

EVALUATION OF TRITICALE: GENOTYPE BY ENVIRONMENT INTERACTION AND GGE BILOT ANALYSIS

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ABSTRACT

Stability and the preferred response of genotypes over various environments are essential for plant breeders. Six registered cultivars (Truva, Alperbey, Collegial, Karma 2000, Melez 2001 and Tatlıcak 97) and two advanced lines (TR-Trp16 and TR-Avk16) were studied across six environments (E) during two growing seasons in 2016-2017 and 2017-2018 at three locations (Kırklareli, Tekirdağ and Edirne) in Turkey. Genotype (G), genotype × year (G × Y), genotype × location (G × L) and genotype × year × location (G × Y × L) interactions were found significant for all investigated traits. Grain yield of the genotypes ranged from 5539 to 6800 kg ha⁻¹ and cultivar Collegial had the highest grain yield (6800 kg ha⁻¹), while cultivar Melez 2001 had the lowest (5539 kg ha⁻¹). In terms of years, grain yield was higher in 2017 (6466 kg ha⁻¹) and lower in 2018 (6016 kg ha⁻¹). Among the test environments, Edirne was the highest for grain yield (7872 kg ha⁻¹) followed by Kırklareli (5638 kg ha⁻¹) while Tekirdağ was the lowest (5214 kg ha⁻¹). Tekirdağ 2018 was found as the most favourable environment in terms of grain yield. Results revealed that Collegial was the most superior genotype across environments and cultivar Alperbey was the most stable genotype. This study indicates that cultivar improvement efforts should be put on to develop triticale genotypes for the specific environments rather than a broad adaptation.

Keywords: Environment, GGE biplot, Grain yield, Stability, Triticale

Published first online June 10, 2022.

Published final November 20, 2022

INTRODUCTION

The hexaploid triticale (*xTriticosecale* Wittmack) was obtained as a result of hybridization aiming to combine the higher yield and quality characteristics of wheat with the non-selective characteristics of rye in terms of soil and climate and its resistance to diseases and pests. It is cultivated in large areas in many countries today (Oettler, 2005; Villegas *et al.*, 2010). Triticale grain is high in protein (Aydoğan Cifci *et al.*, 2010) and energy value which makes it a favourable source for animal feed (Gerdzhikova, 2014) that varies on genotypes. The triticale stands out as an important alternative plant to meet the increasing feed supply and utilizing marginal and unproductive areas (Unver, 1999; Furan *et al.*, 2005; Villegas *et al.*, 2010; Tayyar and Kahrman, 2016).

In 2019, production of triticale was 14 million tons in 3.8 million ha area around the world, while 215 thousand tons were produced in 64.101 ha area in Turkey (FAO, 2019). Developing of triticale cultivars and increasing triticale production in Turkey to recommend different regions of the country is important (Senturk and Akgun, 2014). In literature, researchers have focused on yield, yield components and quality characteristics of

triticale under different ecological conditions. Variation has been reported as 78.7-128.55 cm (plant height), 8.3-13.6 cm (spike length), 21.1-32.3 numbers (spikelet/spike), 34.4-75.6 numbers (kernels/spike), 29-49.35 g (thousand kernel weight), 1310-6429.5 kg ha⁻¹ (grain yield), 66.3-78.5 kg hl⁻¹(test weight), 9.8-15.5% protein ratio (Tayyar and Kahrman, 2016; Mut and Erbas Kose, 2018; Bezabih *et al.*, 2019; Dolgun and Aydoğan Cifci, 2019; Kucukoğdemir *et al.*, 2019).

Plant breeders also put efforts to develop superior cultivars that can adapt to different environmental conditions with desirable features (Oral *et al.*, 2018; Gungor and Dumlupinar, 2019; Kendal, 2020). It is quite difficult to determine genotypes performing well and stable in many aspects. Thus, it is crucial to develop stable cultivars. Genotype (G) + genotype by environment (G×E) interaction is a method that combines interactive effects of two basic components on the same graph and provides plant breeders an opportunity to visually evaluate the data in two directions. In recent years, GGE biplot analysis has been used in several studies in different genotypes, different environments or years, and accepted as an innovative method in plant breeding, due to the power of biplot illustration for many features at the same time and that affects the success in

selection (Yau, 1995; Yan *et al.*, 2007; Kendal *et al.*, 2019; Kocaturk *et al.*, 2019; Karaman, 2020).

This study was aimed to evaluate grain yield, yield components and some quality characteristics of some triticale genotypes in different locations by GGE biplot analysis method and to determine stable genotypes with higher yield and quality.

MATERIALS AND METHODS

Plant materials, agricultural practices and environmental conditions: In this research, a total of eight genotypes including six commercial cultivars (Truva, Alperbey, Collegial, Karma 2000, Melez 2001 and Tatlıcak 97) and two advanced lines (TR-Trp16 and TR-Avk16), were used as material.

The experiments were conducted out in six different environments at Kırklareli, Tekirdağ and Edirne locations during 2016-2017 and 2017-2018 growing seasons, representing the entire Thrace region. The

climate data for the two-year growing seasons in Kırklareli, Tekirdağ and Edirne are given in Table 1.

