

## INTERPRETATION OF SELECTED BREAD WHEAT GENOTYPES GROWN IN MULTIPLE ENVIRONMENTS WITH GGE BIPLLOT TECHNIQUE

MEHMET KARAMAN\*

*Muş Alparslan University, Faculty of Applied Sciences,  
Department of Plant Production and Technologies. Mus, Türkiye*

*Keywords: Wheat, Yield, Quality, Stability*

### Abstract

The study was carried out in three different environments with 25 (G1-G25) bread wheat genotypes. According to the stability biplot model, G7 was found to be moderately stable and high grain yielding, while G10 (Kate A-1) was determined to be the most sensitive genotype. In the genotype, genotype x environment (GGE) biplot graph, showing the ideal environment and genotype, principal component 1 (PC1) constituted 51.57% of the total variation and principal component 2 (PC2) constituted 31.05%. In terms of grain yield, the ideal environment was E2 and the ideal genotype was G7. The results indicated that environmental differences significantly affected selection criteria. E1 was identified as a suitable environment for selections focused on yield-related traits, particularly thousand-grain weight (TGW) and test weight (TW). In contrast, E3 was found to be more suitable for selections targeting quality traits, including zeleny sedimentation (ZS), protein ratio (PR), and wet gluten (WG). These findings indicate that E1 and E3 should be considered as suitable environments depending on the breeding objective. In the study, the fact that G10 was found far from the center of origin indicates that it contributes greatly to the variation and was also the genotype that adapts to specific environments.

### Introduction

Turkey consists of 7 geographically different regions which have very favorable climate for wheat breeding. Southeastern Anatolia Region, which is one of these regions, has a special importance in the world as the origin of wheat. To meet up the increasing demand of food for rapidly growing Turkey's population it is utmost important to develop improved wheat genotypes with high adaptability to different environments- (Kizilgeci *et al.* 2019).

Turkey is the ninth largest wheat producer in the world's with annual production of 19.7 million tons in its 6.6 million hectares land area at around 2.98 tons yield per hectare- (FAOSTAT 2023). In the interpretation of data obtained from genotypes in multiple environments, with ANOVA and similar traditional analysis methods cannot fully explain the effect of interaction. Therefore, Gabriel (1971) developed the GGE (genotype, genotype x environment) biplot model to reveal the status of genotypes under different environmental conditions, and to determine the genotype, environment and genotype environment interaction in multiple environments in particular. In this study, GGE biplot model is taken as reference.

GGE biplot analysis simplifies the visual representation of the data through graphs. The model divides the environments into mega environments clearly reveals which genotype is ideal in which environment (Yan *et al.* 2000, Karaman 2024). Therefore, biplot analysis is used not only in wheat (Karaman 2024), but also in the evaluation of plants such as cotton (Farias *et al.* 2016), corn (Oyekunle *et al.* 2017) and potatoes (Flis *et al.* 2014).

Some of the bread wheat genotypes easily adapt to changing environmental conditions, but while others cannot adapt. Therefore, it is beneficial to test in multiple locations wheat varieties

---

\*Author for correspondence: <m.karaman@alparslan.edu.tr>

developed in different environments in terms of grain yield, quality and other features (Kizilgeci *et al.* 2019). It has been highlighted by different researchers that, genotypes should be tested in multiple environments to determine their response to grain yield, stability and genotype environmental interaction (Yan and Hunt 2001, Kaya *et al.* 2006, Karaman 2024).

The aim of this study was to identify wheat lines suitable for the conditions of the Southeastern Anatolia Region, possessing high grain yield and quality, and potentially eligible for national registration, as well as to test the applicability of the GGE biplot technique in selection.

### Materials and Methods

The study was carried out in the 2015-2016 and 2016-2017 growing seasons under irrigation conditions in Diyarbakır and Kızıltepe/Mardin locations. The experiment included 20 advanced bread wheat lines and 5 control varieties (Table 1). In the experiments, in parcels consisting of 6 rows, the spacing was 20 cm between rows and 500 seeds were planted per square meter. Sowing was carried out between 5 and 20 November dates, depending on weather conditions. In the study, 300 kg/ha of compound fertilizer (20-20-0) was applied with sowing and 170 kg/ha of urea (46%) was applied at Zadoks 25 (tillering time). Across all environments, the experimental plots were irrigated twice to full saturation by furrow irrigation at Zadoks growth stages 57 and 72 (Zadoks *et al.* 1974).

