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Full Length Research Paper

Comparison of stability statistics for yield in barley (*Hordeum vulgare* L.)

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Analysis of multienvironment trials (METs) of crops for cultivar evaluation and recommendation is an important issue in plant breeding research. Evaluating both stability of performance and high yield is essential in MET analyses. The objectives of this study were to assess interrelationship among these measures and to identify high-yield and stable barley (*Hordeum vulgare* L.) cultivars in 11 environments during 2001 - 2003 in the central Black Sea region of Turkey. Significant differences were observed among barley cultivars for grain yield, thousand-grain weight, hectoliter weight, plant height and heading date. In this study, high values of TOP (proportion of environments in which a genotype ranked in the top third) was associated with high mean yield, but the other methods were not positively correlated with mean yield and instead characterized a static concept of stability. The results of principal component (PC) analysis and correlation analysis of parametric and nonparametric stability statistics and yield indicated that only TOP method would be useful for simultaneously selecting for high yield and stability. This method recommended Fahrettinbey and Sladoran as stable and Balkan 96 and Erginel as unstable genotypes. A biplot of the first two PCs also revealed that the stability statistic methods grouped as three distinct classes that corresponded to different dynamic (agronomic) and static (biological) concepts of stability.

Key words: Barley, genotype x environment interaction, parametric and nonparametric measures, dynamic and static stability.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is grown under varying agro climatic situations. It is an important crop grown worldwide for food, feed and forage. In Turkey, it is cultivated on 3.6 million ha with a production of 8 million tonnes and a mean of 2204 kg/ha. It is the second most cultivated cereal after wheat (Anonymous, 2000).

Soil characters and climatic conditions in Turkey are extremely variable and therefore, suitable cultivars should be released for each specific region or wheat cultivars should have proven wide-ranging adaptability. This means the development of cultivars or varieties that can be adapted to a wide range of environments is the ultimate goal of a crop breeding program. In these programmes the improvement of genotype stability and crop yield over a range of environments are the major aims in relation to adaptation capability. Improved genotypes have to be evaluated in multi-environment trials (METs) to test their performance over different environments. However, genotype ×environment interaction is a major problem in the comparisation of genotype performance over environments (Kang, 1990). Information about phenotypic stability is useful for the selection of crop varieties as well as for breeding programs.

Genotype x environment interactions complicates the identification of superior genotypes (Allard and Bradshaw, 1964) but their interpretation can be facilitated by the use of several statistical modeling methods.

Huehn (1996) indicated that there are two major approaches to studying GxE interaction and determining

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adaptation of genotypes. The first and most common approach is parametric, which relies on distributional assumptions about genotypic, environmental and GxE effects. The second major approach is the nonparametric or analytical clustering approach, which relates environments and phenotypes relative to biotic and abiotic environmental factors without making specific modeling assumptions. For practical applications, however, most breeding programs incorporate some elements of both parametric and non-parametric approaches (Becker and Leon, 1988). Several parametric methods including univariate and multivariate ones have been developed to assess the stability and adaptability of varieties. The most widely used is the joint regression including regression coefficient (b_i) and variance of deviations from regression (S^2_{di}) (Eberhart and Russell, 1966).

Nonparametric stability measures based on ranks provide a viable alternative to present parametric measures based on absolute data (Nassar and Huehn, 1987). For many applications, including selection in breeding and testing programs, the rank orders of genotypes are the most essential information. There is ample justifycation for the use of nonparametric measures in the assessment of yield stability of crop varieties.

According to Huehn (1990), the nonparametric procedures have the following advantages over the parametric stability methods; i) they reduce the bias caused by outliers, ii) no assumptions are needed about the distribution of observed values, iii) they are easy to use and interpret and iv) additions or deletions of one or few genotypes do not cause much variation of results.

Several nonparametric methods have been developed to describe and interpret the responses of genotypes to environmental variation (Nassar and Huehn, 1987; Kang, 1988; Ketata et al., 1989; Fox et al., 1990; Thennarasu, 1995).

Nassar and Huehn (1987) proposed four non-parametric statistics of phenotypic stability ($Si^{(1)}$, $Si^{(2)}$, $Si^{(3)}$ and $Si^{(6)}$) based on the classification of the genotypes in each environment and defined stable genotypes as those whose position in relation to the others remained unaltered in the set of environments assessed. Fox et al. (1990) suggested another nonparametric superiority measure for general adaptability. They used stratified ranking of the cultivars. Integration of stability of performance with yield is necessary for selecting high-yielding, stable genotypes. Kang (1988) developed a method for selecting high yielding; stable genotypes where both yield and Shukla's (1972) stability variance are used as selection criteria. Thennarasu (1995) proposed as stability measures the non-parametric statistics based on ranks of adjusted means of the genotypes in each environment and defined stable genotypes using Nassar and Huehn (1987)'s definition.