The research was arranged in a randomized complete block design with four replications. The experiments were planted at the end of October and the first week of November in the first and second growing seasons, respectively. There were 6 rows of 5 m length in each plot with a row spacing of 20 cm and density of 500 seeds per m². There was no chemical usage for the pests and weeds

Fertilizer was applied as 50 kg ha⁻¹ each of nitrogen and phosphorus at planting and top dressing was divided into two doses as 90 kg ha⁻¹ nitrogen at tillering and 60 kg ha⁻¹ nitrogen at grain filling period. All the trials throughout the environments and years were harvested in the first week of July.

Plant height, heading time (the number of days from January 1st until the day when the plants were at 50% heading in each plot), spike length, grain number per spike, grain weight per spike, thousand-grain weight, test weight, protein ratio (NIR), and grain yield traits were evaluated.

Table 1. Mean climatic data belonging to trial years.

Years	2016-2017						2017-2018					
	Temperature (°C)			Precipitation (mm)			Temperature (°C)			Precipitation (mm)		
	Edirne	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ
October	14.3	14.1	15.9	44.4	53.3	82.4	13.6	13.4	14.9	135.2	65.7	111.2
November	0.7	1.2	3.8	3.2	7	43.1	9.5	9.4	11.7	71.6	78.1	85.2
December	0.7	1.2	3.8	3.2	7	43.1	7.4	7.6	9.5	119.6	117.8	94.8
January	-1.9	-0.4	1.9	67.8	48	107	4.3	4.6	6.6	55.6	83.9	76.5
February	5.3	5.5	6.5	43.4	60.3	38.8	5.7	6.1	7.2	101.8	48	95.3
March	10.2	9.5	9.1	51	43.6	32.2	8.9	8.5	10.2	145.6	172.6	63.7
April	12.5	12.1	11.2	65.6	75.5	51.6	16.6	16.1	14	3	2.4	10.6
May	17.9	17.6	16.8	85	43.8	16.7	20.3	19.5	18.5	18.8	34	20.3
June	21.2	23.1	22	44.4	27.8	36.8	22.6	22.5	22.4	148.4	93.8	75.4
Total				408	366.3	451.7				799.6	696.3	633

Statistical analysis: The data obtained from two experiment years were subjected to variance analysis. LSD test was used for comparison of the means. Principal component analyses were calculated based on average data and evaluated with biplot approach (Pearson, 1901; Jolliffe, 2002) performed by JMP 15.1 statistical software. GGE Biplot analyses were calculated (Yan *et al.*, 2007) with software *GenStat*, version 14 over six environments using mean data (VSN International, 2014).

RESULTS AND DISCUSSION

Genotype by Environment Interaction (GEI): Genotype by environment interaction was conducted out

for eight triticale genotypes across two years and three locations. According to the combined analysis of variance, location, genotype, year by location, genotype and genotype by year were found significant for all investigated traits. Years were found significant for all traits except plant height. Genotype by location and genotype × year × location interactions were found significant for all investigated traits except grain yield (Table 2).

For grain yield, the average genotype performances over years and locations ranged from 5539 to 6800 kg ha⁻¹ (Table 3). The highest grain yield was noted in genotype Collegial (6800 kg ha⁻¹), while it was the lowest in genotype Melez 2001 (5539 kg ha⁻¹). In

terms of year means, genotypes produced maximum grain yield in 2017 (6466 kg ha⁻¹) and minimum grain yield in 2018 (6016 kg ha⁻¹). For location means the genotypes produced maximum grain yield at Edirne (7872 kg ha⁻¹) followed by Kırklareli (5638 kg ha⁻¹), while minimum at Tekirdağ (5214 kg ha⁻¹). For genotype × year × location interaction, the grain yield ranged from 4154 to 9113 kg ha⁻¹. The highest grain yield was obtained from genotype Collegial (9113 kg ha⁻¹) in 2018 at Edirne and it was found similar in performance with other genotypes Alperbey and Truva. However, the lowest grain yield was observed in genotype TR-Trp16 (4154 kg ha⁻¹) in 2018 at Kırklareli (Table 3). Grain yield as a quantitative trait is a result of several conditions in terms of genotypic influence, environmental conditions and cultural practices. An 18.5% variation was observed for the grain yield of the triticale genotypes. Average grain yield was 6466 kg ha⁻¹ in 2017, while 6016 kg ha⁻¹ in 2018 which accounts for a 6.96% decrease in 2018. However, 33.8%

difference was detected according to location averages as the lowest location was Tekirdağ with 5214 kg ha⁻¹, while the highest grain yield average was obtained from Edirne location with 7872 kg ha⁻¹. Grain yield differences might be due to environmental conditions and genetic influences. In previous works variations on grain yield of triticale genotypes were also reported as caused by genetic influence and environmental effects (Lule *et al.*, 2014; Kendal *et al.*, 2016; Ozturk *et al.*, 2019). In addition, Gulmezoglu *et al.* (2010) stated that grain yield of triticale was positively affected by grain number per spike, plant height and thousand kernel weight and negatively affected by protein ratio. Nevertheless, Bezabih *et al.* (2019) stated that grain yield of the triticale genotypes was not affected by genotype x environment interaction and genotypes performed almost similar in those environments, which is inconsistent with our findings, that the grain yield of the triticale genotypes varied for the environments.

Table 2. Mean square values of investigated traits.

