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EVALUATION OF WHEAT GENOTYPES: GENOTYPE × ENVIRONMENT INTERACTION AND GGE BIPLOT ANALYSIS

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ABSTRACT

This research was carried out to evaluate the grain yield, yield traits and some quality traits of 18 bread wheat genotypes at seven environments in Thrace region using principal component analysis and genotype (G) + genotype × environment interaction biplot analysis to determine the genotypes with high yield and desired quality characteristics during the 2016-2017 and 2017-2018 growing seasons. The experiments were arranged in a randomized complete block design with four replications. Genotype, environment and genotype × environment interactions (GE) were found statistically significant at $p \leq 0.01$ level for all investigated traits. Mean values of the cultivars varied from 4841-6807 kg ha^{-1} for grain yield, 118.6-131.6 days for heading date, 80.4-104.7 cm for plant height, 7.7-10.4 cm for spike length, 16.4-20.3 for number of spikelets per spike, 34.2-59.6 number of grains per spike, 1.49-2.41 g grain weight per spike, 72.0-77.8 kg hl^{-1} for test weight and 36.6-45.3 g for thousand kernel weight. Principal component biplot analyses explained the relationships between the investigated traits and genotypes at a ratio of 60.9%. According to the principal component (PC) biplot analysis, it was observed that there was a positive and significant relationship between grain yield and test weight, a negative relationship with grain yield and spike length and grain weight per spike. GGE biplot analysis explained 82.65% of the relationship of G + GE for grain yield. According to the GGE biplot analysis, two mega environments were determined and Lucilla and Glosa genotypes took place in the biggest mega environment consisted of four environments as superior genotypes.

Keywords: Environment, GGE-biplot, grain yield, wheat

INTRODUCTION

Due to its wide adaptation ability, high nutritional value, cultivation area, production and yield potential, the bread wheat *(Triticum aestivum* L.*)* has an important role both the world and the Turkey (Kaydan and Yagmur, 2008). The issue of adequate and balanced nutrition is becoming more and more important with each passing day (Dogan and Kendal, 2013; Kilic et al., 2014). Due to the rapid increase in population, the increase in the need for food and the decrease in planting areas require much more effort to develop high yielding and quality cultivars. Wheat yield and quality differ from year to year due to genetic structure of varieties, climatic conditions, soil structure of production areas, abiotic and biotic stresses and cultural practices (Gungor and Dumlupinar, 2019). It is important to determine wheat varieties with high yield and quality, suitable for different ecological conditions and to expand their production in order to reduce the effect of environmental factors (Oral et al., 2018; Aydogan et al., 2020).

According to the recent official data (Anonymous, 2021), during the year 2020, 20.5 million tons of wheat was produced from an area of 6.9 million hectares in Turkey. Four million tons of durum wheat (3180 kg ha^{-1}) was produced from 1.2 million ha, and 16.5 million tons of bread wheat was produced from 5.6 million ha (2910 kg ha^{-1}). Wheat cultivation is carried out on 48% (449.523 ha) of the agricultural lands of the Thrace region (935.259 ha), where includes the provinces of Tekirdag, Edirne and Kirklareli. One million and seven hundred thousand tons of wheat was produced in the Thrace region in 2020, and the average grain yield (3810 kg ha^{-1}) is higher than the average of Turkey (2910 kg ha^{-1}).

Due to the importance of wheat farming in the region, suitable conditions for wheat farming in the Thrace region and the increase in the efficiency of high-yielding, high-quality and stable genotypes that are well adapted to the region will help increase production.

Since Thrace region has suitable conditions for growing wheat and the determination of high yield, quality and stable varieties that are well adapted to the region will benefit to increase the production. Climate and ecological characteristics, which are the main factors that make up the environment, affect the quality of genotype performance positively or negatively.

For this reason, it is desired to develop stable genotypes that perform across the environments. It is important to determine the GE interactions by testing the genotypes in different environments before their production in large areas. One of the most effective methods to determine GE interactions is the GGE (genotype × genotype environment) biplot analysis (Yan et al., 2000; Yan, 2001; Yan and Kang, 2003). The most important reasons that the method preferred by the researchers may be shown as the interactions of genotypes with different environments and might be presented in a simple and understandable way. Many features of genotypes can be displayed graphically, and it allows comparing the relationships between genotypes and features visually (Acikgoz et al., 2007; Ilker et al., 2009; Akcura, 2011; Sahin et al., 2011; Kilic et al., 2012; Basbag et al., 2021; Sayar et al., 2022). In recent years, many researchers working on different plant species have used the graphs created by this analysis (Sayar et al., 2013; Kilic et al., 2014; Kendal and Sayar, 2016; Sayar and Han, 2016; Oral et al., 2018; Wardofa et al., 2019; Tulu and Wondimu, 2019; Aktas, 2020).

