The Journal of Animal & Plant Sciences, 22(2): 2012, Page: 390-398
ISSN: 1018-7081

ASSESSMENT OF PARAMETRIC AND NON-PARAMETRIC METHODS FOR SELECTING STABLE AND ADAPTED SPRING BREAD WHEAT GENOTYPES IN MULTI - ENVIRONMENTS

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ABSTRACT

The objectives of this research were to assess genotype-environment interaction (GEI) and to determine stable bread wheat (*Triticum aestivum* L.) genotypes for grain yield in the South-Eastern Anatolia region of Turkey during the 2004-2007 growing seasons. Twenty five bread wheat genotypes were evaluated in a randomized complete block design with 4 replications. Genotypes, environments main effects and GEI were significant at P < 0.01. Both parametric (b_i, S^2_{di}, R_i^2, W_i^2, $\mathbf{S}_i^2$, CV_i, σ_i^2, $P59$, α_i, λ_i and P_i) and non-parametric ($S_i^{(1)}$, $S_i^{(2)}$ $S_i^{(3)}$ $S_i^{(6)}$, *TOP* and *RS*) univariate stability statistics were used to determine stability of the bread wheat genotypes. Genotypes G16, G6, G3, G5 and G20 were the most stable based on parametric and non-parametric stability measures used. The level of association among the stability measures was assessed using Spearman's rank correlation. The rank correlation matrix indicated that most non-parametric measures were significantly inter-correlated with parametric measures and therefore can be used as alternatives.

Key words: Bread wheat, GE interaction, grain yield, parametric and non-parametric measures and stability.

INTRODUCTION

Wheat is the first important cereal crop of Turkey and now accounts for about 75% of the total cereal production with coverage of 11.9 million hectares (Anonymous, 2008). Bread wheat occupies first place and is grown at about 85% all the wheat cultivated area in Turkey. In South-Eastern Anatolian region, drought occurs when there is irregular precipitation, which causes yield losses in varieties sensitive to drought. Some diseases, such as root rot, yellow and leaf rust negatively affect wheat yield. Furthermore, grain quality is deteriorated significantly by Sunn Pest (*Eurygaster* spp. *Heteroptera:Scutelleridae*).

The development of varieties which can be adapted to a wide range of environments is the ultimate goal of plant breeders in a crop improvement program. A low level of interaction with unpredictable variables such as adverse weather conditions would give more uniform and stable yields, whereas a high level of interaction with a controllable variable such as fertilizer application, is desirable (Mohebodini *et al*., 2006).

High yield stability usually refers to a genotype's ability to perform consistently, whether at high or low yield levels, across a wide range of environments (Annicchiarico, 2002). Although several models for the statistical measurement of the stability have been suggested, each of which show different aspects of stability but not a single method can adequately explain cultivar performance across environments, such as regression slope value (Finlay and Wilkinson, 1963) and deviation from regression (Eberhart and Russell, 1966). Though there are well-recognized statistical and biological limitations in the regression approach (Lin *et al*., 1986; Westcott, 1987; Crossa, 1990; Flores, 1993), it ensures beneficial parameter estimates when number of genotypes and environments considered in the analyses are sufficiently large and when there are no extreme environments that affect regression slopes (Flores, 1993). Some other univariate stability parameters are; environmental variance (S^2_{xi}) (Roemer, 1917 attributed in Becker and Leon, 1988), superiority index (*PI*) (Lin and Binns, 1988); Plaisted and Peterson's (1959) mean variance component for a pair-wise genotype-environment interaction (*P59*), Plaisted's (1960) variance component for GE interaction ($Ø_i$), Wricke's (1962) ecovalence (W_i^2), Shukla's (1972) stability variance (σ_i^2), Francis and Kanenberg's (1978) coefficient of variability (CV_i), Freeman and Perkins (1971) stability method, Hanson's (1970) genotypic stability(D_i^2). All these mentioned methods are parametric. When parametric methods are used for stability, estimations are made about the range of data and the uniformity of variance.

However, non-parametric stability measures are not generally affected by data distribution. As these methods are based on ranks and not on values, a genotype is considered stable if its ranking is relatively constant across environments (Flores *et al*., 1998). Several non-parametric methods have been improved to explain and interpret the responses of genotypes to environmental variation (Huehn, 1979; Kang, 1988; Ketata *et al*., 1989; Fox *et al*., 1990).

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

The objectives of this study were to (i) compare parametric and non-parametric stability statistics of 25 bread wheat genotypes' data collected from a number of different agro-climatic conditions, (ii) determine promising genotypes with high yield and stability (iii) evaluate the level of associations among the parametric and nonparametric stability parameters.

