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Original Research Article

Comparison of parametric stability statistics for grain yield in barley under different drought stress severities

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Abstract

A primary objective of most breeding programs is determining high-yielding and stable genotypes in barley. Genotype by environment interaction (GEI) is a major factor in the development of high and stable yield barley genotypes under drought conditions. Twenty four parametric stability statistics were used to determine yield performance and stability simultaneously as well as compared those statistics of seventeen barley genotypes across non-stress, moderate and severe stress conditions during 2015/2016 and 2016/2017 growing seasons (six environments) in Egypt. The trials were laid down in a randomized complete block design (RCBD) with three replications. The analysis of variance (ANOVA) across environments indicated that both environments and GEI influenced highly significant the genotypes performance for yield. Based on a Spearman's rank correlation and cluster analysis, the parametric stability statistics can be classified into five clusters that corresponded to different dynamic or (agronomic) and static (biological) concepts of stability. The clusters I and II related to the dynamic concept and strongly correlated with mean grain yield of stability. This group was more useful in agronomic goals in comparison with other methods. The cluster III and IV were not correlated with mean grain yield and represents the concept of static stability, which were influenced simultaneously by both yield and stability. The cluster V was not correlated with mean yield and most of the parametric stability statistics; hence they can be excluded as suitable stability indices. The parameteric stability statistics in each the lusters I, II, III and IV were positively and significantly correlated with each other, thus, any parameter of them can be considered as appropriate alternatives for each other. According to the concept of stability and corresponding to most parametric stability statistics, the genotypes G7, G6, G10 and G5 were identified as the most stable genotypes with high yielding performance and a high degree of stability, whereas, the genotypes G17 and G16 with lowest yielding performance considered to be unstable. In conclusion, both yield and stability should be considered simultaneously to exploit the useful effect of GEI and to make selection of genotypes more precise and refined. Therefore, the parameteric stability statistics of P_i, D_i, *GAI*, I_i, CV_i, *IPCA1*, *SF* and *TF* were more useful for simultaneously selecting for high yield and stable, and more convenient than other parameteric stability statistics. The genotype G7 was stable coupled with high yield and it is released for use in drought conditions of Egypt.

Keywords: Parametric stability statistics–drought stress–grain yield–barley.

INTRODUCTION

Barley (*Hordeumvulgare* L.) is an economically important grain crop and has long been an interesting and useful model for genetic analysis (Mather, 2002). Major goal of plant breeding programs is to increase stability and stabilize crop yield across environments. Seed yield is a quantitative trait, which expression is the result of genotype, environment and genotype x environment interaction (Engqvist and Becker 1993). Genotype x environment interaction (GEI) is of major importance to the plant breeder in developing improved varieties. When varieties are compared over a series of environments, the relative rankings usually differ (Eberhart and Russell). GEI is a major problem when comparing the performance of genotypes across environments (Kang 1990). Interpretation of performance for a number of genotypes in a broad range of environments is always affected by large GEI (Gauch and Zobel 1996). The study of the GEI may assist understanding of stability concept. Understanding the structure and nature of GEI is important in plant breeding programs because a significant GEI can seriously impair efforts in selecting superior genotypes relative to new crop introductions and cultivar development programs. It can help determine if they need to develop cultivars for all target environments or if they should develop specific cultivars for specific target environments.

GEI occurs when the performance of the genotypes is not consistent from one environment to another. A significant GEI for a quantitative trait such as grain yield can reduce the correlation between phenotype and genotype, and decreases progress in selection (Comstock and Moll, 1963). The basic cause of differences between genotypes in their yield stability is the wide occurrence of GEI, i.e. the ranking of genotypes depends on the particular environmental conditions where they are grown. These interactions of genotypes with environments can be partly understood as a result of a differential reaction to environmental stress factors like drought or diseases, and consequently resistance breeding is of significance in improving yield stability (Becker and Leon, 1988). When discussing these unexpected variations in yield the term “phenotypic stability” is often used to refer to fluctuations in the phenotypic expression of yield while the genotypic composition of the varieties or populations remains stable. Several methods have been developed by statisticians and applied by plant breeders to explain the GEI at the end of plant breeding programs like phenotypic variances (Roemer, 1917), interaction sums of squares (Shukla, 1972), slope of regression on an environmental index (Finlay and Wilkinson 1963), non-parametric measures (Nassar and Huehn 1987).

The occurrence of GEI has led to the development of several stability parameters that can be used to estimate the stability of cultivar performance. Romagosa and Fox (1993) and Huehn (1996) indicated that there are two major approaches for studying GEI to determine the adaptation of genotypes. First, is the parametric (empirical and statistical) approach, which is based on statistical assumptions about distribution of genotype, environment and GEI effects. Second, is the nonparametric (analytical clustering) approach, which does not need any assumptions when relating to environment and phenotypic relative to biotic and abiotic environmental factors. Although several models for the statistical measurement of stability have been proposed, no single method adequately explains genotype performance across environments. For practical applications, however, most breeding programs are now incorporating some elements of both parametric and non-parametric approaches (Becker and Leon 1988).

Parametric methods for estimating phenotypic stability are widely used in plant breeding and they were mostly related to the variance components and related statistics. The parametric methods range from univariate to multivariate models. Joint regression is the most popular among the univariate methods because of its simplicity of calculation and application (Becker & Leon 1988).Lin et al. (1986) mentioned that, the stability statistics fall into four groups depending on whether they are based on the deviations from the average genotype effect or on the GEI term, and whether or not they incorporate a regression model on an environmental index. These groups of parametric stability are shown to be related to three concepts: A genotype may be considered to be stable (I) if its among-environment variance is small, (II) if its response to environments is parallel to the mean response of all genotypes in the trial, or (III) if the residual mean square from a regression model on the environmental index is small. In first concept, Becker and Léon, (1988) called this stability a static, or a biological concept of stability. Parameters used to describe this type of stability are coefficient of variability (CVi) used by Francis and Kannenburg (1978) for each genotype and the genotypic variances across environments (Si2), and the coefficient of determination (r2). As for second concept, Becker and Léon, (1988) called this stability the dynamic or agronomic concept of stability. Parameters used to describe this type of stability are regression coefficient bi(Finlay and Wilkinon, 1963), Wricke’s (Wricke, 1962) ecovalence (Wi) and Shukla’s stability variance σ2i (Shukla, 1972). The third concept is also part of the dynamic or agronomic stability concept according to Becker and Léon (1988). Parameters used to describe this type of stability are the methods of Eberhart and Russell (1966) and Perkins and Jinks (1968). Unfortunately, these three concepts represent different aspects of stability and do not always provide a complete picture of the response. The advantage of the nonparametric approach is that a cultivar’s response characteristics can be assessed qualitatively, without the need for a mathematical characterization (Lin et al.,1986). These parametric estimates have good properties under certain statistical assumptions, like normal distribution of errors, homogeneity of variance and interaction effects; they may not perform well if these assumptions are violated, for example, in the presence of outliers (Huehn, 1990). That means parametric tests for significance of variances and variance-related measures could be very sensitive to the underlying assumptions. Thus, it is wise to search for alternative approaches that are more robust to departures from common assumptions, such as nonparametric measures. Among the multivariate methods, the additive mean effects and

Table 1. List of seventeen genotypes of barley used for drought tolerance assessment