In this study, it was aimed to evaluate the grain yield, yield components and some quality characteristics of some bread wheat cultivars at different locations in the Thrace region by using PCA and GGE biplot analysis and to determine the genotypes with high yield and adaptability characteristics in different environments.

MATERIALS AND METHODS

In the research, 18 commercial bread wheat cultivars, which are commonly produced in the Thrace region, were used as materials (Table 1). The trials were conducted in seven different environments, at Kirklareli, Tekirdag and Edirne locations, representing the entire Thrace region, during the 2016-2017 and 2017-2018 plant growing seasons (Table 2).

Table 1. Bread wheat cultivars used in the this study.

Cultivars	Owner Company/Institute	Date of registration	Growth type
Masaccio	ProGen Seed Company	2014	Alternative
Lucilla	ProGen Seed Company	2017	Alternative
Kate A-1	Trakya Agricultural Research Institute	1988	Alternative
Gelibolu	Trakya Agricultural Research Institute	2005	Winter
Tekirdag	Trakya Agricultural Research Institute	2005	Winter
Kopru	Trakya Agricultural Research Institute	2015	Winter
Rumeli	Trakya Agriculture Seed Company	2012	Winter
Pehlivan	Trakya Agricultural Research Institute	1998	Winter
Asli	ProGen Seed Company	2017	Winter
Flamura-85	Tareks Seed Company	1999	Winter
Glosa	Tareks Seed Company	2014	Winter
Selimiye	Trakya Agricultural Research Institute	2009	Winter
Esperia	Tasaco Seed Company	2011	Winter
Midas	ProGen Seed Company	2014	Winter
Saban	Trakya Agricultural Research Institute	2014	Winter
Krasunia odes’ka	Yildiz Seed Company	2008	Winter
Aldane	Trakya Agricultural Research Institute	2009	Alternative
Bereket	Trakya Agricultural Research Institute	2010	Winter

Table 2. Growing seasons, code, soil type and amounts of precipitation of environments.

Growing seasons	Code	Environment	Soil type	Precipitation (mm)
2016-2017	E1	Luleburgaz	Clayey loamy	366.3
2016-2017	E2	Edirne	Clayey loamy	408.0
2016-2017	E3	Babaeski	Clayey	366.3
2016-2017	E4	Hayrabolu	Clayey	451.7
2017-2018	E5	Luleburgaz	Clayey loamy	696.3
2017-2018	E6	Babaeski	Clayey loamy	696.3
2017-2018	E7	Kesan	Clayey	799.6

The research was arranged in a Randomized Complete Block Design (RCBD) with four replications. Sowing was done between the end of October and the first week of November in both growing seasons, and it was done by hand in 5 m long plots with 20 cm row spacing and 6 rows with 500 seeds per m^2. In the research, the plot sizes were 6 m^2 both at planting and at harvest (6 m x 1 m). Weed control was done by hand in the trial plots and no application was made for diseases and pests.

Fifty kg ha^{-1} nitrogen and 50 kg ha^{-1} phosphorus were applied at the sowing, and the top dressing was divided into two parts: 90 kg ha^{-1} nitrogen during tillering and 60 kg ha^{-1} nitrogen during jointing stage. Harvest was done in the first week of July in both growing seasons.

Plant height, heading date (the number of days between January 1st and the day when the plants are 50% spike in each plot), spike length, number of spikelets per spike, number of grains per spike, grain weight per spike, thousand kernel weight, test weight (Vasiljevic et al., 1980), and grain yield were all evaluated in the study (Dokuyucu et al., 2004; Karaman, 2017)

Statistical Analyses

The data obtained for two years were subjected to combined analysis of variance, analyses each year and location were considered as environments. A two-way fixed effect model was applied to determine the influence of the main effects of variation (GE) and their interaction (GE) on each trait, and the Duncan test was performed to compare the means. Principal component analysis was calculated over the average data and evaluated with the biplot approach (SAS Institute Inc. JMP 15.1, 2020). GGE Biplot analyzes were calculated with Genstat 14th (VSN International Ltd., 2011) software over seven environments using average data (Yan, 2001).

