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PARAMETRIC STABILITY ANALYSES OF MULTI-ENVIRONMENT YIELD TRIALS IN TRITICALE (*xTriticosecale Wittmack*)

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One of the main goals of Triticale (*xTriticosecale Wittmack*) Breeding Program of Turkey is to improve high yielding and stable genotypes across environments. In this study, 16 parametric stability methods were used to evaluate the genotype x environment interaction (GEI) in 9 (4 officially registered varieties and 5 advanced lines) triticale (*xTriticosecale Wittmack*) genotypes. The genotypes were evaluated for grain yield at 4 different locations for 3 years in rain-fed areas of Turkey. The testing locations have different climatic and edaphic conditions providing the conditions necessary for the assessment of stability. A combined analysis of variance, parametric stability statistics and rank correlations among them were determined. Significant differences were detected between genotypes and their GEIs. Different parametric stability statistics were used to determine stability of the studied genotypes. The level of association among the statistics was assessed using Spearman's rank correlation. Rank-correlation coefficients between yield and some parametric stability statistics were highly significant. Genotypes mean yield was significantly correlated to the parametric stability statistics P_i (r = 0.95**), PCA1 (r = 0.87**) and D_i (r = 0.98**). A principal component analysis based on rank correlation matrix was performed for grouping the different parametric stability statistics studied. In conclusion, based on most parametric stability statistics, the genotype G8 was found to be the most stable and high yielding. This genotype is, therefore, recommended for release as a cultivar for rain-fed areas of Turkey.

Key words: genotype x environment interaction, yield, stability, Triticale (*xTriticosecale Wittmack*)

INTRODUCTION

Triticale (×*Triticosecale Wittmack*) is a man-made cereal formed by crossing wheat with rye. It possesses the genomes of the genus Triticum and Secale ssp., and thus the advantageous

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properties of wheat grain with the features of rye, such as resistance to abiotic and biotic stresses (UKALSKA and KOCIUBA, 2013). Triticale seems to be an interesting alternative to other cereals, particularly bread wheat, in environments where growing conditions are unfavorable or in low-input systems (EREKUL and KOHN, 2006).

According to the data for 2012 from FAO, triticale was grown in 35 countries worldwide, including Turkey (FAOSTAT, 2012). The adopted triticale cultivars have high grain yield potential. Breeders are interested in finding stable genotypes with broad adaptation possibilities, especially those concerning yield and its quality (GOYAL *et al*. 2011).

The adaptability of a genotype in diverse environments is usually tested by the degree of its interaction with the conditions under which it is planted. A genotype is considered to be more adaptive or stable if it has a high mean yield but a low degree of fluctuation in yielding ability when grown in diverse environments. The knowledge of genotype x environment interaction (GEI) and stability of genotypes across environments is essential for breeding program. Some genotypes are adapted to a broad range of environmental conditions, while others are more limited in their potential distribution. Some genotypes that have similar performance regardless of the productivity level of the environment, and there are others whose performance is directly related to the productivity potential of the environment, clearly indicating the importance of stability analysis. GEI creates problems in identifying superior genotypes (ALLARD and BRADSHAW, 1964). Genotype performance depends on the genotype, environment and their interaction. To select broadly adapted and stable genotypes, information dealing with adaptation of genotype and stability over environments (locations and years) is important. Identification of stable genotypes that show the least GEI is an important consideration in sites with noticeable environmental fluctuations. Under these conditions, the performance test of genotypes over a series of environments gives information on GEIs, but does not give measure the stability and adaptability of varieties. Stability of yield refers to the ability of a genotype to avoid substantial fluctuations in yield over a range of environments (HEINRICH *et al*. 1983).

The concept of stability has been defined in more than a few ways and several biometrical methods, including univariate and multivariate ones have been developed to assess stability (LIN *et al*. 1986; WESTCOTT, 1986; BECKER and LEON, 1988; CROSSA, 1990). Although several models for the statistical measurement of the stability have been proposed, each of which reflects different aspects of stability and no single method can adequately explain genotype performance across environments. Regression technique was first discussed by YATES and COCHRAN (1938) and later by FINLAY and WILKINSON (1963) to measure stability and then was improved by EBERHART and RUSSELL (1966). PERKINS and JINKS (1968) reported that regression coefficient is similar to FINLAY and WILKINSON's (1963) regression coefficient (b_i) except the observed values that are adjusted for location effects before the regression. Two stability parameters (α_i and λ_i) similar to those of EBERHART and RUSSELL (1966) were also proposed by TAI (1971) and a coefficient of determination (R_i^2) was proposed by PINTHUS (1973). Regression coefficient (b_i), deviation from regression (S_{di}^2) and coefficient of determination (R_i^2) have been the most widely used in stability parameters which use three selection indices as selection criteria to identify stable genotypes (EBERHART and RUSSELL, 1966). Some other parametric stability statistics are: environmental variance (S_i^2) (ROEMER, 1917 cited 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 GEI (θ_i), PLAISTED's (1960) variance component for GEI ($\theta_{(i)}$), WRICKE's (1962) ecovalence (W_i^2), SHUKLA's (1972) stability variance (σ_i^2), FRANCIS and KANENBERG'S (1978) coefficient of variation (CV_i), HANSON's (1970) genotypic stability (D_i^2) and YAN's GGE-Biplot (2001) axes 1 and 2 (PCA1 and PCA2).