Code genotypes	Cross names/Pedigree
G1	California mariout
G2	Fedora/ Express/Saida
G3	Arar/PI386540/Giza121/Pue/4/Deiralla 106/Cel/3/BcoMr/Mza// Apm/5106.
G4	Alanda/5/Aths/4/Pro/Toll//Cer2/Toll/3//5/06/6/Baca"S"/3/AC253//Clo8887/Clo5761
G5	PETUNIA2 / 3GLORIA-BAR / COME // ESPERANZA /4/… CBSS99M00349T-F-3M-1Y-IM-IY-IM-0M
G6	CHENG DU 105 /4/ EGYPT4 / TERAN78 // P.STOO /3/… CBSS00Y00236T-E-0Y-0M-2Y-0M
G7	TOCTE /3/ CHAMICO / TOCTE // CONGONA /4/ LIGNEE527 /… CBSS99M00468T-H-1M-1Y-1M-1Y-0M
G8	GLORIA-BAR / COME // LIGNEE640 /3/ S.P-B/4/SLLO /5/ CBSS99M00429T-L-1M-1Y-1M-1Y-0M
G9	BBSC / CONGONA // BLLU /3/ CIRU CBSS00Y00225T-C-0Y-0M-2Y-1M-0M
G10	FORRAJERA KLEIN / DELO CBSW98W00054S-8Y-2M-1Y-2M-1Y-0M
G11	ALPHA-BAR / DURRA // CORACLE /3/ ALELI/4/ CBSS99M00317T-AH-2M-1Y-1M-1Y-0M
G12	JANE / TOCTE // PEREGRIN CBSS00Y00402T-AH-0Y-0M-2Y-0M
G13	PETUNIA2 /3/ TOCTE / TOOCTE / TOCTE // BERROS /4/ PENCOO / CBSS00Y00475T-O-0Y-0M-2Y-0M
G14	PETUNIA2 /6/ ALPHA-BAR / DURRA // CORACLE /3/ CBSS00Y00446D-F-0Y-0M-1Y-0M
G15	Rihane 03
G16	Giza 2000
G17	Giza 126

multiplicative interaction (AMMI) (Zobel et al. 1988; Gauch 1992) is the most well-known and appealing method for analysis of GEI data. This model have been developed and applied over the years to analyses GEI and especially yield stability across different environments in different crops.

The objectives of this study were 1) to analyze GEI 2) to identify promising high-yielding and stable genotypes 3) to study the relationships, similarities and dissimilarities among the parametric stability statistics on grain yield of barley under drought conditions in Egypt.

MATERIALS AND METHODS

Genetic Material and Experimental design:

In order to evaluate grain yield stability of barley and comparison between the parametric stability methods under different drought stress severities seventeen genotypes were used as experimental material. The names, origin and genotypic codes of these genotypes are given in Table (1). The trials were conducted at East El-El- Qantra Agricultural Research Station in El-Qntra, El-Ismailia Governorate, Egypt. The genotypes were tested under non-stress, moderate and severe stress conditions separately during two cropping seasons 2015/2016 and 2016/2017. The amounts of irrigation for the under non-stress, moderate and severe stress experiments were 1400, 1100 and 800 m^3 and these rates were stable in the two crop seasons, respectively. A basin irrigation system was used in each experiment, by means of PE pipes and volumetric counter. All experiments were arranged in a randomized complete-block design with three replications. Each replication had contained seventeen plots (genotypes). Each genotype was sown in a plot size of 3m x 3.5m (10.5 m^2). Each plot comprised of 15 rows with 3.5m long, 20 cm distances among rows and 5 cm distance among plants. All the recommended cultural practices of barley production in the area were done as usually. At harvest grain yield was measured per plot for each genotype at each test experiment and converted to Kg/feddan for the statistical analyses.

Statistical Analysis and Procedures:

Combined analysis of variance was done on grain yield that obtained from non-stress, moderate and severe stress conditions under the two seasons (six environments) according to the Eberhart and Russel (1966) Method. A combined ANOVA was conducted to determine the effects of genotype (G), environment (E) and GxE interactions (GEI), leading to estimated variance components for G, E, and GE interactions. Statistical tests of significance for these factors were determined using F-tests.

Table 2. ANOVA for genotypes (G), environments (E) and GEI for combined data from the barley trials

Source of variation	df	Mean squares
Genotypes	16	160134.52**
E + (G X E)	85	35790.69**
a- E (Linear)	1	2828534.15**
b- G x E (linear)	16	5760.18**
c- Pooled deviation	68	1786.94ns
Pooled error	192	18.97

C.V.% = 7.62%
ns, not significant, * and ** significant at the 0.05 and 0.01 probability level, respectively.

Different parametric measures were chosen to cover a wide range of philosophies of stability analysis. According to the mathematical concept of stability, the used stability methods were placed into three main groups namely; regression model, GE variance statistics and other methods. The parametric stability statistics based on regression models were performed in accordance with Eberhart and Russel's (1966) linear regression coefficient $[b_i(ER)]$ and the variance of the regression deviations $[S^2_{di}(ER)]$; Perkins and Jinks (1968) linear regression coefficient $[b_i(PJ)]$ and the variance of the regression deviations $[S^2_{di}(PJ)]$; Freeman and Perkins (1971) linear regression coefficient $[b_i(FP)]$ and the variance of the regression deviations $[S^2_{di}(FP)]$; Hanson's (1970) genotypic stability (D^2_i); Tai's (1971) linear response to environmental effects (α_i) and deviation from the linear response (λ_i); Pinthus's (1973) coefficients of determination (R^2_i); Lin and Binns (1988) superiority index (P_i); Hernandez et al (1993) desirability index (D_i).The parametric stability statistics based on GE variance were performed in accordance with Roemer (1917) environmental variance (S^2_{xi}); Francis and Kannenberg (1978) coefficient of variation (CV_i); Plaisted and Peterson (1959) mean variance component for pair-wise GEI (θ_i); Plaisted (1960) $(\theta_{(i)})$; Wricks's (1962) ecovalance (W^2_i); Shukla's (1972) stability variance (σ^2_i); Zobel et al., (1988) additive main effects and multiplicative interaction (AMMI) model (PCA1 and IPCA2); Purchase et al. (2000) AMMI stability value (ASV); Sharaan and Ghallab (2001) relative deviation (RD_i), relative deviation distance (RDD_i) and the third statistic $(RDDD_i)$ and Kataoka (1963) yield reliability index (I_i).Other parametric stability methods including; stability factor (*SF*) by Lewis (1954),geometric adaptability index (*GAI*) by Mohammadi and Amri (2008) and simple stability model (*TF*) by Thillainathan and Fernandez (2002). Spearman's rank correlation coefficients and cluster analysis were performed for better understanding of the relationships among all possible pair-wise comparisons of grain yield and the parametric stability statistics. For statistical analysis the software's PAST version 2.17c, SPSS and STATISTICA were used.

RESULTS and DISCUSSIONS

G × E interaction effects and genotypic mean performance

A combined analysis of variance (Table 2) for stability showed highly significant differences (P < 0.01) for grain yield among genotypes (G) and environment + (G x E). The variance due to due to environment + (G x E) are partitioned into E (linear), G x E (linear) and pooled deviation (nonlinear) from the regression model. The mean squares due to E (linear) and G x E (linear) which are due to regression were highly significant (P < 0.01), while the mean squares due to pooled deviations was non-significant. It can be concluded that there was a clear linear relationship between grain yield and environmental indices, existence of differences among the regression coefficients as well as lack of differences among genotypes for non - linear response. This reveals that not only the amount of variability existed among environments but also the presence of genetic variability among the genotypes. Clearly, cultivar superiority is conditional on environment and the GE interaction makes selection of elite and adapted cultivars for a wide region more complex. These results indicated the inconsistency in the grain yield of barley genotypes across non-stress, moderate and severe stress conditions. The significant genotype × environment (G × E) interaction for seed yield suggests that some genotypes were not stable, whereas others were stable. Therefore, there is a need for assessing stability of grain yield for each of the seventeen genotypes in order to identify genotypes with superior grain yield. Baker (1988) and Crossa (1990) elaborated that only qualitative or crossover interactions are relevant in agriculture, and appropriate statistical analysis is required to quantify them. To detect the relative stability of genotypes, the analysis of stability is necessary by applying either parametric or nonparametric methods or both. Thus, better understanding of the relative contribution of cultivars, environments and their interaction as a source of variation could potentially help breeders to develop cultivars with more stable performance (Basford and Cooper, 1998). Sabaghnia et al. (2013), Kendal (2016) and Vaezi et al., (2017) stated

Table 3. Mean grain yield and environmental index (E.I.) values of seventeen barley genotypes tested under normal, moderate and severe stress conditions over two seasons

