GGE biplot analysis of genotype by environment interaction of barley cultivars

Análisis de biplot GGE de interacción genotipo por ambiente de cultivares de cebada

Análise de biplot GGE da interação genótipo por ambiente de cultivares de cevada

Hüseyin Güngör[1*]
Mehmet Fatih Çakır[2]
Ziya Dumlupınar[3]

Rev. Fac. Agron. (LUZ). 2023, 40(2): e234021
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v40.n2.11

[1]Department of Field Crops, Faculty of Agriculture, Duzce University, 81620, Duzce, Turkey.
[2]Environment and Health Coordination Technical Specialization, Duzce University, Duzce, Turkey.
[3]Department of Agricultural Biotechnology, Faculty of Agriculture, Kahramanmaras Sutcu Imam University, Kahramanmaras, Turkey.

Crop production
Associate editor: Dr. Rosa Razz
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

Received: 30-03-2023
Accepted: 16-05-2023
Published: 02-06-2023

Keywords:
Grain yield
Yield components
Multi-environments
Stability

Abstract

This study was conducted out to determine grain yield, yield components, and some quality charecteristics of 17 barley (*Hordeum vulgare* L.) genotypes at six environments in Thrace region of Turkey, using principal component analysis (PCA) and genotype (G) + genotype × environment interaction (GGE) biplot analysis to define the genotypes with higher yield and desirable quality traits during the 2016-2017 and 2017-2018 cropping seasons. Mean values of the genotypes varied from 5106-6753 kg.ha^{-1} for grain yield, 103.4-117.1 days for heading date, 94.6-110.3 cm for plant height, 6.26-10.07 cm for spike length, 25.0-75.5 number of grains per spike, 1.20-2.99 g grain weight per spike, 35.0-50.5 g for thousand kernel weight and 56.4-64.1 kg.hl^{-1} for test weight. The relationships among the examined traits and genotypes was 53.9 % as defined by PC biplot analyses. GGE biplot analysis represented 94.77 % of the relationship of G + GE for grain yield. Two mega circles were formed according to grain yield, Zeus genotype for E1, E2 and E5 locations and Arcanda genotype for E3, E4 and E6 locations were determined as prominent genotypes. Zeus and Arcanda cultivars have been identified as the most ideal and stable genotypes.

*Corresponding author: hgungor78@hotmail.com

Resumen

Este estudio se realizó para determinar el rendimiento de grano, los componentes de rendimiento y algunas características de calidad de 17 genotipos de cebada (*Hordeum vulgare* L.) en seis ambientes en la región de Tracia en Turquía, utilizando análisis de componentes principales (PCA) y análisis de biplot de genotipo (G) + interacción genotipo × ambiente (GGE) para definir los genotipos con mayor rendimiento y características de calidad deseables durante las temporadas de cultivo 2016-2017 y 2017-2018. Los valores medios de los genotipos variaron de 5106-6753 $kg.ha^{-1}$ para el rendimiento de grano, 103,4-117,1 días para la fecha de espigado, 94,6-110,3 cm para la altura de la planta, 6,26-10,07 cm para la longitud de la espiga, 25,0-75,5 número de granos por espiga, 1,20-2,99 g de peso de grano por espiga, 35,0-50,5 g para el peso de mil granos y 56,4-64,1 $kg.hl^{-1}$ para el peso de prueba. Las relaciones entre las características y los genotipos examinados fueron del 53,9 % según los análisis de biplot PC. El análisis de biplot GGE representó el 94,77 % de la relación de G + GE para el rendimiento de grano. Se formaron dos mega círculos según el rendimiento de grano, el genotipo Zeus para las ubicaciones E1, E2 y E5 y el genotipo Arcanda para las ubicaciones E3, E4 y E6 fueron determinados como genotipos prominentes. Los cultivares Zeus y Arcanda han sido identificados como los genotipos más ideales y estables.

Palabras clave: rendimiento de grano, componentes de rendimiento, multi-ambientes, estabilidad.

