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EVALUATION OF GRAIN YIELDS OF SELECTED BREAD WHEAT *(TRITICUM AESTIVUM* L.) VARIETIES IN CHANGING CLIMATIC CONDITIONS USING DIFFERENT ANALYTICAL MODELS

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Keywords: Wheat, AMMI, ANOVA, GGE-biplot, Environment, Yield

Abstract

In the present study, the variety or varieties with high grain yield and stability, despite changing climatic conditions, were edeutified to recomment them for production areas and to include these varieties as genetic material in the parent lists for breeding programs. The additive main effect and multiplicative interaction (AMMI) analysis results the effects of cultivars (C), environments (E) and cultivar x environment interaction (CEI) were found to be important over grain yield at $p \leq 0.01$ level. Also, showed that grain yield performance of bread wheats were greatly affected mostly by the environment (70.42%), they from the interaction between environment and cultivar (7.29%), the least by cultivar (6.79%). The polygon graph obtained from genotype, genotype x environment (GGE) biplot analysis showed that two separate mega environments were formed, Nurkent variety was the best for first mega-environment, while Pehlivan variety for the second mega environment. GGE biplot determined that the ideal environment for bread wheat was environment 9 (E9) and the ideal genotype was Nurkent. Due to the visual presentation of AMMI and GGE biplot graphs, analysis results showed that these two models can be used to visually identify the best genotypes.

Introduction

Wheat is one of the most important food sources in the world. The world wheat cultivation was 221.9 million hectares and the production was 775.8 million tons (Yeni 2022). Whereas wheat cultivation was 6.7 million hectares and production was 17.7 million tons in Türkiye (Yeni 2022). Wheat is mostly grown in conditions based on rainfall in Türkiye. One of the main objectives of wheat breeders has been to increase grain yield (Aktas 2016). To achieve high grain yield will be possible with the development, and application of new breeding techniques and the use of high yield varieties in breeding programs.

Complex additive main effect and multiplicative interaction (AMMI) model and genotype, genotype x environment (GGE) biplot analysis model, including main effects and multiplicative interactions, are used by plant breeders. It has been seen by different researchers that these models make it easier to interpret the potential of genotypes as well as the effect of environmental factors on genotypes (Kilic *et al.* 2014, Oral *et al.* 2018, Karaman 2020). It has been reported that AMMI and biplot analysis methods provide convenience in interpreting genotypes (G), environments (E) and their combination (GEI), especially in studies involving multiple environments, in the visual presentation of variety x environment interaction or in estimating the stability of genotypes (Hagos and Abay 2013, Rad *et al.* 2013, Kendal and Sener 2015, Oral *et al.* 2018, Karaman *et al.* 2023).

The aim of this study was to determine the variety or varieties with high grain yield and stability despite changing climatic conditions, to recommend them for production areas, and to include these varieties as genetic material in the parent lists in breeding programs.

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Materials and Methods

This study was carried out in Diyarbakır province (37°56' N; 40°15' E; 605 m altitude) of Türkiye between 2010 and 2015 (Fig. 1). The study experiments were carried out in randomized experiment block design with 4 replications based on supplemented irrigation conditions (E2= 2010-2011, E4= 2011-2012, E6= 2012-2013, E8= 2013-2014 and E10= 2014-2015) and rainfall conditions (E1= 2010-2011, E3= 2011-2012, E5= 2012-2013, E7= 2013-2014 and E9= 2014-2015). The present study was conducted in a total of 10 environments.

Fig. 1. Map of Türkiye showing the trials location.

At the end of the study, grain yield of 5 bread wheat varieties belonging to private sector and research institutions were evaluated with analysis of variance (ANOVA), AMMI and GGE-biplot analysis methods. Nurkent, Cemre and Adana-99 varieties were used as spring type, Pehlivan as winter and Sagittario variety as alternative characters (Table 1). Each parcel belonging to the experiments was established with a length of 5 m, width of 1.2 m, 6 rows and a distance of 20 cm between rows. Four hundred fifty seeds per square meter were planted. The soil structure of the experiment area was clayey, non saline, low in phosphorus and poor in organic matter (Table 2). Nitrogen (N) 140 kg/ha and 60 kg/ha phosphorus (P_2O_5) were calculated for fertilization. While 60 kg/ha N and 60 kg/ha P_2O_5 were applied with sowing, the remaining N amount was given at the end of the tillering stage.