S. V.	Y	L	Y×L	Y×L×R	G	G×Y	G×L	G×Y×L	CV
D. F.	1	2	2	18	7	7	14	14	
GY	97007**	1304654**	109605**	7649 ^{ns}	44741**	25407**	6387 ^{ns}	6530 ^{ns}	12.26
PH	10.407 ^{ns}	2527.56**	233.168**	9.578 ^{ns}	644.046**	44.319*	137.345**	59.509**	3.44
HD	4641.333**	177.646**	41.271**	0.698 ^{ns}	745.14**	23.31**	12.229**	12.497**	0.77
SL	322.9219**	14.0508**	26.13**	1.0888 ^{ns}	89.3187**	5.6575**	6.1124**	4.1772**	7.96
GNS	44165.33**	955.19**	1929.85**	80.67 ^{ns}	1502.52**	442.26**	425.15**	470.30**	13.68
GWS	186.1847**	15.7471**	7.6362**	0.1241 ^{ns}	4.2603**	2.1154**	2.3151**	2.2466**	17.34
TKW	788.9408**	759.7582**	204.6016**	0.4985*	82.0288**	16.4888**	20.0551**	5.2089**	1.38
TW	101.3555**	265.4307**	67.8864**	0.1762 ^{ns}	191.6566**	15.6645**	8.1640**	7.0715**	0.62
PR	0.07922**	8.8727**	1.23938**	0.0162*	12.86684**	1.32124**	1.10869**	0.52926**	0.83

** significant at P<0.01, * significant at P<0.05, ns: not significant, Y: Years, L: Locations, G: Genotypes, R: Replications, CV%: Variation of coefficient, S.V.: Sources of variations, D.F.: Degrees of Freedom, GY: Grain Yield, PH: Plant Height, HD: Heading Date, SL: Spike Length, GNS: Grain number per spike, GWS: Grain weight per spike, TKW: Thousand kernel weight, TW: Test weight, PR: Protein ratio

Table 3. Mean performance of triticale genotypes for grain yield (kg ha⁻¹).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	7183	5111	8835	5604	5425	8199	6726 ab
Alperbey	6177	5665	8375	5038	5833	8060	6525 abc
Collegial	6977	5121	8063	5625	5900	9113	6800 a
Karma 2000	5915	4829	7588	5378	5921	8107	6290 bcd
Melez 2001	5642	4617	7146	4488	4217	7127	5539 e
Tatlıcak 97	6377	5733	6604	4779	5039	8073	6101 cd
TR-Trp16	6577	5586	8179	4154	4296	6854	5872 de
TR-Avk16	5879	4875	8131	4421	5254	7906	6078 d
Year means	2017= 6466 a			2018= 6016 b			
Location means	Kırklareli:5638 b		Tekirdağ = 5214 c		Edirne = 7872 a		

The genotypes mean performances over years and locations for plant height changed from 108.8 to 124.6 cm (Table 4).

Plant height was the shortest for genotype TR-Trp16 (108.8 cm), while the tallest in genotype Truva (124.6 cm). However, Truva was found similar in plant

height with other Tatlıcak 97 genotype (123.9 cm). The plant height of the genotypes were similar in 2017 (118 cm) and 2018 (118.5 cm), while location averages were

different at Tekirdağ (113.7 cm), Kırklareli (118 cm) and Edirne (125.4 cm). In genotype × year × location interactions, the mean plant height values changed from 93.5 to 134.3 cm. Minimum plant height value was determined for genotype TR-Trp16 (93.5 cm) in 2018 at Kırklareli, while maximum plant height was noted for genotype Tatlıcak 97 (134.3 cm) in 2018 at Edirne location (Table 4). Variation on plant height of the triticale genotypes was observed as 12.6%, while there was no significant differences between years. Plant height

mean of the locations Tekirdağ and Kırklareli was closer, while Edirne location's plant height was taller than the other two locations. Similar findings for different locations were also indicated by Kendal and Sayar (2016), Kendal *et al.* (2016) and Mut and Erbas Kose (2018).

The genotype averages across years and locations for heading date varied from 112.7 to 126.6 days (Table 5).

Table 4. Mean performance of triticale genotypes for plant height (cm).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	128.9	117.8	125.8	120.0	122.0	133.3	124.6 a
Alperbey	111.6	111.8	123.8	118.5	112.5	129.3	117.9 b
Collegial	117.0	111.3	114.5	112.0	110.8	115.5	113.5 c
Karma 2000	115.1	118.5	128.8	110.0	120.3	125.8	119.7 b
Melez 2001	126.0	105.0	125.5	120.8	111.5	131.0	118.9 b
Tatlıcak 97	123.9	115.3	131.8	122.0	116.5	134.3	123.9 a
TR-Trp16	108.3	99.9	122.0	93.5	111.0	118.0	108.8 d
TR-Avk16	115.5	114.3	126.5	113.8	120.3	120.8	118.5 b
Year means	2017= 118.0			2018= 118.5			
Location means	Kırklareli:115.6 b		Tekirdağ = 113.7 c		Edirne = 125.4 a		

