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ASSESSMENT OF BREAD WHEAT GENOTYPES (*Triticum aestivum* L.) WITH GGE BIPLOT AND AMMI MODEL IN MULTIPLE ENVIRONMENTS

Mehmet Karaman[1*], Sinan Bayram[2], Evrim Şatana[3]

[1]Department of Plant Production Technologies, Faculty of Applied Sciences, Mus Alparslan University, Mus, Türkiye
[2]Maize Research Institute, Cool Climate Cereals Unit, Sakarya, Türkiye
[3]Directorate of Agricultural Production Enterprise, Agricultural Extension and In-Service Training Center, Adana, Türkiye
[*]Corresponding author. E-mail: karaman2178@hotmail.com

ABSTRACT

Wheat is one of the products with the widest cultivation area and adaptation ability in the world. Although the heritability of the variety is important in grain yield, the environment and genotype x environment interaction is significantly effective. This study was carried out in 6 different environments. According to the Additive Main Effect and Multiplication Interaction (AMMI) model; genotype, environment and genotype x environment interaction were found to be effective on grain yield, respectively, by 9.40%, 56.79% and 16.28%. It has been determined that, there is a positive relationship between grain yield and the number of spike per square meter and the number of grain in each spike. In the study, 3 mega environments were formed. G19 in the first mega environment, G13 in the second mega environment and G21, G22 in the third mega environment came to the fore. G9, G13 and G19 were seen as hopeful lines in the grain yield. Also, E5 was the ideal environment and, G19 had the highest adaptability and grain yield. It has been concluded that G19 may be a candidate for variety because genotypes that are stable in different environmental conditions are preferred by the producers.

Keywords: AMMI, breeding, GEI, wheat, yield component.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) has the most cultivation area in cereals. In addition, products obtained from bread wheat are widely used and have an important place in human nutrition (Hossain et al., 2018; Kizilgeci et al., 2019). Although wheat has grown in different environmental conditions in Türkiye, it is mostly grown as based on rainfall in Southeastern Anatolia Region. In this region, alternative, spring and winter wheat varieties are sowed in 1.3 million hectares area, but ecological differences (rainfall, temperature, soil structure, biotic and abiotic stress factors, etc.) limit wheat production (Aktas et al., 2010; Aktas, 2016).

The yield potential of a genotype is under the influence of environment (E), genotype (G) and environment x genotype interaction (GEI). Wheat growers prefer varieties that are stable in different environments and have superior agronomically features. Therefore, it has been reported that it is important that the new varieties are stable in different environments (Solonechnyi et al., 2015).

The grain yield of genotypes is significantly affected by ecological conditions in terms of stability and adaptation (Singh et al., 2014). Wheat genotypes should be tested in multiple environments in terms of grain yield, stability and genotype x environment interaction in order to determine the candidate varieties. Also, it has been reported that genotype x environment interaction (GEI) has an important role in determining the stability of genotypes (Yan, 2001; Kaya et al., 2006; Verma et al., 2015).

When the yield trials are analyzed in different environments with traditional methods, it can be obtained information about the genotype x environment interaction (GEI). However, it is not easy to notice the effect of GEI in environments where the environment fluctuates. Because of these conditions, the effects of G, E, GEI are not

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obvious. Different environmental conditions and agronomic applications limit the efficiency of genotypes. Therefore, it is necessary to use different models to overcome these problems and to determine the best genotypes in different environments (Mohammadi et al., 2015).

Genotype environment (GE), genotype x environment interaction (GEI) and additive main effect and multiplication interaction (AMMI) models were created to determine the response of genotypes in changing ecological conditions. These models were used by many researchers in the studies involving multiple environments or years (Hagos and Abay, 2013; Mohammadi et al., 2018).

In the current study, 20 advanced lines and 5 control varieties were evaluated with AMMI, GGE-biplot and ANOVA analysis models. The purpose was to determine the best candidate varieties which are suitable to Türkiye's Southeastern Anatolia Region conditions, with grain yield and stability. In addition, it is to contribute researchers with the visual presentation of AMMI and GGE biplot models.