**Table 1. Information about the experiment material**

Genotypes (G)	Pedigree	Origin
G1	ATTILA/PGO/SERI/3/PASTOR	CIMMYT
G2	NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR	CIMMYT
G3	FINSI F 2000 CMSS92Y02157T-50Y	CIMMYT
G4	MINO CMBW94Y02299T-030Y	CIMMYT
G5 (Basri Bey 95)	Check	Public
G6	MXI06-07\M16HRWYT\34 CMSS00Y	CIMMYT
G7	MXI06-07\Mult41IBWS CGSS00B00160	CIMMYT
G8	MXI06-07\Mult41IBWSN\75 CGSS00B00173T	CIMMYT
G9	MXI06-07\Mult41IBWSN\285 CMSA00M00123S	CIMMYT
G10 (Kate A-1)	Check	Public
G11	MXI06-07\Mult41IBWSN\264 CGSS01Y00050T	CIMMYT
G12	MXI06-07\Mult41IBWSN\138 CGSS01B00046T	CIMMYT
G13	MXI06-07\Mult41IBWSN\298 CGSS01B00046T	CIMMYT
G14	MXI06-07\Mult41IBWSN\159CGSS01B00055T	CIMMYT
G15 (Cemre)	Check	Public
G16	MXI06-07\Mult41IBWSN\104	CIMMYT
G17	MXI06-07\Mult41IBWSN\248 CMSS02M00220S	CIMMYT
G18	CROC_1/AE.SQUARROSA(205)//KAUZ/3/PASTOR	CIMMYT
G19	TUJ "S"/ONELTO/ TSI/VEE "S"/SERI-83	CIMMYT
G20 (Sagittario)	Check	Private Company
G21	QAMAR-4 CMSS97M03159T-040Y-0B-0AP	CIMMYT
G22	CHRZ//BOW/CROW/3/WBLL1/4/CROC_1	CIMMYT
G23	MTRWA92.161/PRINIA/5/SERI*3//RL6010/4*YR	CIMMYT
G24	MTRWA92.161/PRINIA/5/SERI*3//RL6010/4*YR	CIMMYT
G25 (Ceyhan-99)	Check	Public

Chemical interventions were made with herbicides against narrow and broad leaf weeds in the period when weeds have 2-4 leaves. Harvesting was done with the parcel combine harvester between 16 June and 6 July dates. The product obtained after the whole parcel harvested for grain yield (GY) was weighted on a scale with a precision of  $\pm 0.001$  and converted to kg/ha. For thousand-grain weight (TGW), 4 x 100 grains were randomly selected. Then, each group was weighted separately and the average result was multiplied by 10 to determine TGW. Test weight (TW), protein ratio (PR), zeleny sedimentation amount (ZS) and wet gluten (WG) ratio were determined by NIT System Infratec 1241 Grain Analyzer (Foss). The number of spikes per square meter (NSPSM) was determined by counting the spikes in a 1 m<sup>2</sup> area at two different randomly selected points of each parcel and taking the average. Number of grain per spike (NGPS) was determined by determining the grain number in 10 randomly selected spikes from each plot and then taking the average.

Annual rainfall, in all environments has been below average long term rainfall (Table 2). Soil structure of the working environments were red-brown, clayey, deep, poor in organic matter, high in calcium and potassium, and medium phosphorus content.

**Table 2. Information about the locations**

Years	Test environments Code	Location	Altitude (m)	Latitude	Longitude	Annual rainfall (mm)	Long- Term rainfall (mm) average
2015-2016	E1	Diyarbakır	605	37 <sup>0</sup> 56'N	40 <sup>0</sup> 15'E	417.2	481.0
2016-2017	E2	Diyarbakır	605	37 <sup>0</sup> 56'N	40 <sup>0</sup> 15'E	453.0	481.0
2016-2017	E3	Kızıltepe	485	37 <sup>0</sup> 11'N	40 <sup>0</sup> 35'E	362.9	389.3

JMP 7.0 and GenStat 12<sup>th</sup> programs were used for statistical analysis (Genstat 2009). GGE biplot analysis was used for visual presentation with graphs of genotype, environment, genotype environment interaction, and grain yield stability. ANOVA analysis was done and variance sources and mean data table were created. The groups formed between genotypes and differences between groups were evaluated according to LSD test ( $p \leq 0.01$  and  $p \leq 0.05$ ) (Gomez and Gomez 1984).

