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Assessment of Parametric and Non-parametric Methods for Selecting Stable and Adapted Durum Wheat Genotypes in Multi-Environments

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Abstract

Seventeen parametric and non-parametric methods for grain yield of 5 cultivars and 20 advanced durum wheat genotypes evaluated across 10 environments during the 2004-2007 growing seasons were used to assess performance stability and adaptability of the genotypes as well as to study interrelationship among these methods. *Biplot* analysis based on the rank correlation matrix indicated that most non-parametric methods were significantly inter-correlated with parametric methods. The results also showed that stability methods could be classified into four groups based on biplot analyses. The group related to the dynamic stability concept and strongly correlated with mean grain yield included the parameters of regression coefficient (b_i), alpha (α_i), *TOP* (proportion of environments in which a genotype ranked in the top third), environmental variance (S_i^2), coefficient of variation (CV_i), D_i^2, $S_i^{(3)}$ and $S_i^{(6)}$. The second group included Wricke's ecovalence (W_i^2), the Huehn's parameters [$S_i^{(1)}$ $S_i^{(2)}$], Shukla's stability variance (σ^2_i), Plaisted and Peterson's parameter (*P59*) and Tai's model (λ_i) which were influenced by both yield and stability simultaneously. The third group included Kang's parameter (*RS*) and superiority index (P_i), which only measures stability. Genotypes 18, 16 and 2 were most stables based on parametric and non-parametric stability methods used.

Keywords: *Biplot* analysis, durum wheat, GE interaction, grain yield, parametric and non-parametric methods and stability

Introduction

Wheat is the most important cereal crop of Turkey and now accounts for about 75% of the total cereal production with an acreage of 11.9 million hectares (Anonymous, 2008). In Turkey, durum wheat ranks second to bread wheat. Durum wheat is grown in about 15% all the wheat cultivated area in Turkey, and has been cultivated for many years, playing a significant role in South-Eastern Anatolia. This region is known as the primary gene center of wheat diversification, as well as the area of first wheat domestication around 10.000 BP (Harlan, 1981; Diamond, 1997; Nesbit and Samuel, 1998; Lev-Yadun *et al.*, 2000; Karagöz and Zencirci, 2005).

Durum wheat varieties have shown narrower adaptation and yield fluctuations over environments than bread wheat (Saini and Gautam, 1990). Hence, development of high yielding, improved grain quality, and stable durum wheat cultivars is very important. Besides, the strategy for durum wheat breeding has to involve multi location testing of progenies to cope with inconsistent and unpredictable climatic conditions (Verma *et al.*, 1988). Also, when selecting genotypes across a number of environments, plant breeders look for a non-crossover type of genotype x environment interaction (GEI), or preferably the absence of GEI for general adaptation (Matus-Cadiz *et al.*, 2003).

Although several models for the statistical methods of the stability have been suggested, each of which shows different aspects of stability, no single method can adequately explain cultivar performance across environments. Regression analysis as detailed by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) has been widely used for a long time. Though there are well-recognized statistical and biological limitations in the regression approach (Westcott, 1986; Lin *et al.*, 1986; Crossa, 1990; Flores, 1993), it ensures obtaining reliable parameter estimates when numbers 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, as reported in Becker and Leon, 1988), desirability index (D_i) (Hernandez *et al.*, 1993), superiority index (P_i) (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 aforementioned 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 methods 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 nonparametric methods have been improved to interpret the responses of genotypes to environmental variation (Huehn, 1979; Kang, 1988; Ketata *et al*., 1989; Fox *et al*., 1990).

The main goal of this study was to compare the most commonly used methods in GEI analysis, to explain their different approaches, to group of stability parameters by *biplot* analysis, and to show their relative advantages when applied to the performance of 25 durum wheat genotypes data collected from a number of different agro-climatic conditions.

Materials and methods

Twenty-five durum wheat genotypes were grown in 10 environments in the localities of Diyarbakir, Hazro, Ceylanpinar and Mardin during the 2004-2007 growing seasons at the South-Eastern Anatolia in Turkey. The 25 genotypes comprised 20 advanced lines from CIMMYT (International Maize and Wheat Improvement Center) and ICARDA (International Center for Agricultural Research in the Dry Areas) and 5 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 500 seeds·m^{-2}. Details of the 25 genotypes (G) and means of grain yield are given in Tab. 1. The growing seasons, environments (E), soil properties are given Tab. 2. Amount of rainfall, together with supplementary irrigation and details of fertilize application at each environment during the growing period are also given Tab. 2.