Table 5. Mean performance of triticale genotypes for heading date (days).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	127.3	126.5	127.3	119.8	117.8	116.5	122.5 cd
Alperbey	120.8	120.3	117.5	109.5	108.5	101.3	113.0 e
Collegial	129.8	129.5	129.0	124.8	119.3	120.8	125.5 b
Karma 2000	118.8	120.3	118.0	110.8	105.8	102.8	112.7 e
Melez 2001	128.3	125.8	127.0	118.0	118.5	115.5	122.2 d
Tatlıcak 97	127.8	125.5	127.0	124.8	116.8	115.0	122.8 c
TR-Trp16	132.5	131.3	128.5	124.3	121.5	119.3	126.2 a
TR-Avk16	133.0	131.0	130.0	121.3	121.5	122.8	126.6 a
Year means	2017= 126.3 a			2018= 116.5 b			
Location means	Kırklareli:123.2 a		Tekirdağ = 121.2 b		Edirne = 119.9 c		

The longest heading date was obtained from genotype Tr-Avk16, while the earliest heading date was obtained from genotype Karma 2000. On the other hand, genotype TR-Avk-16 was found similar to other genotype TR-Trp16 (126.2 days) in terms of heading date. Triticale genotypes had the longest heading date in 2017 (126.3 days) and the earliest heading date in 2018 (116.5 days). The mean heading date of the three locations was changed from 119.9 to 123.2 days. For locations, the longest value of heading date was obtained at Kırklareli while Edirne was the earliest. For genotype × year × location interaction, the mean values for heading date varied from 101.3 to 133.0 days. The longest heading date was obtained from genotype TR-Avk16 in 2017 at Kırklareli, while the earliest heading date was observed

from genotype Alperbey in 2018 at Edirne (Table 5). Heading date is a very important parameter to evaluate vegetation period, and the differentiation was measured as 10.7% for triticale genotypes. The mean of 2017 growing season was 126.3 days, while 116.5 days in 2018. The locations were also differed for heading date as expected due to environmental conditions and Edirne was found earlier, where Kırklareli was longer. In various studies, it is indicated that heading date is affected by genetic structure, growth habits and different environments as well (Villegas *et al.*, 2010; Gungor and Dumlupinar, 2019). On the other hand, it is also indicated that high temperatures after heading often have harmful effects on the grain yield of cereals by reducing kernel

weight (Gibson and Paulson, 1999; Schwarte *et al.*, 2006).

For spike length, genotype mean values across years and location changed from 10.92 to 16.08 cm (Table 6).

Table 6. Mean performance of triticale genotypes for spike length (cm).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	14.23	11.25	16.43	16.60	18.78	19.23	16.08 a
Alperbey	10.13	9.83	11.80	13.30	14.20	12.93	12.03 c
Collegial	9.18	9.63	9.80	12.15	13.18	12.25	11.03 d
Karma 2000	11.00	11.88	12.63	13.23	14.35	11.80	12.48 c
Melez 2001	12.98	14.88	14.75	15.10	17.45	15.63	15.13 b
Tatlıcak 97	11.23	10.00	10.28	12.75	14.60	13.58	12.07 c
TR-Trp16	9.63	9.78	10.38	9.50	15.78	12.88	11.32 d
TR-Avk16	10.83	9.45	10.18	11.70	10.90	12.50	10.92 d
Year means	2017= 11.34 b			2018= 13.93 a			
Location means	Kırklareli: 12.09 b		Tekirdağ= 12.87 a		Edirne= 12.94 a		

The minimum spike length was recorded in genotype TR-Avk16, while the maximum spike length value was determined in cultivar Truva. According to the year's means, the highest spike length was recorded in 2018 (13.93 cm), while the lowest spike length was determined in 2017 (11.34 cm). Among the locations, spike length value of genotypes varied from 12.09 to 12.94 cm. The highest spike length was obtained from Edirne (12.94 cm) and it was followed by Tekirdağ (12.87 cm) and Kırklareli (12.09 cm), respectively. In genotype \times year \times location interactions, the mean spike length values changed from 9.18 cm to 19.23 cm among the genotypes. The highest spike length was noted in genotype Truva (19.23 cm) in 2018 at Edirne, while the lowest spike length was recorded in genotype Collegial (9.18 cm) genotype in 2017 at Kırklareli (Table 6). The spike length is one of the yield components directly affecting the yield and the change of the triticale genotypes over year and environment averages was determined as 32.1% in our study. According to our findings, spike length is mainly under genetic influence and environmental conditions are also significant. In previous works, Cifci Aydoğan *et al.* (2010) and

Gerdzhikova (2014) indicated genetic influence on spike length of triticale genotypes, Gungor and Dumlupinar (2019) reported genetic influence on wheat spike length and Dumlupinar *et al.* (2017) also showed genetic influence on panicle length of oat genotypes. The genotype means across years and locations for grain number per spike ranged from 53.2 to 79.9. The highest grain number per spike was noted in genotype Truva (79.9), while the lowest mean grain number per spike was determined in Tatlıcak 97 (53.2) genotype. In terms of year means of the genotypes, the maximum grain number per spike was recorded in 2018 (80.12), while the minimum grain number per spike was determined in 2017 (49.79). For location means, the highest grain number per spike was observed in Edirne location (68.58) and the lowest was obtained from Kırklareli location (60.89). In genotype \times year \times location interactions, the mean grain numbers per spike values ranked between 35 and 119.5. Greatest grain number per spike was achieved in genotype Truva (119.5) at Tekirdağ in 2018 and the smallest grain number per spike was recorded in genotype Tatlıcak 97 (35) at Tekirdağ in 2017 (Table 7).

Table 7. Mean performance of triticale genotypes for grain number per spike.