Stability indices allow researchers to identify widely adapted genotypes for using in breeding programs and help improving recommendations to the growers (MOHEBODINI *et al.* 2006). The stability parameters were studied in cereals to measure phenotypic stability but it is still very important information that should be available for the triticale genotypes. In Turkey, the information pertaining to GEI for triticale is limited. Therefore, present study evaluates some genotypes of triticale for their yield stability under different agro-climatic conditions and compares the stability parameters that are used in GEI analysis.

MATERIALS AND METHODS

Nine triticale genotypes were grown in 4 rain-fed locations, viz. Konya, Cumra, Eskisehir and Karaman, during the three consecutive cropping seasons (2010-2011, 2011-2012 and 2012-2013) at the Central Anatolian Plateau in Turkey. The 9 genotypes comprised 4 registered cultivars and 5 advanced lines from NTBP (National Triticale Breeding Program, Turkey). 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 rate was 550 seeds m^{-2}. Fertilizer application was 27 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} at the planting and 50 kg N ha^{-1} at the stem elongation stage. Harvesting was done with an experimental combine in 1.2 m x 5 m plots. Grain yield was obtained by expressing plot grain yields on a hectare basis (t ha^{-1}). Details of the 9 genotypes and 4 locations are given in Tables 1 and 2.

Table 1. Codes, pedigrees and grain yield means for nine triticale genotypes

Genotype Code	Variety/Pedigree	Mean Yield (t ha^{-1})
G1[†]	TATLICAK-97	3.38 bc[‡]
G2	MIKHAM-2002	3.65 a
G3	ALPERBEY	3.33 cd
G4	KARMA-2000	3.10 e
G5	MIKHAM-2002/01-02 STBVD-21	3.40 bc
G6	CIMMYT-3/KARMA-2002	3.59 a
G7	23FAHAT5/POLLMER3CTSS/POLLMER_3/FOCA_2-1	3.21 de
G8	CT179.80/3/150.83//2*TESMO_1MUSX603/01-02KTVD-17	3.64 a
G9	33--/42--2	3.52 ab

[†]G1-G4 are officially registered varieties; G5-G9 are advanced lines from NTBP (National Triticale Breeding Program, Turkey); [‡]Lower case letters stand for genotypic rankings based on LSD (0.01)

A combined analysis of variance (ANOVA) was applied to grain yield data from a combination of 4 locations with 3 cropping seasons (hereafter referred to as environment). Once ANOVA revealed that genotype (G) and environment (G) main effects and G x E interaction (GEI) were statistically significant, 16 parametric stability approaches were performed the multi-environment yield data, in order to measure the stability levels of 9 triticale genotypes. Details of parametric stability statistics are given in Table 3.

Table 2. Codes, grain yield means and precipitation amounts for 12 environments (four locations x three cropping seasons)

Environment Code	Cropping Season	Location	Mean† Yield (t ha^{-1})	Precipitation (mm)
E1	2010-2011	Konya	5.28 b	340
E2	2010-2011	Cumra	4.97 c	366
E3	2010-2011	Karaman	3.62 e	358
E4	2010-2011	Eskisehir	6.69 a	398
E5	2011-2012	Konya	2.11 h	320
E6	2011-2012	Cumra	1.64 i	248
E7	2011-2012	Karaman	1.16 j	258
E8	2011-2012	Eskisehir	4.06 d	397
E9	2012-2013	Konya	1.62 i	323
E10	2012-2013	Cumra	3.30 f	271
E11	2012-2013	Karaman	2.66 g	302
E12	2012-2013	Eskisehir	3.99 d	343

†Lower case letters stand for environmental rankings based on LSD (0.01)

ANOVA, Spearman's rank correlation, comparison of the means with LSD test ($p< 0.01$), stability analyses were performed using SAS© 9.1 (2004). SAS codes proposed by HUSSEIN *et al.* (2000) were used in the stability analyses. Principal components and Biplot analyses were performed using Biplot and Singular Value Decomposition Macros for Excel© (LIPKOVICH and SMITH, 2002).

