Acclimatization of CIMMYT Wheat (*Triticum aestivum* L.) Genotypes under Different Climatic Zones of Pakistan

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ABSTRACT

The study was performed to evaluate promising wheat genotypes of semi-arid wheat yield trial (SAWYT) for seed yield in different areas of Pakistan. Fifty genotypes with two replications were tested at different locations using alpha lattice design. Data was recorded for seed yield (kg ha^{-1}) for each genotype. Analysis of variance (ANOVA) revealed that there were significant differences ($P \leq 0.05$) among these genotypes. Moreover, ANOVA also revealed that the total sum of squares of variation for the environment (E), genotype (G) and genotype × environment interaction (G×E) was 65.90%, 2.35%, and 13.29% respectively. Furthermore Tukey's HSD all-pairwise comparison test was conducted to evaluate the variability among genotypes and environment on the basis of their mean yield performance. Genotypes 24 and 43 performed well for yield and stability at all ten locations while other genotypes showed location specific performance. In case of environments, E5 and E8 showed better adaptability for all the genotypes. It was noticed that environments E5 and E8 and genotypes 24 and 43 were superior performers for expressing better output. Moreover, the interaction between G×E was demonstrated by the PCA biplot analysis which highlighted the best genotypes for best environments. All the genotypes exhibited better adaptability in environments E5 and E8. So these locations were suggested as suitable environments for wheat cultivation. In conclusion, it is recommended to consider using environment E5, E8 and genotypes 24 and 43 as selection

criteria for developing high-yielding and stable wheat cultivars, as they showed promising performance across multiple locations and environmental conditions.

Keywords: *Wheat, yield, environment, stability, genotype* × *environment interaction*

INTRODUCTION

Wheat (*Triticum aestivum* L.) a rabi crop, is the major cereal crop in Pakistan which is considered important for food security. Wheat production and area under cultivation is estimated to be 27.464 million tones and 9.168 million hectares respectively (Economic survey of Pakistan, 2022). Environment sensitive genotypes and variable environmental influences cause fluctuation in wheat production. Plant breeders mainly focus on the development of high yielding wheat genotypes for the improvement of bread wheat (Erkul *et al*., 2010; Kusaksiz and Dere, 2010). A genotype with high yield and stable performance among diverse locations is considered to be the most favorable one (Gauch *et al*., 2008). Yield stability of wheat is affected by abiotic (soil, fertility, moisture, temperature, sowing time, day length) and biotic (diseases and pests) environmental factors that varies across different locations. So the main purpose of evaluation of genotype, environment and genotype × environment (G×E) interaction is grain yield (Arain *et al*., 2001; Hamam *et al*., 2009; Sial *et al*., 2007). Plant breeders are more concerned about the yield stability of genotypes across diverse environment of various locations. This is the reason that the study of genotype × environment interaction is considered as one of the basic source of selection of genotypes for general cultivation under suitable areas and defined environments (Nachit *et al*., 1992; Ahmed *et al*., 1996; Peterson *et al*., 1997; Yan and Rajcan, 2002; Khan *et al*., 2007). The evaluation process of multiple genotypes under diverse environments is continued by the plant breeders until a stable cultivar is identified for production (Naghavi *et al*., 2010). Genotype × environment (G×E) interaction is preferred in most of the genotype evaluation trials (Ceccarelli *et al*., 2006). Multiple location yield trials are plotted to evaluate the yield performance of a variety in the defined environments of multiple regions. This process ultimately results in the identification of empirical genotypes (Asenjo *et al*., 2003; Basford *et al*., 2004).

The extent of variation for the cultivar-environment interaction is considerably different from character to character in the same genotype but also varies from cultivar to cultivar at the same location (Patil *et al*., 1992; Tajamul, 1997). Adaptability of different cultivars at diverse regions falls in two categories (1) general adaptability, in which genotypes are able to perform at an acceptable level in multiple environments (2) specific adaptability which refers to the adaptability of those genotypes that show high performance in desirable environment (Farshadfar and Sutka, 2006; Solomon *et al*., 2008). Due to this multiple environmental and varietal behavior, pooled analysis of variance which elaborates the main effects, is not enough to explain the G×E interaction (GEI). So the principal components analysis (PCA) is applied as a multiplicative model to demonstrate the interaction effects from the additive ANOVA model. Biplot graph is constructed for the PCA scores that enable us to visualize and interpret GEI components. In this way, genotypes are grouped on the basis of their similarity in diverse environment with respect to the integrating biplot display and genotypic stability statistical figures (Thillainathan and Fernandez, 2001). PCA model based on genotype main effect (G) plus genotype by environment interaction (GGE) biplot with its genotype-focused scaling form, is a superior source to inspect both mean performance and stability of the tested genotypes (Yan and Kang, 2003). By using the GGE biplot method, plant breeders have developed considerable flexibility to simultaneously select the genotypes for yield and stability (Kendal and Sener, 2015).

