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Stability analyses for grain yield of triticale genotypes

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Tritikale genotiplerinde tane veriminin stabilite analizleri

ÖZET

Bu araştırma, Orta Anadolu koşullarında 8 tritikale genotipi (7 ileri hat ve 1 çeşit) kullanılarak 16 çevrede tesadüf blokları deneme deseninde 3 tekerrürlü olarak yürütülmüştür. Araştırma, tritikalede tane verimi yönünden genotip-çevre interaksiyonlarını açıklamak, stabil genotipleri belirlemek, tane verimi ile stabilite parametrelerini kıyaslamak amacı ile yapılmış ve 9 stabilite parametresi kullanılmıştır. Araştırmada kullanılan stabilite parametreleri: Eberhart ve Russell'ın (1966) regresyon katsayısı (b_i) ve regresyondan sapma kareler ortalaması (S^2_{di}), Wricke's (1962), ekovalans (W_i^2), Shukla'nın (1972), stabilite varyansı (σ_i^2) Francis ve Kannenberg'in (1978) varyasyon katsayısı (CV_i) ve genotipik varyans (S^2_i), Tai'nin (1971) çevresel etkiler (α_i), doğrusal tepkiden sapma (λ_i) ve Pinthus'un (1973) belirtme katsayısı (R_i^2)'dır. Ayrıca, stabilite parametreleri ile tane verimi değerleri kullanılarak oluşturulan üç boyutlu grafiklerle, genotiplerin verim potansiyelleri ve stabiliteleri değerlendirilmiştir. 8 tritikale genotipinin tane verimleri deneme çevrelerinde 1.80 t ha^{-1} ile 7.62 t ha^{-1}arasında değişim göstermiş ve çevreler üzerinden ortalama tane verimi 3.60 t ha^{-1} olmuştur. Bu araştırmada, KTBVD-17 genotipinin genel ortalamadan yüksek tane verimi (3.64 t ha^{-1}) ile kullanılan 9 stabilite parametresinin tamamına göre stabil olduğu belirlenmiştir. Bu genotip en stabil genotip olmuştur. Bunun yanında, Tatlıcak-97 çeşidi ortalama tane verimi (3.60 t ha^{-1}) ile kullanılan 9 stabilite parametresinin tamamında, KTBVD 11 genotipi ise ortalamadan yüksek tane verimi (3.67 t ha^{-1}) ile 9 stabilite parametresinin 6'sında stabil olmuştur.

ANAHTAR KELİMELER: Tritikale, tane verimi, genotip-çevre interaksiyonları, stabilite analizleri, üç boyutlu grafik.

SUMMARY

Grain yield of eight triticale genotypes consisting of seven advanced lines and one cultivar tested in a randomized complete block design with three replications across 16 environments of Central Anatolian Region of Turkey was analysed using nine parametric stability parameters. The objectives were to assess genotype-environment interactions (GEI), to determine stable genotypes, and to compare both average grain yield and the stability parameters. To quantify yield stability, nine stability parameters were calculated: Eberhart and Russell's (1966) regression coefficient (b_i) and deviation from regression (S^2_{di}), Shukla's (1972) stability variance (σ_i^2), Wricke's (1962) ecovalance (W_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), deviation from the linear response (λ_i) and Pinthus's (1973) coefficient of determination (R_i^2). Furthermore, three-dimensional plots of response mean versus each stability statistic are shown to visually evaluate the yield potential and stability estimates of the genotypes. The grain yield of the eight triticale genotypes for each environment varied from 1.80 to 7.62 t ha^{-1} and across environments average grain yield of 3.60 t ha^{-1}.The genotype "KTBVD-17" was the most stable genotype which had 9 (out of 9) stability parameters used and had above average grain yield (3.64 tha^{-1}). Besides, genotypes Tatlıcak-97 and KTBVD 11 could be considered stable genotypes which Tatlıcak-97 had 9 (out of 9) stability parameters used had average grain yield (3.60 tha^{-1}) and KTBVD 11 had 6 (out of 9) stability parameters used had above average grain yield (3.67 tha^{-1}).

KEY WORDS: Triticale, grain yield, genotype by environment interaction stability, three-dimensional plots.