The objectives of this study were (i) to identify high yielding and stable barley cultivars over different locations, and (ii) to study the relationships among parametric and nonparametric stability statistics.

MATERIALS AND METHODS

Plant material and field conditions

Eight barley genotypes (4 six-row barley, cv-Kıral 98, cv-Erginel, cv-Plaisent, cv-Çetin 2000 and 4 two-row barley, cv-Sitap 01/6A, cv-Fahrettinbey, cv-Sladoran, cv-Balkan 96) were used as experimental material. Field experiments were carried out in Amasya-Gökhöyük, Samsun-Bafra, Samsun-Gelemen, Samsun-Center, Samsun-Kavak during in the 2001 - 2003 growing seasons and Amasya-Merzifon in the 2001 - 2002 growing seasons in the central Black Sea region of Turkey (Table 1). All experiments were arranged in accordance with a randomized complete-block design with 4 replicates. The experimental plots consisted of 6 rows, each 6 m in length with 20 cm row spacing. The seeding rate was 450 seeds m^{-2} at each location. All trial plots in the all environments were fertilized with 60 kg of N ha^{-1} and 60 kg of P_2O_5 during sowing and 60 kg of N ha^{-1} was applied at the beginning of the stem elongation stage. All field conditions such as growing seasons, environments, soil properties, fertilization treatments, the rainfall at each location during the growing period and sowing-harvest date are summarized in Table 1. Plots 1.2 m x 5 m size were harvested by a combined harvester.

The following characteristics were evaluated in these trials: heading date, plant height, hectoliter weight, thousand-grain weight and grain yield. Heading date was determined visually when approximately 50% of heads in a plot had cleared the boot. Plant height was measured as the distance from the base of the culm to the tip of the spike (excluding the awns). Thousand-grain weight was calculated from the weight of four sets of 100 grains $plot^{-1}$ counting by hand. Hectoliter weight was determined weighting three times each sample $plot^{-1}$ using the 1 l measure. Grain yield (t ha^{-1}) was determined on the basis of the harvested plot in all 11 environments and corrected to a 120 g kg^{-1} moisture basis.

Statistical analysis and procedures

Combined analysis of variance on phenotypic data from trials in 11 environments was computed according to the method given by Comstock and Moll (1963). We used parametric and nonparametric statistics to estimate stability in this study. The statistical procedures used for the stability analysis of genotypes were those proposed by Finlay and Wilkinson (1963), Eberhart and Russell (1966), Nassar and Huehn (1987), Kang (1988), Fox et al. (1990) and Thennarasu (1995).

In using joint regression analysis to study genotype x environment interaction, genotype effects and/or interaction effects within individual environments are related to environmental effects. The interaction sum of squares is divided into two parts: one part represents the heterogeneity of linear regression coefficients (b_i) whereas the second represents the pooled deviations from individual regression lines (S^2_{di}). Finlay and Wilkinson (1963) and Eberhart and Russell (1966) proposed an assessment of cultivar responses to environmental changes using a linear regression coefficient (b_i) and the variance of the regression deviations (S^2_{di}), respectively:

$$b_i = 1 + \frac{\sum_i (Xij - \bar{X}i. - \bar{X}.j + \bar{X}..)(\bar{X}.j - \bar{X}..)}{\sum_j (\bar{X}.j - \bar{X}..)^2}$$

Table 1. Agro-climatic characteristics of the testing environments.

Growing season	Environments	Soil properties	Fertilization (kg ha^{-1})		Altitude (m)	Rain-fall (mm)	Sowing date/ harvest date
			N	P_2O_5			
2001 - 2002	Amasya-Gökhöyük	pH = 7.35 clayey loam	40[a] + 60[b]	60[a]	449	294	21.10.2001/26.06.2002
2002 - 2003	Amasya-Gökhöyük	pH = 7.80 clayey loam	40 + 60	60	449	236	22.10.2002/24.06.2003
2001 - 2002	Amasya-Merzifon	pH = 7.65 clayey loam	40 + 60	60	700	400	30.10.2001/26.06.2002
2001 - 2002	Samsun-Bafra	pH = 6.95 clayey loam	60 + 60	60	20	695	26.11.2001/30.06.2002
2002 - 2003	Samsun-Bafra	pH = 7.15 clayey loam	60 + 60	60	22	472	24.11.2002/28.06.2003
2001 - 2002	Samsun-Gelemen	pH = 7.20 clayey	60 + 60	60	7	673	24.11.2001/31.06.2002
2002 - 2003	Samsun-Gelemen	pH = 7.30 clayey	60 + 60	60	7	563	29.11.2002/29.06.2003
2001 - 2002	Samsun-Center	pH = 7.10 clayey	60 + 60	60	190	613	15.11.2001/02.07.2002
2002 - 2003	Samsun-Center	pH = 6.75 clayey	60 + 60	60	190	420	20.11.2002/03.07.2003
2001 - 2002	Samsun-Kavak	pH = 7.30 loam	60 + 60	60	575	530[c]	30.11.2001/09.07.2002
2002 - 2003	Samsun-Kavak	pH = 7.36 clayey loam	60 + 60	60	640	530[c]	24.11.2002/10.07.2003