In the experiments carried out under support irrigated conditions, 100 mm of water was given at a time while the plants were in the heading stage. In rainfall condition (Table 3), sowing was carried out between 01-15 November and harvest was carried out between 7-20 June. In support irrigated experiments, sowing was carried out between November 01-15 and harvest between June 20 and July 01. Homogeneity of variances was examined before data of the environments were combined. Since the variances of the environments were homogeneous, combined analysis was performed. The data were analyzed using JMP 13.0.1 pro and GenStat statistical package program 12th Edition (GenStat 2009). Results were interpreted with two way ANOVA, AMMI and GGE biplot models. The resulting groups and differences between groups were evaluated according to LSD test ($p \leq 0.01$ and $p \leq 0.05$) (Gomez and Gomez 1984).

Table 1. Origin and growing type of bread wheat varieties used in the study.

Name of cultivar	Growing type	Origin of cultivar	Registration years
Adana-99	Spring	Eastern Mediterranean Agricultural Research Institute, Türkiye	1999
Cemre	Spring	GAP International Agricultural Research and Training Center, Türkiye	2008
Nurkent	Spring	GAP International Agricultural Research and Training Center, Türkiye	2001
Pehlivan	Winter	Directorate of Trakya Agricultural Research Institute, Türkiye	1998
Sagittario	Facultative	TASACO Agriculture Industry and Trade Inc., Türkiye	2001

Table 2. Soil structure of experiment areas between 2010-2015.

Year	Texture	Salt ratio	pH	Lime ratio ($CaCO_3$)	Phosphorus P_2O_5 (kg/da)	Organic matter ratio	Saturation with water ratio
2010-2015	Clay	0.246-0.290	7.60-7.81	6.26-6.90	1.28-1.86	0.676-0.935	77-81

Source: Anonymous, 2015.

Table 3. Climate data of Diyarbakir.

Months	Average of temperature (ºC)						Precipitation (mm)					
	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Long Term	2010-2011	2011-2012	2012-2013	2013-2014	2010-2011	Long term
September	27.0	25.0	26.1	24.4	24.7	24.8	0.4	9.2	1.8	0.0	27.4	4.1
October	18.1	16.4	18.4	16.9	17.5	17.2	63.0	11.8	107.4	0.0	34.2	34.7
November	11.1	6.4	12.0	11.3	8.3	9.2	0.0	73.0	83.2	54.0	97.6	51.8
December	6.5	2.3	5.1	-3.4	6.7	4.0	48.0	40.2	160.8	50.4	73.6	71.4
January	3.5	2.4	2.7	3.4	2.3	1.8	40.0	78.3	82.2	43.0	64.6	68.0
February	4.7	1.9	6.0	6.0	5.4	3.5	49.9	74.4	85.2	38.6	55.2	68.8
March	9.0	5.1	9.4	10.8	8.2	8.5	46.6	44.0	19.8	60.6	127.0	67.3
April	13.0	15.2	14.4	14.7	12.4	13.8	209.0	26.2	39.4	39.9	48.6	68.7
May	17.7	19.6	19.1	19.8	18.8	19.3	80.1	41.0	98.0	48.8	48.2	41.3
June	25.5	27.7	26.8	26.6	26.1	26.3	13.6	7.0	2.8	21.4	7.4	7.9
Total							550.6	405.1	680.6	357.3	583.8	484.0

Source: Anonymous, 2016.

Results and Discussion

In the ANOVA analysis results the effects of cultivar, environment and cultivar x environment interaction on bread wheat yield grown in 10 different environments were significant at $p \leq 0.01$ level (Table 4). Also, there were significant differences among the varieties in terms of average grain yield values in some environmental (Table 5). Among the statistically significant environments, E4 (8.02 ton/ha) had the highest yield, while E7 (3.27 ton/ha) was with the lowest yield with lowest annual rainfall. When the average yields of varieties were compared on the basis of the environment, Nurkent cultivar (6.90 ton/ha) ranked first in 3 different (E8, E9 and E10) environments and had the highest average yield. The yield of this variety was followed by Cemre (6.50 ton/ha) and the yields in 3 different environments (E5, E6 and E7) showed highest value for Cemre (Table 5).

Table 4. Analysis of variance of grain yield over the environments (ton/ha).