Resumo

Este estudo foi realizado para determinar o rendimento de grãos, componentes de rendimento e algumas características de qualidade de 17 genótipos de cevada (*Hordeum vulgare* L.) em seis ambientes na região de Trácia da Turquia, utilizando análise de componentes principais (ACP) e análise de biplot GGE (genótipo G + interação genótipo x ambiente GE) para definir os genótipos com maior rendimento e características de qualidade desejáveis durante as safras 2016-2017 e 2017-2018. Os valores médios dos genótipos variaram de 5106-6753 $kg.ha^{-1}$ para rendimento de grãos, de 103,4-117,1 dias para data de perfilhamento, de 94,6-110,3 cm para altura de planta, de 6,26-10,07 cm para comprimento de espiga, de 25,0-75,5 número de grãos por espiga, de 1,20-2,99 g de peso de grão por espiga, de 35,0-50,5 g para peso e número de sementes por mil, e de 56,4-64,1 $kg.hl^{-1}$ para peso de teste. As relações entre as características e os genótipos examinados foram de 53,9 % como definido pelas análises de biplot PC. A análise de biplot GGE representou 94,77 % da relação de G + GE para o rendimento de grãos. Dois mega círculos foram formados de acordo com o rendimento de grãos, o genótipo Zeus para as localidades E1, E2 e E5 e o genótipo Arcanda para as localidades E3, E4 e E6 foram determinados como genótipos proeminentes. As cultivares Zeus e Arcanda foram identificadas como os genótipos mais ideais e estáveis.

Palavras-chave: rendimento de grãos, componentes de rendimento, multi-ambientes, estabilidade.

Introduction

The primary uses of barley (*Hordeum vulgare* ssp. *vulgare* L. 2n = 2x = 14), one of the world's oldest cultivars, are in the food, animal feed, and malt industries (Meints *et al.*, 2021).

Barley produces 157 million tons of grain annually, which puts it fourth in the world behind corn, wheat, and rice according to data from 2020 (Food and Agriculture Organization, 2023). Turkey's grain production area is made up of 28 % barley-growing land. In terms of production amount and production area in 2021, barley comes in third place behind wheat and corn (3.1 million ha) (5.75 million tons) (TUIK, 2023).

Barley is less affected by drought and is tolerant to salinity and the use of straw in animal nutrition is the factor that makes barley come to the fore (Khalili *et al.*, 2013; Vaezi *et al.*, 2018).

Breeders are trying to develop superior varieties with desirable characteristics tolerant of various ecological settings. In breeding studies, it is crucial to identify the genotypes that function well and exhibit a wide range of trait stability. The GGE combined analysis method, also known as the GGE Biplot, combines the (G) genotype and G×E (interaction) effects, or the two main components, on the same graph. This allows plant breeders to assess the data in two directions, visually. Plant breeders often use the biplot analysis method because it enables the graphic display of multiple genotype features and the visual comparison of the relationships between genotypes and traits. The biplot analysis method has been accepted as an effective evaluation method applied in plant breeding because it provides the opportunity to evaluate many features at the same time visually and affects success in selection (Yan *et al.*, 2007; Hagos and Abay, 2013; Gungor *et al.*, 2022a).

Based on statistical data and comparative trial results, barley breeding studies have been conducted recently in various countries and have shown a significant increase in yield in barley plants (Laidig *et al.*, 2017).

It is assumed that barley studies, particularly on adaptation and improvement, will help to increase yield in the production areas. Barley agriculture is significant in Turkey in terms of production and amount, and its importance has increased in the livestock sector.

This study aimed to identify the genotypes with high yield and adaptability characteristics in various locations by evaluating some barley genotypes' yield components and quality characteristics in the Thrace region using PCA and GGE biplot analysis methods.

Materials and methods

Plant materials, experimental details, and layout

In the study, seventeen (eight two-row, nine six-row) barley genotypes were used as material. The experiments were carried out at six different environments (Kırklareli, Tekirdağ, and Edirne locations) corresponding to the entire Thrace region, during the 2016-2017 and 2017-2018 cropping seasons (table 1). The research was carried out in a randomized complete block design with four replications.

In both growing seasons, seeds were sown between the late October and early November in plots with a 20 cm row spacing and 5 m in 6 rows, and 500 seeds per m^2. In both sowing and harvest, the experiment's parcel sizes were carried out to be 6 m^2. In the test plots, weeds were manually controlled, and no pesticides were applied.

Table 1. Cultivar, spike type, growing season, environments for trial.