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	58.0	42.5	77.5	77.3	119.5	104.5	79.9 a
Alperbey	39.3	39.0	54.0	65.3	81.5	61.3	56.7 c
Collegial	52.5	45.3	55.3	81.5	102.3	68.8	67.6 b
Karma 2000	58.0	52.5	64.0	68.8	88.8	60.8	65.5 b
Melez 2001	41.8	52.0	59.0	83.8	82.3	80.3	66.5 b
Tatlıcak 97	46.0	35.0	38.0	63.0	70.8	66.5	53.2 c
TR-Trp16	42.8	48.0	60.3	64.0	77.0	99.0	65.2 b
TR-Avk16	50.8	37.0	46.8	81.8	73.3	101.5	65.2 b
Year means	2017= 49.79 b			2018= 80.12 a			

Location means	Kırklareli:60.89 c	Tekirdağ = 65.41 b	Edirne = 68.58 a
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The average of genotypes across years and locations for grain weight per spike changed from 2.32 to 3.61 g. The highest grain weight per spike was obtained by genotypes Truva (3.61 g) and TR-Avk16 (3.37 g), while the lowest grain weight per spike was determined in genotypes Tatlıcak 97 (2.32 g) and Alperbey (2.49 g). The genotypes had the heaviest grain weight per spike in 2018 (3.93 g), while it was lower in 2017 (1.96 g). The highest

grain weight per spike was determined in Edirne (3.50 g) and the lowest grain weight per spike was recorded in Kırklareli (2.54 g). For genotype × year × location interaction, the grain weight per spike ranged from 1.13 to 6.54 g. The highest grain weight per spike was noted in genotype TR-Avk16 (6.54 g) in 2018 at Edirne, and the lowest grain weight per spike was recorded in genotype Tatlıcak 97 (1.13 g) in 2017 at Tekirdağ (Table 8).

Table 8. Mean performance of triticale genotypes for grain weight per spike (g).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	1.94	1.22	3.91	3.24	5.71	5.65	3.61 a
Alperbey	1.43	1.14	2.65	2.99	3.98	2.79	2.49 c
Collegial	2.02	1.53	2.72	4.10	4.58	3.17	3.02 b
Karma 2000	2.05	1.75	3.11	3.06	4.23	2.95	2.86 b
Melez 2001	1.34	1.92	2.79	4.10	4.33	3.71	3.03 b
Tatlıcak 97	1.59	1.13	1.84	2.57	3.30	3.49	2.32 c
TR-Trp16	1.31	1.40	2.73	2.44	3.67	5.72	2.88 b
TR-Avk16	2.11	1.23	2.28	4.46	3.61	6.54	3.37 a
Year means	2017= 1.96 b			2018= 3.93 a			
Location means	Kırklareli:2.54 c			Tekirdağ = 2.79 b		Edirne = 3.50 a	

Grain number and weight per spike are of critical importance to determine final grain yield and quality. A wide variation was detected for grain number per spike and grain weight per spike values of the genotypes (33.4% and 35.7%, respectively). The differences between experiment years and locations were also found significant. The changes in grain number per spike and grain weight per spike of the triticale genotypes were affected by structure of the genotypes and environmental conditions. In earlier studies, it is also indicated that grain number per spike and grain weight per spike were affected by genotypic influence and different environments as well (Gerdzhikova, 2014; Senturk and Akgun, 2014). In addition, Motzo *et al.* (2012) reported high heritability and genetic variation in contrast to less improvement for the genotype by environment interaction feature to the entire variance.

For thousand kernel weight, the genotype means across years and locations varied from 34 to 39.4 g. The lowest thousand kernel weight was recorded in genotype TR-Trp16 (34 g), while the highest thousand kernel weight was obtained from genotype Alperbey (39.4 g) genotype and it was followed by genotype Collegial (39.1 g) and genotype TR-Avk16 (38.5 g). The thousand kernel weight of the genotypes in 2018 (39.7 g) was higher than as it is in 2017 (35.6 g). Kırklareli location had the lowest thousand kernel weight with 35.2 g, while Edirne location had lower thousand kernel weight with 41.6 g. For genotype × year × location interaction, the thousand kernel weight ranged from 28.5 to 45.4 g. The highest thousand kernel weight was recorded from genotype Collegial (45.4 g) at Edirne in 2017, while the lowest thousand kernel weight was observed for genotype TR-Trp16 (28.5 g) in 2017 at Tekirdağ (Table 9).

Table 9. Mean performance of triticale genotypes for thousand kernel weight (g).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	34.3	32.6	40.0	39.8	39.7	40.9	37.8 e
Alperbey	36.1	32.1	40.3	40.8	44.2	43.5	39.4 a
Collegial	33.3	32.3	45.4	41.1	37.9	45.0	39.1 b
Karma 2000	31.6	34.5	44.1	36.3	41.3	42.1	38.3 cd
Melez 2001	31.5	33.7	39.7	39.0	41.0	43.3	38.0 de
Tatlıcak 97	31.5	32.3	39.0	35.0	38.1	38.5	35.7 f
TR-Trp16	29.1	28.5	41.3	32.9	34.3	38.1	34.0 g
TR-Avk16	33.6	35.4	42.5	37.1	41.0	41.6	38.5 c

Year means	2017= 35.6 b	2018= 39.7 a
Location means	Kırklareli:35.2 c	Tekirdağ = 36.1 b Edirne = 41.6 a

Thousand kernel weight is one of the quality parameters of cereals which is also one of the important components of grain yield. After the set of the grain numbers in the spike, the favourability of the grain filling period determines the thousand kernel weight. In the research, triticale genotypes differed for thousand kernel weight and the variation over experiment was measured as 13.7% among triticale genotypes. In literature several researchers investigated thousand kernel weight of cereals as well as triticale. It is indicated that thousand kernel weight is highly influenced by structure of the genotypes and environmental conditions (Cifci Aydogan *et al.*, 2010; Gerdzhikova, 2014; Senturk and Akgün, 2014; Kendal and Sayar, 2016).