Table 3. Parametric stability statistics used in the grain yield stability analyses

Symbol	Name of statistics	Proposed by	Interpretation
μ	Grain yield mean	Reference criterion for GEI analyses	Higher or close to μ refers desirable G
b_i	Coefficient of regression	Eberhart and Russell (1966)	$b_i \approx 1$ refers stable G
S^2_{di}	Deviation from regression	Eberhart and Russell (1966)	$S^2_{di} \approx 0$ refers stable G
S_i^2	Environmental variance	Roemer (1917) cited in Becker and Leon (1988)	Minimum S_i^2 = stable G
CV_i	Coefficient of variation	Francis and Kannenberg (1978)	Low CV_i = stable G
W_i^2	Ecovalence	Wrickle (1962)	Low W_i^2 = stable G, but significance of F test indicates (in)stable G
σ_i^2	Stability variance	Shukla (1972)	Low σ_i^2 = stable G, but significance of F test indicates (in)stable G
P_i	Superiority measure	Lin and Binns (1988)	Low P_i = stable G
D_i^2	Genotypic stability	Hanson (1970)	Low D_i^2 = stable G
R_i^2	Coefficient of determination	Pinthus (1973)	$R_i^2 \approx 1$ refers stable G
θ_i	Mean variance component for pairwise GEI	Plaisted and Peterson (1959)	Low θ_i = stable G
$\theta_{(i)}$	Variance component for GEI	Plaisted (1960)	High $\theta_{(i)}$ = stable G
α_i	Linear response to environmental effects	Tai (1971)	$\alpha_i \approx -1$ refers perfectly stable G $\alpha_i \approx 0$ refers G with average stability
λ_i	Deviation from linear response	Tai (1971)	$\lambda_i \approx 1$ refers stable G
PCA1	GGE Biplot principal components axis 1	Yan (2001)	a)PCA1 score ≈ 0 refers average yielding G b)PCA1 score < 0 refers low yielding G c)PCA1 score > 0 refers high yielding G
PCA2	GGE Biplot principal components axis 2	Yan (2001)	a)PCA2 score ≈ 0 refers stable G b)PCA2 score > < 0 refers unstable G
D_i	Desirability index	Hernandez et al. (1993)	Large D_i = stable or desirable G

G, Genotype; GEI, Genotype x Environment Interaction; GGE, Genotype + Genotype x Environment Interaction Analysis

RESULTS

The results of the combined analysis of variance for grain yield of nine genotypes in triticale are presented in Table 4. The differences among genotypes for grain yield were significant ($P < 0.001$). Similarly, highly significant differences were observed among the environments for grain yield. This reveals that these environments represented a wide range of agro-climatic conditions of the Central Anatolian Region of Turkey to assess the performance and the stability of the genotypes. The highly significant differences of GEI for grain yield indicate the differential response of genotypes to environments.

The combined ANOVA also showed that grain yield was significantly affected by E, which explained 88.6 % of the total (G + E + GEI) variation, whereas G and GEI accounted for 3.2 % and 8.3 %, respectively (Table 4).

Table 4. Combined analysis of variance for multi-environment yield trails in triticale

Source	df	SS	MS	F	P	Model	Explained (%)[†]
Environment (E)	11	1122	102.00	367.2	0.001	Random	88.6
Replication (E)	36	10	0.28				
Genotype (G)	8	40	5.00	4.2	0.001	Fix	3.2
G x E Interaction	88	105	1.19	7.2	0.001		8.3
Error	288	48	0.17				
Total	431	1325					100.0
$CV_{(\%)}$ = 11.94	R^2 = 0.96	Mean = 3.43 (t ha^{-1})					

[†]SS of E+G+GEI;

Genotype grain yields ranged from 3.10 t ha^{-1} for G4 to 3.65 t ha^{-1} for G2 with a mean of 3.43 t ha^{-1} (Table 1). From the registered varieties (G1 to G4), merely G2 had higher grain yield than the average, whereas 3 (G6, G8 and G9) out of 5 advanced lines (G5 to G9) were higher yielding ones.

Environmental grain yield range was large and varied between 1.16 t ha^{-1} for E1, Karaman 2011-2012, and 6.69 t ha^{-1} for E4, Eskisehir 2010-2011 (Table 2). Environmental rankings were dramatically changed by year or season effects. For instance, even though E1, E5 and E9 referred to the same location, Konya, their ranking was from 1.62 t ha^{-1} in E9, Konya 2012-2013, to 5.28 t ha^{-1} in E1, Konya 2010-2011. Thus, it was an obvious evidence for year or seasonal effect on grain yield. Year effect was also valid for the rest of the locations.

Estimates of stability parameters for grain yield of seven out of nine triticale genotypes had regression coefficients (b_i) not significantly different from 1.0 (Table 5). Thus, based on b_i values alone, all genotypes, except G6 and G7, can be considered stable for grain yield. G6 had a b_i value significantly > 1.0, whereas G7 had a b value significantly < 1.0. Regression coefficients have been used to measure genotype response to varying environments. Three, (G5, G8 and G9) of the advances lines (G5 to G9) and all of the registered cultivars (G1 to G4) had b_i values near to unity, consistently well performed in all environments.