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) regression coefficient (b_i), 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), Hernandez *et al.* (1993) desirability index (D_i^2), in which genotypes were identified as desirable if they had low D^2_i values and Lin and Binn's (1988) superiority index (P_i) in which the genotypes of greatest interest would be those with the lowest P_i-values.

It has been used two sets of nonparametric statistics to estimate stability 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 non-parametric superiority method for general adaptability using stratified ranking of cultivars. A genotype that occurred mostly in

Tab. 1. Code, pedigree, selection history and mean yield (tha^{-1}) of genotypes

Code	Pedigree and selection history of cultivars-lines	Mean yield t ha^{-1}
G1	SUOKUKKO=CD96492-A-1M-030Y-040PAP-9Y-0B	5.32
G2	SILK-3/SHAG-23 CDSS92B609-2M-0Y-0M-0Y-1B-0Y	6.20
G3	PATKA-7/YAZI-1 CDSS92B116-9M-OY-OM-OY-2B-OY	5.73
G4	DIPPER-2/BUSHEN-3 CDSS92B128-5M-OY-OM-OY-2B-OY	6.09
G5	AYDIN-93=OMRABİA "S"	5.55
G6	AİNZEN-1	5.73
G7	ALBİT-9	5.96
G8	AZEGHAR-1	5.89
G9	HFN94N MOR NO 40/Blrn	5.47
G10	DİYARBAKIR-81= LD.393 x Belle-Tc2Cit71. SE:0.364-1S-4S-OS	5.57
G11	DON PEDRO 87.1 CD56981-4Y-3M-3Y-0M-1Y-0B	5.76
G12	RASCON-39/TILO-1 CDSS92B611-9M-0Y-0M-0Y-1B-0Y	5.62
G13	SORA/2*PLATA-12 CD96587-G-1M-030Y-040PAP-040YRL-1H-0Y	5.78
G14	YAZI-11.1 CD83744-B-6M-030YRC-040M-11YRC-0PAP-1Y-0B	6.01
G15	FIRAT-93 = AA "S" /Vol "S" //Fg "S" /3/Shwa "s" CM:2798-6-1M-2Y-1Y-OM	5.56
G16	ZÜHRE = SN TURK MI 83-84 375/ NIGRIS-5//TANTLO-1 CD94483-A-3Y-040M-030Y-2PAP-4Y-0B	5.83
G17	SRN-1/LARU/3/YAV-1/FGO//ROH/4/LICAN CD91Y160-2Y-040M-030Y-1M-0Y-0B-1Y-0B	5.50
G18	AUK/GUIL//GREEN CD91Y7-1Y-040M-030Y-3M-0Y-0B-1Y-0B	5.92
G19	SOOTY-9/2*TARRO-1 CDSS92B990-C-1M-0Y-0M-0Y-2B-0Y	5.39
G20	HARAN-95 =Korifla (D.S.15 Gieger) =Korifla CD523-3Y-1Y-2M.OY	5.90
G21	SORA/2*PLATA-12 CD96587-G-1M-030Y-040PAP-040YRL-4H-2Y-0B	5.57
G22	DIPPER-2/BUSHEN-3 CDSS92B128-5M-0Y-0M-0Y-2B-0Y	5.82
G23	THORSHANE-2.2=CD86672-3M-030YRC-040PAP-8Y-0P-AP-2Y-0B	5.41
G24	SN TURK MI 83-84 375/NIGRIS-5//TANTLO-1 CD94483-A-3Y-040M-030Y-2PAP-1Y-0B	5.39
G25	SARIÇANAK-98= Daki "S"	5.77
Mean		5.64

Tab. 2. Data 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	2004-2005	Diyarbakır (rainfed)	pH= 7.43 clay-silt	60[a]+60[b]	60[a]	389.4	-	5.73
E2	2004-2005	Diyarbakır (irrigated)	pH= 7.61 clay-silt	80+60	80	389.4	100	7.25
E3	2004-2005	Hazro (rainfed)	pH= 7.50 clay-silt	60-60	60	NA*	-	5.71
E4	2004-2005	Ceylanpınar (rainfed)	pH= 7.80 clay-silt	60+60	40	323.5	-	3.16
E5	2005-2006	Diyarbakır- (rainfed)	pH=7.50 clay-silt	60+60	60	534.2	-	6.86
E6	2005-2006	Diyarbakır- (irrigated)	pH=7.69 clay-silt	80+60	80	534.2	100	8.09
E7	2005-2006	Hazro (rainfed)	pH=7.56 clay-silt	60+60	60	NA*	-	4.77
E8	2006-2007	Diyarbakır- (rainfed)	pH=7.30 clay-silt	60+60	60	534.2	-	5.75
E9	2006-2007	Diyarbakır- (irrigated)	pH=7.43 clay-silt	80+60	80	534.2	100	6.63
E10	2006-2007	Mardin (rainfed)	pH=7.58 clay-silt	60+60	50	319.0	-	2.49

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

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). All statistical analyses were performed using the SAS (Statistical Analyses Systems) program (SAS Institute, 1999).