Cultivars	Spike type	Owner	Code	Growing seasons	Environments	Precipitation (mm)
Arcanda	2	PG	E1	2016-2017	Lüleburgaz	366.3
Imeon	2	IAK	E2	2016-2017	Hayrabolu	451.7
Orfej	2	IAK	E3	2016-2017	Edirne	408.0
Alena	2	PG	E4	2017-2018	Lüleburgaz	696.3
Sladoran	2	TARI	E5	2017-2018	Keşan	799.6
Harman	2	TARI	E6	2017-2018	Babaeski	696.3
Hasat	2	TARI				
Bolayır	2	TARI				
Zeus	6	PG				
IZ Bori	6	IAK				
Bozhin	6	IAK				
Hemus	6	IAK				
Barberousse	6	TARI				
Kıral 97	6	BDIARI				
Veslet	6	IAK				
Lord	6	TAREKS				
Martı	6	TARI				

PG: ProGen Seed Company, Turkey; TAREKS: Tareks Seed Company, Turkey; BDIARI: Bahri Dağdaş International Agricultural Research Institute, Turkey; TARI: Trakya Agricultural Research Institute, Turkey; IAK: Institute of Agriculture Karnobat, Bulgaria.

With sowing, 50 $kg.ha^{-1}$ nitrogen (N) and 50 $kg.ha^{-1}$ phosphorus (P_2O_5) were purely applied, the top fertilizer was divided into two, and 90 $kg.ha^{-1}$ N was applied during the tillering period, and 60 $kg.ha^{-1}$ nitrogen was applied during the tillering period. Harvest was performed in the first week of July in both growing seasons.

In the research, plant height (PH), heading date (the number of days between January 1st and the day when the plants are 50 % spike in each plot-HD), spike length (SL), number of grains per spike (KNS), weight per spike (KWS), thousand kernel weight (TKW), test weight (TW) and grain yield (GY) were evaluated.

Statistical Analyses

Analysis of variance was conducted on the two years of data, and the least significant difference (LSD) test of the mean data was made by Duncan grouping test. Over the average data, principal component analysis was calculated and evaluated using the biplot method (SAS Institute Inc. JMP 15.1, 2020). Using average data across six environments, GGE Biplot analyses were calculated using Genstat 14th (VSN International Ltd., 2011) software.

Results and discussion

Genotype by Environment Interaction (GEI)

The effects of G, E, and GE interaction were found important at the P<0.01 level in the study using 17 barley genotypes. In this study, the genotype, environment, and GE interactions were found to be statistically significant when the combined analysis of variance for all traits was examined (table 2).

Table 2. Mean square values of investigated traits.

Sources of variations	Genotype (G)	Environment (E)	G x E	C.V. (%)
Degrees of Freedom	16	5	80	
Grain Yield	46000.1**	176862.7**	6322.2**	7.85
Variability (%)	34.62	41.59	23.79	
Heading Date	429.3790**	200.8824**	23.377**	0.94
Variability (%)	70.50	10.31	19.19	
Plant Height	491.537**	2020.104**	116.053**	2.88
Variability (%)	37.07	28.86	34.07	
Spike Length /	27.78565**	13.37041**	2.73987**	9.52
Variability (%)	60.85	9.15	30.00	
No. of Grain /Spike	6009.619**	503.355**	159.953**	15.34
Variability (%)	86.26	2.26	11.48	
Grain Weight/Spike	7.045635**	2.969367**	0.658592**	19.34
Variability (%)	62.54	8.24	29.23	
Test Weight	98.6434**	261.0733**	14.1094**	0.82
Variability (%)	39.34	32.53	28.13	
Thousand Kernel Weight	468.5870**	60.1145**	34.5890**	1.72
Variability (%)	70.96	2.84	26.19	

** Significant at the %1 level of probability.

There was a 34.62 % genotype effect on grain yield, a 41.59 % environment effect, and a 23.79 % genotype x environment interaction effect (table 2). It has been found that environmental variation affects grain yield more than other sources of variation. While the average grain yield of the genotypes was 5901 kg.ha^{-1}, the Lord (5106 kg.ha^{-1}) genotype had the lowest grain yield, and the Arcanda genotype had the highest (6753 kg.ha^{-1}) (table 3).

In similar studies, the environmental effect on grain yield; Vaezi *et al.* (2017), 73.94 %, Ghazvini *et al.* (2022), 53.60 %, and Fana *et al.* (2018) reported 47.29 %. Grain yield is a complex trait governed by genotype (G), environment (E), and genotype x environment interaction (GEI) effects. GEI interaction is essential for breeders and reflects yield variation that cannot be explained by genotype and environmental effects (Yan *et al.*, 2001; Vaezi *et al.*, 2017).

The heading date was 70.50 % affected by genotype, 10.31 % by the environment, and 19.19 % by genotype × environment interaction (table 2). The earliest heading date was determined in the Harman genotype with 103.4 days, and the latest heading date was determined in the Kıral 97 genotype with 117.1 days (table 4). According to the environmental averages, the mean heading date was determined as 108.9 days (table 5). The latest heading date was found at the E2 (111.9 days) location and the earliest at the E5 (106.8 days) location (table 5).