RESULTS AND DISCUSSION

Genotype by Environment Interaction (GEI)

The study conducted with 18 bread wheat cultivars, the effects of genotype, environment and GE interaction were found to be statistically significant at the $p \leq 0.01$ level in terms of all traits examined (Table 3).

The effect of G, E and GE interaction on grain yield were 28.37%, 47.91% and 23.72% respectively (Table 3). It has been determined that the effect of environmental variation on grain yield is higher than other variation sources. In previous studies conducted by different researchers, it was stated that the effect of genotype on grain yield ranged from 1.3 to 33.46%, environment 35.28-90.76%, and GE interaction between 7.12-31.45% (Kaya et al., 2002, Kaya et al., 2006, Mohammed, 2009, Oral et al., 2018; Tulu and Wondimu, 2019; Wardofa et al., 2019; Aktas, 2020). While the cultivars' average grain yield was 5991 kg ha^{-1}, the cultivar Lucilla had the highest grain yield (6807 kg ha^{-1}) and the lowest grain yield was obtained from the cultivar Aldane (4841 kg ha^{-1}) (Table 4). The lowest grain yield was found at the E1 (5469 kg ha^{-1}) location, and the highest grain yield was obtained at the E2 (7251 kg ha^{-1}) location (Table 6). Grain yield is a multi-gene controlled trait and is affected by many factors such as the genetic potential of the genotype, the ecology of the region and the applied cultural practices (Kaydan and Yagmur, 2008; Sahin et al., 2016; Aktas et al., 2017; Tekdal et al., 2017; Gungor and Dumlupinar, 2019; Aydogan et al., 2020; Takač et al., 2021).

Table 3. Mean square values for the investigated traits

Sources of variations	Genotype (G)	Environment (E)	G x E	Error	C.V. (%)
Degrees of Freedom	17	6	102	357	
Grain Yield/	63540.8**	303984.7**	8852.3**	4296.1	10.9
Variability (%)	28.37	47.91	23.72		
Heading Date/	235.38**	308.39**	7.66**	0.38	0.51
Variability (%)	60.33	27.90	11.78		
Plant Height/	1108.68**	1716.59**	85.22**	12.11	3.75
Variability (%)	49.81	27.22	22.97		
Spike Length/	11.18**	19.38**	1.25**	0.41	6.95
Variability (%)	43.76	26.78	29.46		
No of Spikelet /Spike/	24.67**	51.23**	4.61**	1.66	6.77
Variability (%)	35.04	25.68	39.28		
No of Grain/Spike/	950.87**	4380.40**	200.36**	42.31	13.60
Variability (%)	25.71	41.79	32.50		
Grain Weight/Spike/	1.52**	16.33**	0.49**	0.12	16.75
Variability (%)	14.90	56.30	28.81		
Test Weight/	63.36**	827.50**	12.83**	0.32	0.75
Variability (%)	14.65	67.55	17.80		
Tohusand Kernel Weight/	199.16**	1186.38**	21.64**	0.37	1.51
Variability (%)	26.64	56.00	17.37		

** Significant at the P < 0.01 probability level, * Significant at the P < 0.05 probability levels.

The effect of genotype on the heading date was determined as 60.33%, the effect of the environment as 27.90%, and the effect of GE interaction as 11.78% (Table 3). The mean heading date of the cultivars was 122.2 days and the earliest one was 118.6 days (Glosa), and the latest cultivar was Midas with 131.6 days (Table 5). According to the environmental averages, the date of heading varied from 119.4-125.8 days (Table 6). The latest heading date was obtained at the E3 (125.8 days) location and the shortest at the E6 (119.4 days) location. According to previous researchers, it has been stated that the duration of heading date varies between 103-171 days, which were conducted in different ecological conditions, and genotypes and environments were effective together in the formation of significant differences in terms of the duration of heading date. (Kilic et al., 2012; Dogan and Kendal, 2013; Sakin et al., 2017; Gungor and Dumlupinar, 2019; Akan et al., 2021).