MATERIAL AND METHODS

The research was carried out in Diyarbakir Center and Mardin Kiziltepe locations in the 2015-2016 and 2016-2017 growing seasons in Türkiye. Soil structures in test environments have clay-loam, deep structured, low organic matter, high Ph and calcium content, slightly alkaline, high potassium content and moderate phosphorus content. The experiment was conducted with 3 replications in the randomized blocks experiment design and with 20 advanced lines and 5 control varieties in 6 different environments on rainfed and irrigation conditions [rainfed: (E1: 2015-2016 Diyarbakir, E3: 2015-2016 Kiziltepe, E4: 2016-2017 Diyarbakir, E6: 2016-2017 Kiziltepe) and irrigated: (E2: 2015-2016 Diyarbakir, E5: 2016-2017 Diyarbakir)] (Figures 1 and 2).

Figure 1. Map showing the location of the experiment areas

Figure 2. Map of Türkiye showing the experiment region

The experiments were irrigated twice with furrow irrigation method and 100 mm of water per square meter during the Zadoks 50 (heading time) and Zadoks 71 (milk filling stage) periods (Zadoks et al., 1974). In experiment, 60 kg ha^{-1} phosphorus (P_2O_5) and 140 kg ha^{-1} nitrogen (N) were applied as the pure substance. While all of the phosphorus was given together with the planting, half of the nitrogen was applied at the time of planting and the remaining half was applied at the Zadoks 23 stage (tillering period). Experiment parcels are 6 m^2 with 6 rows and 20 cm row spacing and 450 seeds were planted per square meter.

Experiment planting was carried out from November 1 to November 15 depending on weather conditions in all locations. A chemical control was made in all locations, when weeds had 2-4 leaves. Harvesting was carried out between June 1 and June 16 under rainfed, June 15 and July 2 date under irrigation conditions, with the parcel combine harvester named Hege 140.

Table 1. The informations about genotypes used in experiment

Genotypes (G)	Pedigree	Origin
G1	BOW#1/TEVEE'S'// ZORNITCHA SEE02153-0S-0S-0SD.0S…	CIMMYT
G2	SERI//AU/UP301/3/JE93 7.20/4/MILAN/AMSEL SEE02528-0S…	CIMMYT
G3	OPATA*2/WULP/3/SARA1/YACO//ATTILA/4/HAR 1685…	CIMMYT
G4	SUNCO/2*PASTOR CMSS99Y05530T-10M-3Y-010M-2SY-0B.0S…	CIMMYT
G5 (Nurkent)	Check	Public
G6	FEN/VEE#5 /BOW"S"/NKT"S" SA 2003-41-0SA-0SA.0SD-12.6D-0SD…	CIMMYT
G7	ATTİLA//PGO/SERI/3/PASTOR CMSS98Y03455T-040M-020M-040SY…	CIMMYT
G8	FEN/VEE#5 /BOW"S"/NKT"S" SA 2003-41-0SA-0SA.0SD…	CIMMYT
G9	GW/ALD"S"/5/ALD"S"/4/BB/G11//CNo67/7c/3/KVZ/TÝ …	CIMMYT
G10 (Pehlivan)	Check	Public
G11	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR CMSS98Y01814M…	CIMMYT
G12	MILAN/AMSEL/KASIFBEY SA 2003-54-0SA-0SA.0SD-14.3D-0SD…	CIMMYT
G13	WBLL1*2/TUKURU GGSSOOB00173T-099TOPY-099M-099Y-099M…	CIMMYT
G14	BOBWHITE#1/MN72131/PVN/SEYHAN=KAUZ"S" SA 2003-73-0SA-0SA.0SD…	CIMMYT
G15 (Cemre)	Check	Public
G16	V763.2312/V879.C8.11.11/SN.64/HN.4//REX/3/EDCH/MEX/4/SLS"S"/5/BOW"S"…	CIMMYT
G17	TAM200/PASTOR//TOBA97CMSS99Y02667T-060M-040Y-040M-030Y-030M…	CIMMYT
G18	TAM//AGRI/NAC/3/HATUSHA/4/GÖNEN98 SEE03199-0SD…	CIMMYT
G19	VEE#8//JUP/BJY/3/F3.71/TRM/4/BCN/5/KAUZ/6/163HAMIDIYE//VEE…	CIMMYT
G20 (Sagittario)	Check	Private Company
G21	KAUZ/PASTOR CMSS93B00025S-48Y-010M-010Y-010M…	CIMMYT
G22	VEE#7/BOW//SHA4/CHİL SEE01027-0S-4S-0S-4S-5S-11S-SD…	CIMMYT
G23	KRICHAUFF/FINSI CMSA00M00204S-040P0M-040Y-030M…	CIMMYT
G24	EXCALIBUR/4/W462//VEE/KOEL/3/PEG//MRL/BUC-SD…	CIMMYT
G25 (Adana-99)	Check	Public

CIMMYT: International Maize and Wheat Improvement Center.

