype over many environments given by the regression coefficient (b_i); where a genotype with $b_i = 1$ was considered stable.

Eberhart and Russell (1966) further developed the idea by implementing the regression deviation mean squares (S^2_{di}) as a measure of stability. They recommended that the genotype stability is expressed in terms of three empirical parameters: the mean performance, the slope of regression line (b_i), and the sum of squares of deviation from regression (S^2_{di}). Others indices proposed for measuring response of crop cultivars and stability of production in variable environments included the coefficient of determination, (R^2) (Pinthus 1973). This R^2 measures the proportion of a variety's production variation that is due to linear regression. Wricke (1962) suggested using genotype environment interactions (GEI) for each genotype as a stability measure, which he termed as ecovalance (W^2_i). Francis and Kannenberg (1978) used the environmental variance (S_i^2) and the coefficient of variation (CV_i) of each genotype as stability parameters.

The level of association among adaptability or stability estimates of different models is indicative of whether one or more estimates should be obtained for reliable prediction of cultivar behavior, and also helps the breeder to choose the best adjusted and most informative stability parameter(s) to fit his/her concept of stability (Duarte and Zimmermann 1995).

The objectives of this research were (1) to evaluate yield performance and some yield components of barley genotypes under different environments, (2) to measure the genotype-environment interaction in barley genotypes, giving emphasis to grain yields, (3) to study the adaptation of genotypes of barley using six parametric stability statistics and (4) to estimate rank correlations among some parametric stability statistics and mean grain yield across all studied environments.

MATERIALS AND METHODS

Plant materials

The experimental materials for the study consisted of 12 barley genotypes of different geographic origin and type (two rowed and six rowed). These genotypes involved three Egyptian cultivars (*Hordeum vulgare* L.) namely, (Giza 127, 123, 129); and nine exotic germplasm (*Hordeum distichon* L.) (G1, G2, G3, G4, G5, G6, G7, G8 and G9) introduced from Germany and Turkey. Names and genotypes/cultivars code numbers of barley genotypes are given in Table 1.

Table 1. Origin and type of barley genotypes used in this study.

No.	Code No. or name	Origin	Type	No.	Code No. or name	Origin	Type
1	**G1**	**Germany**	**2 -rowed**	**7**	**G7**	**Germany**	**2 -rowed**
2	**G2**	**Germany**	**2 -rowed**	**8**	**G8**	**Germany**	**2 -rowed**
3	**G3**	**Germany**	**2 -rowed**	**9**	**G9**	**Turkey**	**2 -rowed**
4	**G4**	**Germany**	**2 -rowed**	**10**	**Giza 127**	**Egypt**	**2 -rowed**
5	**G5**	**Germany**	**2 -rowed**	**11**	**Giza 123**	**Egypt**	**6 -rowed**
6	**G6**	**Germany**	**2 -rowed**	**12**	**Giza 129**	**Egypt**	**6 -rowed**

Experimental procedures and field conditions

This research was carried out on 12 barley genotypes consisting of 3 local cultivars and 9 introduced genotypes in a randomized complete block design with four replications in 2008–2009 and 2009–2010 growing seasons. The twelve barley genotypes were sown in two dates (December 22 and January 6) during both seasons.

In both seasons, two locations were in cluded; one of them in the old land at the Experimental Station, Faculty of Agriculture, Cairo University, Giza Governorate, whereas the other location was in the new reclaimed land at the Agricultural Experiment Desert Station, Faculty of Agriculture, Cairo University in Wadi El-Natroon, El-Beheira Governorate (Tables 2 and 3) show the growing seasons, sites, soil properties, some geographical and meteorological data of the experimental locations.

In each of the eight environments (the combinations of 2 years x 2 locations x 2 sowing dates) each genotype was planted in a randomized complete blocks design (RCBD) with three replications. Sowing was done by hand in plots of 5 rows, each of 3 m long and spaced 20 and 5 cm between rows and plants in the some row, respectively. Individual plot size

Table 2. Some information on experiments, growing seasons, sites and soil properties for environments where the experiments were conducted.

Code	Growing season	Site	Sowing date	Soil Properties
E1	2008/2009	Giza	22.12.2008	PH= 7.70, Clay Loam
E2	2008/2009	Giza	6.1.2009	
E3	2008/2009	Wadi El-Natroon	22.12.2008	PH= 7.85, Sandy
E4	2008/2009	Wadi El-Natroon	6.1.2009	
E5	2009/2010	Giza	22.12.2009	PH= 7.74, Clay Loam
E6	2009/2010	Giza	6.1.2010	
E7	2009/2010	Wadi El-Natroon	22.12.2009	PH= 7.81, Sandy
E8	2009/2010	Wadi El-Natroon	6.1.2010	

Table 3. Location and some geographical and meteorological data for the two research sites in the two cropping seasons.

Growing season	Site	Location Latitude and Longitude	Elevation (m)	Relative Humidity (%)	Mean Temperature (°C)
2008/2009	Giza	30° 02'N, 31° 13' E	22.50	34.1	16.7
2009/2010				48.6	20.4
2008/2009	Wadi El-Natroon	31° 02'N, 30° 28' E	6.70	66.5	17.23
2009/2010				64.2	17.30

was 1 x 3 m= 3 m^2. Sowing rate was 60 kg seed/feddan for all environments and genotypes. Fertilizers were applied at the rate of 200 kg /fed ammonium nitrate (33.5 % N) in two equal doses, the first dose was added at tillering stage and the second dose was added at shooting stage, while phosphorus and potassium were added at a rate of 200 kg/fed calcium superphosphate (15.5 % P_2O_5) and 100 kg/fed potassium sulfate (48 % K_2O), respectively. In all experiments, weeds were controlled by hand as needed. All other treatments were done according to recommendations.