Table 4. Mean grain yield (kg ha^{-1}) of cultivars across test environments

Cultivars	E1	E2	E3	E4	E5	E6	E7	Mean
Masaccio	6044	9004	6504	6269	5942	6346	7274	6769 a
Lucilla	5871	8344	6102	6702	6325	6621	7687	6807 a
Kate A-1	5867	6452	4965	5911	5854	5173	6952	5882 efg
Gelibolu	5794	6882	5269	5961	5858	5100	6835	5957 def
Tekirdag	5717	5588	4717	6396	5604	5559	5449	5576 gh
Kopru	5613	7413	5419	5900	5384	5875	6843	6064 c-f
Rumeli	5611	7954	6361	5938	5692	5638	7143	6334 bc
Pehlivan	5600	6506	5073	6238	5417	5138	5257	5604 gh
Asli	5459	7581	6162	5892	5717	5946	6432	6170 cde
Flamura-85	5450	7211	5669	5602	5817	5254	6297	5900 d-g
Glosa	5423	8217	6140	6788	6058	5996	7556	6597 ab
Selimiye	5398	6952	5488	5933	5571	6058	6035	5919 d-g
Esperia	5340	6371	5133	5483	5804	5792	6126	5721 fgh
Midas	5244	8598	5619	5971	5913	5745	6525	6230 cd
Saban	5223	7455	6340	6256	4546	5525	6441	5969 def
Krasunia odes'ka	5038	7856	5473	5963	6025	5767	5985	6015 c-f
Aldane	4890	5340	4169	5290	3958	5633	4610	4841 ı
Bereket	4867	6792	4944	5229	4246	6004	6266	5478 h
Mean	5469 e	7251 a	5530 de	5984 c	5541 de	5732 d	6428 b	5991

The effect of genotype on plant height was 49.81%, the effect of environment was 27.22%, and the effect of GE interaction was determined as 22.97% (Table 3). The average plant height of the genotypes varied from 80.4-104.7 cm (Table 5). The longest plant height was obtained from the cultivar Midas (104.7 cm), and the shortest plant height was obtained from the cultivar Esperia (80.4 cm). According to the environmental averages, the highest plant height was found at the E3 (99.6 cm) location, and the shortest plant height was determined at the E4 (87.4 cm) location (Table 6). Plant height is a crucial vegetative factor for the genotypes's adaptation to the area, and it can affect yield and quality indirectly (Dogan and Kendal, 2013). Plant height in wheat can vary depending on genetic structure, climate and soil characteristics and cultural practices applied, and it has been determined that it varies between 71-125 cm in previous works (Dogan and Kendal, 2012; Dogan and Kendal, 2013; Sakin et al., 2017; Gungor and Dumlupinar, 2019; Akan et al., 2021).

The effect of genotype on spike length was determined as 43.76%, the effect of environment as 26.78% and the effect of GE interaction as 29.46% (Table 3). The spike length of the genotypes varied from 7.7-10.4 cm. The highest spike length was measured in the cultivar Kate A-1 (10.4 cm) and the lowest spike length was measured in the cultivar Massacio (7.7 cm) (Table 5). When the environemental averages were examined, they had the highest spike length at the E7 (10 cm) location and the lowest spike length at the E2 and E4 (8.7 cm) locations (Table 6). In the studies carried out in different ecological conditions, the spike length varied from 7.3 to 10.35 cm. (Sakin et al., 2017; Gungor and Dumlupinar, 2019).

The effect of genotype on the number of spikelets per spike was determined as 35.04%, the effect of environment as 25.68%, and the effect of GE interaction as 39.28% (Table 3). The average number of spikelets per spike of genotypes ranged from 16.4 to 20.03. Cultivar Gelibolu (20.3) had the highest number of spikelets per spike, and cultivar Massacio (16.4) had the lowest (Table 5). According to the environmental averages, the highest number of spikelets per spike was found at the E7 (20.3) location and the lowest at the E2 (18.0) location (Table 6). Kurt and Yagdi (2013) reported a 17.3 to 19.5, Gungor and Dumlupinar (2019) showed a 16.5-21.2, while, Akan et al. (2021) indicated an 18.15-22.13 number of spikelets per spike.