[a] Seed-bed; [b] Stem elongation, [c] long-term mean.

$$S_{di}^2 = \frac{1}{E-2}\left[\sum_i\left(X_{ij} - \bar{X}i. - \bar{X}.j + \bar{X}..\right) - (b_i - 1)^2 \sum_i\left(\bar{X}.j - \bar{X}..\right)^2\right]$$

where X_{ij} is the grain yield of cultivar i in environment j, $\bar{X}i.$ is the mean yield of genotype i and $\bar{X}.j$ is the mean yield of the environment j, $\bar{X}..$ is the grand mean and E is the number of environments.

The cultivars are grouped according to the size of their regression coefficients, less than, equal to, or > 1 and according to the size of the variance of the regression deviations. Those geno-types with regression coefficients > 1 would be more adapted to favorable growing conditions, those with regression coefficients < 1 would be adapted to unfavorable environmental conditions and those with regression coefficients equal to one would have an average adaptation to all environments. Genotypes with variances in regression deviations equal to zero would be most stable, whereas a regression deviation greater than zero would indicate low stability because of the environmental stimulus.

Nassar and Huehn (1987) proposed four non-parametric stability statistics ($S_i^{(1)}, S_i^{(2)}, S_i^{(3)}$ and $S_i^{(6)}$) that combine mean yield and stability. The $S_i^{(1)}$ statistic measures the mean absolute rank difference of a genotype over environments. $S_i^{(2)}$ gives the variance among the ranks over environments while $S_i^{(3)}$ is the sum of square deviations in yield units of each classification relative to the mean classification and that $S_i^{(6)}$ is the sum of absolute deviations in yield units of each classification relative to the mean classification. For a two-way data set with "p" genotypes and "q" environments, we denote r_{ij} as the rank of the *i*th genotype in the *j*th environment and $\bar{r}_{i.}$ as the mean rank across all environments for the *i*th genotype. The adjusted rank, r_{ij}^*, is determined on the basis of the adjusted values ($x_{ij}^* = x_{ij} - \bar{x}_{i.} + \bar{x}_{..}$), where $\bar{x}_{i.}$ is the mean performance of the *i*th genotype, x_{ij} is the performance of the *i*th genotype in the *j*th environment and $\bar{x}_{..}$ is the overall mean across environments. The ranks obtained from these adjusted values (x_{ij}^*) depend only on GE interaction and error effects. The genotype with the highest adjusted yield was given a rank of 1 and that with the lowest adjusted yield was assigned a rank of 25. Theoretically, when $S_i^{(1)}, S_i^{(2)}, S_i^{(3)}$ and $S_i^{(6)}$ values are equal zero, maximum stability for a genotype could be pronounced. Four parameters based on yield ranks of genotypes in each environment are derived as follows:

$$S_i^{(1)} = 2\sum_{j}^{q-1} \sum_{j'=j+1}^{q} |r_{ij} - r_{ij'}| / [\ q(q-1)\ ]$$

$$S_i^{(2)} = \sum_{j=1}^{q} (r_{ij} - \bar{r}_{i.})^2 / (q-1)$$

$$S_i^{(3)} = \sum_{j=1}^{q} (r_{ij} - \bar{r}_{i.})^2 / \bar{r}_{i.}$$

Table 2. Analysis of variance and variance components for grain yield, plant height, heading date, thousand grain weight and hectoliter weight of eight barley cultivars grown in 11 environments.

Source of variation	DF	Mean squares				
		Grain yield	Plant height	Heading date	Thousand kernel weight	Hectoliter weight
Block (Env)	33	0.30	27.70	0.86	5.45	0.85
Genotype (G)	7	3.17**	1779.50**	546.18**	816.09**	242.10**
Environment	10	62.33**	12595.81**	408.07**	370.36**	56.70**
GXE	70	1.56**	103.10**	9.72**	14.08**	3.53**
Error	231	0.345	18.30	0.58	3.99	0.90
CV (%)		12.72	4.75	0.58	4.72	4.99

**Significant at the 0.01 probability level.

$$S_i^{(6)} = \sum_{j=1}^{q} \left| r_{ij} - \bar{r}_{i.} \right| / \bar{r}_{i.}$$

Rank-sum proposed by Kang (1988) was another nonparametric stability procedure where both yield and Shukla's (1972) stability variance were used as selection criteria. This index assigns a weight of one to both yield and stability statistics to identify high-yielding and stable genotypes. The genotype with the highest yield was given a rank of 1 and a genotype with the lowest stability variance was assigned a rank of 1. All genotypes were ranked in this manner and the ranks by yield and by stability variance were added for each genotype. The genotype with the lowest rank-sum was the most desirable one. This method assumed equal weight for yield and stability variance. However, plant breeder may prefer to assign more weight to yield than to stability variance.