For grain yield, all genotypes, except G7, had S_{di}^2 values not significantly different from 0 (Table 5). Hence, according to $S_{di}^2 = 0$, G7 could not be considered stable. However, EBERHART and RUSSELL (1966) described a desirable genotype as one with a high mean yield, $b_i = 1.0$ and $S_{di}^2 = 0$. Considering this definition, G2, G8 and G9 can be considered as the most desirable ones among the 9 genotypes.

Regarding environmental variance (S_i^2), a stable genotype has small variance (ROEMER, 1917; LINS *et al*. 1986). G7 was stable with the lowest S_i^2, followed by G2, G3 and G5. On the contrary, G6 was unstable with the highest S_i^2, followed by G2 and G8 (Table 5).

The genotype grouping technique of FRANCIS and KANNENBERG (1978), CV_i, was employed to group genotypes on the basis of their mean yields and their coefficients of variation (CV_i) relative to the grand mean and average CV_i. For grain yield, the procedure identified only one genotype, G9, as most desirable with higher than average yield and smaller than average CV_i (Table 5). G2, G6 and G8, although yielding above average, were judged to be less stable by this procedure because they had larger than average CV_i. G3, G4, G5 and G7 were considered undesirable because, even though they had small CV_i, they produced yields below average. Exclusively one genotype, G1, was identified as very undesirable, because it yielded below average and had large CV_i.

Table 5. Parametric stability statistics† values for 9 triticale genotypes used in the study

Genotype	μ	b_i	S^2_{di}	S_i^2	CV_i	W_i^2	σ_i^2	P_i	D_i^2	R_i^2	θ_i	$\theta_{(i)}$	α_i	λ_i	PCA1	PCA2	D_i
G1	3.38	1.03	0.11	3.16	52.38	1.48	0.13	0.46*	13.90	0.96	0.23	0.32	0.03	0.50	0.73	2.88	3.89
G2	3.65	1.16	0.16	3.99	54.67	2.76	0.28	0.18	15.20	0.96	0.29	0.30	0.16*	0.67	5.29	0.78	4.23*
G3	3.33	0.91	0.05	2.40	46.60	1.09	0.09	0.57**	12.78	0.97	0.21	0.33	-0.09*	0.28	-2.60	0.93	3.77
G4	3.10	0.85	0.23	2.26	48.57	3.46*	0.36*	0.89**	12.37	0.89	0.33	0.29	-0.15	0.93	-3.24	6.23	3.52**
G5	3.40	1.01	0.01	2.94	50.36	0.44	0.01	0.35	13.32	0.99	0.17	0.33	0.01	0.15	0.60	-0.60	3.90
G6	3.59	1.21*	0.19	4.73	60.47	4.44**	0.48**	0.18	15.83	0.96	0.38	0.27	0.26**	0.78	6.89	-1.05	4.22*
G7	3.21	0.71**	0.43*	1.67	40.28	8.29**	0.93**	1.14**	10.54	0.75	0.57	0.22	-0.34**	1.62	-9.12	-2.96	3.54**
G8	3.64	1.13	0.08	3.71	52.88	1.67	0.15	0.15	14.50	0.97	0.23	0.32	0.13*	0.39	3.71	-2.86	4.20*
G9	3.52	0.99	0.22	3.03	49.52	2.62	0.26	0.43*	13.72	0.92	0.28	0.30	-0.01	0.90	-2.26	-3.35	4.01
Mean	3.43	1.00	0.16	3.10	50.64	2.92	0.30	0.48	13.57	0.93	0.30	0.30	0.00	0.69	0.00	0.00	3.92

WRICKE (1962) suggested using ecovalance (W_i^2) as a stability parameter. According to this stability parameter, genotypes with the smallest W_i^2 values are considered stable. The W_i^2 was lowest for genotype G5, followed by G3 and G1 and highest for G7, followed by G6 and G4 (Table 5). G8, G9 and G2 were still accepted as stable because their W_i^2 values were not statistically different from the most stable one. However, G7, G6 and G4 were not stable considering significance test for W_i^2.

SHUKLA's (1972) stability variance statistic, σ_i^2, showed that for grain yield, 6 out of nine genotypes were stable; G5 was the most stable, followed by G3, G1 and G8 (Table 5). G6 and G7 were rated as highly unstable ($P < 0.01$), followed by G4 ($P< 0.05$).

The superior genotype should be the one with the lowest superiority index (P_i) value (LIN and BINNS, 1988). Accordingly, genotypes G8, G2 and G6 had higher grain yield and lower P_i values than the average (Table 5). Even though G5 had relatively small P_i, its grain yield was lower. G9 and G1 were unstable due to higher P_i values ($P<0.05$), while G3, G4 and G7 were unstable at the $P<0.01$.

A genotype with lowest D_i^2 is the most stable one (HANSON, 1970). Judging genotypes by D_i^2 values, G7, G4, G3 and G5 appeared to be stable, but their grain yields were lower than the average (Table 5). Although G9, G8, G2 and G6 were considered instable, they yielded higher than the average.