Variables recorded

During growth period and pre-harvest, the following characters were measured for each experiment: number of days to heading and number of days of grain filling as well as number of spikes/m^2. Heading date was determined visually when approximately 50% of heads in a plot had cleared the boot. The duration of grain filling was the number of days from anthesis to maturity. Number of spikes/m^2 was recorded by counting the number of spikes in one meter length area of the five rows in each plot.

At harvest, a random sample of 10 plants from each plot was taken to measure the spike length (cm), thousand grain weight (g). Thousand-grain weight was calculated from the weight of ten sets of 100 grains/plot counted by hand and their weights were taken by electric balance. To reduce border effects, data were recorded from the three central rows of each plot. The grain yield of each plot was recorded in (kg), which was adjusted to calculate yield in ardab per feddan (ardab=120 Kg and 1 feddan= 4200 m^2).

Statistical analyses

Regular analysis of variance of RCBD as outlined by Gomez and Gomez (1984) was applied on each individual environment. Each trial was subjected to the standard analysis of variance and the combined analysis of variance was first undertaken across the test environments after applying the assumption of analysis of variance according to Gomez and Gomez (1984). To satisfy the assumptions of the ANOVA model, the homogeneity test of the variances was verified using Bartlett's test. Mean separation test was performed using Duncan's multiple range test (L.S.R) at 1 and 5% levels of probability (Duncan 1955).

Stability analysis

Parametric stability statistics were used to estimate stability in this study. Six stability parameters were performed. Stability of the genotypes across environments was assessed by computing mean performance across environments ($\overline{X}_i$).

The statistical procedures used for the stability analysis of genotypes were those proposed by Eberhart and Russell's (1966), i.e. the slope value (b_i) and deviation from regression parameter (S^2_{di}), Pinthus's (1973) coefficients of determination (R^2), Wricke's (1962) ecovalance (W^2_i), and Francis and Kannenberg's (1978) coefficient of variability (CV_i) and environmental stability variance (S_i^2). Also, spearman's rank correlation coefficients were computed for each pair of the possible pair-wise comparisons of the stability parameters and the significance of the rank correlation coefficient was tested according to Steel *et al* (1997). All statistical analyses were carried out using MSTAT-C software package (Freed *et al* 1989), Minitab computer software (Minitab 1996) and MS Excel computer program.

RESULTS AND DISCUSSION

Genotype x environment interactions

The combined analysis of variance of the 12 genotypes tested in eight environments showed that mean squares due to environments, genotypes and GEI were highly significant for all studied traits (Table 4). This result suggests the validity of stability analysis.

Table 4. Analysis of variance of 12 barley genotypes tested across different environments.

Source of variation	df	Mean squares					
		Heading Date (days)	Grain Filling (days)	Number of spikes/m^2	Spike length (cm)	Thousand grain weight (g)	Grain yield (ard/fed)
Environment (E)	7	194.85**	688.43**	290806.98**	44.47**	1638.99**	227.315**
Reps. /Env.	**16**	23.73	66.19	18696.06	0.58	8.54	8.93
Genotypes (G)	11	276.25**	322.31**	104974.05**	10.92**	141.40**	118**
G x E	77	34.22**	95.27**	11089.69**	1.03**	22.01**	7.87**
Error	176	6.07	13.88	3130.33	0.42	10.98	3.98

***, ** Significant at 5 % and 1% probability levels, respectively**

Highly significant genotype x environment interactions for many barley traits were previously reported (El-Sayed *et al* 2007, Bahrami *et al* 2008, Zahia *et al* 2010 and Zeky *et al* 2010). The extent of such performance testing depended on the magnitude of genotype x environment interaction, which occurs when genotypes differ in their relative performance across environments (Bernardo 2002).Singh and Narayanan (2000) reported that, if G x E interaction is found to be significant, the stability analysis can be carried out.

Performance of genotypes

According to the results obtained across environments, the means of genotypes for studied traits are presented in Table 5.

Results showed significant differences between the twelve genotypes in all studied characters (Table 5). The obtained results might be discussed as effects of the genotype x environment interaction across the eight studied environments. These findings are similar to those obtained by El-Kady *et al* (2007), Nanak *et al* (2008) and Zeky *et al* (2010), which revealed that barley genotypes were significantly different in grain yield and yield components under the different environmental conditions.

The earliest genotypes in heading date across environments (Table 5), were; G1, G3, G4, G5, G6, G8 and G9, which headed after 82.42, 81.46, 78.50, 82.79, 76.83, 81.96 and 82.75 days, respectively. Results revealed that the three Egyptian local cultivars Giza 127, Giza 123 and Giza 129 were the latest genotypes in heading date. The genotypes with the shortest grain filling period were; G1, G2, G5, G7, Giza 127, Giza 123 and Giza 129, which completed grain filling within 36.00, 36.58, 35.83, 35.96, 32.42, 35.17 and 34.63 days, respectively. These results are similar to those obtained by El-Kady *et al* (2007), Nanak *et al* (2008) and Zeky *et al* (2010).

Table 5. Means for studied traits of twelve barley genotypes across all environments.