Source of variation	df	Sum of squares	Mean of squarmeter	F ratio
Environment (E)	9	361018231	40113136.78	47.9032**
Replication[environments]	30	25121340	837378	1.848
Cultivar (C)	4	34814058	8703514.5	19.2076**
Environments x Cultivar (ExC)	36	37363820	1037883.889	2.2905**
Error	120	54375338	453128	
Total	199	512692797		
CV(%)	10.6			

**: Significant at the level of 1%

Table 5. Mean performance for grain yield of bread wheat cultivars (ton/ha).

Cultivars	Grain yield (ton/ha)										
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Mean
Adana-99	6.32	7.48	6.64	8.65	4.86	5.93	3.00	4.90	6.79	7.56	6.21
Cemre	5.89	7.32	6.85	8.51	6.55	7.10	4.03	4.50	6.97	7.23	6.50
Nurkent	6.44	7.43	6.31	8.48	6.44	6.90	3.84	6.08	8.37	8.76	6.90
Pehlivan	6.63	7.30	7.22	7.56	5.46	7.00	2.57	4.59	7.74	8.17	6.42
Sagittario	5.54	6.03	5.13	6.89	5.30	5.99	2.90	4.85	6.68	6.98	5.63
Mean	6.20	7.11	6.40	8.02	5.72	6.58	3.27	4.98	7.31	7.74	6.33
LSD(0.05)	n.s.	n.s.	0.96**	0.63**	n.s.	n.s.	0.89*	0.93*	0.71**	0.99*	0.29**

E: environments, n.s.= not significant, *: significant at the level of 5%, **: significant at the level of 1%.

AMMI analysis showed that the variation of cultivar (C), environments (E) and CxE have high significant differences (p≤0.01). However, it was observed that the environmental effect was highest according to variety and variety x environment interaction (CEI) (Table 6). The environmental impact was 10 times more than the CEI effect supports the existence of completely different environments (Table 6). Variation between cultivars, it was reported that the effect of cultivar and CEI was low and the greatest contribution was attributed to by E (Yan 2002). The grain yield of the environments ranged from 3.27 (E7) ton/ha to 8.02 (E4) ton/ha, while the grain yield of the varieties ranged from 5.63 ton/ha to 6.90 ton/ha (Table 5). In the AMMI analysis, Interaction principle component analysis 1 (IPCA1) and IPCA2 were highly significant (p≤0.01). IPCA1 and IPCA2 accounted for 39.79% and 34.95% of the total of CEI (cultivar x environment interaction) squares, respectively. IPCA1 and IPCA2 contributed 74.74% to CEI in total (Table 6). This ratio has been reported to be sufficient to explain genotype x environment interaction (Yan and Rajcan 2002).

Indicated average grain yield of bread wheat varieties ranged from 5.63 ton/ha to 6.90 ton/ha in 10 environments (Table 5). In the AMMI model; Nurkent was the best cultivar in E1, E5, E6, E8, E9 and E10 (6 perimeter) environments. This model indicates a high level of adaptability to many environments of this variety. Some varieties specifically showed better performance in certain environments. Especially, Pehlivan for E2 and E3; Cemre for E4 and E7 environment performed better. This situation shows that some varieties are adapted only to special environments. Table 7 demonstrates that the AMMI analysis model was a very effective method for determining the ideal type cultivar for all environments or for determining the ideal type cultivar for the desireable environment. AMMI model is a very useful method for determining the most appropriate genotype for specific environments or for all environments (Bantayehu *et al.* 2013, Erdemci 2018, Kendal *et al.* 2019a).

Table 6. AMMI analysis of variance for grain yield of 5 bread wheat varieties tested in ten environments.

Source of variation	df	Sum of squares	Mean squares	F ratio	%SS explained
Total	199	512692797	2576346		
Cultivar (C)	4	34814058	8703514	19.21**	6.79
Environments (E)	9	361018231	40113137	47.9**	70.42
Block	30	25121350	837378	1.85	
Interactions (CxE)	36	37363820	1037884	2.29**	7.29
IPCA1	12	14868495	1239041	2.73**	39.79
IPCA2	10	13060154	1306015	2.88**	34.95
Residuals	14	9435171	673941	1.49	
Error	120	54375338	453128		

**: significant at the level of 1%.

Table 7. AMMI selections the first four genotypes for per environment and PCA scores.