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INTRODUCTION

Triticale has been developed for stress environments as an alternative crop species. During its short lifespan as a commercial crop, its agronomic performance and features have changed. At the beginning, the consumption of triticale as a human nutrition became to be limited due to its low milling and baking quality for years. However, with recent progress, triticale has been used alone in food industries in addition to its use as blends with wheat flour for cookies, biscuits, bread and pasta.

A successfully developed new cultivar should have stable performance and broad adaptation over a range of environments. Evaluate performance stability and range of adaptation is becoming increasingly important for breeding programs.

Many methods of analyses for stability have been proposed. The joint regression analysis of either phenotypic values or interactions on environment indices, was first discussed by Yates and Cochran (1938) and was later modified and used by Finlay and Wilkinson (1963) and Eberhart and Russell (1966). Part of the genotype stability is expressed in terms of three empirical parameters: the mean performance, the slope of regression line (b_i), and sum of squares deviation from regression (S^2_{di}) (Crossa 1990, Flores et al. 1998). A two- stability parameter method similar to that of Eberhart and Russell was also proposed by Tai (1971). In this method, environmental effects (α_i) and deviation from the linear response (λ_i) can be regarded as special form of the regression parameters (b_i) and (S^2_{di}), when the environmental index is assumed to be random (Lin et al. 1986). Wricke (1962) proposed to use genotype environment interactions (GEI) for each genotype as a stability measure termed as ecovalance (W_i^2). Shukla (1972) developed an unbiased estimate using stability variance (σ_i^2) of genotypes and a method to test the significance of the (σ_i^2) for determining stability of a genotype. Francis and Kannenberg's (1978) used the environmental variance (S^2_i) and coefficient of variation (CV_i) of each genotype as stability parameter.

The objectives of this research were: (i) to evaluate the grain yield of promising triticale genotypes under different environments. (ii) to study the adaptation of promising genotypes of triticale, using nine parametric stability criteria.

MATERIALS and METHODS

Genotypes and growth conditions

Eight triticale genotypes including one triticale cultivar (Tatlıcak-97) and seven advanced triticale lines (KTBVD-1, KTBVD-11, KTBVD-12, KTBVD-13, KTBVD-17, KTBVD-21 and BDMT-98/8S) from the International Triticale Breeding Programme of Bahri Dağdaş International Agricultural Research Institute were used in this study.

During the 1999, 2000 and 2001 growing seasons, a total of 16 trials were conducted in seven representative environments of Turkey, which are Konya, Çumra, Beyşehir, Ereğli, Koçaş and Obruk in the Central Anatolian region, and Sivas in the north of the Central Anatolian Region. The growing seasons, experimental conditions, together with supplementary irrigation's applied at each location during the growing period and cultural practices are presented in Table 1.

In each trial, genotypes were grown in randomized complete- block design with three replications. The experiments were sown with an experimental drill in 1.2 m x 7 m plots, consisting of six rows with 20 cm between the rows. The seeding rate was 550 seeds m^{-2} for rain-fed and 450 seeds m^{-2} for irrigated environments. Harvesting was done in 1.2 m x 5 m plots by combine harvester and grain yield was determined (t ha^{-1}).

Statistical analyses

A combined analysis of variance was first undertaken across the test environments. Then, stability parameters were performed in accordance with Eberhart and Russell's (1966) the slope value (b_i) and deviation from regression (S^2_{di}); Pinthus's (1973) coefficients of determination (R_i^2); Wricke'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), deviation from the linear response (λ_i). Also, the Spearman rank correlation was determined among stability parameters. All statistical analyses were carried out using the SAS Statistical Packet Program (Anonymous, 1999).

To define genotypic stability, a genotype was considered as stable for grain yield if it appeared stable for nine stability parameters. Genotypes that proved to be stable for all of stability analyses were then selected as the best.

RESULTS and DISCUSSION

The analysis of variance of grain yield (t ha^{-1}) of the eight triticale genotypes tested in 16 environments showed that 91.5 % of total sum of squares was attributable to environmental effects, only 1.6 % genotypic effects, and 6.8 % to GEI effects (Table 3). A large sum of squares for environments indicated that the environments were diverse, with large differences among environment means causing most of the variation in yield. The magnitude of the GEI sum of squares was 4.3 times larger than for genotypes, indicating that there were substantial differences in genotypic response across environments. The mean yield of the eight triticale genotypes for each environment varied from 1.80 (E15) to 7.62 (E8) t ha^{-1} (Table 2) and coefficient of variation of 12.09 %.