The difference in the number of fertile spikelets and florets in the spike according to the genotypes is the source of the difference in the number of grains in the spike (Bayram et al., 2017). The effect of genotype on the number of grains per spike was 25.71%, the effect of environment was 41.79%, and the effect of GE interaction was 32.50% (Table 3). According to the genotype averages, the number of grains per spike varied from 34.2 and 59.6, and the highest number of grains per spike was found in the cultivar Midas (59.6) while the lowest in the cultivar Massacio (34.2) (Table 5). According to the environmental averages, E7 location had the highest value (57.5) in terms of the number of grains per spike, while E2 location had the lowest value (40.4) (Table 6). In other studies, Bayram et al. (2017), 13.7-26.6; Gungor and Dumlupinar (2019), 27.2-49.7; Kara et al. (2016), 34.4-54, Ozen and Akman (2015), 22-46, Aktas et al. (2017) reported that it ranked from 42.21 to 52.34. The difference in the number of grains in the spike varies according to the genetic structure of the genotypes and climatic characteristics. (Ozen and Akman, 2015; Kara et al., 2016; Aktas et al., 2017; Bayram et al., 2017; Gungor and Dumlupinar, 2019).

Table 5. Means of yield components and quality traits of 18 bread wheat cultivars

Cultivars	HD	PH	SL	SNS	GNS	GWS	TW	TKW
Masaccio	121.8 fg	87.0 h	7.7 e	16.4 ı	34.2 ı	1.49 f	75.6 f	38.8 g
Lucilla	121.5 gh	90.3 g	9.5 b	18.9 d-g	50.9 cd	1.77 e	77.0 bc	38.3 h
Kate A-1	121.4 ghı	101.6 b	10.4 a	18.8 e-h	50.8 cd	2.09 cd	76.4 d	38.6 gh
Gelibolu	119.9 j	90.5 g	8.9 c	18.7 e-h	50.0 cd	2.19 bc	77.3 b	42.2de
Tekirdag	118.6 k	85.7 h	9.5 b	19.5 bcd	46.2 ef	2.11 cd	74.9 g	41.9 e
Kopru	123.2 d	94.1 e	9.4 b	20.3 a	55.1 b	2.41 a	73.9 ı	42.2 de
Rumeli	121.6 gh	96.3 d	8.9 c	19.8 abc	47.5 de	1.94 de	77.3 b	37.1 j
Pehlivan	122.4 e	101.1 b	9.4 b	18.9 d-g	39.3 h	1.99 d	76.9 c	45.3 a
Asli	125.6 b	99.1 c	9.0 c	19.0 def	45.6 ef	1.81 e	75.6 f	37.0 j
Flamura-85	122.9 d	91.2 g	9.7 b	18.3 gh	45.8 ef	2.10 cd	77.8 a	43.0 bc
Glosa	118.8 k	86.5 h	8.5 d	18.4 fgh	47.9 de	2.00 d	76.0 e	38.9 g
Selimiye	122.1 ef	90.4 g	9.0 c	18.3 gh	41.5 gh	1.79 e	76.5 d	42.3 d
Esperia	121.6 gh	80.4 ı	8.8 cd	19.3 cde	50.8 cd	2.12 cd	74.6 gh	36.6 k
Midas	131.6 a	104.7 a	8.7 cd	20.1 ab	59.6 a	2.37 ab	76.5 d	37.2 j
Saban	119.9 j	90.6 g	9.6 b	19.1 de	48.9 cde	2.20 bc	75.4 f	42.8 c
Krasunia odes'ka	124.1 c	91.4 fg	10.3 a	20.0 ab	52.3 bc	2.35 ab	74.4 h	38.0 ı
Aldane	121.4 hı	93.2 ef	9.4 b	18.1 h	43.8 fg	2.00 d	74.1 ı	43.2 b
Bereket	121.1 ı	98.2 c	9.6 b	19.9 abc	50.2 cd	2.18 bc	72.0 j	40.3 f
Mean	122.2	93.3	9.3	19.1	48.6	2.1	75.7	40.3

HD: Heading date, PH: Plant height, SL: Spike length, SNS: Number of spikelets per spike, GNS: Number of grains per spike, GWS: Grain weight per spike, TW: Test weight, TKW: Thousand kernel weight

The effect of genotype on grain weight per spike was 14.90%, the effect of environment was 56.30%, and the effect of GE interaction was determined as 28.81% (Table 3). The cultivar Kopru had the highest grain weight per spike of 2.41 g, while the cultivar Masaccio had the lowest grain weight per spike of 1.49 g. (Table 5). According to environmental averages, grain weight per spike ranged from 1.58 to 2.81 g, with the maximum value at the E7 (2.81 g) location and the lowest value at the E1 (1.58 g) location (Table 6). In studies conducted in different environments, the grain weight per spike was determined as 1-2 g, (Ozen and Akman, 2015), 1.4-1.9 g (Kara et al., 2016), 1.9-2.6 g (Aktas et al., 2017) and 0.93-2.25 g (Gungor and Dumlupinar, 2019).