Fox et al. (1990) suggested non-parametric superiority measure for general adaptability. They used stratified ranking of the cultivars. Ranking was done at each location separately and the number of sites at which the cultivar occurred in the top, middle and bottom third of the ranks was computed. A genotype that occurred mostly in the top third was considered as a widely adapted cultivar.

Thennarasu's (1995) nonparametric stability analysis considers adjusted ranks of genotypes within each test environment. The adjusted rank, r_{ij}^*, is determined on the basis of the adjusted phenotype values ($x_{ij}^* = x_{ij} - \bar{x}_{i.}$), where $\bar{x}_{i.}$ is the mean performance of the ith genotype. The ranks, obtained from these adjusted values (x_{ij}^*), depend only on G X E interaction and error effects.

Thennarasu (1995) proposed the four following nonparametric stability measures:

$$NP_i^{(1)} = \frac{1}{q} \sum_{j=1}^{q} \left| r_{ij}^* - M_{\mathrm{di}}^* \right|$$

$$NP_i^{(2)} = \frac{1}{q} \sum_{j=1}^{q} \left| r_{ij}^* - M_{\mathrm{di}}^* \right| / M_{\mathrm{di}}$$

$$NP_i^{(3)} = \sqrt{\sum (r_{ij}^* - \overline{r_{\mathrm{i.}}^*})^2 / q} \, / \, \bar{r}_{i.}$$

In the above formulas, r_{ij}^* is the rank of x_{ij}^*, $\overline{r_{\mathrm{i.}}^*}$ and M_{di}^* are the mean and median ranks for adjusted values, while $\bar{r}_{i.}$ and M_{di} are the same parameters computed from the original (unadjusted) values.

RESULTS

Data presented in Table 2 indicated that significant differences among genotypes, environments and genotype × environment interaction (GEI) were detected for all evaluated traits. The significant GEI indicated that the responses of the genotypes changed depending on environmental conditions. The means for grain yield varied widely, ranging from 6.94 ton at Samsun-Bafra 2001/02 to 3.14 ton ha^{-1}for Amasya-Gökhöyük in 2001/2002. The means for plant height ranged from 67.5 cm at Amasya-Gökhöyük in 2001/2002 to 122.0 cm at Samsun-Gelemen in 2001/02. The means for heading date ranged from 128.3 days at Samsun-Gelemen in 2001/02 to 138.2 days at Samsun-Kavak in 2002/03. The means for thousand grain weight ranged from 37.2 g at Amasya-gökhöyük in 2001/02 to 46.6 g at Samsun-Gelemen in 2001/02 and at Samsun-center in 2002/2003. The means for kernel weight ranged from 63.9 kg at Samsun-center in 2001/02 to 68.2 kg at Samsun-Bafra in 2002/03 (Table 3).

The genotypes displayed different levels of performance across the 11 environments tested and grain yield means, thousand grain means and hectoliter weight means and ranged from 4.10 to 4.94 ton ha^{-1}, 36.4 to 47.9 g and 61.6 to 69.2 kg, respectively. Two-rowed cultivars, Sitap 01/6A, Fahrettinbey, Sladoran and Balkan 96 had higher both thousand grain weight and hectoliter weight than six-rowed cultivars, Kıral 98, Erginel, Plaisent and Çetin 2000. Plaisent had the highest plant height while Kıral 98 had the lowest plant height. However, Kıral 98 had the highest heading date (Table 4).

The result of 11 different parametric and nonparametric stability statistics and genotype mean yields are presented

Table 3. Means for plant height, height date, thousand grain weight, hectoliter weight and grain yield for barley cultivars in 11 environments in the central Black Sea region of Turkey.

Growing Season	Environment	Plant height (cm)	Heading date (days)	Thousand grain weight (g)	Hectoliter weight (kg)	Grain yield (t/ha)
2001-2002	Amasya-Gökhöyük	80.7	133.2	37.2	64.7	3.26
2002-2003	Amasya-Gökhöyük	67.5	132.7	38.6	67.1	3.14
2001-2002	Amasya-Merzifon	79.1	132.2	38.3	65.5	3.39
2001-2002	Samsun-Bafra	111.1	129.4	43.8	67.5	6.94
2002-2003	Samsun-Bafra	113.0	130.0	42.7	68.2	5.54
2001-2002	Samsun-Gelemen	122.0	128.3	46.6	67.4	6.91
2002-2003	Samsun-Gelemen	111.5	129.3	45.0	67.8	5.56
2001-2002	Samsun-Center	70.0	128.4	45.1	63.9	4.04
2002-2003	Samsun-Center	74.0	128.4	46.6	66.7	4.14
2001-2002	Samsun-Kavak	84.1	137.2	41.5	66.5	4.01
2002-2003	Samsun-Kavak	79.2	138.2	40.4	65.7	3.82
Mean		90.2	131.6	42.3	66.5	4.61

Table 4. Means for plant height, height date, thousand grain weight, hectoliter weight and grain yield of eight barley genotypes tested in the central Black Sea region of Turkey.