Table 1. Site description and agronomic details

Code	Growing season	Environments	Soil properties	Fertilization (kg ha $^{-1}$) N	Fertilization (kg ha $^{-1}$) P_2O_5	Rainfall+ (irrig) (mm)	Sowing date	Harvest. date
E1	1999-2000	Konya-Center*	pH= 8.2 clayey, alluvial	27[a]+40[b]	69 [a]	217	23.10.99	20.07.00
E2	1999-2000	Konya-Center**	pH= 8.2 clayey, alluvial	36+40	92	217(100)	23.10.99	20.07.00
E3	1999-2000	Konya-Çumra*	pH= 7.8 clayey loam, hydro-morfic alluvial	27+40	69	355	27.10.99	21.07.00
E4	1999-2000	Konya-Çumra**	pH= 8.2 clayey loam, hydro-morfic alluvial	36+40	92	355(100)	23.10.99	23.07.00
E5	1999-2000	Konya-Koçaş**	pH= 8.3 silty, brown	36+40	92	336(100)	01.11.99	26.07.00
E6	1999-2000	Konya-Beyşehir**	pH=7.7 clayey loam	36+40	92	377(100)	03.11.99	27.07.00
E7	2000-2001	Konya-Center*	pH= 8.2 clayey, alluvial	27+40	69	210	21.10.00	10.07.01
E8	2000-2001	Konya-Center**	pH= 8.2 clayey, alluvial	36+40	92	210(100)	21.10.00	23.07.01
E9	2000-2001	Konya-Çumra*	pH= 7.8 clayey loam, hydro-morfic alluvial	27+40	69	240	27.10.00	16.07.01
E10	2000-2001	Konya-Çumra**	pH= 7.8 clayey loam, hydro-morfic alluvial	36+40	92	240(100)	27.10.00	15.07.01
E11	2000-2001	Konya-Koçaş**	pH= 8.3 silty, brown	36+40	92	265(100)	02.11.00	24.07.01
E12	2000-2001	Konya-Ereğli**	pH =7.9, silty,brown	36+40	92	229(100)	03.11.00	20.07.01
E13	2000-2002	Konya-Center*	pH= 8.2 clayey, alluvial	27+40	69	384	22.11.01	25.07.02
E14	2000-2002	Konya-Çumra*	pH= 7.8 clayey loam, hydro-morfic alluvial	27+40	69	303	27.11.01	20.07.02
E15	2000-2002	Konya-Obruk*	pH= 7.6 clayey. brown	27+40	69	315	31.11.01	14.07.02
E16	2000-2002	Sivas*	pH= 8.2 clayey, alluvial	27+40	69	270	15.10.01	27.07.02

*Rain-fall conditions; ** Irrigation conditions; [a] Seed-bed; [b] Stem elongation

Table 2. Mean grain yield (t ha^{-1}) performance of eight triticale genotypes across sixteen environments of Central Anatolian Region of Turkey, 1999-2002