The results showed that genotype had a 37.07 % effect on plant height, the environment had a 28.86 % effect, and genotype and environment interaction had a 34.07 % effect (table 2). The genotypes' average plant height ranged from 94.6 to 110.3 cm. The Kıral 97 genotype produced the shortest plant height (94.6 cm), while the Harman genotype produced the longest plant height (110.3 cm) (table 4). The most extended plant height was E1 (111.6 cm), and the shortest plant height was E4 (97.4 cm), according to environmental averages (table 5).

Table 3. Mean grain yield (kg.ha^{-1}) of cultivars across test environments.

Cultivars	E1	E2	E3	E4	E5	E6	Mean
Arcanda	7154	6712	6694	6522	6674	6763	6753 a
Imeon	7117	6515	5660	5633	5952	6276	6191 b
Orfey	7071	5377	5927	5773	6331	6657	6189 b
Alena	6969	5788	6458	5842	5581	6170	6134 b
Sladoran	6684	5796	5919	6184	5669	6421	6111 bc
Harman	6621	5891	5444	6345	5998	6025	6053 bc
Hasat	6288	5640	5548	5729	6204	5726	5855 cde
Bolayır	5679	5191	4546	5141	4979	6112	5274 gh
Zeus	7861	6636	5674	5953	6782	6527	6572 a
Izbori	7136	6488	4450	5794	6668	5566	6016 bcd
Bojin	7086	6301	5259	5765	5371	6358	6023 bcd
Hemus	6906	6142	5144	5142	5704	5703	5790 de
Barberousse	6767	6198	4923	5151	5909	5722	5778 de
Kıral 97	6575	6189	4415	5076	5895	5534	5613 ef
Veslet	6529	5592	4552	4624	5532	5805	5438 fg
Lord	6464	4262	4250	4822	5273	5567	5106 h
Martı	6021	5454	4701	4587	5622	6196	5430 fg
Mean	6760 a	5892 c	5268 e	5534 d	5890 c	6066 b	5901

The spike length was 60.85 % affected by genotype, 9.15 % by the environment, and 30.00 % by genotype × environment interaction (table 2). The spike length of the genotypes varied between 6.26-10.07 cm. The longest spike length was measured in the Imeon (10.07 cm) genotype, and the lowest spike length was measured in the Bojin (6.26 cm) genotype (table 4). When the environmental averages were examined, E6 (8.35 cm) locations had the highest spike length, and E1 and E2 (7.33 cm) locations had the lowest spike length (table 5).

Table 4. Mean of yield component and quality traits of 17 barley cultivars.

Cultivars	HD	PH	SL	KNS	KWS	TKW	TW
Arcanda	113.9 b	101.8 f	9.59 b	26.8 g	1.57 e	50.5 a	63.9 ab
Imeon	111.8 d	99.5 g	10.07 a	31.3 f	1.38 efg	42.2 g	63.5 c
Orfey	106.4 gh	99.3 gh	8.85 c	27.5 g	1.26 fg	44.3 e	62.9 d
Alena	114.0 b	98.6 gh	8.69 cd	25.5 g	1.42 ef	49.8 b	64.1 a
Sladoran	105.0 ı	99.7 g	7.30 f	25.3 g	1.20 g	45.0 d	60.3 h
Harman	103.4 k	110.3 a	7.38 f	26.9 g	1.38 efg	45.3 d	63.7 bc
Hasat	104.5 ıj	108.1 b	8.41 de	25.8 g	1.30 fg	45.9 c	62.9 d
Bolayır	104.9 ı	97.7 h	8.28 de	25.0 g	1.20 g	43.4 f	63.8 ab
Zeus	112.6 c	107.1 bc	8.26 e	60.3 b	2.81 a	42.5 g	62.0 e
Iz Bori	106.9 g	103.2 f	6.32 h	60.4 c	2.04 c	39.2 ı	61.4 f
Bojin	112.8 c	103.1 f	6.26 h	56.8 bc	2.30 b	39.6 ı	60.5 gh
Hemus	108.1 f	105.9 cd	7.50 f	50.4 d	1.81 d	37.2 l	61.3 f
Barberousse	105.9 h	103.5 ef	6.82 g	45.6 e	1.78 d	37.1 l	62.0 e
Kıral 97	117.1 a	94.6 ı	6.76 g	75.5 a	2.99 a	35.0 m	56.4 j
Veslet	109.4 e	105.0 de	7.56 f	50.7 d	2.09 c	38.2 k	60.8 g
Lord	111.6 d	109.9 a	7.37 f	48.7 de	1.97 cd	38.7 j	64.0 a
Martı	104.2 j	107.1 bc	7.44 f	47.6 de	1.97 cd	40.6 h	59.7 ı
Mean	108.9	103.2	7.81	41.7	1.79	42.0	61.9

HD: Heading date, PH: Plant height, SL: Spike length, KNS: Number of grains per spike, KWS: Grain weight per spike, TW: Test weight, TKW: Thousand kernel weight.