Biplot analyses based on the correlation matrix in order to obtain an understanding of the relationship among stability parameters were performed using the Microsoft Excel program (Lipkovich and Simith, 2002).

Results and discussions

Combined analysis of variance for grain yield showed that main effects for genotypes and environments, as well as GEI were significant at P<0.01 (Tab. 3). The significance of the GEI effect suggests 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), which showed the necessity to assess the response of the genotypes to environmental variation.

Parametric methods

Grain yield of environments over genotypes ranged from 2.49 t ha^{-1} for E10 to 7.97 t ha^{-1} for E6. Grain yield of genotypes over environments ranged from 5.32 t ha^{-1} to 6.20 t ha^{-1} (Tab. 4). When considering grain yield over environments, genotypes G2, G3, G4, G11, G13, G14, G16, G20, G22 and G25 had higher grain yield than mean

Tab. 3. Combined analysis of variance of yield data of 25 durum wheat genotypes tested across 10 environments

Source	DF	SS	MS	F Ratio	Prob>F
Model	279	3221.105	11.545	28.306	
Environment	9	2983.120	331.458	305.194	<.0001
Repl.[Environment] and Random	30	32.582	1.086		
Genotype	24	53.502	2.229	5.466	<.0001
Environment x Genotype	216	151.901	0.703	1.702	<.0001
Error	720	293.669	0.408		
C. Total	999	3514.774			
	CV (%): 11.0		R^2: 88.4		

grains yields (5.71 t ha^{-1}), while genotype G1 had the lowest grain yield (5.32 t ha^{-1}).

The results of eleven parametric stability parameters and mean grain yield are given in Tab. 5. 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 have poorly adaptation to environments tested 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 greater resistance to environmental variation, and hence, increasing specificity of adaptability to low yielding environments. Genotypes G7, G8 and G20 had higher grain yields and coefficient values above *1.0* (Tab. 5). These genotypes are sensitive to environmental variations and would be suggested for cultivation under favorable conditions, whereas G1, G10, G12, G15, G17, G19, G21, G23 and G24 with b_i<1 and lowest average yields were poorly adapted across environments and might have specific adaptation to harsh conditions. On the contrary, G2, G4, G13, G14 and G16 showed average stability (*i.e.* regression coefficient not sig-

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

Code	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Mean
G1	5.95	6.86	5.33	2.91	7.47	7.27	4.36	5.30	5.75	2.05	5.32
G2	6.09	7.99	6.17	3.53	8.93	8.15	5.43	6.12	6.93	2.66	6.20
G3	5.60	7.07	6.06	3.25	7.80	7.46	4.96	5.64	6.84	2.67	5.73
G4	6.09	7.32	5.95	3.09	8.66	8.47	5.27	6.48	6.89	2.68	6.09
G5	6.10	7.29	5.56	2.96	7.05	8.59	5.42	5.67	5.27	1.59	5.55
G6	5.99	6.89	5.80	3.18	7.96	7.45	4.52	6.34	7.18	1.99	5.73
G7	6.67	8.51	5.61	2.99	8.13	8.05	5.43	5.52	7.15	1.56	5.96
G8	6.09	7.28	5.52	3.06	8.18	8.54	4.55	6.12	7.21	2.37	5.89
G9	5.80	7.36	5.83	2.98	6.72	8.31	3.92	5.18	6.70	1.92	5.47
G10	6.08	7.37	5.80	2.94	7.04	7.82	4.90	5.19	6.10	2.48	5.57
G11	5.68	6.75	5.12	2.97	8.33	8.18	5.01	5.59	7.39	2.60	5.76
G12	5.95	8.10	5.51	3.45	6.24	7.77	4.03	6.05	6.09	3.05	5.62
G13	6.00	7.69	6.13	2.95	7.10	7.52	4.74	5.70	7.26	2.69	5.78
G14	5.11	8.07	6.34	3.12	7.88	8.85	5.28	6.01	6.11	3.37	6.01
G15	4.96	6.30	5.50	3.17	7.50	7.97	4.49	5.92	6.69	3.10	5.56
G16	6.18	6.80	5.80	3.34	7.88	8.12	5.05	5.71	7.03	2.42	5.83
G17	5.47	6.89	5.73	3.05	7.41	7.93	4.80	5.21	6.20	2.28	5.50
G18	6.10	7.28	5.43	3.38	8.30	7.96	4.88	6.08	6.98	2.82	5.92
G19	4.89	6.21	5.34	3.00	7.29	8.10	4.56	5.50	6.40	2.56	5.39
G20	5.18	7.26	6.02	3.37	8.39	8.59	4.98	6.16	6.82	2.22	5.90
G21	5.14	7.86	5.64	3.29	7.14	7.73	4.79	5.52	6.36	2.18	5.57
G22	5.50	7.69	6.01	3.11	7.92	7.74	5.13	5.85	5.91	3.40	5.82
G23	5.84	6.75	5.30	3.17	7.15	7.15	4.45	5.29	6.58	2.37	5.41
G24	5.04	6.45	5.48	3.35	7.08	7.85	3.77	5.71	6.59	2.63	5.39
G25	5.75	7.30	5.75	3.43	7.45	7.69	4.61	5.93	7.32	2.49	5.77
Mean	5.73	7.25	5.71	3.16	7.64	7.97	4.77	5.75	6.63	2.49	5.71