Code	Growing season	Environments	Genotypes[§] 1	2	3	4	5	6	7	8	Mean
E1	1999-2000	Konya-Center*	4.26	3.22	3.63	2.96	3.91	3.75	4.42	3.95	3.76
E2	1999-2000	Konya-Center**	5.25	5.39	5.33	4.95	5.57	5.63	5.61	3.62	5.17
E3	1999-2000	Konya-Çumra*	4.43	4.75	4.31	4.49	4.05	4.69	4.54	3.92	4.40
E4	1999-2000	Konya-Çumra**	7.66	7.30	7.48	7.05	7.24	7.69	7.09	6.85	7.30
E5	1999-2000	Konya-Koçaş**	5.15	4.65	4.32	3.69	3.96	4.64	4.25	4.11	4.35
E6	1999-2000	Konya-Beyşehir**	3.44	3.89	3.8	3.21	3.78	3.35	3.84	3.82	3.64
E7	2000-2001	Konya-Center*	4.49	4.68	5.42	5.67	5.26	5.73	5.11	4.49	5.11
E8	2000-2001	Konya-Center**	7.30	7.33	8.25	8.33	7.35	7.15	7.31	7.90	7.62
E9	2000-2001	Konya-Çumra*	4.99	5.74	5.82	5.28	5.13	5.49	4.95	4.49	5.24
E10	2000-2001	Konya-Çumra**	6.33	5.54	6.00	5.44	5.51	6.66	5.62	5.25	5.79
E11	2000-2001	Konya-Koçaş**	5.59	5.24	4.28	4.86	4.16	4.09	4.85	2.31	4.42
E12	2000-2001	Konya-Ereğli**	3.09	2.65	3.21	3.32	2.85	2.87	2.75	2.43	2.90
E13	2001-2002	Konya-Center*	6.95	6.88	7.66	6.27	7.04	5.44	5.73	6.43	6.55
E14	2001-2002	Konya-Çumra*	3.11	3.54	4.49	3.01	3.91	3.76	3.71	2.49	3.50
E15	2001-2002	Konya-Obruk*	1.62	1.56	2.07	1.68	2.08	1.79	1.62	1.94	1.80
E16	2001-2002	Sivas*	2.32	2.30	2.67	1.85	2.45	1.70	2.13	1.78	2.15
		Mean	4.75	4.67	4.92	4.50	4.64	4.65	4.60	4.11	4.60

[§]1: KTBVD-1; 2: KTBVD-11; 3: KTBVD-12; 4: KTBVD-13; 5: KTBVD-17; 6: KTBVD-21; 7: Tatlıcak-97; 8: BDMT-98/8S
*Rain-fall conditions; ** Irrigation conditions;

Table 3. Analysis of variance for grain yield for of 8 triticale genotypes based on sixteen environments in the Central Anatolian Region of Turkey

Source of variation	Df	Sum of square	Mean square	% Explained
Model	129	1167.94	9.05**	
Environment (E)	15	1068 .48	71.23**	91.5
Genotype (G)	7	19.19	2.74**	1.6
G*E	105	79.17	0.75**	6.8
Pooled error	254	79.00	0.31	
Total	383	1246.46		
CV=12.09 R^2=0.94 Mean=4.60				

** Significant at 0.01 level

Table 4. Analysis of variance for stability parameter for 8 triticale genotypes based on sixteen environments in the Central Anatolian Region of Turkey

Source of variation	Df	Sum of square	Mean square
Genotypes (G)	7	19.19	2.74**
Environment (E)+ G*E	120	1147.64	9.56**
E (linear)	1	1068.48	1068.48**
G*E (linear)	7	54.40	7.77**
Pooled deviations	112	24.76	0.22
Pooled error	224	51.95	0.23
% Explained G*E (linear)		68.72	

**Significant at 0.01 probability level respectively.

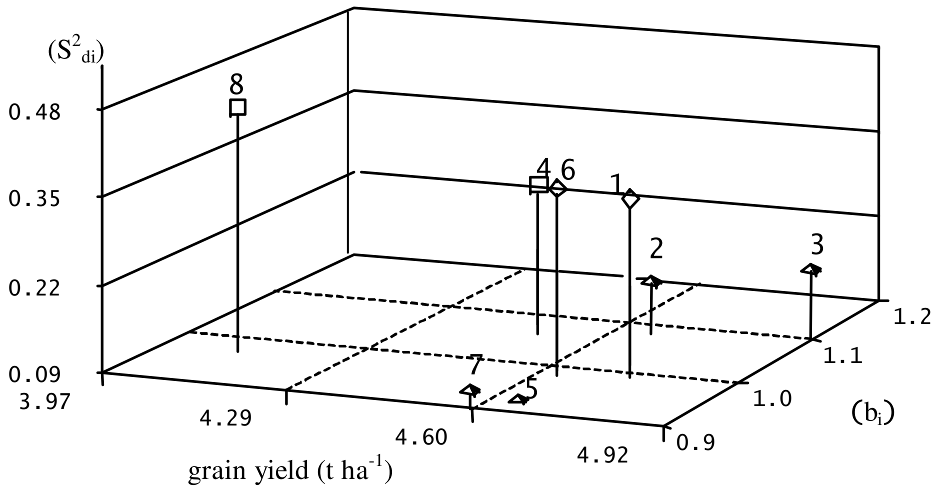
Table 5. Stability parameters and mean grain yields for 8 triticale genotypes hybrids sixteen environments