The number of grains per spike was 86.26 % affected by genotype, 2.26 % by the environment, and 11.48 % by genotype-environment interaction (table 2). According to genotype averages, the number of grains per spike ranged from 25.0 to 75.5, with the genotype Kıral 97 having the highest number of grains per spike (75.5) and Bolayır having the lowest (25.0) (table 4). The E5 (45.1) location had the highest value for the number of grains per spike, while the E2 (38.6) location had the lowest value, according to the environmental averages (table 5).

The results showed that genotype had a 62.54 % effect on the grain weight per spike, the environment had an 8.24 % effect, and genotype and environment interaction had a 29.23 % effect (table 2). The Kıral 97 genotype had the most significant grain weight per spike (2.99 g), and the Sladoron and Bolayır genotypes had the lowest grain weight per spike (1.2 g) (table 4). The grain weight per spike, as calculated by the environmental averages, ranged from 1.52 to 2.01 g, with the E5 location recording the most excellent value (2.01 g) and the E2 location recording the lowest value (1.52 g) (table 5).

The effect of genotype on test weight was found to be 39.34 %, the effect of the environment as 32.53 %, and the effect of genotype × environment interaction was 28.13 % (table 2). Alena (64.1 kg.hl^{-1})

genotype had the highest test weight and the lowest Kıral 97 (56.4 kg.hl^{-1}) genotype (table 4). According to the environmental averages, the lowest test weight was determined in the E6 location (59.5 kg.hl^{-1}) and the highest in the E2 (64.5 kg.hl^{-1}) location (table 5).

The environment had a 2.84 % impact, the genotype had a 70.96 % influence, and the genotype x environment combination had a 26.19 % impact on thousand kernel weight (table 2). The genotype Kıral 97 (35.0 g) had the lowest value, and the genotype Arcanda (50.5 g) had the most incredible thousand kernel weight (table 4). According to environmental averages the thousand kernel weight varied between 40.6-43.2 g, with the lowest measurement coming from location E2 (40.6 g) and the highest value coming from location E6 (43.2 g) (table 5).

Table 5. Average of yield component and quality traits in six environments.

Environments	HD	PH	SL	KNS	KWS	TKW	TW
E1	108.4 d	111.6 a	7.33 d	39.7 b	1.65 b	42.6 b	63.6 b
E2	111.9 a	101.5 d	7.33 d	38.6 b	1.52 c	40.6 e	64.5 a
E3	109.5 b	107.1 b	7.62 c	39.1 b	1.66 b	42.5 b	62.8 c
E4	108.1 d	97.4 e	8.09 b	43.0 a	2.00 a	42.0 c	60.5 e
E5	106.8 e	103.2 c	8.17 ab	45.1 a	2.01 a	41.3 d	60.9 d
E6	109.0 c	98.2 e	8.35 a	43.8 a	1.92 a	43.2 a	59.5 f
Mean	108.9	101.4	7.81	41.5	1.79	42.0	61.9

HD: Heading date, PH: Plant height, SL: Spike length, KNS: Number of grains per spike, KWS: Grain weight per spike, TW: Test weight, TKW: Thousand kernel weight.

Principal Component and GGE-Biplot Analysis

Principal Component two-dimensional score accounted for 53.9 % of the total variation, PC1 had 36.2 %, and PC2 had 17.7 %. The locations were divided into two groups, E1, E2, and E3 circles formed a group, E4, E5, and E6 circles formed a different group (figure 1). Grain yield (GY) correlated positively with the traits SL, TKW, TW, and PH but negatively with the traits KNS, KWS, and HD. In terms of GY, SL, TKW, TW, and PH characteristics, two-row and six-row barley genotypes, stood out, respectively (figure 1).

According to Yan and Tinker (2006), there is a positive relationship between the features in these slices when the angle between the vectors is between 0°-90°, a negative relationship when the angle is between 90°-180°, and no relationship when the angle is 90° evaluated as.