The origin of the advanced lines and control varieties used in the study are shown in listed (Table 1). In addition, information about each environment is given in detail (Table 2).

Table 2. Information about the environments

Years	Test environments Code	Locations	Altitude (m)	Latitude	Longitude	Annual rainfall (mm)	Long-term rainfall (mm) average
2015-2016	E1	Diyarbakir	599	37° 56’N	40° 15’E	417.2	481.0
	E2	Diyarbakir	599	37° 56’N	40° 15’E	417.2	481.0
	E3	Kiziltepe	485	37° 11’N	40° 35’E	325.5	389.3
2016-2017	E4	Diyarbakir	599	37° 56’N	40° 15’E	453.0	481.0
	E5	Diyarbakir	599	37° 56’N	40° 15’E	453.0	481.0
	E6	Kiziltepe	485	37° 11’N	40° 35’E	362.9	389.3

In order to determine the grain yield (GY), after the whole parcel was harvested, it was weighed with 0.01% precision scales and converted to kg ha^{-1}. Thousand grain weight (TGW) was determined by weighing 1000 grains. When determining the number of spike per square meter (NSPSM), spikes at 2 different points of 1 m^2 of each parcel were counted and averaged. For grain number in spike (NGPS), 20 spikes were taken from each plot and after determining the number of grains in each spike, it was determined by taking the average.

Statistical analysis of data

Data analysis was done using JMP 7.0 and GenStat 12th Edition (GenStat, 2009) statistical programs. AMMI model was used to see the order of the genotypes in terms of grain yield and the genotype recommendation list on the basis of environments. GGE biplot analysis was performed to see the genotype, genotype x trait relationship and stability of genotypes in six different environments (Yan and Thinker 2005; Verma et al., 2016). In addition, the differences between groups and groups formed as a result of ANOVA analysis were evaluated according to LSD test (p≤0.01 and p≤0.05) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

According to the ANOVA analysis results, significant differences were observed between the genotypes at level of p≤0.01 in all environments.

Table 3. Grain yield performance of genotypes in different environments (kg ha^{-1})

Genotypes (G)	E1		E2		E3		E4		E5		E6		Mean of E.	
G1	6698	a-d	7258	d-g	6053	a-e	7106	a-d	8945	b-f	7811	abc	7312	BCD
G2	5297	fgh	6815	gh	6306	abc	6136	def	8453	d-g	5408	fgh	6402	K
G3	5478	e-h	7560	c-g	4767	g-j	6656	b-e	9367	abc	5408	fgh	6539	H-K
G4	6546	a-e	7451	c-g	5979	a-e	7094	a-d	8519	def	7839	abc	7238	B-E
G5	6191	b-g	7379	c-g	3833	jk	6547	b-e	8472	d-g	6762	a-e	6531	IJK
G6	6841	a-d	7758	a-g	2867	k	7044	a-e	8886	b-f	5225	gh	6437	JK
G7	5642	d-h	7441	c-g	5236	d-h	6331	cde	8800	c-f	7361	a-e	6802	E-K
G8	5744	c-h	6984	fgh	4914	f-ı	6956	a-e	9014	b-f	7322	a-e	6822	E-K
G9	6869	abc	8469	abc	5231	d-h	7614	ab	9661	ab	7700	abc	7591	AB
G10	6803	a-d	7433	c-g	5631	b-g	7269	abc	7675	gh	7204	a-e	7003	D-H
G11	6005	b-h	7609	b-g	5762	b-g	6522	b-e	9364	abc	7075	a-e	7056	C-G
G12	5485	e-h	8276	a-d	5142	e-h	6950	a-e	8994	b-f	6525	c-h	6895	D-J
G13	7089	ab	8764	a	5419	c-g	7611	ab	9236	a-d	6714	b-f	7472	BC
G14	6744	a-d	8461	abc	4358	hıj	7892	a	8533	c-f	5894	e-h	6980	D-I
G15	5912	b-h	7709	a-g	4055	ıj	6628	b-e	8750	c-f	7564	abc	6770	F-K
G16	6413	a-f	8153	a-e	5438	c-g	6636	b-e	8542	c-f	5903	e-h	6847	D-K
G17	5850	c-h	7839	a-g	5851	a-f	6217	c-f	9197	a-d	6033	d-h	6831	E-K
G18	6040	b-h	7212	d-g	5147	d-h	5931	ef	8286	efg	7075	a-e	6615	G-K
G19	7427	a	7973	a-f	6669	ab	7492	ab	10019	a	8469	a	8008	A
G20	4889	h	6198	h	5798	b-g	5103	f	7014	h	5153	h	5692	L
G21	4993	gh	7834	a-g	6856	a	7217	a-d	8847	b-f	7553	a-d	7217	B-F
G22	4884	h	7020	fgh	6200	a-d	7847	a	9239	a-d	8156	ab	7224	B-F
G23	6459	a-f	8694	ab	4779	g-j	6903	a-e	9044	b-e	7031	a-e	7152	B-F
G24	6013	b-h	7107	e-h	5634	b-g	7244	a-d	8189	fg	6567	c-h	6792	E-K
G25	6147	b-g	7324	d-g	5653	b-g	6564	b-e	8578	c-f	7611	abc	6979	D-I
Mean	6098		7629		5343		6860		8785		6855		6928	
CV (%)	12.1		8.9		12.0		9.9		5.9		13.6		10.2	
LSD (0.05)	121.2**		112.1**		105.4**		111.9**		84.4**		152.9**		46.5**	