Table 6. Average of yield component and quality traits in seven environments

Environments	HD	PH	SL	SNS	GNS	GWS	TW	TKW
E1	122.6 c	95.6 c	9.0 d	19.0 c	41.9 c	1.58 d	75.5 e	35.8 g
E2	122.3 d	92.3 d	8.7 e	18.0 d	40.4 c	1.94 c	80.8 a	45.3 b
E3	125.8 a	99.6 a	9.1 d	18.3 d	42.1 c	1.66 d	77.7 b	39.3 d
E4	123.4 b	87.4 f	8.7 e	18.4 d	42.2 c	1.61 d	76.0 d	37.1 f
E5	120.4 f	89.7 e	9.5 c	19.5 b	53.9 b	2.34 b	73.4 f	37.6 e
E6	119.4 g	87.9 f	9.8 b	19.7 b	56.7 a	2.41 b	69.9 g	40.1 c
E7	121.4 e	97.9 b	10.0 a	20.3 a	57.5 a	2.81 a	76.4 c	46.2 a
Mean	122.1	91.4	9.2	18.8	47.1	2.0	75.6	39.9

HD: Heading date, PH: Plant height, SL: Spike length, SNS: Number of spikelets per spike, GNS: Number of grains per spike, GWS: Grain weight per spike, TW: Test weight, TKW: Thousand kernel weight

The effect of genotype on test weight was found to be 14.65%, the effect of environment was 67.55%, and the effect of GE interaction was determined as 17.80% (Table 3). The cultivar Flamura-85 (77.8 kg hl^{-1}) had the highest test weight, while the cultivar Bereket (72.0 kg hl^{-1}) had the lowest (Table 5). According to the environmental averages, the lowest test weight was determined at the E6 location (69.9 kg hl^{-1}), and the highest at the E2 (80.8 kg hl^{-1}) location (Table 6). In studies conducted by different researchers (Schuler et al., 1994, Diepenbrock et al., 2005; Ozen and Akman, 2015; Kara et al., 2016; Mut et al., 2017; Gungor and Dumlupinar, 2019), it has been determined that the test weight varied from 69.3-82 kg hl^{-1}. In terms of test weight, values above 82 kg hl^{-1} are considered perfect, but at least 72 kg hl^{-1} should be preferred. Test weight is a quality parameter that determines the flour yield in the flour industry has commercial importance and is desired to be high (Mut et al., 2017). They reported that test weight is especially influenced by the environment and can be affected depending on factors such as genotype and agronomic practices.

Environmental factors and climatic conditions affect the thousand kernel weight significantly. The effect of genotype on thousand kernel weight was determined as 26.64%, the effect of environment as 56.00%, and the effect of GE interaction as 17.37% (Table 3). The highest thousand kernel weight was obtained in cultivar Pehlivan (45.3 g), and the lowest value was obtained in cultivar Esperia (36.6 g) (Table 5). According to the environmental averages, the thousand kernel weight varied from 37.6-46.2 g, the lowest thousand kernel weight was obtained at the E1 (35.8 g) location, and the highest thousand kernel weight was obtained at the E7 (46.2 g) location (Table 6). In other studies, it has been reported that the thousand kernel weight varied from 29.2-47.2 g. (Ozen and Akman, 2015; Mut et al., 2017; Tekdal et al., 2017; Gungor and Dumlupinar, 2019; Aydogan et al., 2020).