Code	Genotypes	$\bar{x}$ [a]	b_i [b]	S^2_{di} [c]	S_i^2 [c]	CV_i [c]	σ_i^2 [c]	W_i^2 [c]	α_i [b]	λ_i [b]	R_i^2 [b]	*F*
1	KTBVD 1	**4.75**	**0.99**	0.24	**3.12**	**37.21**	3.35	0.26	**-0.01**	2.47*	**0.93**	**4**
2	KTBVD 11	**4.67**	**1.08**	**0.18**	3.60	40.65	**2.73**	**0.20**	**0.08**	**1.83**	**0.95**	**6**
3	KTBVD 12	**4.92**	**1.10**	**0.20**	3.76	39.23	**3.23**	**0.25**	**0.10**	2.08**	**0.94**	**5**
4	KTBVD 13	4.50	**1.06**	0.23	3.59	42.02	3.40	0.26	**0.07**	2.37*	**0.94**	**2**
5	KTBVD 17	**4.64**	**0.93**	**0.09**	**2.64**	**34.99**	**1.56**	**0.10**	**-0.07**	**0.97**	**0.96**	**9**
6	KTBVD 21	**4.65**	**0.98**	0.26	**3.12**	**37.90**	3.60	0.28	**-0.02**	2.65**	**0.92**	**4**
7	Tatlıcak-97	**4.60**	**0.90**	**0.12**	**2.50**	**34.84**	**2.18**	**0.15**	**-0.10**	**1.26**	**0.95**	**9**
8	BDMT 98/8S	4.11	**0.97**	0.45	**3.18**	43.53	6.35*	0.52*	**-0.03**	4.66**	**0.86**	**1**
	Mean	**4.60**	**1.00**	**0.22**	**3.19**	**38.80**	**3.30**	**0.25**	**0.00**			

[a] Printed values in bold are greater than the mean [b] Printed values in bolds are non-significantly different from unity at P<0.05. Cultivars with values in bolds are considered stables. [c] Printed values in bold are lower than the mean. Cultivars with values in bolds are considered stables. $\bar{x}$ = mean grain yield (t ha^{-1}) b_i: Regression coefficient, S^2_{di}: deviation from regression (Eberhart and Russell 1966). S^2_i: environmental variance, CV_i: coefficient of variation (Francis and Kannenberg 1978), R_i^2: coefficients of determination (Pinthus 1973), σ_i^2: Shukla stability variance (Shukla 1972). W_i^2: ecovalence (Wricke 1962). α_i: genotype to the environmental effects and the λ_i: deviation from the linear response (Tai 1971), *F*=Frequency of the 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 the most stable .

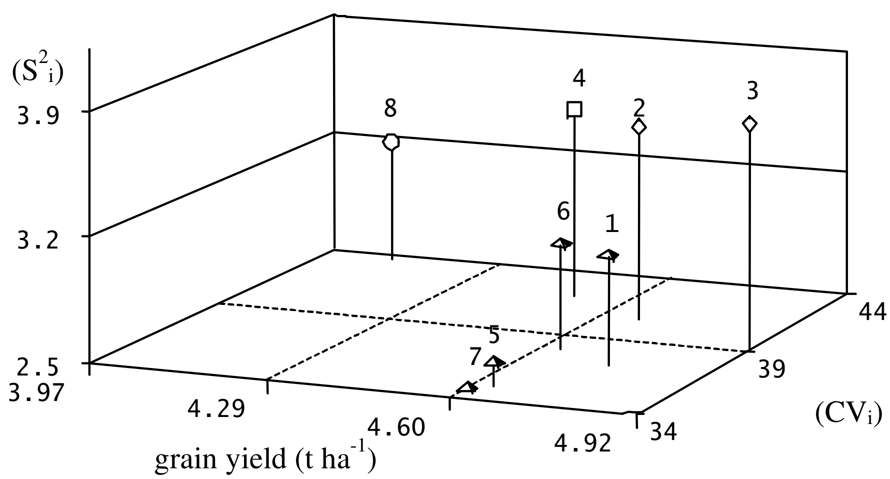
A pooled analysis of variance for stability (Table 4) showed that differences among genotypes were significant for grain yield (P<0.01). Differences between environments were highly significant for grain yield (Table 2). These significant differences and reversal in yield ranks reflect the fluctuations of genotypes in their responses to the different environments of locations and years. This reveals not only the amount of variability that existed among environments but also the presence of genetic variability among the genotypes included in this research. The GEI component was further partitioned into linear (environment and genotypes-environments) and non-linear (pooled deviations) components. Mean squares for both of these components were tested against pooled error mean square. The linear component was highly significant, indicating that the predictable-components shared GEI's.