The GGE-biplot graph of the positions of the locations explained 94.77 %. PC1 81.07 %, PC2 13.70 % were recorded. E1, E2, and E5 locations had positive PC2 values, while E3, E4 and E6 had negative PC2 values. All circles had a positive correlation. While the E1 and E2 locations vectors had the lowest angles, the vectors of E2 and E3 locations had the widest angles (figure 2). While the variation between genotypes increases as the vector moves away from the origin, the variation between genotypes decreases as the vector approaches the origin (Abate *et al.*, 2015).

According to the GGE biplot scatters graph analysis, there are two mega environments and seven sectors. The first mega-circle comprised E1, E2, and E5, and the second comprised E3, E4, and E6. The two-row barley genotypes were found in the second mega-circle, whereas the six-row barley genotypes were found in the first mega

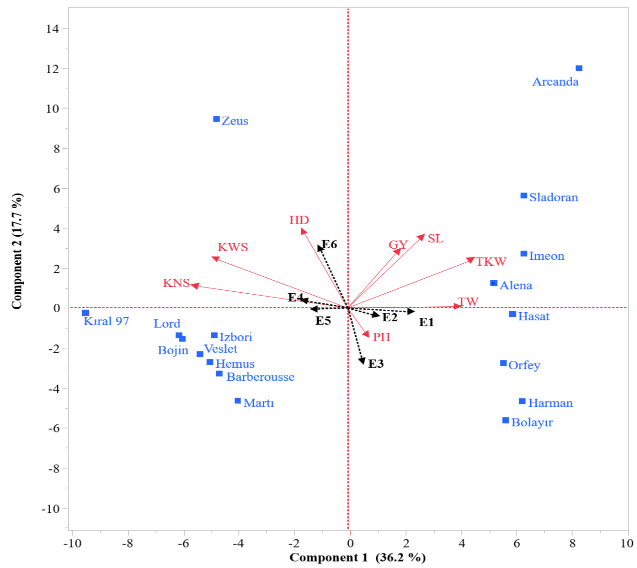

Figure. 1. Relationship among genotypes and distance origin and angles among the vectors.

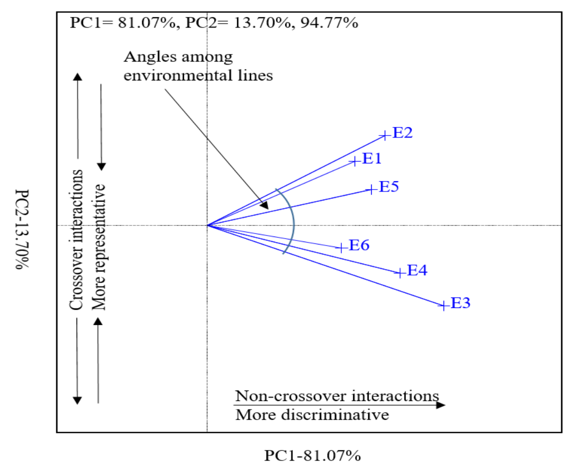

Figure. 2. Position of environments on GGE biplot graph investigated traits for grain yield.

environment. For the first and second mega environments, Zeus and Arcanda took center stage respectively. The farthest genotypes from mega circles were found to be the Martı and Lord genotypes (figure 3). In their mega environment, high performing genotypes are those located at the top of the polygon (Yan, 2014).

The stability of the genotypes regarding grain yield is shown in the mean circumference axis (AEC) Figure 4 was also evaluated. Zeus genotype had the highest PC1 score. Izbon, Arcanda, Imeon, Bojin, Hemus, Barberousse, Orfey, Kıral 97 and Alena genotypes are in front of the AEC ordinate, while Sladoran, Veslet, Harman, Lord, Hasat, Bolayır, and Martı genotypes are behind the AEC ordinate. The Martı genotype had the lowest PC1 value. E1 and E2 locations had the highest PC1 value (figure 4).

The Zeus and Imeon genotypes were placed next to the Arcanda, which was closest to the centeral circle. The farthest genotypes from the centeral circle were found to be Martı, Bolayır, and Lord (figure 5). In GGE Biplot analyses, circles closer to the centeral circle are considered ideal circles. It has been determined that the E4 and E5 locations are located closer to the central circle. E6 location was determined as the furthest perimeter from the central circle (figure 6).

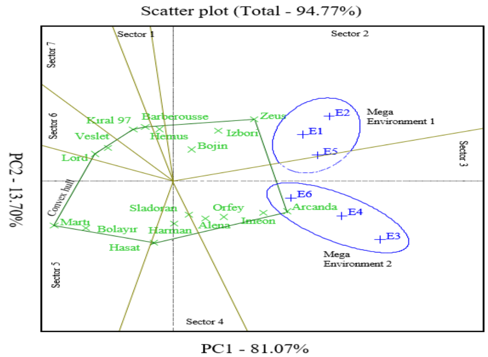

Figure. 3. Scatter plot graph of GGE biplot analysis.