## Results and Discussion

According to the results of ANOVA, it was observed that there were significant differences between the genotypes in all examined features at  $p \leq 0.01\%$  level (Table 3). When Table 4 is examined, it will be seen that G7 is the best genotype in grain yield. It is also seen that G22 is at the forefront in all quality features.

In the current study, when Table 5 is examined; it is seen that the highest values for GY, PR, ZS, WG, NSPSM and NGPS are obtained from E3. The GGE biplot model visually presents genotype, environment and genotype environment interaction via principal component 1 (PC1) and principal component 2 (PC2). In the GGE biplot model, if the angle between the vectors representing the properties and the environment is if  $< 90^\circ$  positive,  $> 90^\circ$  negative, and  $= 90^\circ$  there is no correlation. In addition, if the vector is long, the variation between the genotypes is high, and if the vector is short, the variation was reported to be low (Kendal *et al.* 2019). According to this explanation, when **Fig. 1** is examined, there is a strong positive relationship between GY, NSPSM and NGPS between PR, ZS, and WG. It is also determined that there is a positive relationship between TGW and TW, while there is a negative relationship between TGW and other parameters.

**Table 3. Results of variance analysis.**

Variance resources	df	Squares means							
		GY	TW	TGW	PR	ZS	WG	NSPSM	NGPS
E	2	1104319.5**	41.2	254.2**	22.8**	784.8**	219.6**	286815.5**	706.5**
R [E]	6	11528.9	11.5	3.6	0.2	2.9	0.9	2257.7	36.6
G	24	18804.4**	22.2**	35.0**	5.8**	235.7**	69.1**	4716.6**	43.3**
ExG	48	11147.2**	15.2 <sup>ns</sup>	7.1 <sup>ns</sup>	1.1**	35.3**	10.2**	2777.2**	10.7 <sup>ns</sup>
Error	144	4514.4	11.4	13.8	0.3	6.2	2.4	1638.6	14.8
CV(%)		10.7	4.0	9.7	4.5	10.2	5.6	10.6	8.7

E: Environment, R: Replication, G: Genotype, GY: Grain yield, TW: Test weight, TGW: Thousand-grain weight, PR: Protein ratio, ZS: Zeleny sedimentation amount, WG: Wet gluten, NSPSM: Number of spike per square meter, NGPS: Number of grain per spike, DF: Degree of freedom, \*\*: Statistically significant at 0.01%, CV: Coefficient of variation, ns: not significant

**Table 4. Average values of the investigated features over the environments.**

Genotypes	GY (kg/da)	TW (kg/hl)	TGW (g)	PR (%)	ZS (ml)	WG (%)	NSPSM (units)	NGPS (units)
G1	619.51	83.06	36.86	12.51	24.92	27.99	371.22	45.41
G2	622.13	81.60	37.20	12.05	22.12	26.41	372.33	42.91
G3	542.22	84.83	41.97	12.11	20.32	26.61	315.11	41.97
G4	628.58	84.46	35.96	13.07	27.13	29.89	376.67	47.21
G5	605.58	80.87	36.97	12.15	22.28	26.72	369.44	45.69
G6	563.28	84.43	36.52	13.13	29.29	30.91	370.72	42.39
G7	730.17	82.06	39.86	11.52	15.73	24.62	420.00	44.81
G8	544.74	84.92	37.51	12.85	25.14	28.83	364.00	41.93
G9	686.87	83.61	35.56	11.96	19.96	26.06	415.94	46.82
G10	629.06	83.16	40.54	11.74	19.89	25.18	385.67	40.64
G11	631.39	84.11	34.08	11.46	17.99	24.36	384.11	46.74
G12	679.66	83.41	37.84	11.66	18.42	25.04	393.44	46.49
G13	675.04	83.60	39.91	11.49	17.12	24.47	412.89	42.01
G14	635.35	83.92	38.74	13.26	28.52	30.52	379.11	43.97
G15	651.40	82.00	38.27	13.46	29.91	30.92	396.00	44.44
G16	594.72	84.38	38.67	13.60	30.47	31.64	366.89	42.88
G17	624.74	84.46	38.23	13.33	29.17	30.74	370.56	44.76
G18	689.85	84.95	38.34	12.79	25.18	28.91	408.22	44.88
G19	648.92	78.27	38.41	13.34	29.38	30.81	388.44	44.66
G20	579.61	82.13	40.21	12.55	25.53	28.89	366.44	39.92
G21	679.81	84.06	36.56	10.70	14.33	21.81	407.22	46.31
G22	596.23	85.16	42.02	13.23	30.24	30.33	358.44	40.04
G23	628.59	82.17	37.98	13.31	28.78	30.69	369.44	44.91
G24	643.91	83.40	35.48	13.45	30.47	31.43	398.78	46.94
G25	618.72	84.29	39.62	12.47	24.94	27.89	361.44	43.42
Max.	730.17	85.16	42.02	13.60	30.47	21.81	420.00	47.21
Min.	542.22	78.27	34.08	10.70	14.33	31.43	315.11	39.92
Mean	630.00	83.30	38.10	12.50	24.29	28.07	380.9	44.09
CV (%)	10.66	4.05	9.73	4.48	10.2	5.55	10.62	8.71
LSD (0.05)	42.9**	3.1**	3.5**	0.5**	2.3**	1.5**	37.7**	3.6**