nificantly 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 0.86 to 0.99, in which a variation of mean grain yield was explained by genotype response across environments. None of the values of coefficient of determinations was significantly different from 1.0. In terms of this parameter, all genotypes could be considered stable for grain yield (Tab. 5).

Wricke (1962) suggested the use of 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 G17, G3, G18, G16, G25, G23, G1 and G4 and highest for G12, G5, G7, G14, G9, G15 and G22 (Tab. 5).

According to the environmental variance (S^2_i), G23 followed by G15, G22, G12, G24 and G2 had the lowest variation across environments and G7 followed by G8, G5, G2 and G9 showed the largest variation (Tab. 5). The good correlation between W^2_i and S^2_i (r =0.88**) showed that these two methods led to similar results.

According to Francis and Kannenberg's (1978) Coefficient of variation stability parameter (CV_i), genotypes G22, G15, G12 and G3 were considered to be stable although they had low performance, and the genotypes G7, G5, G9 and G8 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 G17, G3 G16 and G18 had the smallest variance across the environments, while the genotypes G12, G5, G7 and G14 had the largest σ^2_i. The genotypes G17, G3 G16 and G18 were stable while the genotypes G12, G5, G7 and G14 were unstable.

When the stability parameter of Plaisted and Peterson (1959) was used, it indicated that the genotypes G17, G16, G18, G3, G1, G23 and G25 had lower *P59* values and could be considered as stable genotypes.

Hernandez's (1993) desirability index (D_i^2) revealed that G23, G3 and G17 had the lowest D_i^2 values and thus were stable, and G7, G9, G12 and G9 had the highest D_i^2 values and therefore were unstable.

Tai's model (1971) is based upon the principle of structural relationship analyses, in 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 one in which (α_i, λ_i)= (-1, 1). According to these stability statistics, durum wheat genotypes G15 and G23 could be

Tab. 5. Mean grain yield values (t ha^{-1}) and 17 stability parameters of 25 durum wheat genotypes across 10 environments