The stability parameters for all genotypes are given in Table 5, Eberhart and Russell (1966) emphasised the need of considering both linear (b_i) and non-linear (S^2_{di}) components of GEI's in judging the stability of a genotype. A wide adaptability genotype was defined as one with b_i=1.0 and high stability as one with S^2_{di}=0. In this research values for regression coefficient (b_i) ranged from 0.90 (Tatlıcak-97) to 1.10 (KTBVD-12) for grain yield. Eberhart and Russell (1966) stated that genotypes with high mean yield, regression coefficient equal to the unity (b_i) and



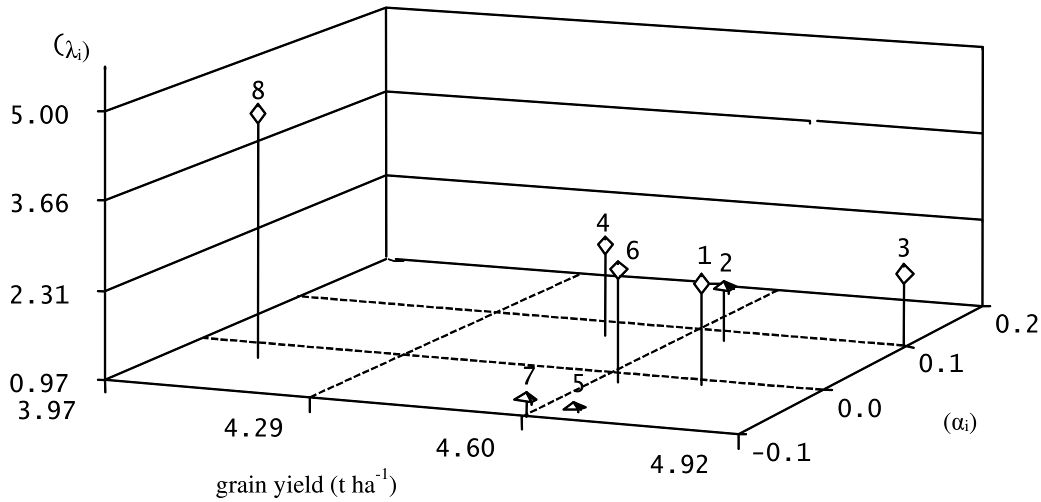
(1: KTBVD-1; 2: KTBVD-11; 3: KTBVD-12; 4: KTBVD-13; 5: KTBVD-17; 6: KTBVD-21; 7: Tatlicak-97; 8: BDMT-98/8S)
Different stability regions are denoted by different symbols
Square: S^2_{di} is greater than mean and grain yield lower than mean;
Diamond: S^2_{di} and grain yield are greater than mean
Pyramid: Stable

Figure 1. Three-dimensional plot for regression coefficient (b_i) and deviation from regression (S^2_{di}) stability parameters versus the genotypic mean response.



(1: KTBVD-1; 2: KTBVD-11; 3: KTBVD-12; 4: KTBVD-13; 5: KTBVD-17; 6: KTBVD-21; 7: Tatlicak-97; 8: BDMT-98/8S)
Different stability regions are denoted by different symbols
Balloon: S^2_i and CV_i are greater than mean and grain yield lower than mean
Square: S^2_i and grain yield are lower than mean, CV_i is greater than mean
Diamond: grain yield, S^2_i and CV_i are greater than mean
Pyramid: Stable

Figure 2. Three-dimensional plot for environmental variance (S^2_i) and coefficient of variation (CV_i) stability parameters versus the genotypic mean response.