The genotype means across years and locations for test weight changed from 65.1 to 72.6 kg. The minimum test weight was noted in genotype Collegial (65.1 kg) and maximum test weight was recorded in genotype Alperbey (72.6 kg). However, genotype

Alperbey was found similar to genotype Tatlıcak 97 (72.4 kg). Test weight of the genotypes in 2017 year was recorded as 70.1 kg, while 68.7 kg in 2018. The highest test weight value was observed in Edirne location (71.6 kg), while it was lowest in Tekirdağ location (67.7 kg). For genotype × year × location, the test weight varied from 61.1 to 76.2 kg. The maximum test weight was recorded in genotypes Alperbey (76.2 kg) and Karma 2000 (74.8 kg) in 2017 at Edirne and the minimum test weight was determined in genotype TR-Trp16 (61.1 kg) in 2018 at Tekirdağ (Table 10). Test weight is one of the crucial traits as a quality parameter which plays a key role in trading of cereals. Large grains increase test weight, while decreases the protein ratio relatively. In our study, triticale genotypes varied for test weight. In literature, researchers reported variation in triticale genotypes caused by genotypic influence and environmental conditions (Gerdzhikova, 2014; Kendal and Sayar, 2016).

Table 10. Mean performance of triticale genotypes for test weight (kg hl⁻¹).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	69.3	70.6	74.8	69.7	67.2	70.8	70.4 c
Alperbey	69.5	71.3	76.2	72.4	71.4	74.7	72.6 a
Collegial	65.4	62.5	70.4	64.1	63.4	65.1	65.1 g
Karma 2000	67.5	70.5	74.8	72.1	69.3	74.2	71.4 b
Melez 2001	69.2	68.3	72.4	71.1	66.2	70.8	69.6 d
Tatlıcak 97	73.5	73.6	73.4	73.0	68.8	72.4	72.4 a
TR-Trp16	65.3	67.3	70.3	67.2	61.1	67.2	66.4 f
TR-Avk16	66.6	68.6	72.4	64.2	64.5	67.6	67.3 e
Year means	2017= 70.1 a			2018= 68.7 b			
Location means	Kırklareli:68.7 b		Tekirdağ= 67.7 c	Edirne= 71.6 a			

Protein ratio values overall the experiment ranged from 10.87 to 13.06%. The highest protein ratio was recorded in genotype TR-Trp16 (13.06%) and the lowest protein ratio was determined in genotype Tr-Avk16 (10.87%). Maximum protein ratio was noted in 2018 (11.88%), while the minimum protein ratio was recorded in 2017 (11.84%). Kırklareli location had the highest protein ratio (12.26%), while the minimum protein ratio was observed in Tekirdağ (11.53%). For genotype × year × location interaction, the protein ratio was changed from 10.2 to 14.1%. The maximum protein ratio was determined in genotype TR-Trp16 (14.1%) at Kırklareli in 2017, while the minimum protein ratio was recorded in genotype TR-Avk16 (10.2%) at Tekirdağ in 2018 (Table 11).

Protein ratio depends on favourable growing conditions besides genotypic background. Protein ratio of triticale genotypes was found divergent, which was predictable as the genotypes derived from different

backgrounds. Kendal and Sayar (2016) reported a huge variation both for genotypes and environments.

GGE-biplot Analysis: The multi-environment variety trials are crucial to determine genotypes performing moderate or superior under different locations and minimize genotype × environment interactions since the environmental conditions are unpredictable. Genotype (G), genotype by environment interaction (GE) model was used to evaluate the performance of environments and genotypes. Scatter plot of genotypes and environments was divided into five sectors. The environments were located in two separate sectors, which was concluded as the environments had different ecological conditions. Genotype Collegial was the ideal genotype and represented with E4, E5 and E6 environments, while genotype Truva took place in E1 and E2 environments with Alperbey in the same sector. The result of the study showed that genotypes Truva and Collegial were superior to be recommend for special

environments. Other genotypes Tatlıcak 97, Melez 2001 and TR-Trp16 performed worse in all six environments (Figure 1). In previous studies, researchers reported different grain yield performances of genotypes among the environments (Lule *et al.*, 2014; Kendal *et al.*, 2019). A ranking biplot analysis based on grain yield was conducted out to evaluate the stability of genotypes at different environments and Alperbey was found the most stable genotype as it fell into the right quadrants and closest to the stability line that performed moderately at different environments in terms of grain yield. On the other hand, genotypes Collegial and Truva had the highest grain yields (Figure 2). The vector visualization of the GGE-biplot brings an outline of the inter-relationships among the locations, that all locations were positively related. A great environmental vector comprises a high ability to differentiate the genotypes. E6 was the most differentiating environment for the genotypes as the longest vector from the origin, while E4 and E5 environments were separating fairly. On the other hand, the shortest vector E2 showed little data about the genotype variations. Genotype Truva was the winning genotype in E1 and E3 while Collegial was the winning genotype in E4, E5 and E6. Genotypes Tr-Avk16, Melez 2001 and Tatlıcak 97 took place distant from x axis, thus these genotypes are unstable over locations (Figure 3). Kendal and Sayar (2016) reported environmental differences influencing agronomical performances of genotypes. According to the scatter plot of GGE biplot analysis, three mega environments were detected. Testing