Sites	Mean (ton/ha)	Score	1	2	3	4	PCA[1]	PCA[2]
E1	6.20	-8.62	Nurkent	Pehlivan	Adana-99	Cemre	-8.62	11.07
E2	7.11	-14	Pehlivan	Cemre	Nurkent	Adana-99	-13.99	-1.52
E3	6.40	-26.75	Pehlivan	Adana-99	Cemre	Nurkent	-26.74	-2.06
E4	8.02	-9.77	Cemre	Nurkent	Adana-99	Pehlivan	-9.77	-13.35
E5	5.72	15.84	Nurkent	Cemre	Sagittario	Adana-99	15.83	-16.12
E6	6.58	0.35	Nurkent	Cemre	Pehlivan	Adana-99	0.35	-5.16
E7	3.27	12.76	Cemre	Nurkent	Adana-99	Sagittario	12.76	-20.43
E8	4.98	18.79	Nurkent	Pehlivan	Sagittario	Cemre	18.78	11.00
E9	7.31	8.45	Nurkent	Pehlivan	Adana-99	Cemre	8.45	16.69
E10	7.74	2.95	Nurkent	Pehlivan	Adana-99	Cemre	2.94	19.87

In the AMMI model, the graphics are interpreted as bidirectional. The main effect of varieties and environments is indicated by the *x*-axis, and the effects of interaction are indicated by the *y*-axis (Fig. 2). When the AMMI graph is examined, the effects of interaction are seen along the *y* axis, while the main effects of genotype and environment are seen along the *x* axis. In the AMMI analysis model, while interpreting genotypes and environments on the graph, interpretations are made considering the *x* (stability) and *y* (mean yield line) axis (Mirosavlievic *et al.* 2014, Kendal *et al.* 2019a, Karaman 2023).

It was emphasized that the genotypes were stable as they approached the *x* axis and their stability decreased as they moved away (Kendal *et al.* 2019b, Karaman 2020). In addition, the AMMI graph showed that the seed yield of genotypes on the right side of the *y*-axis was higher than the experiment average, whereas the genotypes on the left side of the *y*-axis had a yield below the experiment average (Kendal *et al.* 2019a). Accordingly, when the AMMI graph of the current study was examined; grain yield of E2, E3, E4, E6, E9 and E10 environments were above average and E1, E5, E7 and E8 environments had lower grain yield than average (Fig. 2). It was clearly observed that the highest grain yield was E4 and the lowest was E7. In addition, according to the results of AMMI analysis, E7 and E10 environment had the highest effect on cultivar x environment interaction and E2 and E3 were the least effective (Fig. 2). According to AMMI graph, Nurkent variety had the highest grain yield because had the farthest distance to *y* axis and it was moderately stable because its middle distance to *x* axis line. Adana-99 and Sagittario were the most stable varieties due to their closeness to the *x* axis. However, the Sagittario cultivar on the left of the *y* axis was found to have the lowest yield and Adana-99 cultivar near the origin yielded near average yield (Fig. 2).

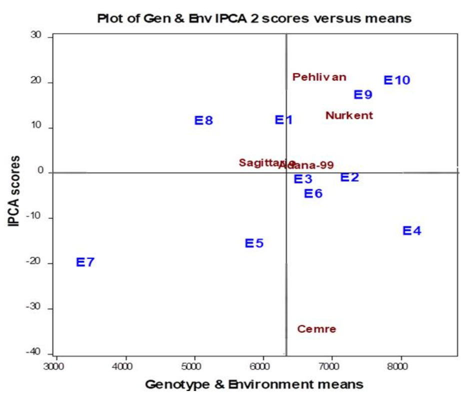

Fig. 2. The AMMI model based on grain yield (kg/ha) of cultivar (C) in 10 environments (E).

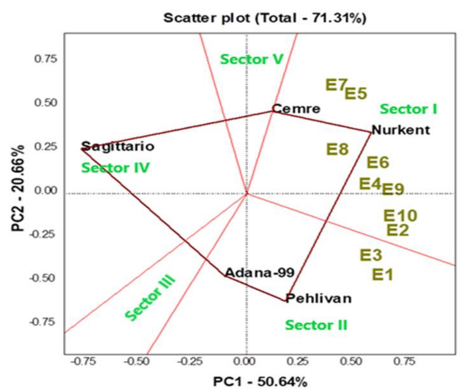

Fig. 3. Polygon view of the GGE biplot based on symmetrical scaling of 5 bread wheat varieties across ten environments.