Principal Component (PCA) and GGE-Biplot Analysis

Principal component analysis resulted in a two-dimensional PCA score accounted for 60.9% of the total variation (Figure 1). Principal component 1 had a value of 23.5%, which indicates the genotype effect that was low in this case, and PC2 was 37.4%, which demonstrates the environment effect that was high in the study. Many researchers reported that higher total variation value (PC1+PC2) (≥50%) ensures to more reliable interpretation of a biplot graph (Sayar and Han, 2015; Kendal et al., 2016; Basbag et al., 2021; Sayar et al., 2022). Additionally; it was reported that when the angle between the vectors representing the features from 0° to 90°, there is a positive relationship. (Ilker et al., 2009; Sayar and Han, 2015; Dogan et al., 2016; Karaman, 2020). Grain yield was found to have a negative relationship with spike length, thousand kernel weight and grain weight per spike, but a positive relationship with test weight. It was determined that there was a positive relationship between the number of grains per spike, the number of spikelets per spike, plant height and heading date. Since the plant height and test weight traits had a short vector, their effects within the variation were determined to be lower than the other traits. Karaman (2020) reported that grain yield had a positive relationship with test weight and thousand kernel weight traits. Kahraman et al. (2021) stated that there was a positive relationship between grain yield and thousand kernel weight, and a negative relationship between grain yield and test weight.

Yan et al. (2000) stated that according to the GGE biplot analysis method, the genotypes located at the corners of the polygon were the genotypes with the highest value or the ideal characteristics for the related characters. The cultivars evaluated in the research were found superior; Midas for heading date, Lucilla, Masaccio Rumeli and Asli cultivars for grain yield, Aldane for thousand kernel weight, Bereket for spike length. In addition, Esperia and Kate A-1 cultivars were more stable than other genotypes.

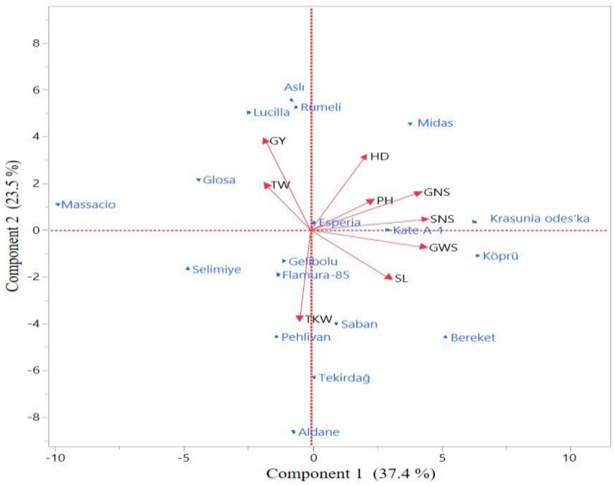

Figure 1. Relationship among genotypes and investigated for grain yield

GGE Biplot is a software program that analyzes graphs. With PC1 70.53%, PC2 12.12%, and total PC1+PC2 82.65%, a scatter plot graph demonstrated the relationship between genotype + GE. E5, E1, E4 and E7 locations developed a similar environment, as did E3, E2, E6 locations, resulting in two different mega-environments. Cultivars Rumeli, Asli and Masaccio were located in the mega environment formed by E2, E3, E6 locations, while cultivars Lucilla, Glosa and Gelibolu were located in the same zone with the mega environment formed by E1, E4, E5 and E7 locations and became superior genotypes for those environments. Cultivars Aldane, Bereket and Tekirdag were the farthest from the origin and mega-circles, had low stability, while cultivars Lucilla and Glosa were determined as the most ideal and stable cultivars. Cultivars Kopru (6064 kg ha^{-1}) and Krasunia odes'ka (6015 kg ha^{-1}) were determined to be more stable with a grain yield above the experiment mean (5991 kg ha^{-1}) which were on the right quadrant and close to the origin. GGE biplot analyses are used by many researchers as a selection tool in the evaluation of different plant species in terms of many characteristics (Figure 2).