PINTHUS's (1973) stability parameter or coefficient of determination (R_i^2) values for the triticale genotypes tested indicated that G5, G8, G3 and G2 were stable taking into account that they had R_i^2 values close to 1. However, G7 had a low R_i^2 value and then was considered unstable.

Mean variance component for a pair-wise GEI (θ_i) as proposed by PLAISTED and PETERSON (1959) was computed. This stability statistic measures a genotype's contribution to the GEI. The lower θ_i indicates the more stable the genotype. Genotypes G5, G3, G8 and G1 had lower θ_i and were stable (Table 5). Conversely, G7, G6 and G4 were instable due to higher θ_i.

The GE variance component stability statistic ($\theta_{(i)}$) is the GE variance component of the experiment with genotype i deleted (PLAISTED, 1960). The higher $\theta_{(i)}$ indicates the more stable the genotype. Genotype ranking based on $\theta_{(i)}$ was the same as that of θ_i (Table 5). In other words, Genotypes G5, G3, G8 and G1 had higher $\theta_{(i)}$ and were stable. In contrast, G7, G6 and G4 were instable considering lower $\theta_{(i)}$.

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 is measured by (λ_i) statistic. A perfectly stable genotype is that in which (α_i, λ_i)= (-1, 1). According to these stability statistics, none of genotypes could be considered as stable (Table 5), because none of them was near to (α_i, λ_i) = (-1, 1). However, G9 had average stability with (α_i, λ_i) = (0, 1).

The first and second principal component axes (PCA1 and PCA2) scores of a genotype provide indicators of the yield performance and stability of a genotype across environments, respectively, (YAN, 2001). Genotypes that had PCA1 scores > 0 were identified as higher yielding (like G2, G6 and G8; Table 5) and those that had PCA1 scores < 0 were identified as lower yielding (like G7, G3 and G4 except G9). Genotypes that had PCA1 scores ≈ 0 were identified as average yielding (like G1 and G5). Unlike the PCA1, PCA2, which was related to genotypic stability or instability, divided the genotypes of interest into 2 groups based on their scores. Group 1 consisted of 4 stable genotypes (G2, G3, G5 and G6). Among them, G2 and G6 were higher yielding and stable. G5 was average yielding and stable, whereas, G3 was lower yielding and stable. As for Group 2, it consisted of 5 unstable genotypes (G1, G4, G7, G8 and G9). From them, G8 and G9 were higher yielding and unstable. In case of G1, G4 and G7, they were lower yielding as well as unstable (Table 5).

Desirable genotypes are those with a large D_i, Desirability Index, (HERNANDEZ *et al.* 1993). Genotypes G2, G6 and G8 had D_i values that were significantly different from those of the standard genotype (D_i = 3.93) (Table 5). Of these, genotypes, G2 and G8 were more desirable because they had higher yield than the average, b_i close to 1 as well as larger D_i. In contrast, G4 and G7 had lower yield than the average, $b_i < 1$ as well as smaller D_i (HERNANDEZ *et al.* 1993).

Rank-correlation coefficient between yield and some parametric stability statistics were significant ($P < 0.01$; Table 6). The means of genotype yield (μ) were positively correlated to the stability parameters P_i (r = 0.95**), D_i (r = 0.98**) and PCA1 (r = 0.87**) and negatively correlated to the stability parameters S_i^2 (r = -0.88**), CV_i (r = -0.83**) and D_i^2 (r = -0.88**).

The stability parameter b_i had significantly correlated with parameters W_i^2 (r = 0.80**), σ_i^2 (r = 0.80**), θ_i (r = 0.77**), $\theta_{(i)}$ (r=0.67*) and α_i (r = 1.00**). Deviation from the regression (S_{di}^2) was positively correlated with W_i^2 (r = 0.90**), σ_i^2 (r = 0.90**), Ri2 (r = 0.93**), θ_i (r = 0.92**), $\theta_{(i)}$ (r=0.95**) and PCA2 (r = 0.65*), but negatively with λ_i (r = -0.65*).

Environmental variance (S_i^2) had significant positive correlation with the CV_i (r = 0.97**) and D_i^2 (r = 1.00**), but had a negative correlation with P_i (r = -0.87**), PCA1 (r = -0.98**) and D_i (r = -0.92**). Rank correlation coefficient between CV_i and D_i^2 was significant (r = 0.97**). The former was also correlated with P_i (r = -0.87**), PCA1 (r = -0.98**) and D_i (r = -0.87**).