Irrigation Environments	Normal			Moderate stress			Severe stress		
Seasons / Genotypes	2015/ 2016	2016/ 2017	Mean	2015/ 2016	2016/ 2017	Mean	2015/ 2016	2016/ 2017	Mean
G1	1176.26	1451.73	1314.00	1163.71	1235.19	1199.45	959.74	1011.08	985.41
G2	1285.26	1555.89	1420.58	1271.38	1357.55	1314.47	1043.65	1094.80	1069.22
G3	1242.11	1528.55	1385.33	1228.62	1335.66	1282.14	1123.14	1159.20	1141.17
G4	1343.29	1622.29	1482.79	1328.83	1401.34	1365.09	1172.45	1217.16	1194.80
G5	1624.90	1900.92	1762.91	1607.42	1436.12	1521.77	1384.78	1436.12	1410.45
G6	1608.16	1903.52	1755.84	1590.94	1685.99	1638.46	1442.93	1506.96	1474.94
G7	1630.85	1923.05	1776.95	1613.35	1707.89	1660.62	1423.42	1499.23	1461.33
G8	1389.05	1721.24	1555.15	1374.04	1428.39	1401.22	1185.33	1236.48	1210.90
G9	1419.92	1727.75	1573.84	1404.56	1500.52	1452.54	1243.10	1281.56	1262.33
G10	1619.32	1881.39	1750.35	1601.89	1714.33	1658.11	1359.02	1397.48	1378.25
G11	1523.71	1804.57	1664.14	1507.22	1598.41	1552.81	1249.36	1306.03	1277.70
G12	1381.98	1631.41	1506.69	1367.08	1576.51	1471.80	1217.34	1281.56	1249.45
G13	1275.96	1568.91	1422.44	1262.24	1343.38	1302.81	1159.20	1219.74	1189.47
G14	1156.55	1761.61	1459.08	1144.00	1354.98	1249.49	959.74	1014.94	987.34
G15	1307.21	1588.44	1447.82	1293.15	1402.63	1347.89	1030.77	1081.92	1056.34
G16	1146.88	1446.52	1296.70	1134.60	1356.26	1245.43	936.56	998.20	967.38
G17	1161.76	1479.07	1320.41	1149.28	1241.63	1195.46	901.60	946.68	924.14
Grand Mean	1370.19	1676.29	1523.24	1355.43	1451.58	1403.50	1164.24	1217.01	1190.63
E.I	-2.27	303.83		-17.02	79.12		-208.21	-155.45	

that the main effects due to genotype (G), environment (E) and GE interaction were significant, representing differential responses of the barley genotypes to the environments and the need for stability analysis.

Mean values of grain yield of barley genotypes across three irrigations and two years are shown in Table (3). Grain yield of environments over seasons ranged from 1296.70 to 1776.95 (kg/fed.), from 1195.46 to 1660.62 (kg/fed.) and from 924.14 to 1474.94 (kg/fed.) during normal, moderate and severe stress conditions, respectively. The largest grain yield was recorded for normal conditions followed by the moderate stress condition and then severe stress conditions for all the studied genotypes during the two seasons. The yield potential of the genotype at moderate stress condition was higher than at severe stress condition and could be cultivated under moderate stress condition. The grain yield of all genotypes over 2016/2017 season had higher than grain yield at 2015/2016 season, this increase could be due to increasing rainfall in 2016/2017 season. Most studied genotypes had higher grain yield than grand means under non-stress, moderate, severe stress conditions as well as the growing seasons. Values of environmental index varied between -208.21 to 303.83 in six environments. These genotypes produced the best values of the studied traits during the normal conditions but some genotypes could perform well under drought stress conditions, indicating their inconsistent relative performance and high sensitivity to environmental variation. Consistent performances across different sites and/or years are referred to as yield stability (Thillainathan and Fernandez 2002). This differential yield ranking of genotypes across the environments showed that the G × E interaction effect was of the crossover type (Yan and Hunt 2001).

Stability parameters

Stability analyses were conducted using different parametric stability statistics. The mean grain yield and the parametric stability statistics based on regression models are given in Table (4). The studied genotypes showed significant differences in grain yield. The mean grain yield of all genotypes across six environments ranged from 1146.67 to 1632.97 (kg/fed) and the overall mean grain yield was 1385.34 (kg/fed). Taking mean yield as a first parameter for evaluating the genotypes, eight genotypes (from G5 to G12) had means exceeding the average. In general, G7, G6, G5 and G10 gave the better mean grain yields whilst G17, G1, and G16 had the lowest mean yields under six environments.

According to the parameters of Eberhart& Russell model, regression coefficients $b_i(ER)$and deviation from regression $S^2_{di}(ER)$ranged from 0.77 to 1.58 and from 66.72 to 12799.48, respectively, indicating that genotypes already had different responses to environmental changes. All genotypes showed significant $S^2_{di}(ER)$ values of greater than zero but, in contrast, some genotypes showed regression coefficient (bi) values that were not significantly different from unity (G1, G2, G7, G8, G9, G10, G11 and G16). Genotypes G7 and G9

Table 4. Mean grain yield (Y) and parametric stability statistics based on regression models for seventeen barley genotypes tested in six environments

Methods Genotypes	Y_i	$b_i(ER)$	$b_i(PJ)$	$b_i(FP)$	$S^2_{di}(ER)$	$S^2_i(PJ)$	$S^2_{di}(FP)$	D^2_i	α_i	λ_i	R^2_i	P_i	D_i	C. to GE (%)
G1	1,166.29	0.96^{ns}	-0.04^{ns}	1.11^{ns}	107.27**	39844.59	426.02	408.52	-0.04	0.03	1.00	111658.74	1212.07	0.42
G2	1,268.09	1.01^{ns}	0.01^{ns}	1.06^{ns}	410.77**	42446.19	785.43	410.00	0.01	0.10	0.99	68980.78	1316.39	1.41
G3	1,269.55	0.80**	-0.20**	1.06**	546.74**	33470.07	23.59	410.67	-0.21	0.13	0.98	68447.00	1307.57	1.86
G4	1,347.56	0.87*	-0.13*	1.00*	84.80**	36288.55	906.08	408.41	-0.13	0.02	1.00	42433.32	1389.17	0.34
G5	1,565.04	0.89*	-0.11*	1.04*	12799.48**	50048.43	13823.03	466.54	-0.11	2.99	0.72	7196.60	1607.73	42.20
G6	1,623.08	0.88*	-0.12*	0.92*	259.61**	36821.13	1913.75	409.27	-0.12	0.06	0.99	183.46	1665.13	0.92
G7	1,632.97	0.95^{ns}	-0.05^{ns}	1.13^{ns}	66.72**	39952.88	675.69	408.32	-0.05	0.02	1.00	40.13	1678.60	0.28
G8	1,389.09	1.02^{ns}	0.02^{ns}	1.25^{ns}	562.50**	43355.43	408.13	410.74	0.02	0.14	0.99	31478.38	1438.06	1.91
G9	1,429.57	0.95^{ns}	-0.05^{ns}	0.95^{ns}	73.65**	39797.79	8795.04	408.36	-0.05	0.02	1.00	21889.23	1475.11	0.30
G10	1,595.57	1.06^{ns}	0.06^{ns}	1.28^{ns}	1273.22**	45237.72	178.84	414.19	0.06	0.30	0.97	1752.17	1646.18	4.25
G11	1,498.22	1.10^{ns}	0.10^{ns}	1.29^{ns}	816.56**	46290.76	1360.11	411.98	0.10	0.19	0.98	10671.50	1550.65	2.75
G12	1,409.31	0.85**	-0.15**	1.25**	3220.22**	38526.49	5102.20	423.49	-0.15	0.75	0.90	27360.59	1449.92	10.66
G13	1,304.91	0.77**	-0.23**	0.82**	1087.15**	32899.82	5812.28	413.29	-0.24	0.25	0.96	56269.96	1341.58	3.64
G14	1,231.97	1.58**	0.58**	1.98**	3828.35**	69453.79	17114.57	426.35	0.59	0.85	0.96	89666.09	1307.47	12.66
G15	1,284.02	1.12*	0.12*	1.05*	1188.10**	47492.19	374.18	413.78	0.12	0.28	0.98	63910.39	1337.41	3.97
G16	1,169.84	1.05^{ns}	0.05^{ns}	1.16^{ns}	3352.10**	47036.03	816.80	424.11	0.05	0.79	0.93	111164.00	1220.04	11.10
G17	1,146.67	1.15**	0.15**	1.50**	378.25**	47785.31	876.50	409.85	0.15	0.09	0.99	121909.68	1201.42	1.31