Genotype	Days to Heading	Grain filling period (days)	Number of spikes/m^2	Spike length (cm)	Thousand grain weight (g)	Grain yield (ard/fed)
G1	82.42 cd	36.00 cd	680.26 cd	9.19 b	53.72 bc	10.58 c
G2	84.88 b	36.58 cd	716.45 b	8.77 c	54.06 bc	11.30 c
G3	81.46 d	40.33 b	683.40 b-d	8.46 c-e	51.89 cd	10.13 c
G4	78.50 e	43.04 a	635.46 ef	8.58 cd	49.68 ef	8.33 d
G5	82.79 cd	35.83 cd	700.91 bc	9.21 b	54.92 b	10.74 c
G6	76.83 f	45.08 a	590.07 g	7.78 gh	48.88 f	7.61 d
G7	83.75 bc	35.96 cd	707.00 bc	8.70 c	52.53 cd	10.70 c
G8	81.96 d	38.17 bc	661.56 de	8.28 d-f	52.62 cd	10.03 c
G9	82.75 cd	39.46 b	710.80 bc	9.89 a	53.65 bc	10.51 c
Giza 127	86.88 a	32.42 e	839.50 a	8.10 e-g	58.18 a	13.17 b
Giza 123	87.58 a	35.17 d	617.80 fg	7.93 fg	52.99 b-d	14.94 a
Giza 129	87.96 a	34.63 d	609.79 fg	7.54 h	51.31 de	14.60 a
Mean	83.15	37.72	679.42	8.54	52.87	11.05

In each column, any two means having a common letter are not significantly different at the 5% level of significance according to the Duncan's Multiple Range (L.S.R) test.

The highest genotypes in number of spikes/m^2, were G1, G2, G3, G5, G7, G9 and Giza 127, which produced, 680.26, 617.45, 683.40, 700.91, 707.00, 710.80 and 839.50 spikes/m^2, respectively. The lowest number of spikes / m^2 (590.70-661.56) was observed for genotypes G4, G6, G8, Giza 123 and Giza 129 (Table 5). The shortest and largest spike was recorded by Giza 129 and G9, respectively. Thousand grain weight, ranged from 48.88 to 58.18 (g) for genotypes G6 and Giza 127, respectively.

Mean grain yield for the 12 barley genotypes across eight environments is summarized in Table 5. The grand mean yield was 11.05 ard/fed . Four genotypes were above grand mean yield. The highest yield was produced by cultivar Giza 123 (14.94 ard /fed) followed by cultivar Giza 129 (14.60 ard / fed). Six-rowed genotypes Giza 123 and Giza 129 had the highest grain yield than other studied two-rowed genotypes.

Stability analysis

Pooled analysis of variance for all six traits across the eight environments is presented in Table (6). The results revealed that there was significant differences among the genotypes tested for heading date, grain filling, number of spikes/m^2, spike length, thousand grain weight and grain yield (ard/fed).

In the analysis of phenotypic stability of Eberhart and Russell (1966), the performance of individual genotype is regressed on an environmental index (deviation of the mean yield at that environment from the overall mean yield of all environments). The analysis provides the linear regression coefficient, b_i, (performance response index) and the deviation from regression mean square, S^2_{di}, (stability index).

The analysis of variance for stability revealed highly significant differences between the genotypes (Table 6), which suggested that the genotypes differed considerably with respect to yield performance.

Joint regression analysis of variance showed that the mean squares due to genotypes (G) and environment (E) difference tested against the G x E interaction were significant for all the traits studied, indicating the presence of wide variability among the genotypes as well as environments under which the experiments were conducted. The significant estimates of G x E interaction indicated that the characters were unstable and may considerably fluctuate with change in environments. These findings are in close agreement with those of Mohamadi *et al* (2005), Nanak *et al* (2008) and Muluken (2009).

Table 6. Joint regression analysis of variance for studied traits of the 12 genotypes tested in eight environments.

Source of Variance	df	Mean squares					
		Heading Date (days)	Grain filling Period (days)	Number of spikes/m^2	Spike Length (cm)	Thousand grain weight (g)	Grain yield (ard/fed
Total	95	24.694	55.09	14190.42	1.79	51.65	12.264
Genotypes	11	92.08**	107.43 **	34991.38**	3.64 **	47.12**	39.341**
Environments(Env)	7	64.95**	229.47 **	96935.73**	14.82 **	546.31**	75.75**
Genotype x Env.	77	11.40**	31.75 **	3696.56**	0.34 **	7.33*	2.62**
Env.+(Genotype x Env.)	84	15.86**	48.23 **	11466.49**	1.54 **	52.25**	8.718**
Environment(Linear)	1	454.66**	1606.35 **	678550.17**	103.76 **	3824.22**	530.28**
Gen x Env. (Linear)	11	10.86**	45.98 **	4563.15**	0.54 **	18.35**	3.532*
Pooled deviation	72	10.53**	26.94 **	3256.12**	0.28	5.04	2.26**
Pooled Error	176	2.023	4.63	1043.45	0.14	3.01	1.32

***, ** significant at 0.05 and 0.01 levels of probability, respectively.**

The genotype x environment interaction was further partitioned into linear and non-linear components and mean squares for both sources were significant ($P < 0.01$). Thus, both linear (predictable) and non-linear (un-predictable) components significantly contributed to genotype x environment interactions observed for all characters. This suggested that predictable as well as un-predictable components were involved in the differential response of stability. Similar results were reported by El-Kady *et al* (2007), Nanak *et al* (2008) and Zeky *et al* (2010). Significant environment (linear) variance implies linear variation among environments for all the characters. The G x E (linear) interaction was significant against pooled deviation, suggesting the possibility of the variation for all characters and indicated the presence of genetic differences among genotypes for their regression on the environmental index (Table 6). The linear component of genotype x environment interaction was found to be more than the non-linear component (pooled deviation) for all characters. Hence, prediction of performance of barley genotypes appears to be feasible from their linear regression on environmental indices. These results are in consistence with those of Nanak *et al* (2008) who have reported predominance of linear component of G x E interaction for grain yield per plant.