MATERIALS AND METHODS

Twenty-five bread wheat genotypes were grown in 10 environments, Diyarbakır rainfed, Diyarbakır irrigated, Hazro, Ceylanpınar and Mardin during the 2004-2007 growing seasons at the South-Eastern Anatolian in Turkey. The 25 genotypes comprised 20 advanced lines from National program, CIMMYT (International Maize and Wheat Improvement Center) and ICARDA (International Center for Agricultural Research in the Dry Areas) and 5 Turkish cultivars. The experimental layout was a randomized complete block design with 4 replications. Sowing was done with an experimental drill in 1.2 m x 7 m plots, consisting of 6 rows spaced 20 cm apart. The seeding density was 450 seeds per m^{-2}. Harvesting was done in 1.2 m × 5 m plots by combine harvester and yield was determined and expressed in t ha^{-1}. Details of the 25 genotypes and means of grain yield are given in Table 1.

The growing seasons, environments, soil properties together with details of fertilizer application are given Table 2. Amounts of rainfall, together with supplementary irrigation applied at each location during the growing period are also given Table 2.

Table 1. Code, pedigree and selection history of 25 bread wheat genotypes.

Code	Pedigree and selection history of cultivars-lines	Code	Pedigree and selection history of cultivars-lines
G1	ZG-1004.82/KATYA-A.1 GD 2807-0D-0D-0D-0D-0D	G14	SHUHA-7/4/NIF/3/SOTY//NAD63/CHRIS ICW92-0671-4AP-0L-2AP-0L-1AP-0AP
G2	COQ/NAC*2//F.12-71/COC CMBW 89-Y-01530-OTOPM-1D-0D-0D-0D-0D	G15	**GÖNEN-98**
G3	MANGO*2/5/SU.92/CI.13465//PPEN/3/PHO/4/ YMH/TOB//BEZ CMBW 89-Y-01588-OTOPM-3D-0D-0D-0D-0D	G16	SHUHA-6/3/RMN F12-71/SKA//CA8055 ICW92-0717-1AP-0BR-4AP-0AP
G4	BOW"S"/MOR"S"//OPATO/BOW"S" CMBW 89-Y-2584-5D-0D-0D-0D-0D	G17	HP 1731 - (RAJLAXMIN)- OIND
G5	**NURKENT**	G18	F6.74/BUN//SIS/3/LIRA CM90561-21Y-0M-0Y-2M-0Y-2M-0Y
G6	KT/BAPE//FN/GU/3/BZA/4/TRM/5/ALDEN/6/S ERİ/7/BOW CMBW 89-Y-00830-OTOPM-4D-0D-0D-0D-0D	G19	OPATA/RAYON//KAUZ CMBW90Y3180-0 TOPM-3Y-010M-010M-010Y-1M-...
G7	AROONA*3/YR 15 (S)	G20	**ADANA-99**
G8	BEI JING 411	G21	CAZO/KAUZ//KAUZCMBW90Y3284-0 TOPM-14Y-010M-010M-010Y-6M- ...
G9	440259/AKHALTSIKHIS TSITELI DOLI	G22	SKAUZ*2/SRMA CMBW91M02694F-0 TOPY-12M-010Y-010M-010Y- ...
G10	**PEHLİVAN**	G23	SW89.3064*2/BORL65 CMBW91M03786F-0 TOPY-17M-010Y-010M-015Y- ...
G11	MOMCHIL/KATYA 1 LS316	G24	BOW/PRL//BUC/3/LUAN CMSS93Y00118S-105Y-3B-3Y-0100B
G12	TUI//CMH76-252/PVN"S" ICW92-0214-0AP-1AP-2AP-0AP	G25	**BASRİBEY-95**
G13	TUI//CMH76-252/PVN"S"ICW92-0214-0AP- 1AP-3AP-2AP-0AP		

Table 2. Some information on experiment, soil properties and climate for environments where the experiments were conducted

Code	Growing seasons	Environments	Soil properties	Fertilization kg ha^{-1}		Rain-fall mm	Irrigation mm	Mean yield t ha^{-1}
				N	P_2O_5			
E1	2004-05	Diyarbakır (rainfed)	pH = 7.43 clay-silt	60[a] + 60[b]	60[a]	389.4	-	5.74
E2	2004-05	Diyarbakır (irrigated)	pH = 7.61 clay-silt	80 + 60	80	389.4	100	7.65
E3	2004-05	Hazro (rainfed)	pH = 7.50 clay-silt	60 + 60	60	NA*	-	5.81
E4	2004-05	Ceylanpınar (rainfed)	pH = 7.80 clay-silt	60 + 60	40	323.5	-	2.72
E5	2005-06	Diyarbakır- (rainfed)	pH = 7.50 clay-silt	60 + 60	60	534.2	-	7.64
E6	2005-06	Diyarbakır- (irrigated)	pH = 7.69 clay-silt	80 + 60	80	534.2	100	8.15
E7	2005-06	Hazro (rainfed)	pH = 7.56 clay-silt	60 + 60	60	NA*	-	4.77
E8	2006-07	Diyarbakır- (rainfed)	pH = 7.30 clay-silt	60 + 60	60	534.2	-	6.09
E9	2006-07	Diyarbakır- (irrigated)	pH = 7.43 clay-silt	80 + 60	80	534.2	100	6.93
E10	2006-07	Mardin (rainfed)	pH = 7.58 clay-silt	60 + 60	50	319.0	-	3.16

[a]: Sed bed [b]: Stem elongation *, data not available.