Genotype	Plant height (cm)	Heading date (days)	Thousand grain weight (g)	Hectoliter weight (kg)	Grain yield ($t\ ha^{-1}$)
Kıral 98	79.0	137.6	36.4	61.6	4.48
Sitap 01/6A	90.1	128.3	47.9	67.7	4.76
Erginel	94.9	134.9	39.3	64.4	4.10
Plaisent	96.4	130.6	37.7	65.1	4.69
Çetin 2000	95.9	133.9	41.8	65.2	4.55
Fahrettinbey	92.9	129.5	43.7	69.2	4.94
Sladoran	82.8	128.5	45.4	67.0	4.89
Balkan-96	88.9	129.3	46.8	67.1	4.50
Mean	90.1	131.5	42.4	65.9	4.61

in Table 5. A wide adaptability genotype was defined as one with $b_i = 1$ and high stability as one with $S^2_{di} = 0$. In this study values for the regression coefficient (b_i) ranged from 0.471 (Çetin 2000) to 1.240 (Sitap 01/6A) for grain yield. The regression coefficient of cultivars Erginel, Plaisent, Fahrettinbey, Sladoran and Balkan-96 for grain yield was non-significantly different from the unity ($b_i = 1$). Cultivar Sitap 01/6A with regression coefficient (b_i) higher than one had high yield performance and were adapted to favorable environments, whereas Kıral 98 and Çetin 2000 with $b_i < 1$ and low average yields were poorly adapted across environments and might have specific adaptation to harsh conditions. The cultivars Erginel and Balkan-96 had below average performance for grain yield. Furthermore, the cultivar Plaisent showed that deviation from regression was significant. Hence the performance of these cultivars seems to be unpredictable. The cultivars Fahrettinbey and sladoran gave above average performance and had deviation from regression as small as possible ($S^2_{di} = 0$). Accordingly, these cultivars "Fahrettinbey" and "Sladoran" were the most stable cultivars for grain yield (Table 5).

Two rank stability measures ($S_i^{(1)}$ and $S_i^{(2)}$) from Nassar and Huehn (1987) were based on the ranks of cultivars across environments and they gave equal weight to each environment. For a genotype with maximum stability ($S_i^{(1)} = 0$), $S_i^{(2)}$ gives the variance among the ranks across environments. Accordingly, $S_i^{(1)}$ and $S_i^{(2)}$ of the tested cultivars showed that cultivars Erginel, Balkan-96 and Fahrettinbey had the lowest values; therefore, these genotypes were regarded as the most stable genotypes according to $S_i^{(1)}$) and $S_i^{(2)}$. On the other hand Plaisent, Sitap 01/6A and Çetin 2000 had the highest $S_i^{(1)}$ and $S_i^{(2)}$ values; therefore, they were determined to be unstable (Tables 5 and 6).

Two other nonparametric statistics ($S_i^{(3)}$ and $S_i^{(6)}$) combine yield and stability based on yield ranks of genotypes in each environment (Nassar and Huehn, 1987). $S_i^{(3)}$and $S_i^{(6)}$ ranged from 2.11 to 23.77 and 1.32 to 7.71, respectively. Cultivars Erginel, Balkan-96 and Fahrettinbey

Table 5. Mean values (Y) and parametric and nonparametric stability measures for grain yield and test of parametric and nonparametric stability results for eight cultivars across 11 environments.

Genotype	Y[a]	(b_i)	(S^2_{di})	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	RS[b]	TOP[c]	MID[c]	LOW[c]	$NP_i^{(1)d}$	$NP_i^{(2)d}$	$NP_i^{(3)d}$
Kıral 98	4.48	0.865**	0.262*	2.69	5.56	8.40	4.00	10	36.4	9.1	54.5	2.165	0.361	0.484
Sitap 01/6A	4.76	1.240*	0.637**	3.05	7.27	16.11	5.43	11	45.5	18.2	36.3	2.215	0.442	0.397
Erginel	4.10	0.969	0.097	1.85	2.45	2.11	1.32	9	0.0	18.2	81.8	1.306	0.186	0.425
Plaisent	4.69	1.156	0.391**	3.24	7.62	18.76	6.67	10	63.6	0.0	36.4	2.347	0.782	0.850
Çetin 2000	4.55	0.471**	0.217*	2.91	7.60	23.77	7.71	11	45.5	54.5	0.0	2.182	1.091	0.842
Fahrettinbey	4.94	1.163	0.162	2.11	3.21	4.32	3.46	7	63.6	18.2	18.2	1.388	0.348	0.541
Sladoran	4.89	1.159	0.137	2.66	5.16	12.00	5.35	4	54.5	9.1	36.4	1.983	0.662	0.586
Balkan-96	4.50	0.999	0.198	1.85	2.67	2.63	1.72	10	18.2	63.6	27.3	1.223	0.203	0.325
Mean	4.61	1.000												