environments E4, E5 and E6 took place into mega-environment I, E1 and E3 fell into mega-environment II and E2 was in mega-environment III. E4, E5 and E6 were identified as desirable environments and determined close to the optimum environment. Collegial, Truva and Alperbey were desirable genotypes because they were located near the centre. Melez 2001, Tatlıcak 97 and TR-Avk16 were identified as undesirable genotypes for all three mega-environments. Some of the environments tend to perform together, hence in our study three mega-environments were detected among six environments. It is important to determine environments with closer or unlike ecologies for sustainable production (Figure 4). Lule *et al.* (2014), Stoyanov *et al.* (2017) and Kendal *et al.* (2019) reported diverse environments in terms of grain yield performances of triticale genotypes. In the GGE biplot analysis, the genotypes in the first circle are determined as optimum genotypes. Ideal genotypes took place closer to the desired genotype. In this study, genotype Collegial was close to the desired genotype and placed on the first circle observed before Truva and Alperbey located in the third circle. Genotypes Tr-Trp16 and Melez 2001 were distant from the first circle thus determined as undesired genotypes (Figure 5). As desired genotypes and environments were located in the first circle, Tekirdağ 2018 (E5) was located in the first circle followed by E4 (Kırklareli 2018) which was identified as a desirable environment and found close to the ideal environment (Figure 6).

Table 11. Mean performance of triticale genotypes for protein ratio (%).

Genotypes	2017			2018			Means
	Kırklareli	Tekirdağ	Edirne	Kırklareli	Tekirdağ	Edirne	
Truva	11.9	10.6	11.3	11.4	10.6	10.9	11.10 f
Alperbey	12.1	10.4	12.1	12.2	12.0	12.3	11.82 d
Collegial	11.8	12.3	11.1	12.0	11.6	11.1	11.65 e
Karma 2000	12.2	10.9	12.2	11.8	11.3	11.6	11.66 e
Melez 2001	13.0	12.1	12.2	13.5	13.1	12.3	12.68 b
Tatlıcak 97	12.0	11.5	12.5	12.1	11.9	12.0	11.99 c
TR-Trp16	14.1	12.3	12.2	13.8	13.0	13.1	13.06 a
TR-Avk16	11.9	11.0	10.8	10.7	10.2	10.7	10.87 g
Year means	2017= 11.84 b			2018= 11.88 a			
Location means	Kırklareli: 12.26 a		Tekirdağ= 11.53 c		Edirne= 11.78 b		

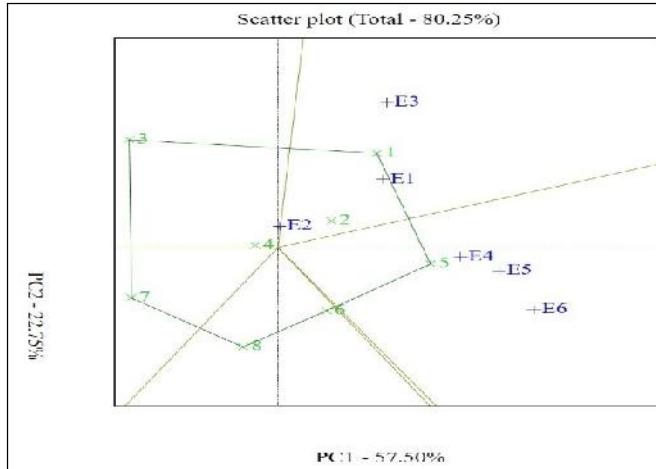


Figure 1. “Which-won-where” pattern of GGE biplot for eight triticale genotypes evaluated over multiple environments

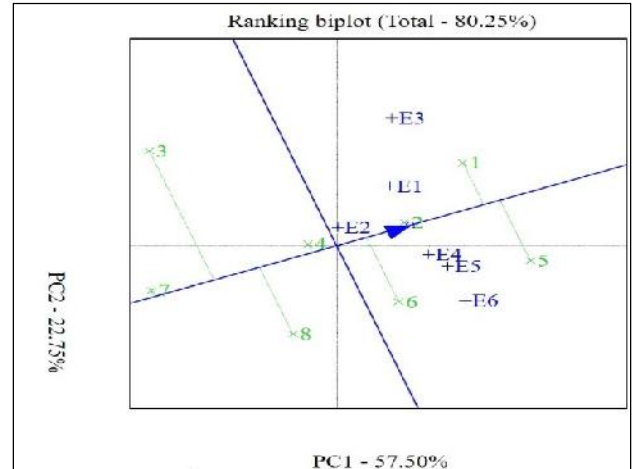


Figure 2. Ranking biplot analysis based on grain yield focused on scaling stabilities of eight triticale genotypes