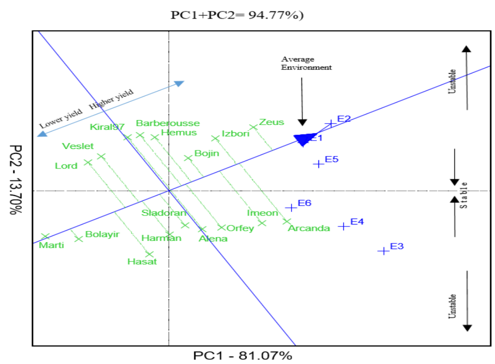

Figure. 4. Average environment coordinate, grain yield performance of the cultivars, vectors to AEC.

The mean coordination of environments is used to interpret the yield stability of genotypes (AEC). The AEC ordinate's line of stability, which intersects the origin and passes the ideal circumference, is the line with the arrow on it. The genotypes with the highest values are those that are on the right side of the general mean line, and the genotypes with the lowest values are those that are on the left. A genotype is less stable the longer its projection is in absolute terms. Genotypes and environments close to the center circle in the comparison plot are considered ideal genotypes and environments (Yan and Tinker, 2006).

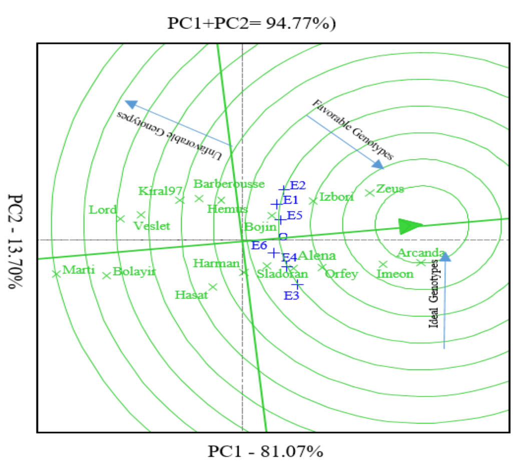

Figure. 5. Comparison biplot "ideal genotype"using GGE biplot with scaling focused on genotypes.

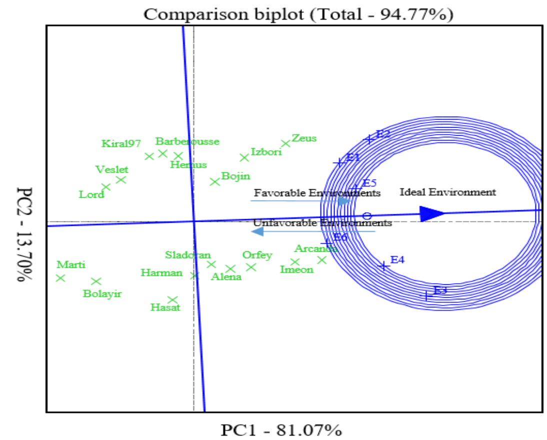

Figure. 6. Comparison biplot of ''ideal environment" for grain yield using GGE biplot.

In similar studies conducted, they stated that genotypes could be evaluated in terms of many traits with GGE Biplot methods, and it provides convenience in visually examining genotypes that show high performance in more than one trait and provides in selection (Vaezi *et al.*, 2017; Gungor *et al.*, 2022b).

Conclusions

In this study, seventeen barley genotypes Arcanda and Zeus genotypes as the ideal genotypes. In contrast, Martı and Bolayır genotypes were determined as non-ideal genotypes in the study carried out in six different environments. While the E1 location had the highest grain yield, E4 and E5 locations were determined as the most representative circles. As the study was conducted over two years in different environments in the Thrace region, Zeus and Arcanda genotypes were found outstanding genotypes in terms of both high yielding and stable.