Max: Maximum, Min: Minimum.

**Table 5. Mean of features based on environments.**

Environment	GY	TW	TGW	PR	ZS	WG	NSPSM	NGPS
E1	507.03	84.02	40.18	12.00	21.77	26.46	314.34	40.68
E2	633.34	83.43	36.62	12.48	23.16	27.87	391.79	44.94
E3	749.64	82.55	37.60	13.10	27.94	29.87	436.57	46.64
LSD (0.05)	42.9**	n.s.	0.8**	0.2**	0.7**	0.4**	4.3**	2.4**

E: Environment

TW vector is short, all vectors representing other features are long. This indicates that the variation among genotypes is low in terms of TW and high variation among genotypes in terms of other features. For GY; G7, G9, G12, G18, and G21 TW; G3, G8, G18, and G22 TGW; G3 and G22 PR, ZS, and WG; G6, G15, G16, G17, G19, G22, G23, and G24 were the best genotypes (Fig. 1).

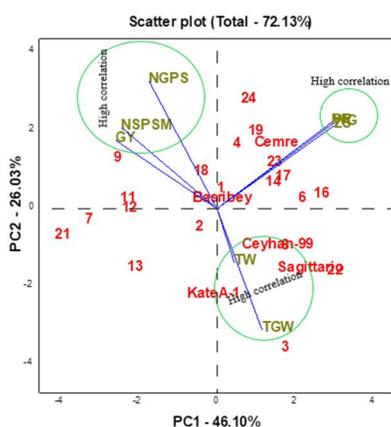


Fig. 1. GGE biplot graph showing the genotype feature relationship.

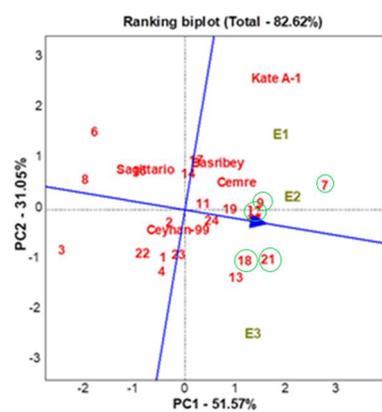


Fig. 2. GGE biplot graph showing the stability of genotypes.

When the ranking biplot graph is examined, it is seen that the genotype with the highest grain yield (PC1 value is the highest, because it is at the most right of the stability line) is G7. Since G12 is very close to the stability line, it is more stable than G7. However, grain yield is lower than G7 (Fig. 2). In the study, the grain yield of the genotypes located above the x axis (PC1) is above the experimental average. On the contrary, the grain yield of the genotypes located under the x axis remains below the experimental average (Fig. 2). Also, the grain yield of the genotypes located close to the center of the axis is close to the experiment average (Fig. 2 and Table 4).

When Fig. 3 is examined, it is seen that the ideal genotype is G7, since the closest genotype to the central circle is G7. PC1 explains 51.57% of variation, PC2 31.05%, PC1 and PC2 explain 82.62% of total variation. As can be seen in the graph, genotypes on the upper side of the x-axis represent desired, and genotypes on the lower represent undesirable genotypes (Fig. 3). In the comparison biplot model, genotypes close to the ideal genotype in the central circle are the desired genotypes (Yan and Tinker 2006, Farshadfar *et al.* 2013). GGE biplot analysis offers plant breeders the opportunity to compare genotypes and environments and identify the appropriate genotype for each environment. Biplot analysis was previously used by researchers to evaluate

bread wheat for different purposes. For example, biplot analysis was used to evaluate grain yield (Aktas 2019), quality (Aktas *et al.* 2017) and disease data (Akcura *et al.* 2017).