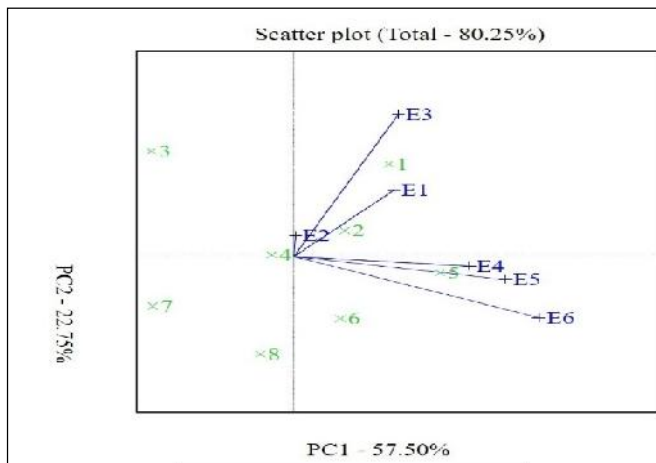


Figure 3. Scatter plot of six environments using GGE biplot for the evaluation of the relationships among the six environments

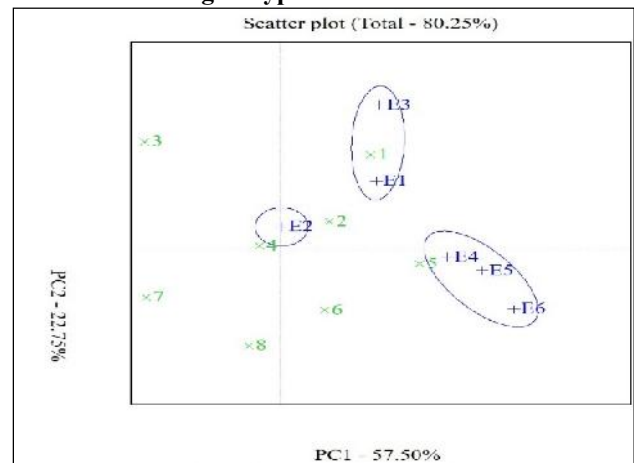


Figure 4. Scatter plot of mega-environment using GGE biplot for 8 triticale genotypes evaluated over multiple environments

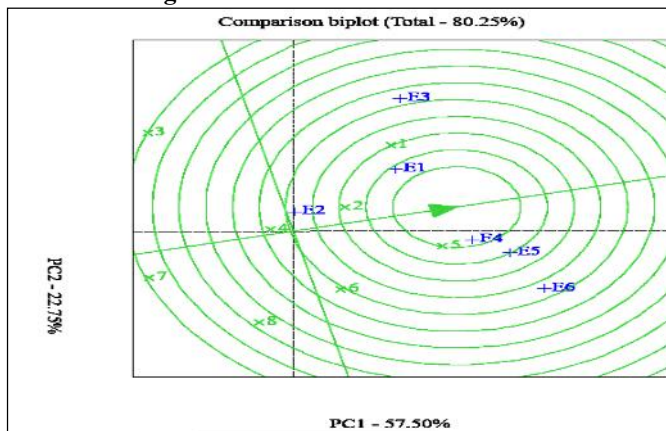


Figure 5. Comparison biplot “ideal genotype” using GGE biplot with scaling focused on genotypes

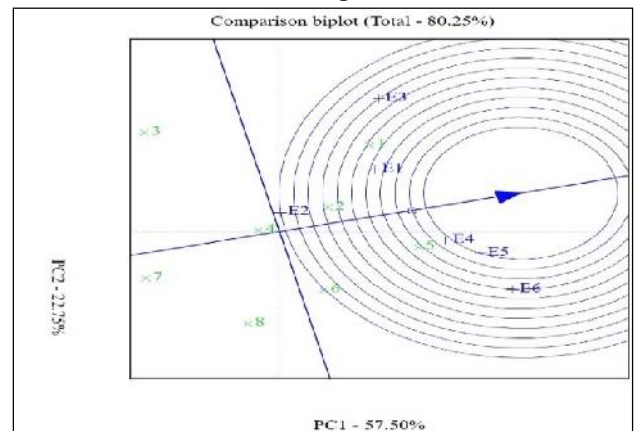


Figure 6. Comparison biplot of “ideal environment” for grain yield using GGE biplot

†Environments: E1 (Kırklareli 2017), E2 (Tekirdağ 2017), E3 (Edirne 2017), E4 (Kırklareli 2018), E5 (Tekirdağ 2018), E6 (Edirne 2018); *Genotypes: 1 (Truva), 2 (Alperbey), 3 (TR-Trp16), 4 (TR-Avk16), 5 (Collegial), 6 (Karma 2000), 7 (Melez 2001), 8 (Taticak 97)

Conclusion: Based on genotype \times environment interactions and GGE-biplot analyses, the genotypes Collegial, Truva and Alperbey were performed well and found to be superior cultivars. Also, Tekirdağ 2018 and Kırklareli 2018 locations were determined as ideal environments. In addition, 2016-2017 cropping year was more productive than 2017-2018 in terms of grain yield.

Furthermore, Edirne location was found to be the most favourable environment for triticale production. This may provide significant advantages in crop rotation for Edirne. To sum up, GGE biplot analysis provided convenient results and high visualization of genotype performances under different environments, thus it was concluded that triticale genotypes might perform well in Thrace region.

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