[a]Y is the general grain yield (kg ha^{-1}) of each genotype across all environments; [b]RS is the rank-sum of Kang (1988); [c]TOP, MID and LOW are the parameters of Fox et al. (1990); [d]NP = nonparametric stability parameters.

had the lowest $S_i^{(3)}$ and $S_i^{(6)}$ values; hence, these cultivars were characterized as the most stable genotypes, as well as with regard to $S_i^{(1)}$ and $S_i^{(2)}$ statistics (Table 5). None-theless, while the mean yield of Fahrettinbey was high, the mean yields of Erginel and Balkan-96 were lower than total mean. On the other hand cultivar Sladoran was high mean yielding, it was characterized as un-stable cultivar according to $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$ parameters (Tables 5 and 6).

According to rank-sum (RS) statistics (Kang, 1988), genotypes with a low rank-sum are regarded as the most desirable. This parameter revealed that cultivars Sladoran and Fahrettinbey had the lowest values and were stable cultivars, whereas cultivars Sitap 01/6A and Çetin 200, which had the highest values, were undesirable (Tables 5 and 6).

Cultivars Plaisent, Fahrettinbey and Sladoran were stable genotypes according to the non-parametric superiority parameter (TOP) (Fox et al., 1990), because these genotypes were placed mostly in the top 3. The superiority parameter of Fox et al. (1990) consists of scoring the percentage of environments in which each genotype ranked in the top, middle and bottom third of trial entries. A genotype usually observed in the top third of entries across environments can be considered relatively well adapted and stable. The undesirable genotypes according to this method were Erginel, Balkan-96 and Kıral 98 (Tables 5 and 6).

Using the stability statistics $NP_i^{(1)}$, $NP_i^{(2)}$ and $NP_i^{(3)}$ genotypes with minimum low values are considered more stable (Thennarasu, 1995). According to $NP_i^{(1)}$ and $NP_i^{(2)}$, cultivars Balkan 96, Erginel and Fahrettinbey were considered stable in comparison to the other cultivars; because these cultivars had lower values (Tables 5 and 6). But, the mean yields of Erginel and Balkan-96 were lower than total mean yield.

Cultivars Balkan 96, Sitap 01/6A and Erginel had the lowest $NP_i^{(3)}$ values and therefore, they were the most stable genotypes. Nonetheless, these cultivars except Sitap 01/6A had lower mean yields than the total mean yield. The cultivars that were unstable based on $NP_i^{(3)}$ were Fahrettinbey and Sladoran, which had the highest mean yields (Tables 5 and 6).

Relationships between mean yield and stability parameters

The results of Spearman's coefficient of rank correlations between mean yield and the different nonparametric stability measures are shown in Table 7. Mean yield was statistically significant ($P < 0.01$) and positively correlated with TOP para-meters. The strong correlation between mean yield and this stability parameter was expected because the values of this statistic were high for high-yielding cultivars. Furthermore, the correlation was positive between mean yield and b_i and rank-sum, but this correlation was statistically non-significant.

On the other hand mean yield was negatively correlated with Nassar and Huehn's (1987) $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ statistics and Thennarasu's (1995) $NP_i^{(1)}$, $NP_i^{(2)}$ and $NP_i^{(3)}$ measures. Nevertheless, this correlation was non-significant (Table 7).

Nassar and Huehn's (1987) $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$ parameters were significantly ($P < 0.01$) and positively correlated to each other and to Thennarasu's (1995) $NP_i^{(1)}$ and $NP_i^{(2)}$ measures.

Table 6. Ranking of eight cultivars after yield data from 11 environments were analyzed for GEI and stability using 12 different parametric and nonparametric methods.

Genotype	Yield rank	b_i	S^2_{di}	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	RS	TOP	$NP_i^{(1)}$	$NP_i^{(2)}$	$NP_i^{(3)}$
Kıral 98	7	3	2	5	5	4	4	10	6.0	5	4	4
Sitap 01/6A	3	2	3	7	6	6	6	11	4.5	7	5	2
Erginel	8	1	1	1	1	1	1	9	8.0	2	1	3
Plaisent	4	1	3	8	8	7	7	10	1.5	8	7	8
Çetin 2000	5	3	2	6	7	8	8	11	4.5	6	8	7
Fahrettinbey	1	1	1	3	3	3	3	7	1.5	3	3	5
Sladoran	2	1	1	4	4	5	5	4	3.0	4	6	6
Balkan-96	6	1	1	2	2	2	2	10	7.0	1	2	1

Table 7. Spearman's rank correlation coefficients between the different parametric and non parametric stability parameters for grain yield of 8 barley genotypes.