Checks: Nurkent (G5), Pehlivan (G10), Cemre (G15), Saittario (G20), Adana-99 (G25), Mean of E.: Mean of Environments.

According to the ANOVA analysis results of the current study, grain yield ranged from 5692 kg ha^{-1} to 8008 kg ha^{-1}. In E1, E5 and E6; G19, E2; G13, E3; G21 and E4; G14 were ranked first in grain yield (Table 3).

Table 4. AMMI analysis of variance for grain yield (kg ha^{-1}) over six environments

Source of variation	df	Sum of squares	Mean squares	F ratio	%SS explained
Total	449	9441733	21028		
Genotypes	24	887992	37000	7.35**	9.40
Environments	5	5362420	1072484	62.85**	56.79
Block	12	204765	17064	3.39	
Interactions	120	1536816	12807	2.54**	16.28
IPCA 1	28	763969	27285	5.42**	49.71
IPCA 2	26	360618	13870	2.76**	23.47
Residuals	66	412229	6246	1.24	
Error	288	1449740	5034		

Environment with 56.79%, genotype x environment interaction with 16.28% and genotype with 9.40% were effective on grain yield (Table 4). This result clearly shows that environmental factors have great importance on grain yield. In addition, it reveals the importance of environmental factor in selection studies.

The first four genotypes recommended for environments

Table 5. The first four genotypes selected according to the environment and PCA score in the AMMI model

Environment	Mean (kg ha^{-1})	Score	1	2	3	4	IPCA [1]	IPCA [2]
E1	6098	-8.788	13	9	19	1	-8.79	0.35
E2	7629	-8.47	13	14	9	19	-8.47	4.77
E3	5343	16.435	21	19	22	2	16.43	9.74
E4	6860	-4.025	19	9	13	23	-4.03	-1.08
E5	8785	-2.942	19	9	13	23	-2.94	1.27
E6	6855	7.791	19	22	1	4	7.79	-15.04

According to IPCA 1 and IPCA 2 values, it is determined that the grain yields of G9, G13 and G19 are high and the ability of these genotypes are good to adapt to multiple environments. It was observed that G14, G21 and G22 are compatible with special environments (Table 5, Figure 7). The AMMI model is an effective for determining the best genotype for multiple environments or the specific genotype for desired environments. It is also an effective method to determine the appropriate genotype for special environments (Bantayehu et al., 2013).

The AMMI model showing Genotype x Environment means

AMMI model is interpreted in two ways. The *x*-axis shows the basic effect of genotype and environment, the *y*-axis shows the effect of interaction (Figure 3). Genotypes mean stable if close to the *x*-axis and unstable if far from the *x*-axis (Mirosavlievic et al., 2014; Kendal et al., 2019). In addition, the yields of the genotypes located on the right part of the *y*-axis are above average and the yields of those located on the left part of the *y*-axis are below the average (Kendal et al., 2019).