Statistical analyses: A combined analysis of variance was first undertaken across the test environments. Then ten parametric stability parameters were performed in accordance with Eberhart and Russel's (1966) the regression coefficient (b_i) and deviation from regression (S^2_{di}), Pinthus's (1973) coefficients of determination (R^2), Wricks's (1962) ecovalance (W_i^2), Shukla's (1972) stability variance (σ_i^2), Francis and Kannenberg's (1978) coefficient of variability (CV_i) and genotypic variance (S^2_i); Tai's (1971) environmental effects (α_i) and deviation from the linear response (λ_i); Plaisted and Peterson's (1959) mean variance component for pair-wise GEI (*P59*). Lin and Binn's (1988) superiority index (P_i) which the genotypes of greatest interest would be those with the lowest P_i values,

Two sets of non-parametric statistics to estimate stability were used in this study. One of them (Huehn, 1979; Nassar and Huehn, 1987) consisted of four nonparametric stability statistics ($S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and $S_i^{(6)}$) combining mean yield and stability (see also Becker and Leon, 1988; Akçura and Kaya, 2008). We also used the methodology described by Fox *et al*., (1990), who proposed a nonparametric superiority measure for general adaptability using stratified ranking of cultivars. A genotype that occurred mostly in the top third (high *TOP*-value) was considered a widely adapted cultivar. Kang's (1988) rank-sum (*RS*) is another non-parametric 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 is given a rank of one and a genotype with the lowest stability variance is assigned a rank of one. All genotypes are ranked in this manner, and the ranks of yield and stability variance are summed for each genotype. Genotypes with the lowest rank-sum are the most desirable (Mohammadi and Amri, 2008).

Rank measures and adjusted means of grain yields were used to depict plot by SAS PLOT procedure (Lu, 1995; Akçura *et al*., 2008). Besides, the stability parameters were compared using Spearman's rank correlation (Steel *et al*., (1997). All analysis was performed using SAS Software (SAS Institute, 1999).

RESULTS AND DISCUSSION

Combined analysis of variance for grain yield showed that genotypes' and environments' main effects and GEI were significant at P<0.01 (Table 3). In the case GEI effect suggest that there are significant differences in responses of genotypes to environments, and hence sensitivity and instability (Akçura *et al*., 2009). Genotypic rank differences over environments showed the existence of crossover GEIs (Crossa, 1990). This was fitted by the significant effect of GEI in the joint analysis of variance (Table 3) and showed the necessity to assess the response of the genotypes to environmental variation.

Table 3. Analysis of variance for stability parameter for 25 bread wheat genotypes.

Source of variation	DF	Sum of Squares	Mean Squares
Genotype (G)	24	99.916124	4.163172**
Environments E + G*E	225	3309.206	14.7**
E (linear)	1	3112.73069	
G x E (Linear)	24	159.879	6.661 **
Pooled Deviations	200	36.596	0.18298
Pooled Error	720	312.744940	0.434368
CV(%) : 11.23			
** P < 0.01			

Parametric measures: Considering environment, grain yield of environments over genotypes ranged from 3.16 t ha^{-1} for E10 to 8.15 t ha^{-1} for E6. Grain yield of genotypes over environments ranged from 5.29 t ha^{-1} to

6.31 t ha^{-1} (Table 4). Taking the grain yield over environments as the first parameter genotypes, G4, G5, G6, G7, G11, G13, G16, G17, G18, G19, G20, G22, G24 and G25 had higher grain yield than grand mean grain yields (5.87 t ha^{-1}), while genotypes G1, G2, G3, G8, G9, G10, G12, G14, G15, G21 and G23 had lower values than mean grain yield.

Table 4. Mean yield of 25 bread wheat genotypes tested across 10 environments (t ha^{-1}).