Measure	Yield	b_i	S^2_{di}	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	RS	TOP	$NP_i^{(1)}$	$NP_i^{(2)}$
b_i	24.7										
S^2_{di}	- 2.6	53.5									
$S_i^{(1)}$	- 31.0	45.4	92.6**								
$S_i^{(2)}$	- 26.2	49.5	87.4**	97.6**							
$S_i^{(3)}$	- 35.7	49.5	74.6*	90.5**	95.2**						
$S_i^{(6)}$	- 35.7	49.5	76.3*	90.5**	95.2**	1.00**					
RS	27.0	70.2*	74.3*	57.7	57.7	54.0	54.0				
TOP	85.5**	18.8	- 27.3	- 55.4	-55.4	-55.4	-55.4	19.9			
$NP_i^{(1)}$	- 26.2	45.4	92.6**	97.6**	95.2**	88.1**	88.1**	52.8	- 53.0		
$NP_i^{(2)}$	- 38.1	41.2	61.7	83.3**	90.5**	97.6**	97.6**	38.1	- 59.0	81.0**	
$NP_i^{(3)}$	- 33.3	4.1	28.3	52.4	64.3	66.7	66.7	- 11.0	- 69.9*	57.1	76.2*

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level.

The correlation between b_i and rank-sum parameters was significant ($P < 0.05$). Spearman's rank correlations between the S^2_{di} statistic and $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, rank-sum and $NP_i^{(1)}$ parameters were significant. On the other hand TOP was significantly and negatively correlated to the stability parameter of Thennarasu's (1995) $NP_i^{(3)}$. Furthermore, TOP was negatively correlated to all the stability parameters of Nassar and Huehn (1987). However, this correlation was statistically non-significant (Table 7).

To better understand the relationships among the parametric and nonparametric methods, a principal component analysis (PCA) based on the rank correlation matrix was performed. When applying the PC analysis, the two first PCs explained 84.63% (62.60 and 22.03% by PCA1 and PCA2, respectively) of the variance of the original variables. The relationships among the different stability statistics are graphically displayed in a biplot of PCA1 and PCA2 (Figure 1). In this biplot, the PCA1 axis mainly distinguishes the method of TOP from the other methods. Mean yield (Y) also groups near TOP, which we referred to as group 1 (G1) stability measure. The second PC axis separated b_i, $S^2_{di,}$ $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$, rank-sum and $NP_i^{(1)}$ (group 2, [G2]) from $NP_i^{(2)}$ and $NP_i^{(3)}$ (Figure 1).

DISCUSSION

Genotype-by-environment interactions are important sources of variation in any crop and the term stability is sometimes used to characterize a genotype, which shows a relatively constant yield, independent of changing environmental conditions. On the basis of this idea, genotypes with a minimal variance for yield across different environments are considered stable. This idea of stability may be considered as a biological or static concept of stability (Becker and Leon, 1988). This concept of stability is not acceptable to most breeders and agronomists, who prefer genotypes with high mean yields and the potential to respond to agronomic inputs or beter environmental conditions (Becker, 1981). The high yield performance of released varieties is one of the most important targets of breeders; therefore, they prefer a dynamic concept of stability (Becker and Leon, 1988). The parameter TOP was related to the dynamic concept of stability. Additionally, Flores et al. (1998), Sabaghnia et al. (2006),