$b_i(ER)$and $S^2_{di}(ER)$Eberhart and Russel's (1966) linear regression coefficientand the variance of the regression deviations, respectively; $b_i(PJ)$ and $S^2_{di}(PJ)$Perkins and Jinks (1968) linear regression coefficient and the variance of the regression deviations, respectively; $b_i(FP)$ and Freeman and Perkins (1971) linear regression coefficient [$b_i(FP)$] and $S^2_{di}(FP)$the variance of the regression deviations; D^2_iHanson's (1970) genotypic stability; $\alpha_i$and λ_iTai's (1971) linear response to environmental effects (α_i) and deviation from the linear response, respectively; R^2_iPinthus's (1973) coefficients of determination; P_iLin and Binns (1988) superiority index; D_iHernandez et al (1993) desirability index; C. to GE (%) contribution to GEI (%).

($b_i(ER)$<1) as well as G8, G10 and G11 ($b_i(ER)$>1) with $b_i(ER)$ close to unity and deviation significantly different from zero had the highest grain yield performance and showing specific adaptability to all the environments. While, G17 and G16 with $b_i(ER)$>1 and lowest average yields were poorly adapted across environments and might have specific adaptation to harsh conditions. G5 with the highest $S^2_{di}(ER)$ had ranked fifth for grain yield performance and G7 with the highest mean grain yield had the minimum$S^2_{di}(ER)$. This genotype had a good combination of yield and stability. The yield performance of genotypes G1 and G2 were below average, $b_i(ER)$ close to unity and low$S^2_{di}(ER)$. Therefore, these genotypes could be stable, but with low seed yield. Thus, six genotypes, namely G7, G8, G9, G10 and G11, with above average grain yield performances, $b_i(ER)$values not significantly different from unity, and $S^2_{di}(ER)$ values significantly different from zero, were found to be more stable than the other genotypes.

Regression coefficients $b_i(FJ)$ (Perkins and Jinks 1968) represent type 2 stability, that is, a genotype is stable when its response approaches the average response of all tested genotypes ($b_i(FJ)$= 0). The genotypes have different $b_i(FJ)$ values, suggests that they responded differently to different environments. Genotypes with $b_i(FJ)$ values greater than zero (such as, G14, G15 and G17) indicated higher yield in more favorable environments. Genotypes, G7, G8, G9, G10 and G11, with values closer to zero, non-significant and highest grain yield were would have an average adaptation to all environments, whereas, the genotypes, G1, G2 and G16 with values closer to zero and lowest grain yield. The other genotypes with values less than zero were adapted to marginal environments. Another important regression procedure for analyzing stability of two way classification dataset was the Freeman and Perkins (1971) linear regression method. In Freeman and Perkins method, the values of$b_i(FP)$ for the 17 genotypes ranged from 0.82 - 1.98. The results of this model (Table 5)

Table 5. Parametric stability statistics based on GE variance and other methods for seventeen barley genotypes tested in six environments

Methods Genotypes	S^2_{xi}	CV_i	θ_i	$\theta_{(i)}$	W_i^2	σ_i^2	IPC A1	IPC A2	ASV	RD_i	RDD_i	$RDDD_i$	I_i	SF	GAI	TF
G1	30616.20	15.00	1420.89	2837.61	804.00	12.53	-0.74	-3.71	3.92	0.92	0.83	0.92	878.45	1.51	1155.63	MML
G2	34308.32	14.61	1519.98	2824.40	1736.55	646.66	-0.22	-2.62	2.65	1.03	0.66	1.03	963.39	1.49	1256.94	MMM
G3	21498.44	11.55	2316.90	2718.14	9237.02	5746.99	-2.29	2.18	4.46	0.65	1.18	0.65	1028.35	1.36	1262.87	MMM
G4	25281.56	11.80	1677.44	2803.40	3218.55	1654.43	-3.85	-0.71	6.58	0.76	1.04	0.76	1086.00	1.38	1340.06	MMM
G5	36785.50	12.25	6986.08	2095.58	53182.25	35629.74	1.33	4.80	5.31	1.11	1.63	1.11	1249.54	1.37	1555.78	MMH
G6	25960.24	9.93	1710.77	2798.96	3532.30	1867.78	-4.68	1.00	8.01	0.78	1.05	0.78	1358.04	1.32	1616.68	MMH
G7	30389.26	10.68	1408.41	2839.27	686.47	-67.39	-4.84	-2.36	8.56	0.91	0.84	0.91	1346.20	1.35	1625.42	MMH
G8	35381.25	13.54	1593.06	2814.65	2424.40	1114.41	-0.14	-1.83	1.84	1.06	1.34	1.06	1079.67	1.45	1379.02	MMM
G9	30268.49	12.17	1414.62	2838.44	744.94	-27.63	-3.78	-2.29	6.82	0.91	1.17	0.91	1143.38	1.39	1421.12	MMM
G10	38318.79	12.27	1945.17	2767.70	5738.40	3367.93	1.11	0.59	1.97	1.15	0.52	1.15	1273.56	1.38	1585.57	MMH
G11	40697.50	13.47	1856.12	2779.58	4900.28	2798.00	1.44	-0.95	2.62	1.22	0.60	1.22	1166.36	1.44	1486.95	MMM
G12	26596.84	11.57	3113.37	2611.94	16733.18	10844.37	-0.63	4.56	4.68	0.80	0.32	0.80	1141.04	1.34	1401.58	MMM
G13	20464.22	10.96	2764.84	2658.41	13452.92	8613.80	-2.69	4.11	6.14	0.61	1.24	0.62	1069.58	1.35	1298.77	MMM
G14	86055.79	23.81	8899.16	1840.51	71187.72	47873.46	7.28	0.90	12.40	2.59	2.69	2.59	749.40	1.84	1205.97	MMM
G15	42468.48	16.05	2089.56	2748.45	7097.35	4292.01	3.73	-1.04	6.42	1.28	0.54	1.28	945.02	1.54	1270.22	MMM
G16	39391.19	16.97	2812.53	2652.06	13901.81	8919.04	4.65	0.87	7.95	1.18	0.45	1.18	843.35	1.54	1156.02	MML
G17	43959.72	18.28	1876.99	2776.79	5096.71	2931.58	4.33	-3.51	8.15	1.32	0.91	1.32	801.77	1.64	1130.98	MML

S^2_{xi}Roemer (1917) environmental variance; CV_iFrancis and Kannenberg (1978) coefficient of variation; $\theta_i$and $\theta_{(i)}$Plaisted and Peterson (1959) and Plaisted (1960) mean variance component for pair-wise GEI, respectively; W_i^2Wricks's (1962) ecovalance; σ_i^2Shukla's (1972) stability variance; PCA1 and IPCA2 Zobel et al., (1988) additive main effects and multiplicative interaction (AMMI) model; ASV Purchase et al. (2000) AMMI stability value; RD_i, $RDD_i$and $RDDD_i$Sharaan and Ghallab (2001) relative deviation, relative deviation distanceand the third statistic, respectively; I_iKataoka (1963) yield reliability index; *SF* Lewis (1954) stability factor; *GAI* geometric adaptability index Mohammadi and Amri (2008); *TF* simple stability model Thillainathan and Fernandez (2002).

showed that genotype G9 were stable, but genotype G14 was unstable.