The estimates of 6 different parametric stability statistics and genotype mean yields (ard/fed) are presented in Table 7. The average grain yield and their ranks for 12 barley genotypes tested across eight environments are presented in Table 7 and 8, respectively. The genotypes showed significant differences in grain yield. The highest yield 14.94 ard /fed was obtained from the Egyptian local cultivar Giza 123, while the lowest one was 7.61 ard/fed from genotype 6 (Table 7).

The stability results were generally based on grain yield ranking and stability parameters. The stability parameters (within genotype regression coefficient (b_i), deviation from regression mean square (S^2_{di}), coefficient of determination (R_i^2), ecovalence (W_i^2), environmental variance (S_i^2) and genotype coefficient of variation ($CV_i\%$), revealed a range of stability for grain yield.

Mean grain yield across eight environments showed substantial changes in ranks among the genotypes, reflecting the presence of high G-E interactions (Baker 1998). Taking mean yield as the first parameter for evaluating the genotypes, Giza 123, Giza 129, Giza 127 and G2 gave the best mean yields while G6 and G4 had the lowest mean yields across environments (Tables 7 and 8). The highest yield ard/fed was given by genotype Giza 123 being 14.94 ard/fed followed by genotypes Giza 129, Giza 127 and G2 that produced 14.60, 13.17 and 11.30 ard/fed, respectively. On the other hand, the lowest yield/fed was given by genotypes G6, and G4 recording 8.33 and 7.61 ard/fed, respectively.

Table 7. Mean grain yield values (ard/fed) and 6 parametric stability statistics for 12 barley genotypes across 8 environments.

Genotypes	**Mean ($\bar{x}$)^a**	**b_i^{b}**	**S^2_{di}^{c}**	**R^2%^{a}**	**W^2_i^{d}**	**S_i^2^{d}**	**C.V%^{d}**	**Fr.**
G1	10.58	**1.287**	**2.345**	**84**	17.71	1246.16	33.36	3
G2	**11.30**	**0.856**	2.762*	66	17.49	**698.35**	**23.39**	4
G3	10.13	**0.867**	4.602**	53	30.32	896.39	29.55	2
G4	8.33	**0.945**	**2.632**	**71**	**15.93**	**788.96**	33.70	5
G5	10.74	**0.850**	4.580**	54	28.47	**848.54**	**27.13**	3
G6	7.61	**0.673**	**1.850**	64	**15.82**	**444.47**	27.70	4
G7	10.70	1.742**	**0.972**	**96**	30.16	1998.92	41.80	2
G8	10.03	**1.158**	**1.334**	**88**	**9.11**	961.64	30.90	4
G9	10.51	**0.910**	4.633**	57	28.16	919.93	28.86	1
Giza 127	**13.17**	**0.996**	**0.638**	**92**	**3.83**	**680.37**	**19.80**	7
Giza 123	**14.94**	**0.844**	**0.211**	**96**	**2.34**	**467.27**	**14.47**	7
Giza 129	**14.60**	**0.874**	**0.343**	**94**	**2.76**	**511.62**	**15.50**	7
Average	11.05	1.00	2.241	69.58	16.84	871.88	27.18	

***,** Significantly different from 1.0 for the regression coefficients and from 0.0 for the deviation mean squares at the 0.05 and 0.01 levels of probability , respectively.**

[a] printed values in bold are higher than the mean; [b] printed values in bold are not significantly different from unity at $P < 0.05$; [c] printed values in bold are not significantly different from zero at $P < 0.05$;genotypes with values in bold are considered stable; [d] printed values in bold are lower than the mean; genotypes with lower values than the mean for seven stability parameters are regarded as stable, *Fr.* = frequency of the number of stability parameters showing stability for each genotype, if a genotype had seven values of *Fr.*, it could be considered most stable.

According to Finlay and Wilkinson (1963), who defined varieties with general adaptability as those with average stability ($b_i = 1.0$) when associated with high mean yield across tested environment. Eberhart and Russell (1966) proposed that an ideal genotype is the one which has the highest yield across a broad range of environments, a regression coefficient (b) value of 1.0 and deviation mean squares of zero.

It is well known that regression coefficient (b_i) should be a parameter of response and deviation to regression as a parameter of stability along with above average grain yield. Accordingly regression coefficient value near 1.00 indicates less response to environmental changes, and hence showing more adaptiveness. Thus, a genotype with unit regression coefficient (b_i=1) and deviation not significantly different form zero (S^2_{di}=0) is said to be the most stable genotype.

Table 8. Ranking of 12 barley genotypes for mean yield across 8 environments and 6 different parametric stability statistics.