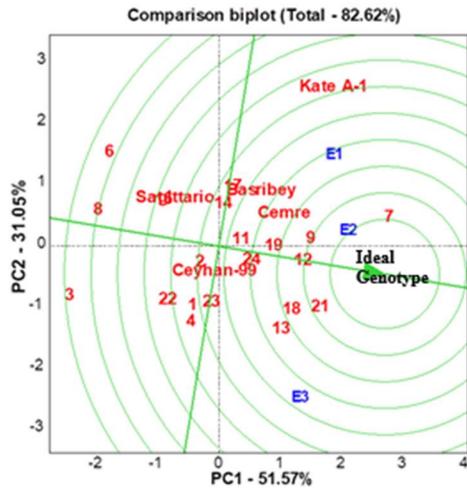


Fig. 3. Comparison biplot graph based on ideal genotype.

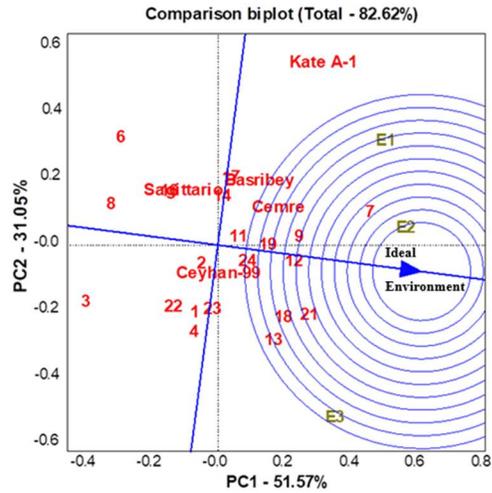


Fig. 4. Comparison biplot graph based on ideal environment.

It has been reported that the ideal environment is representative and has the highest power to distinguish genotypes (Yan and Tinker 2006). The ideal environment is at the center of the concentric circles, and the circles close to the ideal environment are desirable. According to Fig. 4, the closest environment to the ideal environment for grain yield is E2. Therefore, it is understood that E2 is the most suitable environment in selection studies to be conducted with a focus on grain yield.

In the biplot graph showing the relationship between environment and feature (Fig. 5). GGE biplot graph; PC1 explains 91.37% of the variation, PC2 8.63, and 100% of the variation in total. According to Fig. 5; it is seen that there is a high level of positive correlation between E1 with TW and TGW, between E3 with ZS, WG and PR. The GGE biplot model distinguished the environments and features perfectly in the environment-feature relationship. It clearly revealed the features that is specific to specific environment or multiple features.

In the current study, in terms of all the features examined; genotype, environment and genotype environment interaction has been significant. G7, G9, G12, G13, G18, and G21 are prominent in terms of grain yield, whereas G3, G8, G10, G16, G18, G20, G22, and G24 are prominent genotypes in quality features. In terms of grain yield, the ideal genotype is G7 and the ideal environment is E2. However, it has been determined that E1 is more suitable environment in test weight and thousand-grain weight focused selection studies, and E3 is more suitable in studies focused on protein, zeleny sedimentation and wet gluten. In addition, it was observed that Kate A-1 (G10) variety is a genotype compatible with special environments and has a great contribution to the variation between genotypes. It was determined that G12 is compatible with multiple environments and stable, but its yield is lower than G7, which is moderately stable.

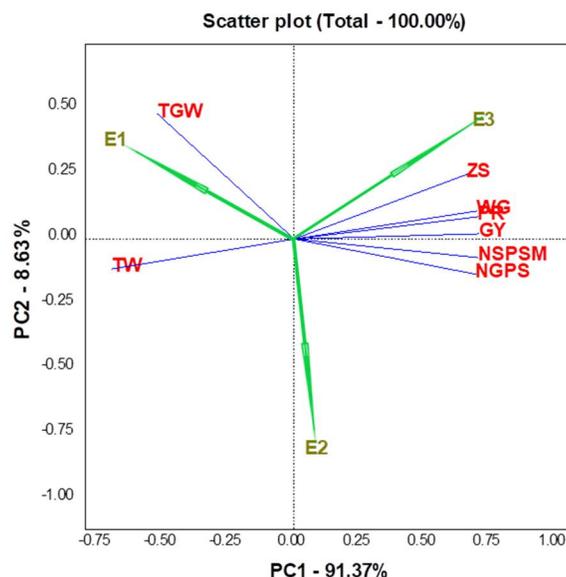


Fig. 5. GGE biplot graph showing environmental features relationship.