As you see it in the AMMI graph (Figure 3), it is seen that the variation among the genotypes in E3 and E6, which is the subject of the research, is the highest. It has been presented visually that G6, G11 and G23 are the most stable lines, but their grain yields are lower than G19 (Figure 3). It is understood that the grain yield of G19 is highest and G19 is moderately stable among the existing genotypes. Based on the IPCA score, E5 can be recommended for testing genotypes. Because it is seen as having the highest yield potential and also ideal environment (Table 5, Figure 8).

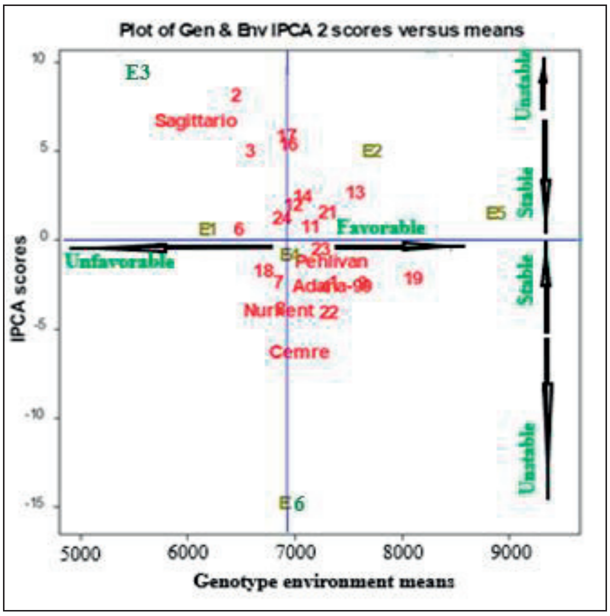

Figure 3. The AMMI model based on grain yield (kg ha^{-1}) of genotypes (G) in six environments (E)

Table 6. Average values of traits for twenty-five genotypes

Genotypes	GY (kg ha^{-1})		TGW (g)		NSPSM		NGPS	
G1	7312	bcd	36.5	ij	428.6	abc	46.9	d-g
G2	6402	k	36.6	hi	386.1	hi	45.5	f-k
G3	6539	h-k	35.6	jkl	395.0	fgh	46.3	e-i
G4	7238	b-e	33.3	mn	428.1	abc	51.2	a
G5	6531	ijk	36.3	ijk	401.8	d-h	45.0	g-k
G6	6437	jk	37.1	ghi	388.6	gh	44.3	jk
G7	6802	e-k	37.1	ghi	396.1	e-h	46.1	e-j
G8	6822	e-k	35.1	l	409.2	c-g	47.7	cde
G9	7591	ab	43.4	ab	397.9	e-h	44.0	k
G10	7003	d-h	44.1	a	361.4	j	44.2	jk
G11	7056	c-g	38.1	ef	400.4	d-h	46.4	e-h
G12	6895	d-j	37.2	f-i	395.0	fgh	46.7	d-g
G13	7472	bc	40.5	d	404.6	d-h	45.7	f-k
G14	6980	d-i	42.5	bc	365.6	ij	44.6	h-k
G15	6770	f-k	38.8	e	393.9	fgh	44.1	k
G16	6847	d-k	33.6	m	422.2	a-d	48.6	bcd
G17	6831	e-k	40.0	d	384.1	hi	44.5	ijk
G18	6615	g-k	33.0	mn	411.8	c-f	49.1	bc
G19	8008	a	37.5	fgh	434.1	ab	49.4	abc
G20	5692	l	37.6	fg	347.3	j	43.7	k
G21	7217	b-f	35.2	l	428.6	abc	47.8	cde
G22	7224	b-f	32.6	n	441.9	a	49.8	ab
G23	7152	b-f	41.9	c	387.4	ghi	44.1	k
G24	6792	e-k	33.7	m	421.3	a-d	48.1	b-e
G25	6979	d-i	35.6	kl	417.9	b-e	47.1	def
Mean	6928		37.3		402.0		46.4	
CV (%)	10.2		3.7		8.3		6.4	
LSD (0.05)	46.5**		0.9**		21.9**		1.9**	

GY: Grain Yield, TGW: Thousand Grain Weight, NSPSM: Number of Spike per Square Meter, NGPS: Number of Grain per Spike.