Table 6. Spearman's rank correlation coefficients among parametric stability statistics[†]

	μ	b_i	S_{di}^2	S_i^2	CV_i	W_i^2	σ_i^2	P_i	D_i^2	R_i^2	θ_i	$\theta_{(i)}$	α_i	λ_i	PCA1	PCA2	D_i
μ	1.00																
b_i	0.03	1.00															
S_{di2}	0.32	0.52	1.00														
S_i^2	-0.88**	0.03	-0.27	1.00													
CV_i	-0.83**	0.08	-0.27	0.97**	1.00												
W_i^2	0.08	0.80**	0.90**	-0.02	0.00	1.00											
σ_i^2	0.08	0.80**	0.90**	-0.02	0.00	1.00**	1.00										
P_i	0.95**	0.10	0.47	-0.87**	-0.87**	0.22	0.22	1.00									
D_i^2	-0.88**	0.03	-0.27	1.00**	0.97**	-0.02	-0.02	-0.87**	1.00								
R_i^2	0.53	0.35	0.93**	-0.42	-0.43	0.73*	0.73*	0.68*	-0.42	1.00							
θ_i	0.15	0.77**	0.92**	-0.03	-0.02	0.98**	0.98**	0.30	-0.03	0.80**	1.00						
$\theta_{(i)}$	0.20	0.67*	0.95**	-0.08	-0.08	0.97**	0.97**	0.35	-0.08	0.85**	0.98**	1.00					
α_i	0.03	1.00**	0.52	0.03	0.08	0.80**	0.80**	0.10	0.03	0.35	0.77**	0.67*	1.00				
λ_i	0.07	-0.12	-0.65*	-0.25	-0.25	-0.55	-0.55	0.02	-0.25	-0.57	-0.57	-0.60	-0.12	1.00			
PCA1	0.87**	-0.05	0.37	-0.98**	-0.98**	0.08	0.08	0.88**	-0.98**	0.52	0.10	0.17	-0.05	0.13	1.00		
PCA2	0.33	0.02	0.65*	-0.28	-0.30	0.43	0.43	0.32	-0.28	0.65*	0.40	0.50	0.02	-0.63	0.40	1.00	
D_i	0.98**	-0.02	0.27	-0.92**	-0.87**	0.02	0.02	0.92**	-0.92**	0.48	0.07	0.12	-0.02	0.12	0.90**	0.38	1.00

*P<0.05; **P<0.0; [†]Details of parametric stability statistics are given in Table 3

Ecovalence (W_i^2), stability variance (σ_i^2), stability parameters of θ_i and $\theta_{(i)}$ were highly correlated with each other (from r = 0.80** to r = 1.00**), which indicated that one of these four parameters could be used as a substitute for the others in GEI.

The parameter P_i was positively correlated with R_i^2 (r = 0.68*), PCA1 (r = 0.88**) and D_i (r = 0.92**), while negatively with D_i^2 (r = -0.87**). Genotypic stability parameter (D_i^2) had significant negative correlation with PCA1 (r = -0.98**) and D_i (r = -0.92**). Coefficient of determination (R_i^2) was also associated with θ_i (r = 0.80**), $\theta_{(i)}$ (r = 0.85**) and PCA2 (r = 0.65*).

Mean variance component for a pair-wise GEI (θ_i) was related with $\theta_{(i)}$ (r = 0.98**) and α_i (r = 0.77*). The GEI variance component stability statistic ($\theta_{(i)}$) had a relationship with α_i (r = 0.67*). Principal components axis 1 (PCA1) was positively correlated with D_i (r = 0.90**).

The Spearman's rank correlation matrix was calculated and a principal components analysis (PCA) based on this rank correlation matrix was performed. Figure 1 shows the biplot depicted by the loadings of the first two principal components (PCA1 vs. PCA2) of ranks of parametric stability statistics, which these accounted for 83 percent of the variance of the original variables. When both axes were considered simultaneously, three groups (Figure 1) can be defined as follows:

Group 1: CV_i, D_i^2 and S_i^2

Group 2: μ, PCA1, D_i and P_i

Group 3: b_i, S_{di}^2, R_i^2, PCA2, α_i, W_i^2 , σ_i^2, θ_i, and $\theta_{(i)}$.