Genotypes	Stability statistic						
	Mean	b_i	S^2_{di}	R^2%	W^2_i	S_i^2	C.V%
G1	7	10	7	6	8	11	10
G2	4	6	9	8	7	5	4
G3	9	5	11	12	12	8	8
G4	11	2	8	7	6	6	11
G5	5	7	10	11	10	7	5
G6	12	11	6	9	5	1	6
G7	6	12	4	2	11	12	12
G8	10	9	5	5	4	10	9
G9	8	3	12	10	9	9	7
Giza 127	3	1	3	4	3	4	3
Giza 123	1	8	1	1	1	2	1
Giza 129	2	4	2	3	2	3	2

The linear regression of the average yield of a single genotype on the average yield of all genotypes in each environment generated the regression coefficients (b_i), which ranged from 0.673 to 1.742 for grain yield (Table 7 and Figure 1). This wide range of regression coefficients indicates that the 12 genotypes had different responses to environmental changes. Most barley genotypes tested (92%) had regression slopes for grain yield that did not differ from 1.0, indicating good potential for yield response under environmental conditions. Based on results of the regression analysis, the genotypes Giza 123, Giza 129, Giza 127 and G2 were classified as highly stable across environments because the regression coefficients of these genotypes did not differ significantly from 1.0, and produced grain yields above the overall mean, indicating that these genotypes had general adaptability (Table 7). Moreover, the S^2_{di} values (Table 7) of the three Egyptian local cultivars were not significantly different from zero, and therefore it can be considered that these genotypes are of good adaptability. The genotype G7 had larger b_i value, indicating greater sensitivity to environmental change and was relatively suitable in favorable environments. Genotypes G2, G3, G5 and G9 were unstable genotypes according to the S^2_{di} values. Higher values of S^2_{di} explained to us that there is high sensitivity to environmental changes.

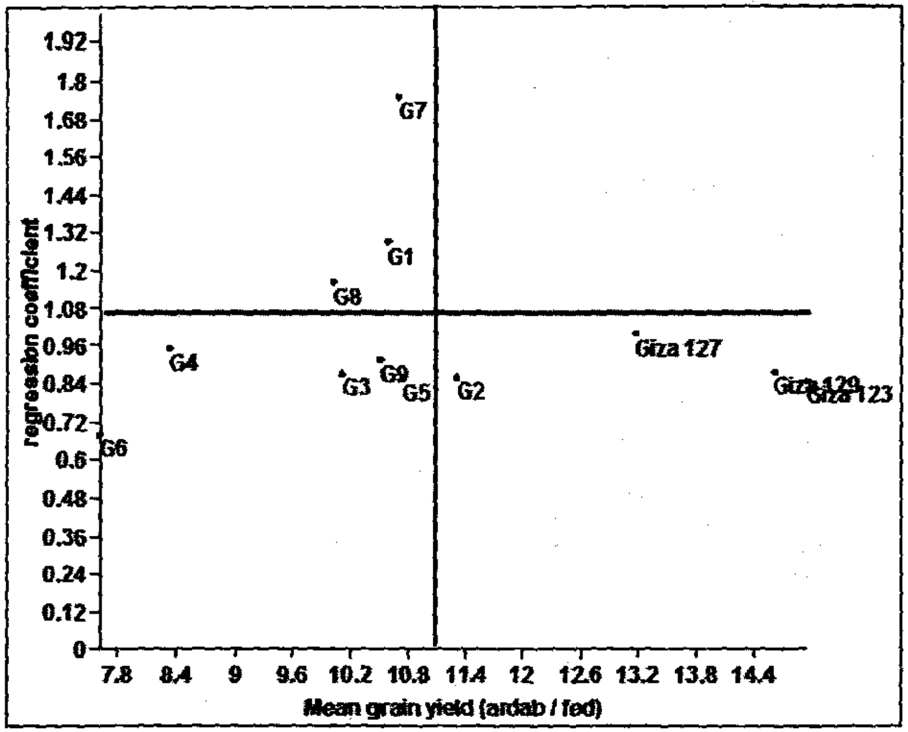

Fig. 1. Mean grain yield and regression coefficients of 12 barley genotypes tested across 8 different environments.

Figure 1 is a graphic summary of the data that would be useful in the identification of stable genotypes. The vertical lines are the grand mean yields and confidence limits, and the horizontal lines the regression coefficients (b_i = 1.0) and its confidence limits. Also, the other stability parameters for Giza 123, Giza 129 and Giza 127 genotypes were parallel to results of graphic.

With regard to the coefficient of determination (R_i^2), the results in Table 7 showed that the coefficients of determination (R_i^2) ranged from 53% to 96%, which indicated that 53% to 96% of the mean grain yield variation was explained by genotype response across environments and indicating stability differences among genotypes. The coefficient of determination is often considered a better index for measuring the validity of the linear regression than S^2_{di}, because its value ranges between zero and one. In addition, Bilbro and Ray (1976) suggested that coefficient of determination (R_i^2) could be useful in measuring dispersion around the regression line and therefore related to the predictability and repeatability of the performance within environments. The predictability of genotypes for the yield varied. R^2 values for Giza 123, G7, Giza 129 and Giza 127 were 96%, 96%, 94% &