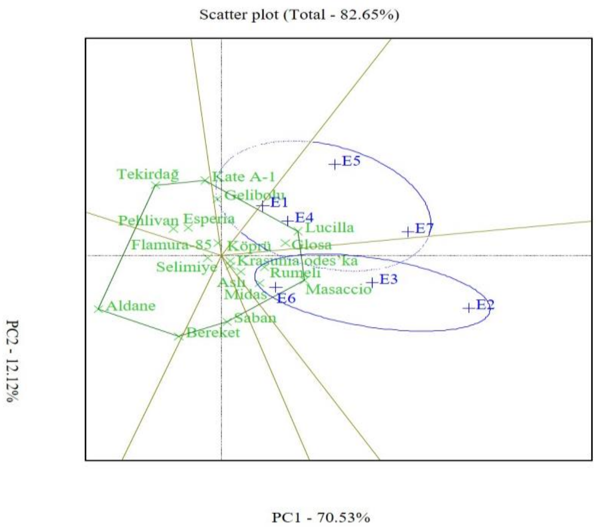

Figure 2. Scatter plot graph of GGE biplot Analysis

Genotypes in the first circle in the GGE biplot analysis are considered as ideal genotypes. While cultivar Lucilla was closest to the center circle, it was followed by cultivars Glosa, Masaccio and Rumeli, respectively. Cultivars Aldane, Bereket and Tekirdag were determined as the furthest genotypes from the first circle (Figure 3).

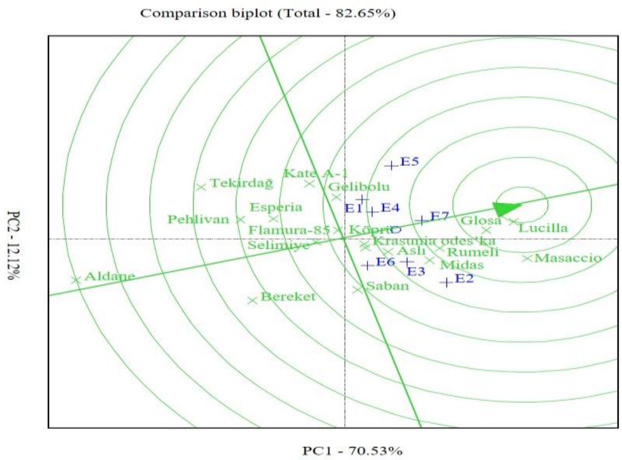

Figure 3. Comparison biplot "ideal genotype" using GGE biplot with scaling focused on genotypes

In GGE Biplot analyses, environments closer to the center circle, same as genotypes, are considered ideal environments. While E2 environment had the highest yield average (7251 kg ha^{-1}), E7 stood out as the ideal environment by taking place in the center circle which may be due to lack of separation power among the cultivars of the E2 environment. Aktas (2020) also reported the same situation, which is consistent with our findings. The E2 and E3 circles were determined as the circles close to the central circle after the E7 location, respectively. E6 was determined as the furthest environment from the central circle (Figure 4).

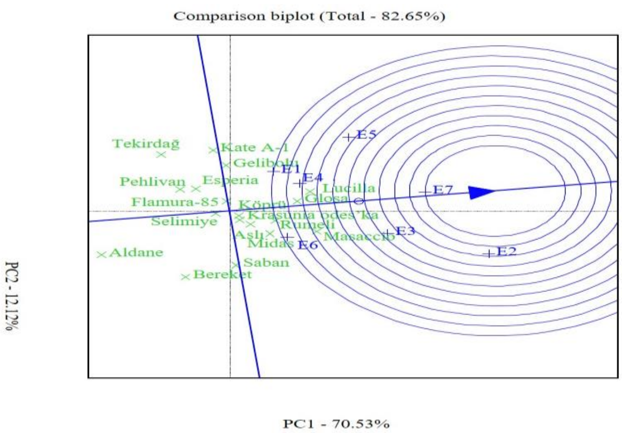

Figure 4. Comparison biplot of "ideal environment" for grain yield using GGE biplot

CONCLUSION

This research was carried out with 18 commercial bread wheat genotypes in seven environments in the Thrace region. The effect of environment was detected for grain yield, number of grains per spike, test weight and thousand kernel weight. In addition genotype effect was found significant on heading date, plant height and spike length traits, and number of spikelets per spike trait was affected by GE interaction. According to PC biplot analysis, grain yield was positively correlated with test weight, while negatively correlated with grain weight per spike and spike length. According to the results of the GGE biplot analysis, cultivars Rumeli and Masaccio were located at Edirne (E2), Babaeski (E3) and Babaeski (E6) environments. cultivars Lucilla, Glosa and Gelibolu were located in the same zone with the Luleburgaz (E1), Hayrabolu (E4), Luleburgaz (E5) and Kesan (E7) locations and became the superior genotypes for those environments. In this study, which was carried out at different environments for two years in the Thrace region, cultivars Lucilla, Glosa, Masaccio and Rumeli were found outstanding genotypes in terms of both high yielding and stable.

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