According to Perkins and Jinks (1968) and Freeman and Perkins (1971), all studied genotypes with variances in regression deviations greater than zero, they would have low predictability because of the environmental stimulus. According to Perkins and Jinks (1968) and Freeman and Perkins (1971), G13 and G3 with the lowest values of $S^2_{di}$and moderate grain yield performance, respectively. These genotypes had a good combination of yield and stability. As for Hanson's (1970) genotypic stability parameter (D_i^2), the genotypes G7, G9, G4 and G1 had the lowest D_i^2 values and thus were identified as stable genotypes, while the genotypes G5, G14, G16 and G12 had the highest Di2 values and therefore were unstable.

Tai's (1971) stability method is based upon the principle of structural relationship analyses, in which partitions the GEI effect into two components: α_i, which measures the linear response to environmental effects, and λ_i, which measures deviation from the linear response in terms of magnitude of the error variance. According to these parameters, a perfectly stable genotype is one in which (α_i, λ_i) = (–1, 1). According to these stability statistics, none of these genotypes showed aα_i and λi values of –1 and 1, respectively. This result indicated that none of the tested genotypes showed perfect/static stability. It could thus be assumed that genotypic performances across the environments were not consistent. Alternatively, genotypes with (α_i, λ_i) > (0, 1) below-average, those with (α_i, λ_i) = (0, 1) showed average and those with (α_i, λ_i) < (0, 1) above-average performances for stability across test environments. Based on the definition of stable cultivars by α_i, the genotypes G10, G11, G14, G15, G16 and G17 showed below-average stability performances, the genotypes G2 and G8 showed average performance stability and nine other genotypes showed above average stability. As for λ_i statistic, all studied genotypes gave consistently above-average except G5 had below-average performances for stability across test environments.

Based on Pinthus's (1973) coefficients of determination (R_i^2), the stability parameter values are the predictability of estimated response. The coefficient of determination (R_i^2) represents agronomic stability (Becker, 1981). A genotype with a high coefficient of determination can be considered to be stable. The predictability of genotypes for the grain yield ranged from 0.72 to 1.00, indicating that 72–100% of the mean grain yield variation was explained by genotype response across different environments. None of the values of coefficient of determinations was significantly different from 1.00 for all genotypes except G5. In terms of this parameter, these genotypes could be considered stable for grain yield across environments. The genotype G7 has highest mean grain yield and coefficient of determination (R_i^2 =1.0), was considered to be most stable genotype.

Lin and Binns (1988) suggested the use of stability index (P_i) when describing the performance of one genotype across a range of environments. The superiority can be assessed by the index P_i based on the GEI. The estimate of P_i could be partitioned into a portion attributed to genetic deviation, that is, the sum of the squares of the genotypes. This would be troublesome to breeders since it does not necessarily imply alteration in the genotypes ranking or in the portion attributed to GEI. Therefore, the genotypes of most stable must be those with the lowest P_i values, most of which would be attributed to genetic deviation (Lin and Binns, 1988). Accordingly, the genotypes G7, G6, G10 and G5 have the highest mean grain yield, the lowest P_i-values and were the most stable genotypes, whereas the genotypes G17, G1 and G16 were the least stable ones.

According to Hernandez et al (1993) parameter (D_i) genotypes are identified as desirable if they high D_i values. In this study, genotypes G7, G6, G10 and G5 recorded the highest $D_i$values and mean grain yield, thus were stable, while the genotypes G17, G1 and G16 were unstable. Based on contribution to GEI (%), the genotypes G7, G9, G4 and G6 were considered stable because they were responsible for 0.28%, 0.30%, 0.34% and 0.92% of the respective contributions to the total interaction sum of squares, whereas G5, G14, G16 and G12 with the highest contributions to GEI were unstable.

The results of the parametric stability statistics based on GE variance and other methods are presented in Table (5). According to environmental variance (S_{xi}^2), phenotypic stability was measured by the magnitude of the variance of a genotype across environments. Environmental variance (S_{xi}^2) of genotypes detects all deviations from the mean seed yield. In this method, the genotypes with low S_{xi}^2values under different environments are considered more stable than the others. Hence, the genotypes G13, G3, and G4 (moderate grain yield) followed by the genotypes G6, G9 and G7 (highest grain yield) had the lowest variation across environments, thus were the most stable genotypes, respectively. While, G14 followed by G17 and G15 were classified as the least stable ones. Regarding to Francis and Kannenberg's (1978) Coefficient of variation stability parameter (CV_i), genotypes with minimum value are considered more stable. Hence, the genotypes G6 and G7 with the highest grain yield performance were more stable ones, and the genotypes G14, G17 and G16 with the lowest grain yield performance were considered as unstable.

According to Plaisted and Peterson (1959) and Plaisted (1960), the genotypes G7, G9 and G1 had lower $\theta_i$values and higher $\theta_{(i)}$values, respectively, and could be considered as stable genotypes, while the genotypes G14, G5 and G12 were unstable. Wricke (1962) proposed the use of ecovalence (W_i^2), which an alternative method that is frequently used to determine stability genotypes based on the GE interaction effects. It indicates the contribution of each genotype to the GEI by partitioning it into variance components assignable to each genotype. An unbiased estimate using Shukla's stability statistic (σ_i^2) of genotypes was determined according to Shukla (1972). A lowest values of $W_i^2$and 2iσ, indicates that a genotype's performance was more stable across environments (Wricke, 1962 and Shukla, 1972). The $W_i^2$and σ_i^2were lowest for genotypes G7, G9 and G1, thus these genotypes were considered more stable, because they contributed the least to the GEI. Unlike, the values ofW_i^2 and σ_i^2 were highest for genotypes G14, G5 and G12, and these genotypes with higher contribution to GEI were recognized as unstable ones.

The use of the AMMI model revealed successively smaller patterns within the GEI. Partitioning of GE interaction indicated the AMMI4 model described the GE interaction patterns for yield using the first four IPCA scores based on cross validation. Results from AMMI analysis also showed that the first PC axis (IPCA1) of the interaction captured 46.39% of the interaction sum of squares. Similarly, the second PC axis (IPCA2) explained a further 27.32% of the G × E interaction sum of squares. The four IPCAs accounted for 94.35% of the total interaction, the remaining 5.65% being the residual or noise, which is not interpretable and thus discarded. According to the AMMI model, the genotypes G7, G6 and G9 as well as the genotypes G1, G17 and G2 had lower values of IPCA1 and IPCA2, respectively, thus were the most stable genotypes, while the genotypes G14, G16 and G17 as well as the genotypes G5, G12 and G13 were unstable, respectively. In proportion to better option ASV, the genotypes G8, G10 and G11 with minimum value and were stable across environments, but the genotypes G14, G7 and G17 with maximum value and were unstable.

The genotypes G7 and G1 according to RD_i, $RDD_i$and $RDDD_i$, the genotype G9 according to $RD_i$and $RDDD_i$, as

Table 6. Ranks of seventeen genotypes using parametric stability statistics in six environments