According to ANOVA analysis, there were significant differences between the genotypes in terms of all the features at level of $p \leq 0.01$ (Table 6). The best genotypes are G19 for grain yield, G10 (Pehlivan) for thousand weight, G22 for number of spike per square meter and G4 for number of grain per spike (Table 6).

GGE biplot analysis

GGE biplot analysis presents two-way data in the form of visual graphics. This model can show the main effects of genotypes (G) and the effects of genotype x environment (GE) interaction at the same time (Yan et al., 2000). In GGE biplot analysis, the angle between the vectors is interpreted as positive if < 90°, negative if > 90° and no correlation if = 90° (Yan and Tinker, 2005; Erdemci, 2018).

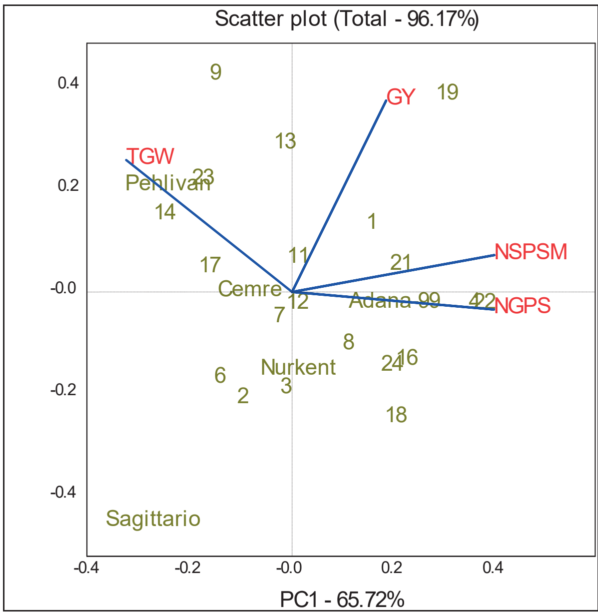

Figure 4. GGE biplot graph showing the genotype traits relationship

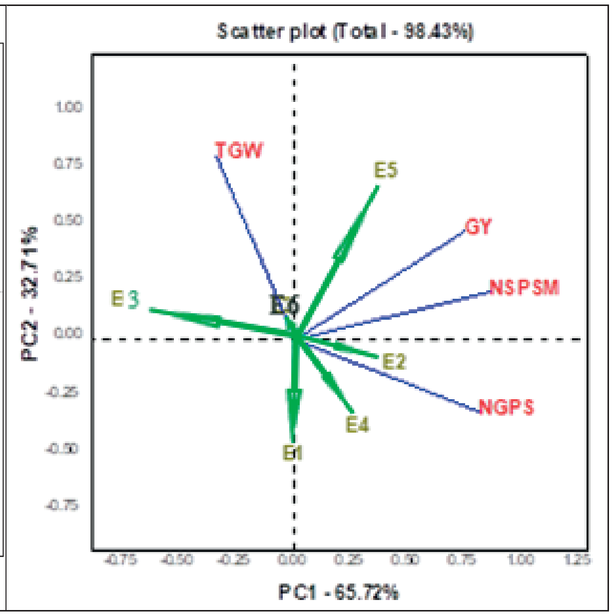

Figure 5. GGE biplot graph showing the relationship between the environment and traits

Accordingly, it is seen that there is a positive relationship between GY and NSPSM (Figure 4). In addition, it is clearly seen that there is no correlation between TGW and GY, and there is a negative relationship between TGW and all other features. In Figure 5, which shows the relationship between environment and feature, it is seen that there is a strong positive relationship between GY and E5.

As for the vectors, the vector representing E5 is the longest and the vector representing E2 is the shortest. This shows that the variation among genotypes is highest in E5 and lowest in E2 (Figure 5). Also, there is a positive relationship between NGPS and E2/E4 and a negative relationship with E3. Ranking biplot graph (Figure 6) made it clear that G9, G13 and G19 are the best genotypes in terms of grain yield by explaining PC1 by 44.65%, PC2 by 24.74% and total variation by 69.38%. As a result of the analysis made to show which genotype is best in which environment; 6 different sectors and 3 mega-environments were formed (Figure 7).