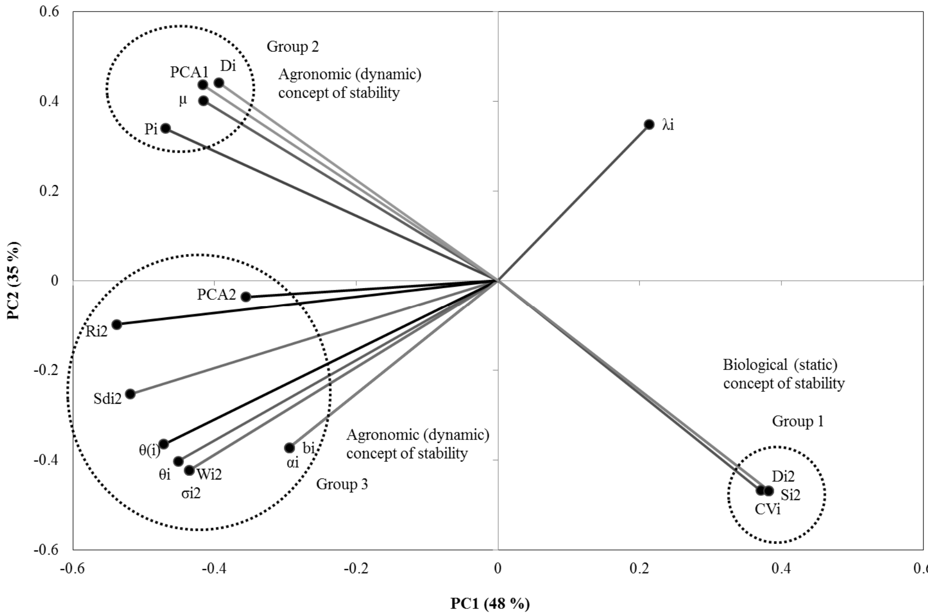

Figure 1. Grouping of parametric stability statistics used in the grain yield stability analyses (Details of parametric stability statistics are given in Table 3)

DISSCUSSION

Phenotypic stability is 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 static (biological) 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 better 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 (agronomic) concept of stability (BECKER and LEON, 1988).

The parametric stability statistics S_i^2, CV_i and D_i^2 were in the first group. They are related with the static (biological) concept of stability (ROEMER, 1917 cited in BECKER and LEON, 1988; HANSON, 1970; FRANCIS and KANNENBERG, 1978). These stability parameters, which were not generally associated with yield level, were measured independently for crop yield. In the static concept of stability, a genotype which showing a constant performance in all environments does not necessarily respond to improved growing conditions with increased yield. Therefore, stable genotypes according to these methods recommended for regions where growing conditions are unfavorable (LIN *et al.* 1986). According to KANG (2002), this type of stability would not be beneficial for the farmer because a genotype in this sense would not respond to high levels of inputs.

MOHEBODINI *et al.* (2006), DEHGHANI *et al.* (2008) and MOHAMMADI and AMRI (2008) found that the statistics S_i^2 and CV_i were in the same group, and followed by the biological (static) stability concept. Similar to statistics S_i^2 and CV_i, D_i^2 might be a static stability statistic (YONG-JIAN *et al*. 2011). Although static stability statistics are theoretically sound, breeders have used it infrequently. One reason seems to be that a breeder would like to find cultivars not only with good static stability but also with high yield. Static stability is often associated with a relatively poor response and low yield in environments. Another reason is that although a high level of performance under a wide range of environments may be desirable, it is difficult to achieve in practice. Even if it can be achieved, the effort is not entirely necessary because several less widely adapted genotypes can be bred and then grown separately in different environments to achieve maximum production. Thus, the usefulness of a static stability depends very much on the range of environments under which the experiment is conducted (LIN *et al*. 1986). The yield potential range for the environments used in this study is remarkably large, so making selection in triticale genotypes tested based on static stability statistics may not be very meaningful.

Mean yield (μ) and the stability statistics D_i (HERNANDEZ *et al*. 1993), PCA1 (YAN, 2001) and P_i (LIN and BINNS, 1988) were in the second group (Figure 1). MOHEBODINI *et al.* (2006) found that the statistics P_i, D_i and μ were in the same group in lentil (*Lens culinaris* Medik). Similarly, FLORES et al. (1998), MOHAMMADI and AMIRI (2008) and YONG-JIAN *et al*. (2011) reported that Pi and μ were in the same group. YAN (2001) also indicated that PCA1 was strongly related with μ.

Mean grain yield was included in the group 2 suggesting group 2 comprised those methods where yield had the main influence on the ranking across environments. LIN and BINNS (1988) proposed P_i as a measurement of genotypic performance, in a possible attempt to integrate both yield and stability. Consequently, selection of stable genotypes based on statistic P_i might cause high yield genotypes to be introduced as stable genotypes.

Based on parameters μ, D_i, P_i and PCA1, making selection is in favor of grain yield, because they are related to dynamic concept of stability. In the dynamic concept of stability, for each environment the performance of a stable genotype corresponds completely to the estimated level or the prediction. In the dynamic concept of stability, it was not required that the genotypic response to environmental conditions should be equal for all genotypes (BECKER and LEON, 1988). Thus, stable genotypes according to these parameters recommended for Central Anatolian Region of Turkey where growing conditions are favorable.