Polygon image biplot graphs are useful in determining genotype-environment interaction and mega environments in yield experiments (Yan *et al.* 2007). In the study, it was seen that five different cultivars are tested in 10 different environments. It was observed that the environments were located in two different mega environments and the varieties were in three different sectoral regions (Fig. 3). Environments E2, E4, E5, E6, E7, E8, E9 and E10 were taking place in sector I, and formed the mega environment I. Nurkent and Cemre varieties took place in the diagonals of the sector that constituted this mega environment. These cultivars were the most useful cultivars for these environments. E1 and E3 environments took part in sector 2 and formed the mega environment II. Pehlivan cultivar was the most decisive variety for these environments. It was understood that the Sagittario cultivar in sector 4, where no environment exists, grain yield was low and below the trial average. It has been understood that the cultivars located at the corner of the polygon (Nurkent, Cemre, Pehlivan and Adana-99) have high adaptation to the environments in the sector and come forward in terms of grain yield (Fig. 3).

Islam *et al.* (2014) reported that there was a positive correlation if genotypes and environments were in the same sector and there was a negative correlation if they were in different sectors. Accordingly, in this study, it was understood that the environments and varieties in the same sector show similar characteristics.

In the GGE biplot chart (Fig. 4); representing the two environments there is a positive relationship if the angle between the two vectors is <90°, there is a negative relationship if >90°, and there is no relationship if = 90° (Yan and Tinker 2006, Erdemci 2018, Karaman 2019a, 2019b, Kendal *et al*. 2019a, 2019b). When Fig. 4 was examined, E1 and E 7 environments with the longest vector were more distinctive according to other environment in the differentiation of cultivars and E8 with the shortest vector was the least or no discriminator. The most ideal environment for selection of superior genotypes was E9 that it had the narrow angle with average environment coordinate *(*AEC) apse and also the longest vector. In addition, E4, E6, E9 and E10 environments represented the mega environment more than the other environments (Fig. 3). In the interpretation of the GGE biplot graph with vectors, the appearance of the vectors provides a summary of the relationship between the characteristics examined (Yan 2002).

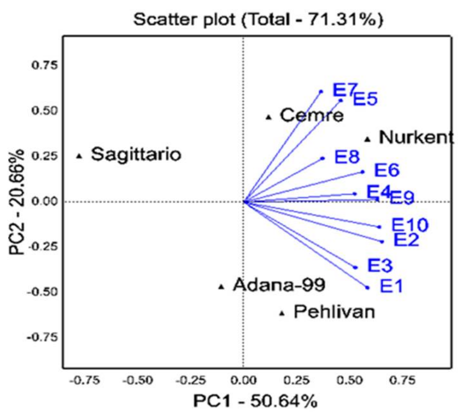

Fig. 4. GGE biplot graph showing relationships between test environments.

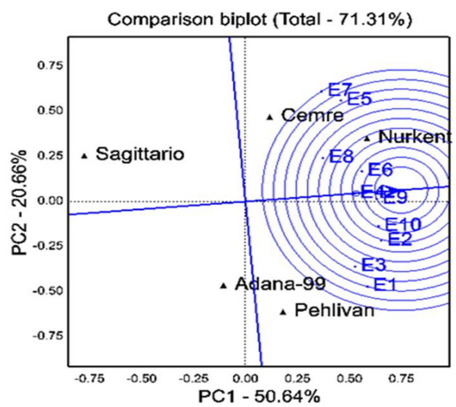

Fig. 5. GGE biplot graph based on environment-focused scaling for comparison the environments.

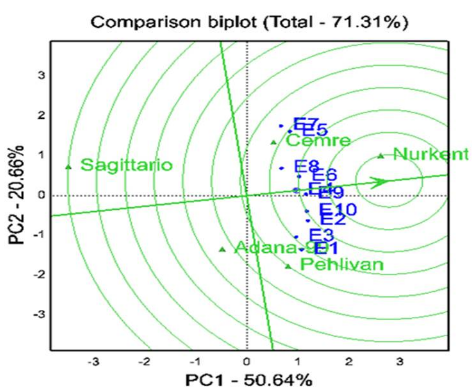

Fig. 6. GGE biplot graph based on cultivar-focused scaling for comparison of cultivar with ideal cultivar.