Code	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Mean
G1	5.15	6.49	5.93	2.70	6.88	7.35	4.36	5.09	5.55	3.41	5.29 m *
G2	5.49	8.05	5.36	3.08	7.08	7.50	5.43	6.08	7.20	1.80	5.71 g-k
G3	4.73	6.25	5.51	2.88	6.85	7.02	4.96	5.38	6.39	2.98	5.29 m
G4	5.46	7.27	5.41	3.20	8.26	8.12	5.27	6.23	7.19	3.36	5.98 b-g
G5	5.93	8.81	6.22	3.69	7.73	8.62	5.42	6.27	7.09	3.36	6.31 a
G6	5.72	7.30	6.11	2.34	7.19	7.58	4.52	5.93	6.25	3.04	5.60 i-l
G7	5.93	7.63	6.66	2.56	8.40	8.33	5.43	5.23	6.48	3.38	6.00 b-f
G8	3.90	7.10	5.67	3.29	7.18	7.90	4.55	5.30	6.68	2.09	5.37 lm
G9	6.11	7.52	6.20	3.26	7.64	8.04	3.92	6.01	6.67	3.14	5.85 e-i
G10	6.21	7.04	6.42	2.47	7.05	7.53	4.90	6.01	6.57	3.28	5.75 f-j
G11	6.13	7.84	5.84	2.96	7.29	8.44	5.01	5.70	6.64	3.28	5.91 c-h
G12	5.81	7.79	5.66	2.86	7.21	8.31	4.03	6.48	7.47	2.78	5.84 e-i
G13	5.80	7.04	6.20	2.82	7.60	7.99	4.74	6.59	7.30	2.84	5.89 d-h
G14	5.57	6.61	5.56	2.17	6.60	7.97	5.28	5.33	6.00	3.24	5.43 klm
G15	5.71	7.76	6.37	2.08	6.60	7.82	4.49	6.01	6.78	2.94	5.66 h-l
G16	6.30	8.34	5.72	3.36	7.67	8.61	5.05	6.52	7.51	2.90	6.20 abc
G17	6.26	8.13	6.03	2.53	8.07	8.62	4.80	7.08	7.94	3.65	6.31 a
G18	6.51	8.54	5.96	2.63	8.95	9.05	4.88	6.24	7.46	2.91	6.31 a
G19	6.01	8.43	5.78	2.15	8.64	8.66	4.56	6.69	7.74	3.69	6.23 ab
G20	6.19	7.76	5.97	2.53	7.30	8.20	4.98	6.22	6.49	3.42	5.91 d-h
G21	5.27	7.18	4.34	2.88	7.16	7.75	4.79	6.03	6.80	3.23	5.54 j-m
G22	5.54	8.33	5.96	2.29	8.42	8.61	5.13	6.72	7.94	3.42	6.24 ab
G23	5.78	7.58	5.51	1.84	8.06	9.01	4.45	5.76	6.93	3.12	5.80 e-j
G24	5.80	7.47	5.57	2.68	8.70	8.30	3.77	7.13	7.45	4.59	6.15 a-d
G25	6.24	8.88	5.39	2.78	8.52	8.32	4.61	6.11	6.80	3.11	6.08 a-e
Mean	**5.74**	**7.65**	**5.81**	**2.72**	**7.64**	**8.15**	**4.77**	**6.09**	**6.93**	**3.16**	**5.87**
LSD (0.05)											**0.29**

*: Means in a column with the same letter are not significantly different at the 5% level.

The results of eleven parametric stability parameters and mean grain yield are given in Table 5. The measures of adaptability and stability are necessary for its suggestion to target environments for preferring genotypes. According to Eberhart and Russell (1966), regression coefficients (b_i) approximating 1.0 coupled with deviation from regression (S^2_{di}) of zero indicate average stability. Genotypes have general adaptability when associated with high mean yield while genotypes are poorly adapted to environments when associated with low mean yield. Regression coefficient (b_i) values above 1.0 define genotypes with higher sensitivity to environmental alteration. Regression coefficients decreasing below 1.0 ensure a measure of greater resistance to environmental variation, and hence, increasing specificity of adaptability to low yielding environments. Genotypes G17, G18, G19, G22 and G25 had higher grain yields and a coefficient values greater than 1.0 (Table 5). These genotypes are sensitive to environmental variations and would be suggested for cultivation under favourable conditions, whereas G1, G3, G14 and G21 with b_i<1 and lowest average yields were poorly adapted across environments and might have specific adaptation to harsh conditions. On the contrary, G5, G7, G16 and G24 had higher grain yields and a coefficient values near 1.0. These genotypes showed average stability. Among these cultivars G16 was the most appropriate one, because it had higher yield value than the mean, b_i values near 1.0 and low S^2_{di} (i.e. regression coefficient not significantly different from 1.0 with grain yields above grand mean).

Pinthus's (1973) stability parameter or coefficient of determination (R^2_i) values which are the predictability of response estimates (R^2_i=1), ranged from 0.87 to 0.99, in which a variation of mean grain yield was explained by genotype response across environments. None of values of coefficient of determinations was significantly different from 1.0. In terms of this parameter, all of genotype could be considered stable for grain yield (Table 5).

Wricke (1962) suggested using ecovalance (W_i^2) as a stability parameter. According to this stability parameter, genotypes with the smallest ecovalance (W_i^2) values are considered stable. The W^2_i was lowest for genotypes G6, G13, G16, G20 and highest for G1, G2, G3, G7, G8 and G24 (Table 5). The good correlation between W_i^2 and S_i^2 (r = 0.85**) showed that these two measures led to similar results. According to the environmental variance (S^2_i), G3 followed by G1, G21, G19 and G10 had the lowest variation across environments and G18 followed by G19, G23, G25, G22 and G17 showed the largest variation (Tables 5).