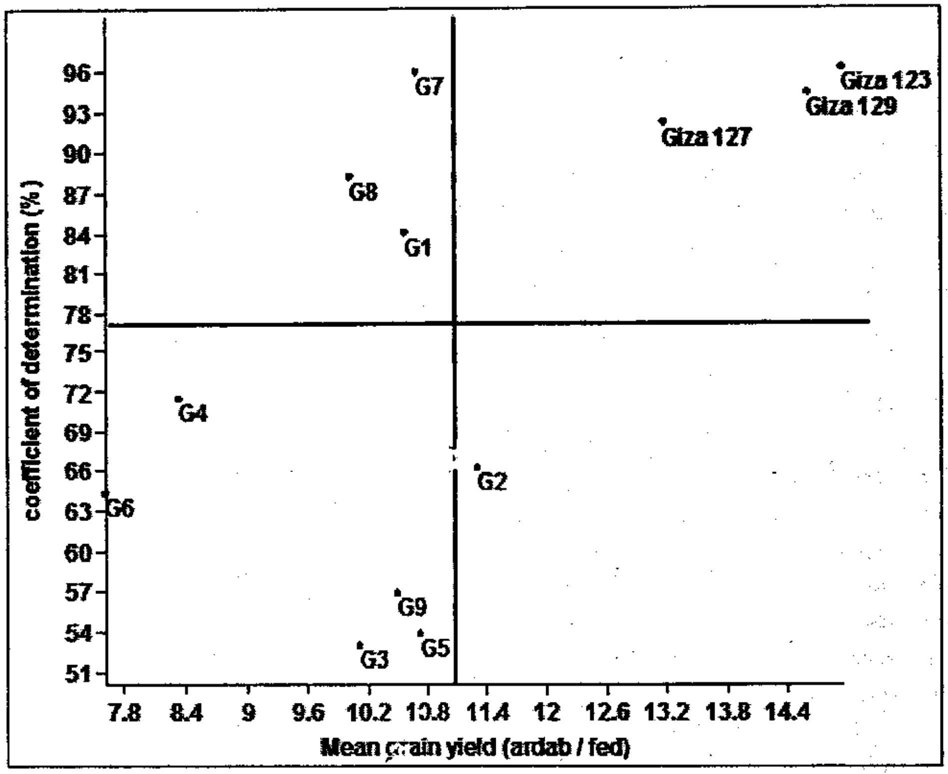

Fig. 2. Grain yield averaged over 8 environments and coefficient of determination in 12 barley genotypes.

92% (Table 7), respectively indicating the reliability of the linear response of these genotypes. Figure 2 show that genotypes Giza 123, Giza 129 and Giza 127 had higher yields and higher R^2% than the average of all studied genotypes.

Wricke's (1962) ecovalence is an alternative method that is frequently used to determine stability of genotypes based on the G x E interaction effects. It indicates the contribution of each genotype to the G x E interaction. The cultivars with the lowest ecovalence contributed the least to the G x E interaction and are therefore more stable. Using Wricke's (1962) stability parameter, W^2_i, the genotypes Giza 123 followed by Giza 129 and Giza 127 with the lowest ecovalence were considered to be stable which being responsible for 2.34 %, 2.76% and 3.83 % of the total interaction sum of squares, respectively, whereas the G3, G7, G5 and G9 with the highest W^2_i were unstable and had the highest contribution to GE interaction. The genotypes like Giza 123 (2.34), Giza 129 (2.76) and Giza 127 (3.83) showed good stability and high correlation with the mean yield ranking. The least stable genotypes like G3 (30.32), G7 (30.16), G5 (28.47) and G9 (28.16) showed no correlation with mean yield ranking.

Francis and Kannenberg (1978) reported that the coefficient of variation (CV_i %) estimated from the variances across environments of the genotypes grown in different environments is used as the stability parameter. In this study, the coefficient of variation varied from 14.47% to 41.80% (Table 7). Ortiz *et al* (2001) suggested that it may possible to select simultaneously for high and stable grain yield by selecting out yielders that exhibit a low CV_i.

According to Francis and Kannenberg (1978), genotypes exhibiting low environmental variance (S^2_i) and coefficient of variation (CV_i) are considered as stable (Lin *et al* 1986). Figures 3 and 4 shows that genotypes Giza 123, Giza 129, Giza 127, G2 and G5 genotypes had smaller environmental variance (S^2_i) and coefficient of variation (CV_i) than those of the rest for grain yield, confirming their high stability. Moreover, the three Egyptian local cultivars had grain yield greater than grand mean yield. The unstable genotypes, G1, G3, G7, G8 and G9 had the highest CV_i and S^2_i values for grain yield.

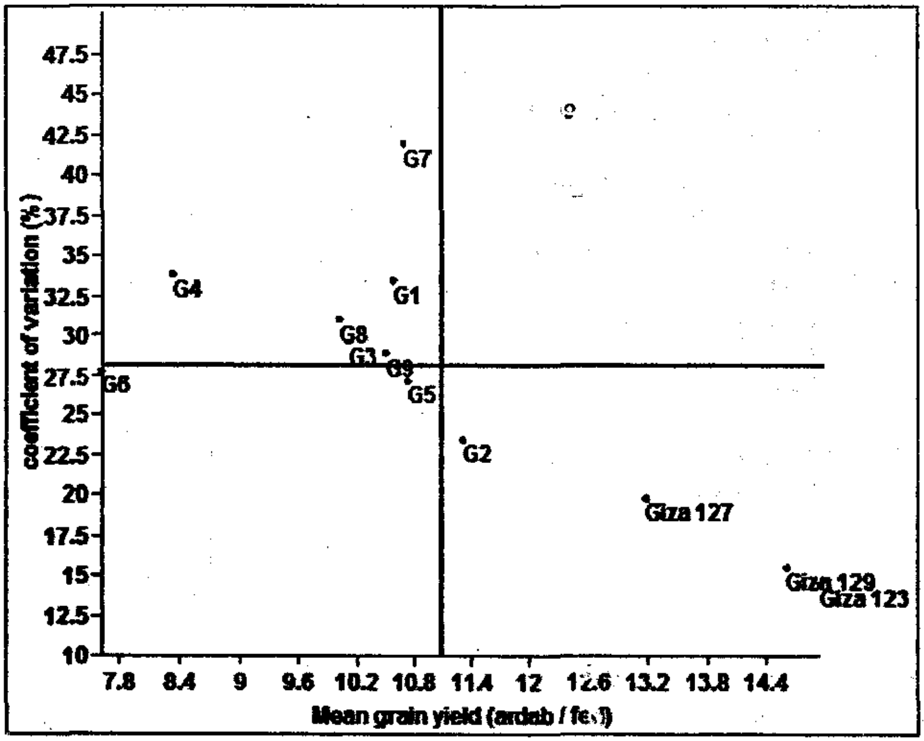

Fig. 3. Grain yield averaged over 8 environments and coefficient of variation in 12 barley genotypes.