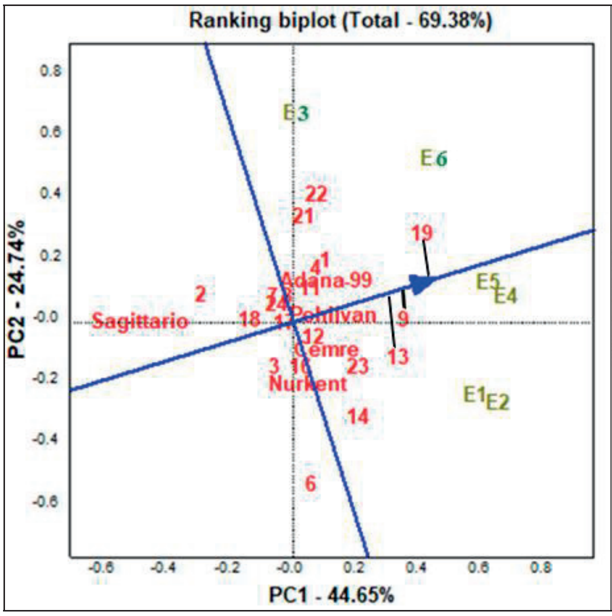

Figure 6. The rank of genotypes based on grain yield stability

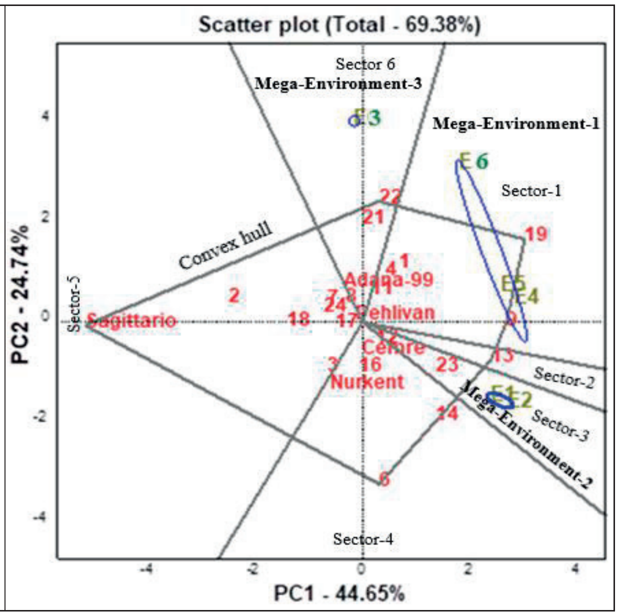

Figure 7. Which-won-where/what of GGE biplot based on across environment data

The yields of genotypes can change depending on environmental conditions. The polygon view created with the biplot model shows which genotype is the ideal genotype in which mega environment (Figure 7).

All genotypes can be grouped within a polygon, but only by linking genotypes (good or bad genotype) far from the origin center to the center. Genotypes at the top of the polygon are more sensitive to the environment than other genotypes (Yan and Kang, 2003; Aktas, 2016). G6 and Sagittario genotypes, located far from the origin center and at the top of the polygon, are environmentally sensitive and have low grain yields.

In the current study, the ideal genotype was found to be G19 in the first mega environment (E4, E5 and E6). In the second mega environment (E1 and E2), the ideal genotype was found to be G13. Finally, in the third mega environment (E3), ideal genotypes were found to be G21 and G22 (Figure 7). It can be said that G11 and G12, which are close to the center of the axis and whose efficiency is around the average of experiment, are less sensitive to environmental conditions.

The closest environment to the ideal environment in the central circle was E5. Therefore, it is clearly seen that the most ideal environment among all environment is E5 (Figure 8). G9 and G13, which are close to the center circle where the ideal genotype is located, are promising genotypes in terms of grain yield. However, the most ideal genotype was the G19 located on the center circle (Figure 9).