Code	Parametric methods												Non-parametric methods						
	X	b_i	R_i^2	W_i^2	S_i^2	CV_i	σ_i^2	$P59$	D_i^2	α_i	λ_i	P_i	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	TOP	RS	F
G1	5.32	0.97	0.97	0.79	3.20	33.58	0.09	0.13	1.11	-0.03	0.86	0.82	6.71	32.01	8.76	1.65	0.00	32.00	10
G2	6.20	1.07	0.98	1.01	3.91	31.90	0.11	0.15	2.20	0.07	0.96	0.10	6.56	35.21	20.22	6.00	80.00	12.00	9
G3	5.73	0.94	0.98	0.59	2.95	29.95	0.06	0.12	0.63	-0.07	0.52	0.42	7.00	40.04	20.15	3.35	10.00	15.00	8
G4	6.09	1.09	0.98	0.94	3.99	32.77	0.11	0.14	2.23	0.09	0.81	0.15	8.69	53.78	22.46	4.44	70.00	10.00	6
G5	5.55	1.06	0.90	3.74	4.15	36.67	0.44	0.30	4.85	0.06	4.12	0.74	10.82	82.23	48.93	5.03	30.00	43.00	2
G6	5.73	1.04	0.96	1.53	3.76	33.84	0.18	0.18	2.46	0.04	1.68	0.46	10.13	68.50	36.66	4.83	30.00	30.00	2
G7	5.96	1.21	0.95	3.72	5.14	38.02	0.44	0.30	6.07	0.21	2.68	0.32	12.07	105.34	62.51	6.84	50.00	27.00	2
G8	5.89	1.13	0.99	0.99	4.26	35.00	0.11	0.15	2.62	0.13	0.59	0.27	8.73	53.60	31.78	5.28	50.00	16.00	2
G9	5.47	1.08	0.95	1.84	4.03	36.68	0.21	0.19	3.06	0.08	1.89	0.72	10.84	84.72	29.90	3.98	20.00	42.00	2
G10	5.57	0.96	0.97	0.99	3.13	31.71	0.11	0.15	1.20	-0.05	1.06	0.57	9.22	58.90	24.84	3.58	20.00	26.00	2
G11	5.76	1.05	0.95	1.81	3.87	34.14	0.21	0.19	2.84	0.05	1.96	0.41	10.13	71.16	46.16	5.32	40.00	30.00	2
G12	5.62	0.86	0.86	4.06	2.84	29.96	0.48	0.32	3.48	-0.14	3.95	0.69	11.42	94.32	55.15	5.95	40.00	40.00	4
G13	5.78	0.97	0.95	1.39	3.27	31.31	0.16	0.17	1.73	-0.03	1.55	0.41	9.76	71.78	42.84	5.44	40.00	25.00	3
G14	6.01	1.00	0.92	2.72	3.62	31.62	0.32	0.25	3.30	0.00	3.09	0.29	10.58	81.88	64.41	7.50	60.00	25.00	3
G15	5.56	0.88	0.94	1.83	2.76	29.85	0.21	0.19	1.45	-0.12	1.63	0.66	9.47	61.73	26.15	3.52	10.00	38.00	5
G16	5.83	1.00	0.98	0.63	3.38	31.50	0.07	0.12	1.20	0.00	0.71	0.35	6.47	30.71	22.35	3.60	40.00	12.00	11
G17	5.50	0.98	0.99	0.33	3.22	32.65	0.03	0.11	0.75	-0.02	0.36	0.62	6.69	31.79	4.91	1.33	0.00	21.00	10
G18	5.92	1.00	0.98	0.61	3.36	30.96	0.07	0.12	1.16	0.00	0.69	0.24	6.31	28.84	31.81	5.11	60.00	8.00	10
G19	5.39	0.94	0.96	1.22	3.03	32.31	0.14	0.16	1.27	-0.06	1.24	0.82	8.00	45.21	12.03	2.05	0.00	37.00	2
G20	5.90	1.11	0.97	1.36	4.18	34.63	0.16	0.17	2.83	0.11	1.15	0.31	8.13	47.60	43.96	6.12	50.00	20.00	3
G21	5.57	0.99	0.97	1.05	3.39	33.09	0.12	0.15	1.58	-0.01	1.19	0.58	7.40	39.73	16.70	2.79	20.00	29.00	2
G22	5.82	0.90	0.94	1.83	2.82	28.85	0.21	0.19	1.54	-0.10	1.70	0.36	9.42	62.27	37.62	4.95	40.00	28.00	6
G23	5.41	0.90	0.98	0.76	2.73	30.53	0.08	0.13	0.50	-0.10	0.52	0.75	7.82	45.82	10.89	2.09	0.00	28.00	9
G24	5.39	0.91	0.95	1.57	2.90	31.57	0.18	0.18	1.41	-0.09	1.52	0.83	9.71	68.77	21.07	3.14	10.00	40.00	2
G25	5.77	0.97	0.98	0.69	3.21	31.02	0.08	0.13	1.04	-0.03	0.75	0.40	7.24	38.00	24.86	3.69	20.00	16.00	6
Mean	5.71																		

KEY: X=Grain yield (t ha^{-1}); b_i= Regression coefficient, R^2 = Pinthus's coefficient of determination; 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; D_i^2 = Hernandez's desirability index; 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 considered as stable

considered as stable (Tab. 5) because these genotypes had values close to (α_i, λ_i)=(-1,1) and G16 and G2 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, and thus we obtained a negative correlation (r = –0.97**) between yield and P_i-value (Tab. 6). 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 (Scapim *et al.*, 2000). 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 G2, G4, G11, G14 and G20 have the greatest mean yield and the lowest P_i values (Tab. 5).