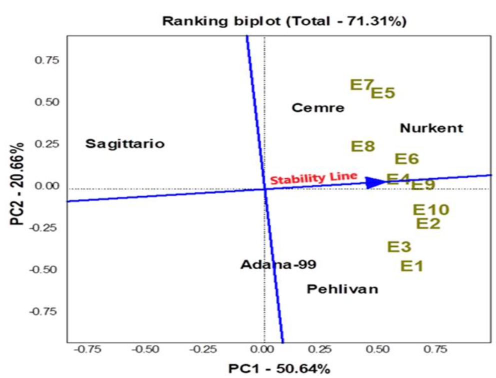

Fig. 7. Status of cultivars and environments according to stability graph.

According to Fig. 4 since there was an angle of about 90° between E1 and E5**,** E3 and E7, there was no correlation between these environments. Due to, angle between other environmental vectors was <90°, there was a positive relationship between these environments (Fig. 4). In the GGE biplot analysis, the correlation coefficient between any two environments was reported to be reliable if ≥50% or more of the total variation was explained (Yan *et al*. 2000, Erdemci 2018). Based on this data, the total variation of all visual graphs in the study was found to be > 50%. Which indicates that results of these visual graphics were reliable (Figs. 3, 4, 5, 6 and 7).

According to GGE biplot graph, based on environment-focused scaling (Fig. 5) principal components 1 (PC1) accounts for 50.64%, PC2 accounts for 20.66%, and CEI 71.31% were explained the variation between environments. E9 was located at the most centers of eccentric circles with a focus on the environment and it has been identified as the most ideal environment for differentiating cultivars. This environment was followed by E4, E6 and E10 respectively (Fig. 5). The common feature of these environments was the early fall of rainfall in the autumn season and rainfall regime was more regular (Table 3). Differences between environments were due to soil structure, climate change and other environmental factors.

The ideal cultivar is the one closest to the first of the concentric circles based on genotype-focused scaling. When Fig. 6 was evaluated, it was observed that Nurkent cultivar was the ideal cultivar. In addition, it can be said that Cemre cultivar, which was closest to Nurkent cultivar, was a suitable cultivar. In study, Sagittario, which was located at the outer most of concentric circles and whose grain yield was below the experiment average, was found to be the most non-ideal cultivar (Fig. 6). The ideal genotype is stable in different environments and same time has the highest grain yield (Yan and Kang 2003).

Rankin biplot was used to show visually ideal and at the same time stable genotypes in different environments (Fig. 7). The horizontal axis line shows the stability and the vertical axis line shows the average yield. The distance to the horizontal axis indicates stability. Also, the genotypes on the right of the vertical axis line yield above the average and those on the left yield below the average (Yan and Tinker 2006). According to this explation, Nurkent variety located to the right of the vertical axis line and closest to the horizontal axis line was moderately stable and has the highest yield. Pehlivan variety that yields above average was the most unstable variety. In addition, while the yield of Cemre cultivar was above average, the yield of Adana-99 and Sagittario cultivars had below average grain yield (Fig. 7). Some researchers reported that due to the visual presentation of the biplot ranking model, genotypes could be compared more easily, providing convenience in determining the stability and adaptability of genotypes and in practical recommendations (Mortazavian *et al*. 2014, Oral *et al*. 2018, Karaman *et al*. 2023).

When the factors affecting the yield of the varieties used in the research were evaluated; the environmental effect was highest with 70.42%, followed by CxE (interaction) with 7.29% and cultivar with 6.79%, respectively. From the tested environments it was observed that 8 environments (E2, E4, E5, E6, E7, E8, E9 and E10) constituted the 1st mega environment and 2 environments (E1 and E3) constituted the 2nd mega environment. Nurkent bread wheat variety stood out in mega environment I and Pehlivan in II. It was found that Nurkent cultivar had the potential to adapt to multiple environments and Pehlivan cultivar had the potential to adapt to specific environments. E1 and E7 environments were more discriminating than other environments in the separation of cultivars and the most ideal environment was E9 and the most ideal genotype was Nurkent cultivar. It was concluded that AMMI and GGE biplot graphs would be useful in determining the ideal environment in breeding programs, evaluating the performance of genotypes in multiple environments, determining the genotype suitable for a certain environment and making the right decision in selection.

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