According to Francis and Kannenberg's (1978) coefficient of variation stability parameter (CV_i), genotypes G3, G1, G5, G10 and G4 were considered to be stable although they had low performance except G5, and the genotypes G23, G18, G19, G25, and G22 with the highest yield performance were considered unstable.

An unbiased estimate using stability variance (σ^2_i) of genotypes was determined according to Shukla (1972). The stability variance (σ^2_i) revealed that the genotypes G6, G11 G20, G16, G13, G4 and G5 had the smallest variance across the environments, while the genotypes G24, G8 and G2 had the largest σ^2_i. Hence, the genotypes G6, G11 G20, G16, G13, G4 and G5 were stable while the genotypes G24, G8 and G2 were unstable. When the stability parameter of Plaisted and Peterson (1959) was used, the genotypes G6, G11, G20, G13, G16, G4 and G5 had lower *P59* and stable genotypes

Tai's model (1971) is based upon the principle of structural relationship analyses, which the GEI effect of genotype is portioned into two components. They are the linear response to environmental effects, which is measured by statistic (α_i) and deviation from the linear response, which are measured by (λ_i) statistic. A perfectly stable genotype is that in which (α_i, λ_i)= (-1, 1). According to these stability statistics, durum wheat genotypes G2, G1 and G10 could be considered as stable (Table 5) because these genotypes were near to (α_i, λ_i)=(-1, 1) and G12 had average stability with (α_i, λ_i) = (0, 1).

The superior genotype should be the one with the lowest superiority index (P_i) value, thus the negative (r = –0.98**) correlation between yield and P_i-value (Table 6). In such cases, the genotypes of greatest interest would be those with the lowest P_i values, most of which would be attributed to genetic deviation (Lin and Binns, 1988). Accordingly, genotypes G17, G5, G19, G22, G18 and G16 have the greatest mean yield and the lowest P_i values (Table 5).

Non - parametric measures: The result of 6 different non-parametric stability statistics and genotype mean grain yields are presented in Table 5. Two rank stability measures ($S_i^{(1)}$ and $S_i^{(2)}$) from Nassar and Huehn (1987) are based on ranks of genotypes across environments and they give equal weight to each environment. Genotypes with fewer changes in ranking are considered to be more stable (Becker and Leon, 1988). Zero variance is an indication of maximum stability. Accordingly, $S_i^{(1)}$ and $S_i^{(2)}$ of the tested genotypes showed that genotypes G6, G20 and G16 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, G24, G1, G3, G2, G18 and G10 had the highest $S_i^{(1)}$ and $S_i^{(2)}$ values; therefore, they were determined to be unstable

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 9.4 to 59.22 and 1.54 to 7.37, respectively. Genotypes G6, G21, and G3 had the lowest $S_i^{(3)}$ and $S_i^{(6)}$ values hence, these genotypes were characterized as the most stable genotypes, as well as with regard to $S_i^{(3)}$ and $S_i^{(6)}$ statistics (Table 5). However, mean yields of G17, G1 and G23 were lower than total mean. While genotypes G13, G19 and G24 were the 3 highest mean yielding genotypes, they were characterized as unstable genotypes according to $S_i^{(3)}$ and $S_i^{(6)}$ parameters (Tables 5).

According to the non-parametric (TOP) superiority index (Fox *et al*., 1990), G17 was an adapted genotype, because it ranked in the Top third of genotypes in a high percentage of environments (high *TOP* value, 80%), and was followed by G16 (70%), G22 (70%), G5 (60%) and G19 (60%) (Table 5). 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. The undesirable genotypes identified by this method were G3 and G21.

According to rank-sum (*RS*) statistics (Kang, 1988), genotypes with a low rank-sum are regarded as the most desirable. This parameter revealed that genotypes G5, G16 and G17 had the lowest values, and were stable genotypes, whereas genotypes G1, G3 and G8, which had the highest values, were undesirable (Table 5).