As a result, it was concluded that E2 in grain yield focused breeding studies, E1 (TW and TGW) and E3 (PR, ZS and WG) environments in quality focused studies will be suitable for selection studies. Also, G7 is the best genotype in grain yield, G22 is general the best genotype in terms of quality parameters. It was concluded that G7 and G22 could be candidates for national registration.

## References

- Akcura M, Akan K and Hocaoglu O 2017. Biplot analysis of leaf rust resistance in pure lines selected from eastern Anatolian bread wheat landraces of Turkey. *Turkish J. Field Crop* **22**(2): 227-234.
- Aktas B 2019. Assessment of value for cultivation and use (vcu) trial data by GGE-biplot analysis in bread wheat (*Triticum aestivum* L.) *Applied Ecol. Env. Res.* **17**(6): 12921-12936.
- Aktas H, Erdemci I, Karaman M, Kendal E and Tekdal S 2017. Evaluation of grain yield and some quality traits of winter bread wheat genotypes using GGE biplot analysis. *Turkish J. Nature Sci.* **6**(1): 43-51.
- FAOSTAT 2023. FAO Database. <http://www.fao.org/faostat/en/> (Access Date: 03 February 2026).
- Farias FJC, Carvalho LP, Silva Filho JL and Teodoro PE 2016. Biplot analysis of phenotypic stability in upland cotton genotypes in Mato Grosso. *Gen. Mol. Res.* **15**(2): gmr.15028009.
- Farshadfar E, Rashidi M, Jowkar MM and Zali H 2013. GGE biplot analysis of genotype  $\times$  environment interaction in chickpea genotypes. *European J. Exp. Biol.* **3**(1): 417-423.
- Flis B, Domanski L, Zimnoch-Guzowska E, Polgar Z, Pousa SA and Pawlak A 2014. Stability analysis of agronomic traits in potato cultivars of different origin. *Am. J. Potato Res.* **91**: 404-413.
- Gabriel KR 1971. The biplot graphic display of matrices with application to principal component analysis. *Biometrika* **58**: 453-467.
- Genstat 2009. Genstat for windows (12<sup>th</sup> edition) introduction. VSN International, Hemel Hempstead.
- Gomez KA and Gomez AA 1984. *Statistical Procedures for Agricultural Research*. 2nd Ed. John Wiley and Sons, Inc. New York. 641 pp.
- Karaman M 2024. Evaluation of grain yields of selected bread wheat (*Triticum aestivum* L.) varieties in changing climatic conditions using different analytical models. *Bangladesh J. Bot.* **53**(3): 545-554.

- Kaya Y, Akçura M and Taner S 2006. GGE-biplot analysis of multi-environment yield trials in bread wheat. *Turkish J. Agric. Forest.* **30**: 325-337.
- Kendal E, Tekdal S and Karaman M 2019. Proficiency of biplot methods (AMMI and GGE) in the appraisal of triticale genotypes in multiple environments. *Appl. Ecol. Env. Res.* **17**(3): 5995-6007.
- Kizilgeci F, Yildirim M and Hossain A 2019. Evaluation of growth, yield, quality and physiological parameters of eleven Australian bread wheat (*Triticum aestivum* L.) cultivars grown under the ecological condition of Diyarbakir, Turkey. *Int. J. Agric. Env. Food Sci.* **3**(1): 34-40.
- Oyekunle M, Haruna A, Badu-Apraku B, Usman IS, Mani H, Ado SG, Olaoye G, Obeng-Antwi K, Abdulmalik RO and Ahmed HO 2017. Assessment of early maturing maize hybrids and testing sites using GGE biplot analysis. *Crop Sci.* **57**: 29422950.
- Yan W and Hunt LA 2001. Interpretation of genotype x environment interaction for winter wheat yield in Ontario. *Crop Sci.* **41**: 19-25.
- Yan W and Tinker NA 2006. Biplot analysis of multienvironment trial data: Principles and applications. *Can. J. Plat. Sci.* **86**: 623-645.
- Yan W, Hunt LA, Sheng Q and Szlavnic Z 2000. Cultivar evaluation and megaenvironment investigation based on the GGE biplot. *Crop Sci.* **40**: 597-605.
- Zadoks JC, Chang TT and Konzak CF 1974. A decimal code for the growth stages of cereals. *Weed Res.* **14**: 415-421.

*(Manuscript received on 10 March, 2026; revised on 06 March, 2026)*