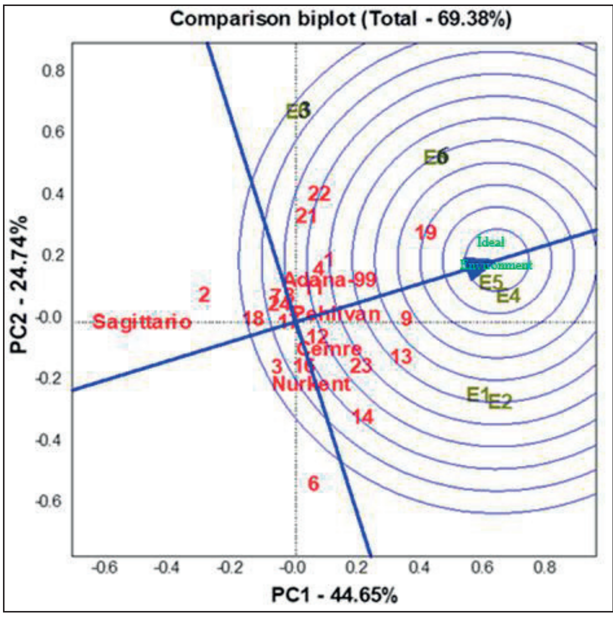

Figure 8. GGE biplot graph based on environment focused scaling for comparison the environments

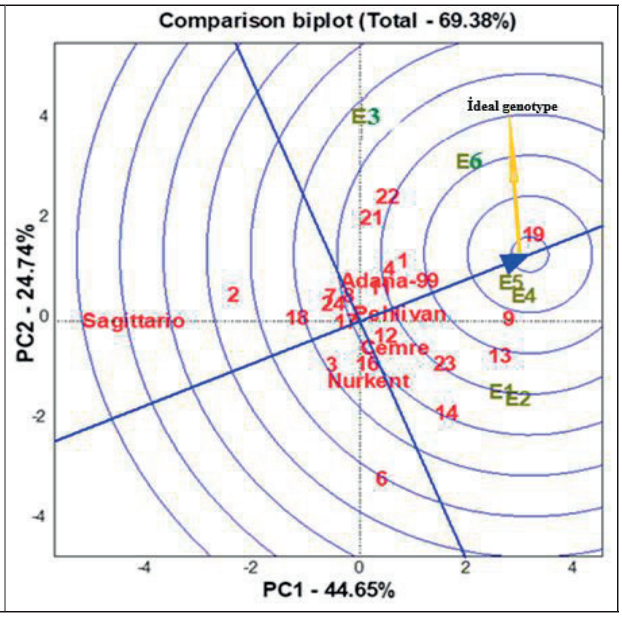

Figure 9. GGE-biplot model based on the ideal genotype to compare genotypes

GGE biplot analysis offers to researcher an opportunity to compare genotypes and environments, and to identify genotypes suitable for each environment (Aktas, 2019).

Table 7. Average of features examined from over the environments

Environments	GY (kg ha^{-1})		TGW (g)		NSPSM		NGPS	
E1	609.8	d	34.35	d	381.9	d	46.7	a
E2	762.9	b	35.65	c	449.6	b	47.9	a
E3	685.5	c	40.02	ab	308.6	e	43.2	b
E4	686.0	c	34.60	cd	419.1	c	47.7	a
E5	878.5	a	40.32	a	473.1	a	46.5	a
E6	534.3	e	38.92	b	379.4	d	46.5	a
Mean	692.8		37.31		402.0		46.4	
CV (%)	10.2		3.7		8.3		6.4	
LSD (0.05)	46.5**		1.1**		20.9**		1.5**	

GY: Grain Yield, TGW: Thousand Grain Weight, NSPSM: Number of Spike per Square Meter, NGPS: Number of Grain per Spike.

In the current study, it was determined that there were significant differences between environments at the level of $p \leq 0.01$. The environment with the highest grain yield is E5 and the lowest is E6.

CONCLUSIONS

According to the results of the study done with 25 genotypes in 6 different environments, genotype (G) 9.40%, environment (E) 56.79% and, genotype x environment interaction (GEI) 16.28% in rate had an impact on grain yield. In line with this result, attention should be paid to the environment factor in selection studies to be carried out in breeding programs. In the study, 3 mega environments have formed for grain yield. G19 in the first mega environment, G13 in the second mega environment, G21 and G22 in the third mega environment were the best genotypes. Genotypes that stand out in the first and second mega environments have high adaptability to multiple environments. However, genotypes that stand out in the third mega environment are only genotypes that have good adaptability to special environments. In the study, it was also determined that the ideal environment is E5 and the ideal genotype is G19. G19 with high ability to adapt to multiple environments can be a national cultivar candidate. In addition, G19 must be used as a parent for grain yield in bread wheat breeding studies.

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