Interrelationship among parametric and non-parametric measures: The rank correlations between grain yield and stability measures are given in Table 6. Grain yield is significantly correlated with b_i, $S_i^{(2)}$, α_i, $S_i^{(6)}$, *TOP* (P<0.01) and with the measures of $S_i^{(3)}$ and R^2 (P<0.05) and showed a negative and significant correlation with Pi and *RS* (P<0.01). The coefficient of regression (b_i) is significantly correlated with $S_i^{(2)}$, CV_i, D_i^2, α_i, $S_i^{(3)}$, $S_i^{(6)}$, *TOP* (P<0.01) and R^2 (P<0.05), and showed a negative and significant correlation with P_i (P<0.01). Coefficient of determination (R^2_i) had negative and significant correlations with S_{di}^2, W_i^2, σ_i^2, *P59*, λ_i, $S_i^{(2)}$, *RS* (P<0.01) and with the measures of α_i, P_i and $S_i^{(1)}$ (P<0.01). Deviation from Regression (S_{di}^2) is significantly correlated with W_i^2, σ_i^2, *P59*, λ_i, (P<0.01) and with the measures of $S_i^{(1)}$ $S_i^{(2)}$and RS (P<0.05). Ecovalance (W_i^2) was positively associated with σ_i^2, *P59*, λ_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and *RS* (P<0.01).

Table 5. Mean grain yield values (t ha^{-1}) and stability parameters of 25 bread wheat genotypes across 10 environments.

		Parametric measures								Non-parametric measures									
Code	$\bar{X}$ [a]	b_i [b]	R_i^2 [c]	S_{di}^2	W_i^2	S_i^2	CV_i	σ_i^2	*P59*	α_i	λ_i	P_i	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	*TOP*	*RS*	*F*
G1	5.29	0.77	0.94	0.15	2.74	2.20	28.05	0.32	0.27	-0.23	1.22	1.43	10.24	74.68	20.74	2.84	10.00	47.00	5
G2	5.71	*1.01*	0.91	0.42	3.36	3.92	34.67	0.40	0.31	0.01	3.58	0.95	10.60	80.54	43.29	4.98	30.00	41.00	2
G3	5.29	0.77	0.95	0.11	2.57	2.13	27.54	0.30	0.26	-0.24	0.92	1.44	10.51	78.10	16.03	2.30	0.00	44.00	**8**
G4	5.98	0.94	0.96	0.14	1.25	3.19	29.85	0.14	0.19	-0.06	1.21	0.49	7.89	43.79	30.54	4.50	30.00	18.00	4
G5	*6.31*	*0.97*	0.96	0.15	1.24	3.41	29.23	0.14	0.19	-0.03	1.30	0.24	7.33	40.49	20.34	5.36	60.00	7.00	**8**
G6	5.60	*0.95*	0.98	0.08	0.72	3.17	31.80	0.08	0.16	-0.05	0.67	0.90	6.36	29.33	9.40	1.54	10.00	22.00	**10**
G7	*6.00*	*1.00*	0.92	0.33	2.62	3.80	32.44	0.31	0.27	0.01	2.79	0.56	9.56	63.73	48.94	5.58	40.00	30.00	2
G8	5.37	*0.96*	0.89	0.45	3.68	3.59	35.	0.43	0.33	-0.04	3.86	1.38	9.31	63.66	19.17	2.17	10.00	47.00	2
G9	5.85	*0.95*	0.95	0.17	1.43	3.27	30.89	0.16	0.20	-0.05	1.44	0.62	7.89	46.50	24.27	3.46	30.00	24.00	2
G10	5.75	0.88	0.95	0.17	1.78	2.83	29.24	0.21	0.22	-0.12	1.42	0.80	10.11	70.77	32.05	4.16	20.00	30.00	5
G11	5.91	*0.96*	0.98	0.08	0.74	3.24	30.43	0.08	0.16	-0.04	0.72	0.56	7.82	45.60	17.28	3.38	40.00	14.00	6
G12	5.84	1.06	0.97	0.16	1.41	4.05	34.44	0.16	0.20	0.06	1.37	0.64	8.53	51.29	25.59	3.75	20.00	24.00	1
G13	5.89	*0.99*	0.97	1.29	1.04	3.48	31.66	0.12	0.17	-0.01	1.11	0.60	8.16	46.28	24.19	3.49	30.00	18.00	5
G14	5.43	0.86	0.93	0.23	2.42	2.78	30.66	0.28	0.25	-0.14	1.95	1.26	11.02	88.00	19.74	2.50	10.00	41.00	2
G15	5.66	*1.01*	0.95	0.20	1.64	3.71	34.07	0.19	0.21	0.01	1.74	0.89	8.22	48.49	20.37	2.49	10.00	30.00	2
G16	*6.20*	*1.04*	0.97	0.12	0.99	3.87	31.70	0.11	0.17	0.04	0.10	0.33	6.76	34.40	40.30	5.77	70.00	10.00	**11**
G17	*6.31*	1.10	0.98	0.12	1.25	4.29	32.83	0.14	0.19	0.10	0.99	0.23	7.67	44.46	35.13	5.85	80.00	10.00	7
G18	*6.31*	1.23	0.99	0.08	2.33	5.34	36.60	0.27	0.25	0.24	0.64	0.30	10.53	81.29	50.53	6.86	50.00	19.00	3
G19	*6.23*	1.19	0.98	0.14	2.24	5.01	35.91	0.26	0.24	0.19	1.20	0.29	9.42	68.00	59.22	7.37	60.00	21.00	3
G20	5.91	*0.96*	0.99	0.08	0.71	3.30	30.74	0.08	0.16	-0.03	0.71	0.55	6.67	33.16	18.63	3.26	20.00	13.00	**8**
G21	5.54	0.89	0.94	0.21	2.02	2.94	30.92	0.23	0.23	-0.11	1.77	1.01	8.04	46.40	13.34	2.50	0.00	36.00	4
G22	*6.24*	1.17	0.98	0.12	1.77	4.79	35.10	0.20	0.22	0.17	0.99	0.29	8.98	56.93	47.49	6.22	70.00	16.00	5
G23	5.80	1.18	0.98	0.11	1.97	4.96	38.36	0.23	0.23	0.19	0.95	0.69	7.42	41.51	25.68	3.18	10.00	30.00	2
G24	*6.15*	*1.00*	0.87	0.61	4.87	4.02	32.61	0.58	0.40	0.00	5.19	0.42	11.04	92.50	54.06	6.07	40.00	32.00	2
G25	*6.08*	1.13	0.96	0.23	2.36	4.63	35.40	0.28	0.25	0.13	1.94	0.42	9.16	62.67	35.68	4.56	30.00	26.00	1
Mean	5.87																		