Non-parametric methods

The result of six different non-parametric stability statistics and genotype mean grain yields are presented in Tab. 5. Two rank stability methods ($S_i^{(1)}$ 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 G18, G16, G2, G17 and G1 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, G7, G12, G11, G9, G5 and G6 had the highest $S_i^{(1)}$ and $S_i^{(2)}$ values, and therefore, they were determined to be the most 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 4.90 to 64.41 and 1.33 to 7.50, respectively. Genotypes G17, G1, and G23 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 (Tab. 5). Nevertheless, mean yields of

G17, G1 and G23 were lower than the total mean. While genotypes G2, G4 and G14 were the 3 highest mean yielding genotypes, they were characterized as unstable genotypes according to $S_i^{(3)}$ and $S_i^{(6)}$ parameters (Tab. 5).

Genotypes G7, G9, G16, G18, G20, G21, G23, and G24 were stable genotypes according to the nonparametric superiority parameter (TOP) (Fox *et al.*, 1990), because these genotypes were placed mostly in the top third. 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 G5, G12, G15, and G17 (Tab. 5).

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 G18, G4, G2 and G16 had the lowest values, and were stable genotypes, whereas genotypes G7, G19 and G23, which had the highest values, were undesirable (Tab. 5).

Relationship among parametric and non-parametric methods

The rank correlations between grain yield and stability methods are given in Tab. 6. Grain yield is significantly correlated with b_i, $S_i^{(2)}$, α_i, $S_i^{(6)}$, *TOP* (P<0.01) and with the methods of $S_i^{(3)}$ (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, $S_i^{(6)}$ and *TOP* (P<0.01), 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 W_i^2, σ_i^2, *P59*, D_i^2, α_i, λ_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$ and *RS* (P<0.05). Ecovalance (W_i^2) was positively associated with σ_i^2, *P59*, D_i^2, λ_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and *RS* (P<0.01). Environmental variance (S^2_i), is significantly correlated with CV_i, Di^2, αi, $S_i^{(6)}$, *TOP* (P<0.01) and with the methods of $S_i^{(3)}$ (P<0.05). The CV_i was positively and significantly associated with D_i^2 and α_i (P<0.01). Stability variance (σ_i^2) had positive and significant correlations with D_i^2, λ_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and *RS* (P<0.01). *P59* is significantly correlated with D_i^2, λ_i $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and *RS* (P<0.01). Desirability index (D_i^2) is significantly correlated with α_i, λ_i, $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, $S_i^{(6)}$ and *TOP* (P<0.01). Alpha (α_i) is significantly correlated with $S_i^{(6)}$ 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 $S_i^{(1)}$, $S_i^{(2)}$, $S_i^{(3)}$, and *TOP* (P<0.01) and the method of $S_i^{(6)}$ (P<0.05). The superiority index (P_i) was negatively associated with $S_i^{(6)}$ and TOP (P<0.01) and positively correlated with RS (P<0.01). The non-parametric method of $S_i^{(1)}$, was significantly correlated with $S_i^{(2)}$, $S_i^{(3)}$ and *RS* (P<0.01) and with the methods of $S_i^{(6)}$ (P<0.05). $S_i^{(2)}$ had positive and significant correlations with $S_i^{(3)}$, *RS* (P<0.05), and $S_i^{(6)}$ (P<0.01). $S_i^{(3)}$, as well as $S_i^{(6)}$ parameters were positively correlated with *TOP* (P<0.01). *TOP* was negatively and significantly associated with *RS* (P<0.05).

In order to better understand the relationships among parametric and non-parametric stability methods and to assess their relationships with the concepts of stability, *biplot* analysis based upon the rank correlation matrix was done. The rank correlation matrix was calculated and *biplot* analysis based upon this rank correlation matrix was

Tab. 6. Spearman's rank correlation coefficients between yields and stability parametric and non-parametric methods for 25 durum genotypes across 10 environments