The parametric stability parameters b_i and S_{di}^2 (EBERHART and RUSSELL, 1966), R_i^2 (PINTHUS, 1973), θ_i (PLAISTED and PETERSON, 1959), $\theta_{(i)}$ (PLAISTED, 1960), W_i^2 (WRICKLE, 1962), σ_i^2 (SHUKLA, 1972), α_i (TAI, 1971) and PCA2 (YAN, 2001) were in the third group (Figure 1). They were also strongly correlated with each other (Table 6). As the group 3 was intermediate between group 1 and group 2, it consists of the parameters of methods that were influenced simultaneously by both yield and be as good as the responsive ones under favorable conditions. KANG and PHAM (1991) indicated that W_i^2 showed a stronger correlation with σ_i^2. LIN *et al.* (1986) and KANG *et al.* (1987) suggested that W_i^2 and σ_i^2 were the same; σ_i^2 is a coded value of W_i^2, thus these two methods should not be treated as separate procedures. MOHEBODINI *et al.* (2006), TAIWO (2007), YONG-JIAN *et al*. (2011) and KARIMIZADEH *et al.* (2012) found strongly positive correlations among stability statistics θ_i, $\theta_{(i)}$, W_i^2 and σ_i^2 in lentil (*Lens culinaris* Medik), cowpea (*Vigna unguiculata* [L.] Walp), maize (*Zea mays* L.) and durum wheat (*Triticum turgidum* L), respectively. It was indicated that only one of these parameters would be sufficient to select the stable genotypes in a breeding program. FLORES *et al*. (1998) and KILIC (2012) found that the statistics σ_i^2 and S_{di}^2 were related to each other. Similarly, only one of these parameters would be sufficient to select the stable genotypes in a breeding program.

The statistic PCA2 was based on the results of GGE biplot analysis (YAN, 2001). YONG-JIAN *et al*. (2011) found that PCA2 was correlated with S_{di}^2, θ_i, $\theta_{(i)}$, W_i^2 and σ_i^2. The stability statistics, already discussed in group 3, were not correlated positively with genotypes mean yield (μ). DUARTE and ZIMMERMANN (1995) indicated that the variance of the deviations from regression can provide assessment of the relative contribution of the genotype to GEI as well as its biological stability in common bean (*Phaseolus vulgaris* L.). DEHGHANI *et al.* (2008) and YONG-JIAN *et al.* (2011) also found that the stability statistics S_{di}^2, θ_i, $\theta_{(i)}$, W_i^2 and σ_i^2 were in the same group, and followed the biological stability concept. Therefore, they suggested that these statistics probably measured biological aspects of phenotypic stability similar to the stability statistics in group 1 (Figure 1). In our case, these statistics were also strongly correlated with b_i, so they were accepted as dynamic (agronomic) stability statics (FLORES *et al.* 1998; MOHEBODINI *et al.* 2006). For a certain case, some of parametric stability statistics could not be apparently distinguished based on static (biological) and/or dynamic (agronomic) concepts of stability. In addition, like our study, FLORES *et al.* (1998) that the stability statistic α_i was strongly correlated with b_i and σ_i^2. The statistic α_i could be considered as a special form of the statistic b_i, when the environmental index is assumed to be random (LIN *et al.* 1986). Therefore, the stability statistics in group 3 might be considered as the agronomic concept of stability. In this concept of stability, a stable genotype shows constant performance across different environments. If selection of stable genotypes is based on these methods, a narrowly adapted genotype with less general adaptability but good specific adaptability may be discarded. Thus, stable genotypes, according to these statistics, are recommended for favorable environments.

In conclusion, several parametric stability statistics that were used in this study quantified genotype stability with respect to yield. Both yield and stability of performance should be considered simultaneously to exploit the useful effect of GEIs and to make genotype selection more precise and refined. Genotype G8 can be recommended as the most stable genotype with regard to both stability and yield. It was the most stable genotype based on 14 out of 16 parametric stability statistics (except α_i and D_i) and had the second highest grain yield among the nine triticale genotypes studied. This genotype is, therefore, recommended for release as a cultivar by the Bahri Dagdas International Agricultural Research Institute of Turkey.

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PARAMETARSKA ANALIZA STABILNOSTI PRINOSA TRITICALE (*xTriticosecale Wittmack*) U MULTILOKACIJSKIM EKSPERIMENTIMA

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Izvod

Vršena su ispitivanja stabilnosti prinosa korišćenjem 16 metoda za određivanje parametara stabilnosti u cilju evaluacije interakcije genotip x spoljna sredina (GEI) kod 9 genotipova (4 zvanično registrovane sorte i 5 novih linija T*riticale* (*xTriticosecale Wittmack*) . Vršene su kombinovane analize variance, statistika parametara stabilnosti i korelacije ranka među njima.. Prosečan prinos genotipa je bio u značajnoj korelaciji sa statistikom parametara stabilnosti P_i (r = 0.95**), PCA1 (r = 0.87**) and D_i (r = 0.98**). Analiza glavnih komponenata zasnovana na matriksu korelacije ranka je vršena za grupisanje različitih statističkih parametara stabilnosti. Zaključak istraživanja je da , na osnovu većine statističkih parametara stabilnostiIn genotpe G8 je bio najstabilniji i imao visok prinoswas i preporučen je za gajenje kao kultivar u normalnim uslovima Turske.

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