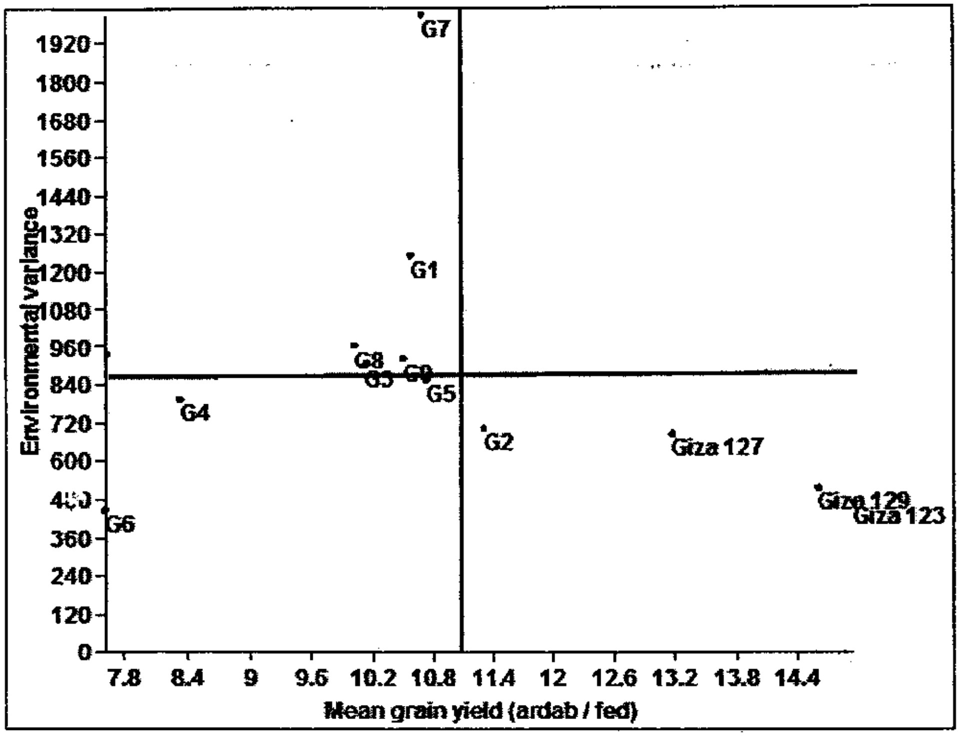

Fig. 4. Grain yield averaged over 8 environments and environmental variance in 12 barley genotypes.

In summary, parametric stability analysis for grain yield of barley genotypes revealed that genotypes Giza 123, Giza 129, Giza 127, G4, G2, G6 and G8 were more stable genotypes, expressed in 7, 7, 7, 5, 4, 4 and 4 out of all 7 stability statistics used, respectively. Thus, these genotypes would be suggested to be more stable thaw others for these statistics. They have a low contribution to the genotypic by environment interaction. Among these genotypes, Giza 123, Giza 129 and Giza 127 that were the most stable ones, because all of them expressed 7 out of 7 studied stability statistics. Therefore, the above mentioned genotypes could be recommended to be as commercial stable and high yielding cultivars and/or incorporated to be as breading stocks in any future breading programs aiming at producing high yielding lines of barley.

Interrelationships among stability parameters

Correlation analysis was used to study the relationships between mean yield and stability parameters, as well as between studied stability parameters. Table 8 shows the ranking of the 12 barley genotypes, after applying the methods of stability analysis. The ranks of 12 genotypes and 8 environments after applying the method stability analysis were used for rank correlation. The results of Spearman's coefficient of rank correlations between mean yield and the different parametric stability measures are presented in Table 9. Mean yield was statistically significant ($P < 0.05$) and positively correlated with coefficient of variation (CV_i) parameter (*r* = 0.71*). The strong correlation between mean yield and this stability parameter (CV_i) was expected because the values of this statistic were low for high-yielding genotypes. Furthermore, the correlation was positive between mean yield and other stability parameters, but this correlation was statistically non-significant.

The results in (Table 9) showed, that b_i tended to be independent of the other stability statistics. These results were in harmony with those obtained by El-Kadi *et al* 2007 and Shah *et al* (2009).

Table 9. Correlation coefficients between grain yield and stability parameters.

Variable	**Mean yield**	**b_i**	**S^2_{di}**	**R^2_i**	**W_i^2**	**S_i^2**	**CV_i%**
Mean yield	**1**	**0.18**	**0.49**	**0.53**	**0.37**	**0.27**	**0.71***
b_i		**1**	**-0.19**	**-0.18**	**0.18**	**0.26**	**0.32**
S^2_{di}			**1**	**0.92****	**0.75****	**0.37**	**0.36**
R^2_i				**1**	**0.62***	**0.10**	**0.17**
W_i^2					**1**	**0.67***	**0.62***
S_i^2						**1**	**0.77****
CV_i%							**1**

***, ** Correlation coefficients are significantly different from zero at the 0.05 and 0.01 levels of probability, respectively.**

Deviations from regression (S^2_{di}) and coefficient of determination (R^2) exhibited the highest positive and highly significant correlation (r=0.92**) between themselves. These findings agree with other researchers (Letta 2007, Muluken 2009 and Shah *et al* 2009). Also, rank correlation coefficient between coefficient of variation (CV_i) and phenotypic variance (S^2_i) was strong and highly significant (r = 0.77**). This was in agreement with the results of Jalaluddin and Harrison (1993).