	Methods	YLD	Parametric methods											Non-parametric methods				
			b_i	R^2	W_i^2	S_i^2	CV_i	σ_i^2	*P59*	D_i^2	α_i	λ_i	P_i	$S_i^{(1)}$	$S_i^{(2)}$	$S_i^{(3)}$	$S_i^{(6)}$	*TOP*
Parametric methods	b_i	0.54**																
	R^2	0.11	0.19															
	W_i^2	-0.02	0.06	-0.93**														
	S_i^2	0.51**	0.98**	0.07	0.17													
	CV_i	0.01	0.81**	0.00	0.23	0.84**												
	σ_i^2	-0.02	0.06	-0.93**	1.00**	0.17	0.23											
	P59	-0.02	0.06	-0.93**	1.00**	0.17	0.23	1.00										
	D_i^2	0.34	0.55**	-0.63**	0.83**	0.65**	0.55**	0.83**	0.83**									
	α_i	0.54**	1.00**	0.19	0.06	0.98**	0.81**	0.06	0.06	0.55**								
	λ_i	-0.01	0.06	-0.95**	0.96**	0.18	0.23	0.96**	0.96**	0.80**	0.06							
	P_i	-0.97**	-0.57**	-0.27	0.18	-0.52**	-0.03	0.18	0.18	-0.22	-0.57**	0.17						
Non-parametric	$S_i^{(1)}$	-0.05	0.11	-0.78**	0.90**	0.21	0.30	0.90**	0.90**	0.78**	0.11	0.86**	0.20					
	$S_i^{(2)}$	0.00	0.09	-0.78**	0.89**	0.19	0.24	0.89**	0.89**	0.77**	0.09	0.84**	0.16	0.99**				
	$S_i^{(3)}$	0.48*	0.32	-0.65**	0.72**	0.40*	0.17	0.72**	0.72**	0.79**	0.32	0.73**	-0.36	0.72**	0.72*			
	$S_i^{(6)}$	0.76**	0.51**	-0.39	0.51**	0.56**	0.20	0. 51**	0.51**	0.75**	0.51**	0.50*	-0.66**	0.46*	0.50*	0.86**		
	TOP	0.90**	0.63**	-0.12	0.25	0.65**	0.22	0.25	0.25	0.63**	0.63**	0.26	-0.84**	0.19	0.23	0.64**	0.88**	
	RS	-0.72**	-0.31	-0.70**	0.69**	-0.22	0.18	0.69**	0.69**	0.33	-0.31	0.67**	0.81**	0.64**	0.59**	0.14	-0.19	-0.45*

*Significant at the 0.05 probability level. **Significant at the 0.01 probability level performed (Lipkovich and Simith 2002). Figure 1 shows the loading of the first two principal components (PCs) of ranks of stability methods. These first two PCs accounted for 83 % of the variation of the original variables. According to the *biplot* analyses, the first PC1 and PC2 main axes distinguished b_i, α_i, *TOP*, $S_i^{(2)}$, CV_i, $S_i^{(3)}$, $S_i^{(6)}$ D_i^2 and mean yield (group I) from the other stability methods. The methods of $S_i^{(1)}$, *P59*, $S_i^{(2)}$, W_i^2, σ_i^2 *and* λ_i related to the concept of static stability and do not relate to genotypic mean yield and are referred to as group II. The *RS* and P_i stability methods were negatively associated with mean grain yield and were included in group III. The coefficient of determination (R^2_i) stability method was included in group IV.

The relationships among the different stability statistics are graphically showed in a *biplot* of PC1 and PC2 (Fig. 1) allowing four groups to be distinguished:

Group I included the regression coefficient (*bi*), alpha (*αi*), *TOP*, environmental variance (S_i^2), $S_i^{(6)}$; CV_i, $S_i^{(3)}$, desirability index (D_i^2) method and mean yield. Fig. 1 shows that these eight methods are strongly related to grain yield. According to these parameters, selection based on grain yield is favored, and is related to the dynamic concept of stability (Mohammadi and Ahmed, 2008). Becker and Leon (1988) stated that it was not a requirement that the genotypic response to environmental conditions should be equal for all genotypes. Hence, these parameters can be used to recommend genotypes adapted to favorable conditions in South-Eastern Anatolia of Turkey.

Group II included ecovalance (Wi^2), which was strongly correlated with σ_i^2; *P59*, λ_i, $S_i^{(1)}$ and $S_i^{(2)}$ stability parameter. Group II plots intermediate between group I and group III, and includes methods that are influenced by both yield and stability simultaneously.

Group III included the methods of P_i and *RS* which were negatively associated with the mean grain yield. The methods in group III, where phenotypic stability seems to be measured independently of yield level.

Group IV included the coefficient of determination (R^2_i) which was negatively associated W_i^2, σ_i^2; *P59*, D_i^2; λ_i, $S_i^{(2)}$, $S_i^{(3)}$ and RS while not correlated with yield, CV_i, b_i, $S_i^{(2)}$; CV_i, α_i, P_i, $S_i^{(6)}$ and *TOP* stability parameters.