Genotypes Methods	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17
Y_i	16	13	12	9	4	2	1	8	6	3	5	7	10	14	11	15	17
$b_i(ER)$	8	9	2	4	6	5	7	10	7	12	13	3	1	16	14	11	15
$b_i(PJ)$	8	9	2	4	6	5	7	10	7	12	13	3	1	16	14	11	15
$b_i(FP)$	8	7	7	4	5	2	9	11	3	12	13	11	1	15	6	10	14
$S_{di}^2(ER)$	4	7	8	3	17	5	1	9	2	13	10	14	11	16	12	15	6
$S_i^2(PJ)$	7	9	2	3	16	4	8	10	6	11	12	5	1	17	14	13	15
$S_{di}^2(FP)$	5	7	1	10	16	12	6	4	15	2	11	13	14	17	3	8	9
D_i^2	4	7	8	3	17	5	1	9	2	13	10	14	11	16	12	15	6
α_i	8	9	2	4	6	5	7	10	7	12	13	3	1	16	14	11	15
λ_i	2	5	6	1	15	3	1	7	1	11	8	12	9	14	10	13	4
R_i^2	1	5	9	1	17	5	1	5	1	12	9	16	13	13	9	15	5
P_i	16	13	12	9	4	2	1	8	6	3	5	7	10	14	11	15	17
D_i	15	13	12	9	4	2	1	8	6	3	5	7	10	14	11	16	17
S_{xi}^2	8	9	2	3	11	4	7	10	6	12	14	5	1	17	15	13	16
CV_i	13	12	4	6	8	1	2	11	7	9	10	5	3	17	14	15	16
θ_i	3	4	12	6	16	7	1	5	2	10	8	15	13	17	11	14	9
$\theta_{(i)}$	3	4	12	6	16	7	1	5	2	10	8	15	13	17	11	14	9
W_i^2	3	4	12	6	16	7	1	5	2	10	8	15	13	17	11	14	9
σ_i^2	3	4	12	6	16	7	1	5	2	10	8	15	13	17	11	14	9
IPCA1	7	9	6	3	12	2	1	10	4	11	13	8	5	17	14	16	15
IPCA2	1	3	14	9	17	13	4	6	5	10	8	16	15	12	7	11	2
ASV	5	4	6	11	8	14	16	1	12	2	3	7	9	17	10	13	15
RD_i	7	8	2	3	10	4	6	9	6	11	13	5	1	16	14	12	15
RDD_i	7	6	13	10	16	11	8	15	12	3	5	1	14	17	4	2	9
$RDDD_i$	7	8	2	3	10	4	6	9	6	11	13	5	1	16	14	12	15
SF	11	10	4	6	5	1	3	9	7	6	8	2	3	14	12	12	13
I_i	14	12	11	8	4	1	2	9	6	3	5	7	10	17	13	15	16
GAI	16	13	12	9	4	2	1	8	6	3	5	7	10	14	11	15	17

well as the genotype G17 according to RDD_i had the close to be one values; therefore, these genotypes were regarded as the most stable genotypes. Based on stability factor (*SF*) by Lewis (1954), the genotypes G6, G12 and G7 having relatively lower values of the statistic and were considered stable in comparison to other genotypes. However, the genotypes G14, G15, G16 and G17 having highest values of the statistic of S.F. and were therefore, considered highly unstable. Kataoka's (1963) yield reliability index (I_i) is obtained from a combination of yield and stability. In this study, the $Z_{(0.95)}$ = 1.645 derived from standard normal distribution was used to calculate the yield reliability index. A genotype is stable if it has a high I_i value. The genotype G6 followed by G7, G10 and G5 had the highest yield reliability index and were stable, whereas genotype G14 followed by G17, G16 and G1 had the lowest reliability index and were unstable. Geometric adaptability index (GAI) exhibited that the genotypes G6, G7, G10 and G5 were the most stable, whereas the genotypes G17, G1 and G16 were the most unstable genotypes. In respect to Thillainathan and Fernandez (2002) [TF], the genotypes G5, G6, G7 and G10 were the most stable in the LOW, MEDIUM and HIGH grain yielding environments, due to its high grain yielding performance through the three environmental groups (LYE, MYE and HYE). On the other hand, the genotypes G1, G16 and G17 were judged to be unstable because they had a code "L" through at least one of the three environmental groups (LYE, MYE and HYE) which confirmed that they highly environmentally sensitive genotypes.

According to ranks of seventeen genotypes using the parametric stability statistics, the similar ranking for stability were found among the parameters $b_i(ER)$, $b_i(PJ)$ and α_i, among the parameters $S_{di}^2(ER)$ and D_i^2, among the parameters P_i and D_i, among the parameters θ_i, $\theta_{(i)}$, W_1^2 and σ_i^2, among the parameters RD_i and $RDDD_i$ as well as among the parameters SF, I_i, GAI and TF (Table 6), therefore it is sufficient to use one of them. For this reason, it is could be considered as appropriate alternatives for each other.

Various methods use GEI to facilitate genotype characterization, and as a selection index together with the mean yield of the genotypes. Accordingly, genotypes (both high and low yielding) with minimal variance for yield across environments are considered stable. This may be considered as a biological or static concept of stability. This concept of stability is not acceptable to

Table 7. Spearman's rank correlation coefficients between grain yield and different parametric stability statistics for seventeen barley genotypes under six environments.

Methods	Y_i	b_i(ER)		b_i(FP)	S^2_{di}(ER)	δ^2_i(PJ)	S^2_{di}(FP)						D_i				θ			*IPCA1*	*IPCA2*	*ASV*	*RD*			*SF*	
b_i(ER)	0.31																										
	0.31	1.00**																									
b_i(FP)	0.24	0.69**	0.69**																								
S^2_{di}(ER)	0.11	0.23	0.23	0.32																							
δ^2_i(PJ)	0.19	0.85**	0.85**	0.60*	0.51*																						
S^2_{di}(FP)	-0.13	-0.14	-0.14	-0.16	0.22	0.09																					
	0.11	0.23	0.23	0.32	1.00**	0.51*	0.22																				
	0.31	1.00**	1.00**	0.69**	0.23	0.85**	-0.14	0.23																			
	0.09	0.24	0.24	0.33	1.00**	0.53*	0.21	1.00**	0.24																		
	0.02	0.01	0.01	0.20	0.95**	0.33	0.28	0.95**	0.01	0.95**																	
	1.00**	0.31	0.31	0.24	0.11	0.19	-0.13	0.11	0.31	0.09	0.02																
D_i	1.00**	0.32	0.32	0.25	0.13	0.21	-0.12	0.13	0.32	0.12	0.05	1.00**															
	0.28	0.95**	0.95**	0.70**	0.44*	0.96**	-0.02	0.44*	0.95**	0.45*	0.24	0.28	0.29														
	0.70**	0.84**	0.84**	0.59*	0.36	0.77**	-0.08	0.36	0.84**	0.35	0.13	0.70**	0.71**	0.85**													
	0.19	0.03	0.03	0.20	0.89**	0.32	0.33	0.89**	0.03	0.88**	0.93**	0.19	0.22	0.24	0.20												
	0.19	0.03	0.03	0.20	0.89**	0.32	0.33	0.89**	0.03	0.88**	0.93**	0.19	0.22	0.24	0.20	1.00**											
	0.19	0.03	0.03	0.20	0.89**	0.32	0.33	0.89**	0.03	0.88**	0.93**	0.19	0.22	0.24	0.20	1.00**	1.00**										
	0.19	0.03	0.03	0.20	0.89**	0.32	0.33	0.89**	0.03	0.88**	0.93**	0.19	0.22	0.24	0.20	1.00**	1.00**	1.00**									
IPCA1	0.49*	0.77**	0.77**	0.65**	0.72**	0.85**	0.03	0.72**	0.77**	0.72**	0.56*	0.49*	0.51*	0.88**	0.86**	0.58*	0.58*	0.58*	0.58*								
IPCA2	-0.30	-0.48*	-0.48*	-0.22	0.64*	-0.16	0.39	0.64*	-0.48*	0.63*	0.77**	-0.30	-0.27	-0.29	-0.41	0.78**	0.78**	0.78**	0.78**	0.02							
ASV	0.10	0.09	0.09	-0.09	-0.15	0.14	0.44*	-0.15	0.09	-0.14	-0.09	0.10	0.12	0.10	0.01	0.11	0.11	0.11	0.11	-0.04	0.02						
RD	0.29	0.95**	0.95**	0.69**	0.44*	0.96**	-0.01	0.44*	0.95**	0.45*	0.24	0.29	0.30	1.00**	0.85**	0.24	0.24	0.24	0.24	0.88**	-0.29	0.09					
	-0.02	-0.19	-0.19	-0.25	-0.04	-0.03	0.38	-0.04	-0.19	-0.05	-0.06	-0.02	-0.03	-0.17	-0.13	0.08	0.08	0.08	0.08	-0.14	0.21	0.20	-0.16				
	0.29	0.95**	0.95**	0.69**	0.44*	0.96**	-0.01	0.44*	0.95**	0.45*	0.24	0.29	0.30	1.00**	0.85**	0.24	0.24	0.24	0.24	0.88**	-0.29	0.09	1.00**	-0.16			
SF	0.72**	0.83**	0.83**	0.50*	0.18	0.69**	-0.12	0.18	0.83**	0.17	-0.05	0.72**	0.73**	0.79**	0.97**	0.05	0.05	0.05	0.05	0.76**	-0.53*	0.09	0.79**	-0.06	0.79**		
	0.97**	0.42*	0.42*	0.32	0.22	0.32	-0.08	0.22	0.42*	0.20	0.10	0.97**	0.97**	0.40	0.77**	0.28	0.28	0.28	0.28	0.59*	-0.25	0.17	0.40	0.02	0.40	0.79**	
GAI	1.00**	0.31	0.31	0.24	0.11	0.19	-0.13	0.11	0.31	0.09	0.02	1.00**	1.00**	0.28	0.70**	0.19	0.19	0.19	0.19	0.49*	-0.30	0.10	0.29	-0.02	0.29	0.72**	0.97**