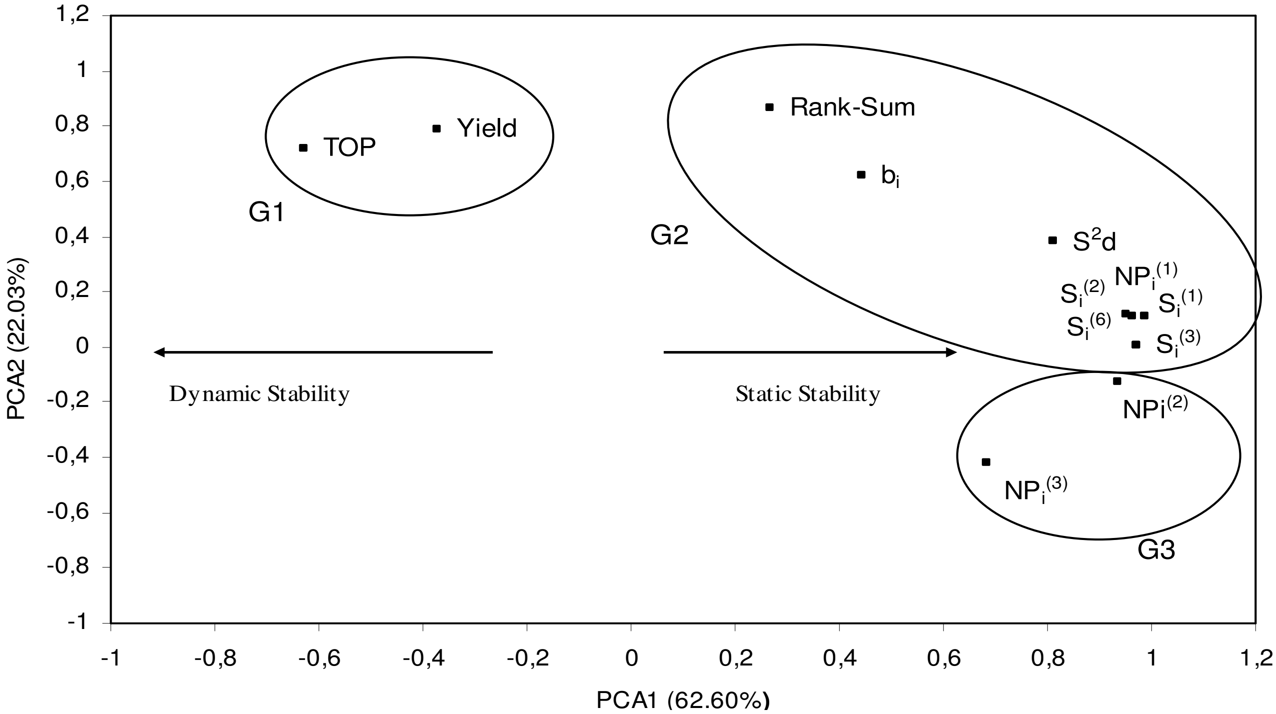

Figure 1. Principal component analysis (PCA1 and PCA2) plot of ranks of stability of yield, as estimated with 11 methods based on yield data from 8 barley cultivars grown in 11 environments, showing the interrelationships between these parameters.

Mohammadi and Amri (2008) and Mut et al. (2009) pointed out that the TOP procedure was associated with mean yield and the dynamic concept of stability. According to Becker and Leon (1988), the genotypic response to environmental conditions should be equal for all cultivars; therefore, these parameters could be used to recommend cultivars adapted to favorable conditions.

The other remaining methods are associated with static stability (Figure 1). Regression coefficient (b_i) and variance of deviations from regression (S^2_{di}) Eberhart and Russell (1966), the 4 nonparametric statistics $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ of Nassar and Huehn (1987) and Thennarasu's (1995) $NP_i^{(1)}$ parameter came together as G2 (Figure 1). These methods classify genotypes as stable or unstable in a similar manner. Consequently, only one of these parameters would be sufficient for selecting stable genotypes in a breeding program. Kara (2000) and Mut (2004) also reported the same correlations in wheat. Flores et al. (1998) reported high rank correlations between $S_i^{(1)}$ and $S_i^{(2)}$ in faba bean (*Vicia faba* L.) and pea (*Pisum sativum* L.). Adugna and Labuschagne (2003), Altınbaş (2004) and Abdulahi et al. (2007) also reported similar results in linseed, chickpea and safflower, respectively. Furthermore, Sabaghnia et al. (2006), Mohammadi and Amri (2008) and Mut et al. (2009) reported high rank correlations between $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ in lentil, wheat and wheat, respectively. Nassar and Huehn (1987) reported that $S_i^{(1)}$ and $S_i^{(2)}$ were associated with the static biological concept of stability, as they defined stability in the sense of homeostasis. Therefore, group 2 stability parameters represent a static concept of stability and could be used as compromise methods that select genotypes with moderate yield and high stability. The parameters $NP_i^{(2)}$ and $NP_i^{(3)}$ were in G3. As with G2, these methods identified stable genotypes based on the static or biological concept of stability, but unlike G2 they were negatively correlated with high yield. Therefore, we do not recommend use of these statistics for cultivar selection (Figure 1).

Environmental variations seemed to be of importance in determining performance and therefore evaluation based on several years and locations is a good strategy to pursue in breeding for varying environments. Farmers in developing countries which use none or limited inputs and grow cereals under harsh and unpredictable environments, require stable varieties. In these cases, genotypes with good performance and stability should be recommended (Mohammadi and Amri, 2008). 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. Therefore, group I statistic (TOP) is crucial because farmers would prefer to use high-yielding cultivars that perform consistently from one environment to another (Figure 1).

In the present study the significant and positive correlation ($P < 0.01$) between TOP and mean yield indicated that TOP was the best parameter for identifying high-yielding genotypes. Considering TOP statistic, cultivars

Fahrettinbey, Sladoran and Sitap 01/6A were the best genotypes. Furthermore, these cultivars had also higher thousand grain weight and hectoliter weight. Therefore, these cultivars could be cultivated successfully in the tested environments and similar ecology. Consequently, to select superior cultivars we recommend the use of TOP as the best parameter.

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