KEY: $\bar{X}$=Grain yield (t ha^{-1}); b_i= Regression coefficient, R^2= Pinthus's coefficient of determination; S_{di}^2; W_i^2= Wrick's ecovalance; S_i^2= Environmental variance; CV_i=Coefficient of variation; σ_i^2=Shukla's stability; P59= Plaisted and Peterson's stability parameter; α and λ= Tai's stability parameters; PI=Lin and Binns superiority measure; Genotype absolute rank difference mean over n environments (S_i^1); between ranks variance over n environments (S_i^2); sum of the absolute deviations of the squares of ranks for each genotype (S_i^3); the sum of squares of ranks for each genotype relative to the mean of ranks(S_i^6); Kang's rank-sum(RS); number of sites at which the genotype occurred in the top third of the ranks (TOP). F= Frequency of number of stability parameters over all of stability parameters for each genotype, if a genotype had nine values of *F*, it could be as stable. [a]Values in italics of are significantly higher than the mean at P < 0.05. [b]Values in italics of are non significantly different from the unity at P < 0.05. None of values of coefficient of determinations was significantly different from 1.0

Table 6. Spearman's rank correlation coefficients between yields and stability parametric and non-parametric measures for 25 bread wheat genotypes across 10 environments

	Measures	YLD	Parametric measures										Non-parametric measures					
			b_i	R^2	S_{di}^2	W_i^2	S_i^2	CV_i	σ_i^2	P59	α_i	λ_i	P_i	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP
Parametric measures	b_i	0.67**																
	R^2	0.46*	0.46*															
	S_{di}^2	-0.22	-0.11	-0.81**														
	W_i^2	-0.30	-0.02	-0.67**	0.51**													
	S_i^2	0.66**	0.98**	0.38	-0.04	0.09												
	CV_i	0.30	0.86**	0.24	0.06	0.24	0.89**											
	σ_i^2	-0.30	-0.02	-0.67**	0.51**	1.00**	0.09	0.24										
	P59	-0.30	-0.02	-0.67**	0.51**	1.00**	0.09	0.24	1.00									
	α_i	0.67**	1.00**	0.46*	-0.11	-0.02	0.98**	0.86**	-0.02	-0.02								
	λ_i	-0.23	-0.14	-0.90**	0.91**	0.62**	-0.05	0.07	0.62**	0.62**	-0.14							
Non-parametric	P_i	-0.98**	-0.65**	-0.50*	0.25	0.37	-0.63**	-0.28	0.37	0.37	-0.65*	0.27						
	$S_i^{(1)}$	-0.21	-0.06	-0.58*	0.47*	0.86**	0.02	0.10	0.86**	0.86**	-0.06	0.50*	0.29					
	$S_i^{(2)}$	-0.19	-0.05	-0.55**	0.42*	0.86**	0.04	0.12	0.86**	0.86**	-0.05	0.47*	0.27	0.99**				
	$S_i^{(3)}$	0.63*	0.69**	0.02	0.17	0.33	0.73**	0.53**	0.33	0.33	0.69**	0.19	-0.59**	0.39	0.39			
	$S_i^{(6)}$	0.87 **	0.66**	0.21	-0.01	0.05	0.68**	0.34	0.05	0.05	0.66**	-0.01	-0.84**	0.17	0.18	0.88**		
	TOP	0.95**	0.66**	0.37	-0.11	-0.24	0.65**	0.30	-0.24	-0.24	0.66**	-0.15	-0.94**	-0.14	-0.12	0.69**	0.89**	
	RS	-0.79**	-0.37	-0.69**	0.47*	0.81**	-0.29	0.03	0.81**	0.81**	-0.37	0.55*	0.82**	0.66**	0.65**	-0.17	-0.51**	-0.74**
		-0,7854	-0,3738	-0,6869	0,4692	0,8054	-0,2946	0,0315	0,8054	0,8054	-0,3738	0,5508	0,82	0,6592	0,6477	-0,1662		