* and **: significant at the 0.05 and 0.01 probability level, respectively

most of plant breeders and agronomists, who prefer genotypes with high mean yields and having the potential of response to agronomic inputs or better environmental conditions. The high yield performance of released cultivars is one of the most important targets of breeders; therefore, they prefer a dynamic (agronomical) concept of stability (Becker and Leon 1988). In dynamic stability, a genotype changes in a predictable manner across a wide range of environmental conditions. According to Backer (1981) and Becker and Leon (1988), in this stability concept, it was not a requirement that the genotypic response to environmental conditions should be equal for all genotypes. The parametric stability statistics P_i, D_i, CV_i, IPCA1, SF, $I_i$and GAI were related with dynamic stability, and other remaining statstics are associated with static stability. In barley, the $b_i(ER)$ and $S^2_{di}(ER)$ by Mut et al., (2010), D_i by Sabaghnia et al., (2013), GAI and P_i by Verma et al., (2018) are associated with dynamic stability but other methods are associated with static stability.

Interrelationship among mean yield and different parametric stability statistics:

Spearman's rank correlation coefficients were calculated for each pair of grain yield and parametric stability statistics and are shown in Table (7). The mean grain yield across environments showed significant positive rank correlation coefficients with parameter *IPCA1* (P<0.05) and with the stability statistics of P_i, D_i, CV_i, *SF*, I_i and *GAI* (P<0.01), but it was not correlated with the other parametric stability statistics. The strong association between mean grain yield and these parametric stability statistics were expected because the values of these parameters were the best for high yielding genotypes. Mean grain yield of barley had significant positive correlation with $b_i(ER)$, $S^2_{di}(ER)$, CV_i, GAI, P_i, I_i, (Mohammadi and Mahmoodi 2008), D_i (Sabaghnia et al., 2013), GAI and P_i (Verma et al., 2018), but the other stability methods were not positively correlated with mean yield. The non-significant correlation among grain yield and parametric stability parameters suggest that stability parameters provide information that cannot be gleaned from average yield alone (Mekbib 2002). Significant positive rank correlation coefficients were obtained between all possible pairs for $b_i(ER)$, $b_i(PJ)$, $b_i(FP)$, α_i, S^2_{xi}, CV_i, *IPCA1*, RD_i, $RDDD_i$and *SF*; for $S^2_{di}(ER)$, D^2_i, λ_i, R^2_i, θ_i, $\theta_{(i)}$, W^2_1, σ^2_i and *IPCA1*; for $S^2_{di}(PJ)$, D^2_i, λ_i, S^2_{xi}, *IPCA1*, $RD_i$and $RDDD_i$; for D^2_i, R^2_i and *IPCA2*; for λ_i, R^2_i and *IPCA2*, for P_i, CV_i, *IPCA1*, *SF*, I_i and *GAI*; and for D_i, *IPCA1*, *SF*, I_i and *GAI*. The parameters $b_i(ER)$ and $b_i(PJ)$ are positively and significantly correlated with I_i (P<0.05) and with $S^2_{di}(PJ)$ (P<0.01), while the parameter $b_i(FP)$ is significant positive correlation with$S^2_{di}(PJ)$ (P<0.05). The statistic $S^2_{di}(ER)$ had positive and significant correlations with the measures of$S^2_{di}(PJ)$, S^2_{xi}, *IPCA2*, $RD_i$and $RDDD_i$. However, the parameter δi^2(PJ) had positive and highly significant correlations with the measures of αi, CV_i and SF. The significant positive correlation were observed among $S^2_{di}(FP)$ and *ASV* (P<0.05), among αi and I_i (P<0.05) as well as among $RD_i$and $RDDD_i$(P<0.01). The IPCA2 was positively associated with θ_i, $\theta_{(i)}$, $W^2_1$and σ^2_i (P<0.01) and negatively correlated with $b_i(ER)$, $b_i(PJ)$, α_i and *SF* (P<0.05). The significant positive correlation between these stability parameters suggests that these parameters would play similar roles in stability ranking of genotypes. Similar findings were mentioned by Sabaghnia et al., (2013) and Verma et al., (2018) in barley, Temesgena et al., (2015) in faba bean and Yaghotipoor et al., (2017) in wheat. Perfect correlation was observed between Y_i, P_i, D_i and *GAI*; between $b_i(ER)$, $b_i(PJ)$ and α_i; between $S^2_{di}(ER)$, D^2_i and λ_i; between θ_i, $\theta_{(i)}$, $W^2_1$and σ^2_i and between S^2_{xi}, $RD_i$and $RDDD_i$. This result indicated the close similarity and effectiveness of these parametric stability statistics in ranking genotypes for stability across environments. Therefore, any parameter of them can be used to characterize the genotypes. Yong-jian et al., (2012) stated that the statistics θ_i, $\theta_{(i)}$, W^2_1 and σ^2_i as well as the statistics $b_i(ER)$, $b_i(PJ)$and $\alpha_i$are equivalent for ranking purposes and were strongly correlated (r=1.00) to each other. Thus these methods should not be treated as separate procedures (Lin et al. 1986).

To find out the relationships among the rank-based parametric stability statistics, cluster analysis with Ward's method based on mean grain yield and 28 parametric stability statistics were performed for seventeen barley genotypes. Dendrogram showing hierarchical classification of relationships among the parametric stability methods is illustrated in Figure 1. Based on cluster analysis, the different parametric stability statistics could be divided into five separate clusters. The first cluster (I) contained mean grain yield (Y_i) and the parametric stability statistics P_i, D_i, GAI and I_i. The second cluster (II) consists of the parametric stability statistics CV_i, IPCA1 and SF. The third cluster (III) consisted of the parametric stability statistics $b_i(ER)$, $b_i(PJ)$, $b_i(FP)$, α_i, $S^2_{di}(PJ)$, S^2_{xi}, $RD_i$and $RDDD_i$. The fourth cluster (IV) comprised of the parametric stability statistics $S^2_{di}(ER)$, D^2_i, λ_i, R^2_i, θ_i, $\theta_{(i)}$, W^2_1, σ^2_i and IPCA2. The fifth cluster (V) comprised of remaining parameters (ASV, $S^2_{di}(FP)$and RDD_i).