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. Some improvements may be expected from the use of nonparametric methods, which are less susceptible to errors of measurements as are parametric methods (Nassar and Huhn, 1987). Several multivariate methods which have been proposed allow for 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 wide use in plant breeding (Flores *et al.*, 1998). Although 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 Ahmed 2008). Thus, group I

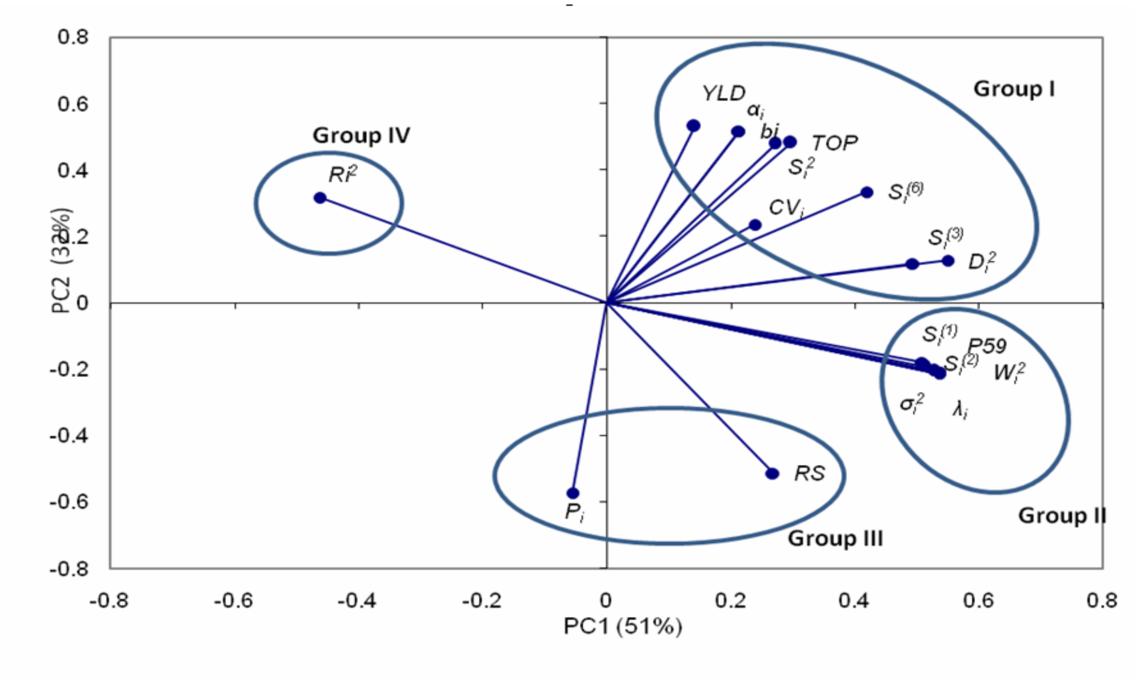

Fig. 1. *Biplot* of PC1 versus PC2 for different parametric and non-parametric methods of stability

statistics (b_i, α_i, TOP, S_i^2, $S_i^{(6)}$,CV_i, $S_i^{(3)}$, D_i^2) are necessary because farmers prefer to use high-yielding genotypes that perform consistently from one environment to another. On the contrary, many stability methods that have been used in this study considered stability of genotypes related to yield and stability. Hence, it is essential that both yield and stability are considered simultaneously to select the genotypes.

According to the correlation matrix and the *biplot* analysis, parametric and non-parametric methods used in this study revealed that these parameters could be used for evaluating the responses of durum genotypes to changing environments. The repeatability, reliability and suitability of parametric and non-parametric methods to select the best genotypes in different crops need to be further investigated. This subject should be considered in detailed in different crops by researchers.

Conclusions

Durum wheat genotypes G16, G18, G17, G1, G2 and G23 were more stable varieties, which had 11, 10, 10, 10, 9 and 9 out of 17 stability statistic used, respectively. Among these cultivars G16, G18 and G2 were the most appropriate ones, because three of them had higher yield values than the mean

According to *biplot* analysis based on the rank correlation, if the breeder is interested primarily in yield, the methods to be used are to be found in group I; if the selection is to be based primarily on stability, and then the methods to be used are grouped in group III. The methods grouped in group II would be useful tools for selecting simultaneously for yield and yield stability.

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