Ecovalence (w^2_i) stability parameter had a strong correlation with S^2_i (r=0.67*) and CV_i (r=0.62*). This was in agreement with the findings of Lin *et al* (1986).

The stability parameter of coefficient of determination (R^2) significantly correlated with the parameter of ecovalence (r = 0.62*). Deviations from regression (S^2_{di}) was strongly and positively correlated with the coefficient of determination (R^2) stability parameter (r=0.92**) and Ecovalence W^2_i (r=0.75**), which indicated that one of these three parameters could be used as a substitute for the others in GE interaction study of barley. Hence, it is possible to use only one of them as a measure of stability.

CONCLUSION

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

- 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;
- Several stability statistics that have been used in this study quantified stability of genotypes with respect to mean yield, stability and both of them. Therefore, both of mean yield and stability should be considered simultaneously to exploit the useful effect of GE interaction and to make selection of the genotypes more precise and refined;
- Among the genotypes used in this study, Giza 123, Giza 129 and Giza 127, showed high mean grain yield and was found to be stable across the environments and therefore; could be used in the breeding program, for the development of high yielding stable genotypes across environments for future use;
- Mean yield, S^2_{di} , R^2_i , W^2_i , S^2_i and CV_i were generally found to be important in determining the comparative stability of the barley genotypes tested and this fact also was reflected by spearman's rank correlation coefficient that displayed significant correlations among these stability parameters;
- Our results showed that high-yielding genotypes can differ in yield stability, and suggest that yield stability and high mean grain yield are not mutually exclusive.

RECOMMENDATION

These results emphasis significant G × E effects and the necessity for multiple environmental testing through time and space so as to characterize genotypic differences and stabilities. It is advisable to test new genotypes in the environments of intended use before release to farmers. It is essential to identify genotypes, which manifest relatively low G×E interactions with stable yields in test environments. Genotypes Giza 123, Giza 129 and Giza 127 are likely to be stable and may be recommended for cultivation in different locations in Egypt as they had high relative yield performance and revealed high stability.

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استخدام إحصاءات الثبات المعلمية لتقييم بعض التراكيب الوراثية من الشعير

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تهدف الدراسة إلى تقييم اثني عشر تركيب وراثي من الشعير، اختبرت عبر ثمان بيئات (سنتان ، موقعان ، موعدان للزراعة) في تصميم القطاعات الكاملة العشوائية بثلاثة مكررات خلال الموسمين 2009/2008 ، 2010/2009 . أوضحت النتائج وجود اختلافات عالية المعنوية بين التراكيب الوراثية لصفات ميعاد طرد السنابل، وفترة امتلاء الحبوب، وعدد السنابل في وحدة المتر المربع، وطول السنبلة، ووزن الألف حبة، ومحصول الحبوب (إردب/فدان) . كما أظهر تحليل التباين التجميعي متوسطات مربعات عالية المعنوية للتراكيب الوراثية ، والبيئات ، وكذلك لتفاعل التركيب الوراثي مع البيئة لجميع الصفات تحت الدراسة، مما يشير إلى وجود فروق في استجابة التركيب الوراثية عبر البيئات، مما يصلح لإجراء تحليل الثبات، تم تقدير ستة من إحصاءات الثبات المعلمية وهي CV_i , S^2_i , W^2_i , R^2_i , S^2_{di} , b_i . وأوضحت نتائج تحليل الثبات أن التراكيب الوراثي Giza 123, Giza 129, Giza 127, G4, G2, G6, G8 كانت على درجة عالية من الثبات عبر البيئات المستخدمة ، حيث حققت تلك التراكيب الوراثية ثباتا من خلال 7 ، 7 ، 7 ، 5 ، 4 ، 4 ، 4 مقاييس من إحصاءات الثبات المستخدمة على التوالي. وبالتالي تم الحكم على هذه التراكيب الوراثية أنها الأكثر ثباتا من خلال إحصاءات الثبات، وهذا يعني بالتالي أن هناك مساهمة منخفضة لهذه التراكيب الوراثية في تفاعل التركيب الوراثي مع البيئة. ويمكن الاستفادة من هذه التراكيب الوراثية وإدراجها للمساهمة في برامج تحسين الشعير. أظهر تحليل الارتباط وجود ارتباط رتبي عالي المعنوية بين مقاييس الثبات (R^2_i , W^2_i , S^2_{di}) ، حيث أنها كانت متكافئة في قياس الثبات وهذا يعني التشابه الوثيق فيما بينها في الكشف وتحديد ثبات التراكيب الوراثية. ومن هنا يمكن استخدام أي من هذه الإحصاءات المعلمية للثبات لوصف ثبات التراكيب الوراثية. كذلك أظهرت النتائج أن التراكيب الوراثية ذات الغلة المرتفعة يمكن أن تختلف في ثبات الغلة ، وتشير النتائج إلى أن الجمع بين صفتي ثبات المحصول وارتفاع محصول الحبوب لا يستبعد أيهما الأخر.

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