* P < 0.05, ** P < 0.01

Environmental variance (S^2_i), is significantly correlated with CV_i, αi, $S_i^{(3)}$, $S_i^{(6)}$ *TOP* (P<0.01) and showed a negative and significant correlation with P_i (P<0.01). The coefficient of variation (CV_i) was positively and significantly associated with α_i and $S_i^{(3)}$ (P<0.01). Stability variance (σ_i^2) had positive and significant correlations with λ_i, $S_i^{(1)}$, $S_i^{(2)}$ and *RS* (P<0.01). *P59* is significantly correlated with λ_i $S_i^{(1)}$, $S_i^{(2)}$ and *RS* (P<0.01). Alpha (α_i) is significantly correlated with $S_i^{(3)}$, $S_i^{(6)}$ and *TOP* (P<0.01), and showed a negative and significant correlation with P_i (P<0.01). Lamda (λ_i) had positive and significant correlations with $S_i^{(1)}$, $S_i^{(2)}$ and *RS* (P<0.05). The superiority index (P_i) was negatively associated with $S_i^{(3)}$, $S_i^{(6)}$ and *TOP* (P<0.01) and positively correlated with *RS* (P<0.01).

Non-parametric measure of $S_i^{(1)}$, is significantly correlated with $S_i^{(2)}$ and *RS* (P<0.01). $S_i^{(2)}$ had positive and significant correlations with *RS* (P<0.01). $S_i^{(3)}$, as well as $S_i^{(6)}$ parameters were positively correlated with *TOP* (P<0.01). The *TOP* was negatively and significantly associated with *RS* (P<0.01).

Environmental variations are important in determining performance, and hence, evaluations based on several years and locations are a good strategy to pursue in breeding for varying environments. Agricultural producers in developing countries which use restricted inputs and grow cereals under harsh and unstable environments require stable varieties. In these cases, genotypes with good performance and stability should be recommended.

The most severe limitation of the regression approach is the poor repeatability of both b_i and S^2_{di} (Jalaluddin and Harrison, 1993); its usefulness in measuring genotype adaptability depends largely on the assumption that genotypes respond linearly to the environments. In such cases, the results of nonparametric estimation and testing procedures, which are based on ranks, can be more reliable (Mut *et al*., 2009). Several multivariate methods which have been proposed allow a more detailed analysis of GEI, but the complexity of these methods, sometimes regarded as their main advantage, paradoxically is the main obstacle to their widely usage in plant breeding (Flores *et al*., 1998). Though, different stability methods are indicative of high, intermediate or low stability performance, the stability values do not provide information for reaching definitive conclusions (Mohammadi and Amri, 2008). Many stability measures that have been used in this study considered that stability of genotypes related to yield and stability. Hence, it is essential that both yield and stability should be considered simultaneously to reveal the beneficial effects of GEI and to select the genotypes.

According to the matrix correlation analysis, parametric and non-parametric measures used in this study revealed that these parameters can be used for evaluating the responses of bread wheat genotypes to changing environments. Also, mean grain yield ($\overline{X}$) and coefficient of regression (b_i) of genotypes were significantly positively correlated to the non-parameters of $S_i^{(3)}$, $S_i^{(6)}$ and *TOP* used. Similarly, Akçura and Kaya (2008); Kılıç *et al*. (2010) reported high rank correlations between grain yield and these measures of stability. Although they do not supply information about genotype adaptability, non-parametric stability measurements seem to be useful alternatives to parametric measurements (Yue *et al*., 1997). The repeatability, reliability and suitability of parametric and non-parametric methods to select the best genotypes in different crops need to be further investigated.

Conclusion: The study of genotypic stability identified new suitable advanced lines and revealed why some varieties are grown in the South Eastern Anatolia region. According to both parametric and non-parametric stability parameters, bread wheat genotypes G16, G6, G3, G5 (Nurkent) and G20 (Adana-99) were more stable varieties, which had 11, 10, 8, 8 and 8 stability parameters out of 17 stability statistics used, respectively. In fact, Adana-99, Turkish commercial variety, has high grain quality. This variety was released by the Cukurova Agricultural Research Institute (one of the costal regions). It not only appears to have a specific adaptation to this region but can also be grown successfully in other spring zones of Turkey. Nurkent, another Turkish commercial variety, also showed high stability and may still be of interest for growers in South Eastern Anatolia. From the advanced lines, genotypes G16, G6 and G3 could be used success fully as progenitors in breeding programmes for the production of high grain yield and stability bread wheat in the costal zones of Turkey

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