(1: KTBVD-1; 2: KTBVD-11; 3: KTBVD-12; 4: KTBVD-13; 5: KTBVD-17; 6: KTBVD-21; 7: Tatlicak-97; 8: BDMT-98/8S)
Different stability regions are denoted by different symbols
Diamond: Only λ_i is significantly different from unity
Pyramid: Stable

Figure 3. Three-dimensional plot for α_i and λ_i stability parameters versus the genotypic mean response

deviation from regression as small as possible (S^2_{di}=0) are considered as stable. According to these stability parameters, KTBVD-11, KTBVD-12, KTBVD-17 and Tatlıcak-97 could be considered widely adapted and stable Their regression coefficients nearly 1.0 with S^2_{di} values both not significantly differently from zero and lower than mean for grain yield (Table 5). Also, a three-dimensional plot of response mean versus Eberhart Russell's stability estimates (b_i, S^2_{di}) is shown in Figure 1. These figure also sowed that KTBVD-11, KTBVD-12, KTBVD-17 and Tatlıcak-97 were the most stable genotypes for grain yield.

According to Francis and Kannenberg's (1978), genotypes exhibiting low environmental variance (S^2_i) and coefficient of variation (CV_i) are considered as stable (Lin et al. 1986). KTBVD-1, KTBVD-17, KTBVD-21 and Tatlıcak-97 had smaller environmental variance (S^2_i) and mean of coefficient of variation (CV_i) for grain yield confirming their high stability. On the other hand these genotypes had grain yield greater than grand mean yield (Figure 2).

Shukla (1972) developed an unbiased estimate using stability variance (σ_i^2) of genotypes. Comparison (σ_i^2) with (σ_0^2) (pooled error from ANOVA) for each genotype is made. Genotypes with a significant *F* value are considered to be unstable. In this research, genotypes with smaller (σ_i^2) value were the considered the most stable. According to stability variance (σ_i^2) genotypes KTBVD-11, KTBVD-12, KTBVD-17 and Tatlıcak-97 were the most stable.

Wricke's (1962) was used ecovalence (W_i^2) stability parameter. According to this stability parameter genotypes with the smaller ecovalence (W_i^2) values are considered most stable. According to this stability parameter KTBVD-11, KTBVD-12, KTBVD-17 and Tatlıcak-97 were the most stable.

Tai's model (1971) is based on the principle of structural relationship analysis, the GEI effect of variety is partitioned in two components. They are the linear response to environmental effects, which is measured by a statistic (α_i) and the deviation from the linear response, which is measured by (λ_i) statistic. A three-dimensional plot of response mean versus Tai's stability estimates (α_i, λ_i) is shown in Figure 3. This three-dimensional plot is useful to visually evaluate the yield potential and stability estimates of the genotypes (Thillainathan and Fernandez 2001). The different symbols used in the three-dimensional plot separate the genotypes based on the statistical significance of Tai's stability statistics. According to these stability statistics, KTBVD-11, KTBVD-17 and Tatlıcak-97 could be considered as the most stable (Table 5 and Figure 3).

The coefficient of determination (R_i^2), which is the predictability of estimates response (R_i^2=1).The values ranged from 0.86 to 0.96, which indicated that % 86 to % 96 of the variation in, mean yield was explained by genotype response across environments. None of coefficient of determinations was significantly different from 1.0, with regard to parameter, high yielder genotypes could be considered stable for grain yield (Table 5).

The study of genotypic stability revealed why some genotypes are grown in the Central Anatolian Region. In fact, KTBVD-17, introduced Bahri Dağdaş International Agricultural Research Institute, demonstrated higher stability for grain yield. This genotype can also be grown in other winter regions of Turkey, particularly under drought conditions. Besides, Tatlıcak-97, which introduced Bahri Dağdaş International Agricultural Research Institute, also showed average stability and may still, be of interest for growers in Turkey. The genotypes KTBVD 11 can be used as progenitor in triticale breeding programmes for the production of high grain yield triticale in the Turkey.

Finally the following major finding can be summarised from this research: (i) KTBVD-17 was the most stable genotype, genotypes Tatlıcak 97 and KTBVD 11 were stable genotypes for grain yield. (i) Stability and wide adaptation are of vital importance in Turkey where fluctuations in growing conditions are very high. In addition to defining genotypic stability, several methods or parameters should be used; a genotype is considered stable for grain yield if it appeared stable in more than majority (out of all) stability analyses.

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