The presence of the GEI (non-stress and stress conditions) suggests to some breeders that one of the goals in breeding programmes is to produce high-yielding cultivars for a wide range of environments such as drought stress conditions. Alternatively, the GEI may be reduced by stratifying the environments, particularly by grouping homogeneous locations together (Miller et al. 1959, Liang et al. 1966) or by using irrigation, fertilization, and pest control (Baker, 1971). Conversely, enhancing

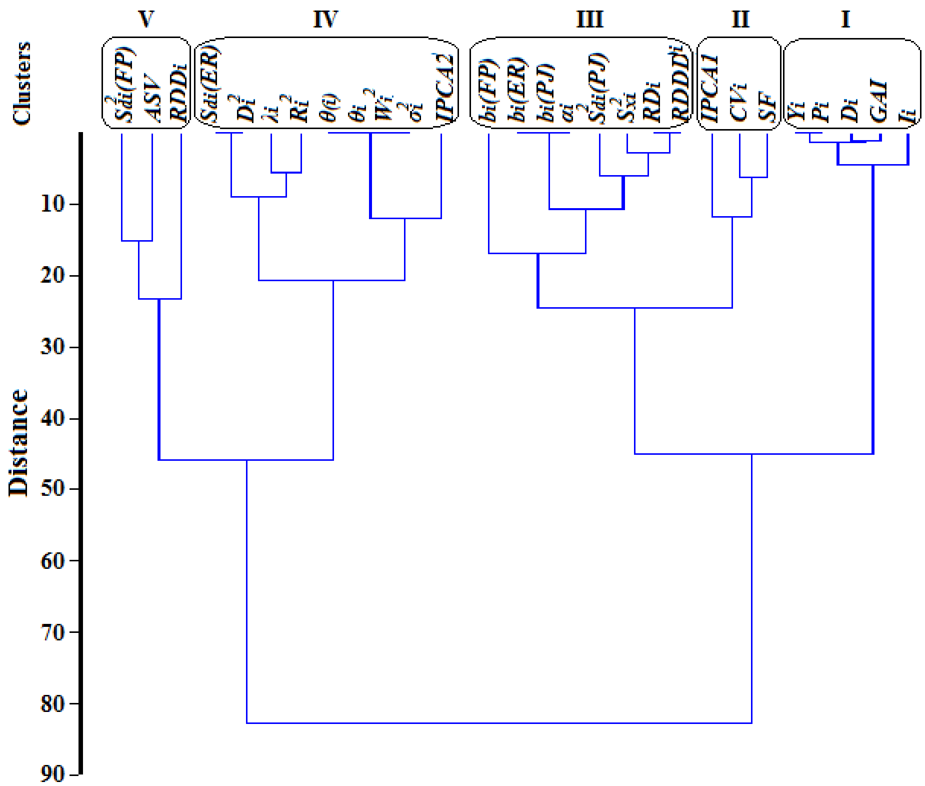

Figure 1. Dendrogram showing hierarchical classification of the parametric stability statistics and mean yield in barley genotypes over six environments.

genetic diversity and providing materials that perform well in poor and in favourable environments, are desirable to achieve sustainable agriculture. Several of the parametric stability statistics employed in the present investigation quantified stability of barley genotypes with or without respect to yield. Genotype evaluation under variable environments and adoption of simultaneous selection for yield and stability is the most valuable selection index that can be used in any plant breeding program. Measures of GEI proved to supplement or complement each other for adaptability behavior of genotypes. The genotypes with good performance and stability should be recommended. The genotypes with a minimum variance for yield across different environments are considered stable. However, both mean yield and stability should be considered simultaneously to exploit the useful effects of GEI and to make the selection of favorable genotypes more precise. Despite the fact that different stability measures are indicative of high, intermediate or low stability performance, the stability values do not provide information for reaching definitive conclusions (Mohammadi and Amri, 2008).

Mean yield was included in the cluster I suggesting that the genotypes G7, G6, G10 and G5 comprised those methods where yield mean had the main influence on the ranking across environments. The parametric stability statistics in the two clusters I and II as measures of genotypic performance, are attempting to integrate both yield and adaptability. These statistics were significantly positively correlated with each other and with mean yield (Table 6) and the introduction of similar stable genotypes shows that using only one of them is sufficient. For this reason, it is could be considered as appropriate alternatives for each other. Thus, the parametric stability statistics P_i, D_i, *GAI*, I_i (cluster I), CV_i, *IPCA1*, *SF* (cluster II) and *TF* would be useful to select high yielding and stable genotypes; therefore, these statistics are related to the dynamic (agronomic) concept of stability. In this concept of stability, a stable cultivar showed constant performance across different environments. This result indicates that the selection of stable genotypes, based on these measures, caused high yield genotypes to be introduced as stable genotypes. Consequently, to select superior and stable genotypes we recommend the use of these parametric stability statistics as the best parameters under drought conditions in Egypt. Similar results reported that selection based on P_i and GAI in wheat (Mohammadi and Amri, 2008); CV_i and $D_i$in barley (Sabaghnia, et al., 2013); P_i, *GAI* and $D_i$in corn (Changizi et al., 2014); P_i in sunflower (Noruzi and Ebadi 2015) and *GAI* and P_i in barley (Verma et al., 2018) would favour selection of the most stable genotypes based on these measures caused high yield genotypes to be presented as most stable genotypes. The parametric stability statistics in clusters III and IV were positively linearly correlated with each other indicating that they were similar for classifying genotypes according to their stability under different environmental conditions (Tables 4 and 5). Hence, in each the clusters III and IV only one of these statistics is sufficient for selecting stable genotypes. Not all of these parameters were significantly correlated with mean yield, indicating that they provide information that cannot be gleaned from average yield alone.

The parametric stability statistics in the two clusters III and IV identify genotypes that are stable based on the static or biological concept of stability. it is essential that both yield and stability are considered simultaneously to select the genotypes. Therefore, these parameters allow the identification of genotypes adapted to environments with unfavorable growing conditions and could be used as compromise methods that select genotypes with moderate yield and high stability. Mut et al., (2010), Sabaghnia, et al., (2013) and Verma et al., (2018) in barley; Changizi et al., (2014) in corn and KILIÇ et al., (2010) in wheat also reported the same results. The parametric stability statistics in the fifth cluster (V) were not correlated with grain yield and other the parametric stability statistics. It should be noted that genotypes identified according to these measures showed an average stability, however, these genotypes may not be as good as the responsive ones under favorable conditions. The methods in cluster V, where phenotypic stability seems to be measured independently of yield level. These measures may not be as suitable as the other methods. Therefore, we do not recommend use of these statistics for cultivar selection. The repeatability, similarity and power of parametric stability statistics for selecting the best genotypes in different crops need to be further investigated. Yong-jian et al., (2011) in corn and Danyali et al., (2012) in chickpea reported that the parametric stability statistics allowing four and three groups that corresponded to different agro-nomic and biological concepts of stability, respectively.

In summary, the parametric stability statistics identified the genotypes G7, G6, G10, G9 and G5 as the most stable genotypes, and G17 and G16 as unstable ones. The remaining genotypes were intermediate between these two groups. With regards to most of the parametric stability statistics, the genotype G7 was found to be the most stable with high grain yield and we are recommended for use under non-stress, moderate and severe conditions in Egypt.

CONCLUSIONS

The parametric stability statistics that have been employed in this study quantified stability of genotypes with respect to yield, stability and both 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. Based on Spearman's rank correlation coefficients and cluster analysis, the parametric stability statisticsP_i, D_i, *GAI*, I_i (cluster I), CV_i, *IPCA1*, *SF* (cluster II) and TF were relatively better than other parametric stability statistics in identifying the stability genotypes during non-stress and stress conditions. Because, these parameters were located under the concept of dynamic or agronomic stability since they are associated with grain yield. While, the other parametric stability statistics were fell within the static or biological stability concept due to they are not correlated with grain yield. The parametric stability statistics grouped in the clusters I and II are useful statistics in breeding programmes where grain yield, popping expansion and stability are essential traits for selecting genotypes. The parametric stability statistics grouped in the clusters III and IV would be useful tools for selecting simultaneously for grain yield and yield stability. The parametric stability statistics in each cluster can be alternated by another; it is not necessary to use all of them. However, in general, most of the parametric stability statistics gave similar rankings to the genotypes and also showed correspondence in ranks given by the parametric. Barley genotypes G5, G6, G7, G8, G9, G10 and G11 were more stable varieties according to all of the parametric stability statistics except $S^2_{di}(PJ)$, $S^2_{di}(FP)$and *IPCA2* measures, because these genotypes had higher grain yield values than the grand mean. The genotype G7 can be recommended as the most stable genotype with regard to both stability and yield across drought conditions in Egypt.

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