Literature cited

Abate, F., Mekbib, F. & Dessalegn, F. (2015). GGE biplot analysis of multi-environment yield trials of durum wheat (*Triticum turgidum* Desf.) genotypes in North Western Ethiopia. *Journal of Expanded Agriculture International*, *8*, 120-129.https://doi.org/10.9734/AJEA/2015/9994

Fana, G., Tadese, D., Sebsibe, H. & Verma, R.P. (2018). Multi-environment trial analysis of food barley in Ethiopio using AMMI and GGE biplot methods. *Journal of Plant Breeding and Genetics*, *6*, 75-85. https://doi.org/10.33687/pbg.006.03.2579

FAOSTAT. (2023). Food and Agriculture Organization of the United Nations. Rome-Italy. (Online Database). http://www.faostat/en/

Ghazvini, H., Bagherikia, S., Pour-Aboughdareh, A., Sharifalhossaini, M., Razarvi, S. A., Mohammadi, S., Ghasemi-Kalkhoren, M., Fathihafshejani, A. & Khakizade, G. (2022). GGE biplot analysis of promising barley lines in the cold regions of Iran. *Journal of Crop Improvement*, *36(4)*, 461-472. https://doi.org/10.1080/15427528.2021.1977448

Gungor, H., Cakir, M.F., & Dumlupinar, Z. (2022a). Evaluation of triticale: genotype by environment interaction and GGE biplot analysis. *Journal of Animal and Plant Science*, *32(6)*, 1637-1647. https://doi.org/10.36889/JAPS.2022.6.0573

Gungor, H., Cakir, M.F., & Dumlupinar, Z. (2022b). Evaluation of wheat genotypes: genotype × environment interaction and GGE biplot analysis. *Turkish Journal of Field Crops*, *27(1)*, 149-157. https://doi.org/10.17557/tjfc.1081513

Hagos, G. & Abay, F. (2013). AMMI and GGE biplot analysıs of bread wheat genotypes in the Northen part of Ethiopia. *Journal of Plant Breeding Genetics*, 1:12-18. https://esciencepress.net/journals/index.php/JPBG/article/view/50/76

Khalili, M., Pour-Aboughadareh, A. & Naghavi, M.R. (2013). Screening of drought tolerant cultivars in barley using morphophysiological traits and integrated selection index under water deficit stress condition. *Advanced Crop Science.*, *3*, 462–471. https://www.researchgate.net/publication/257208136

Laidig, F., Piepho, H. P., Rentel, D, Drobek, T. & Meyer, U. (2017). Breeding progress, genotypic and environmental variation and correlation of quality traits in malting barley in German official variety trials between 1983 and 2015. *Theorethical and Applied Genetics*, *130*, 2411–2429. https://doi.org/10.1007/s00122-017-2967-4

Meints, B., Vallejos, C. & Hayes, P. (2021). Multi-use naked barley: A new frontier. *Journal of Cereal Science*, *102,* 103370. https://doi.org/10.1016/j.jcs.2021.103370

SAS. (2020). JMP® 15 Design of Experiments Guide. Cary, NC 27513. USA.

TUIK. (2023). Turkish Statistical Institute. Retrieved from 30 January 2023 from https://www.tuik.gov.tr

Vaezi, B., Pour-Aboughadareh, A., Mohammadi, R., Armion, M., Mehraban, A., Hossein-Pour, T. & Dorii, M. (2017). GGE biplot and AMMI analysis of barley yield performance in Iran. *Cereal Research Communications*, *45(3)*, 500-511. https://doi.org/10.1556/0806.45.2017.019

Vaezi, B., Pour-Aboughadareh, A., Mehraban, A., Hossein-Pour, T., Mohammadi, R., Armion, M. & Dorii, M. (2018). The use of parametric and non-parametric measures for selecting stable and adapted barley lines. *Archives of Agronomy and Soil Science*, *64(5)*, 597–611. https://doi.org/10.1080/03650340.2017.1369529

VSN-INTERNATIONAL. (2011). Genstat for windows 14. ed. VSN International, Hemel Hempstead, UK. https://vsni.co.uk/software/genstat

Yan, W., Cornelius, P. L., Crossa, J. & Hunt, L. A. (2001). Two types of GGE biplots for analyzing multi-environment trial data. *Crop Science*, *41*, 656–663. https://doi.org/10.2135/cropsci2001.413656x

Yan, W. & Tinker, N.A. (2006). Biplot analysis of multi-environment trial data: principles and applications. *Canadian Journal of Plant Science*, *86*, 623-645. http://doi.org/10.4141/P05-169

Yan, W, Kang, M. S., Ma, B., Woods, S. & Cornelius, P.L. (2007). GGE Biplot vs. AMMI analysis of genotype by environment data. *Crop Science*, *47*, 643-655. https://doi.org/10.2135/cropsci2006.06.0374

Yan, W. (2014). Crop Variety Trials: Data Management and Analysis. John Wiley & Sons. pp 360. https://doi.org/10.2135/cropsci2014.08.0002br