The objectives of this study were therefore to (i) interpret GEI obtained by principal components analysis (PCA) of yield performances of 50 bread wheat genotypes over 10 environments, (ii) visually assess the variation of the yield performances across environments based on the biplot, and (iii) to determine genotypes with high yields, depending on the differential genotypic responses to environments.

MATERIALS AND METHODS

The purpose of the present study was to evaluate the performance of 50 advanced wheat genotypes for both yield and stability. The present study was carried at 10 different research stations of different ecological zones of Pakistan, such as National Agricultural Research Center (NARC), Wheat Research Institute (WRI) Faisalabad, Quaid-e-Awam Agriculture Research Institute (QARI) Larkana, Agricultural Research Institute (ARI) Tarnab, Agriculture Research Institute (ARI) Quetta, Arid Zone Research Center (AZRC) Dera Ismail (DI) Khan, Regional Agricultural Research Institute (RARI) Bahawalpur, Agricultural Research Station (ARS) Serai

Naurang, Wheat Research Institute (WRI) Sakrand, and Barani Agricultural Research Institute (BARI) Chakwal. The experiment was conducted in the year 2017-18 during the winter season (November-May).

The experiment was executed in alpha lattice design with two replications. The plot areas were maintained as $8.1m^2$ for Faisalabad, $7.5m^2$ for Islamabad, $6m^2$ for Larkana, $3.6\ m^2$ for Tarnab, $5m^2$ for Quetta, $3m^2$ for DI Khan, $9m^2$ for Bahawalpur, $3.6m^2$ for Serai Naurang, $3.6m^2$ for Fatehjhang, $6.75m^2$ for BARI Chakwal and $2.5m^2$ for Sakrand.

Data for grain yield (kg ha^{-1}) was recorded from two replications of all the wheat genotypes from all locations. The data was evaluated by the pooled analysis of alpha lattice design to test the significance level. There were highly significant differences for yield among genotypes and locations. All pairwise mean comparisons for seed yield for all the genotypes and locations were analyzed by using Tukey's HSD all-pairwise comparison test at 5% level of probability. To evaluate the performance of genotypes across diverse locations for seed yield and stability, Biplot Principal Component Analysis (PCA) was done according to Yan *et al*., (2000) through XLSTAT software. This software was developed by Addinsoft (2010) for MS Excel which was used to compute results of PCA. Biplot graph was partitioned into ten interaction principal components axes (IPCA) which determined the impact of GEI on yield.

RESULTS AND DISCUSSION

Interpretation of results and discussion was categorized into two components. First step involved the results of analysis of variance (ANOVA), which computed the percentage contribution of sum of squares of genotype (G), environment (E) and G×E interaction for selected tested locations. Second step involved the stability analysis which exhibited the yield performance and stability of genotypes across different environments. It helped in selection of best suited genotype which criteria depended on high yield performance and stability in specific environment.

The results of yield component of multiple genotypes were interpreted by the combined ANOVA which revealed that genotype (G), environment (E) and G×E interaction exhibited highly significant differences (Table 1). The genotypes performed significantly different from each other at multiple locations. The significant results can help to proceed for further calculation of phenotypic stability (Farshadfar and Sutka, 2003; Farshadfar and Sutka, 2006).

The effect of genotype (G), environment (E) and G×E interaction was accounted for 65.90%, 2.35% and 13.29% of treatment combination sum of squares, respectively. Environmental effects were more than genotype and G×E interaction effects. Significant differences also existed between environments. Kaya *et al*., (2002) and Solomon *et al*., (2008) had almost same results in their stability analysis. The environmental effect was responsible for most of the total sum of squares (SS) of grain yield (69.90 %) after subtraction of SS due to blocks and error, corroborating other studies (De Vita *et al*., 2010; Hagos and Abay 2013; Roostaei *et al*., 2014). De Vita *et al*., (2010) reported that selection for more productive genotypes over the years contributed to the improvement of phenotypic stability in modern genotypes of *Triticum durum* L.

Tukey HSD all-pairwise comparisons test ranked the genotypes and environment on the basis of their mean yield and demonstrated significance level among genotypes and environments. Bayram and Demir (2009) found the same results in their research as genotype 24 showed best performance with highest mean yield and was significantly different from all other genotypes. This genotype gave highest performance in environments (E) E5 and E8 and also showed average stability in all other environments. Genotype 43 ranked second with highest mean yield and performed best in E8 followed by E5 and E7 and also showed stable behavior in all other environments. On the contrary to this, genotype 22 and 13 proved to be low performing genotypes with lowest mean yield as compared to all other genotypes. Similarly in E5, genotypes expressed maximum mean yield and had significant variation from all other locations. Genotypes 15 and 8 gave highest yield in environment E5. While all other genotypes also showed good performance in E5 for both yield and stability. Therefore, E5 proved to be the best and suitable location for all the genotypes. While E6 had a bad influence on all genotypes producing lowest mean yield in almost all the environment.

Biplot analysis showed performance of 50 genotypes in multiple locations of Pakistan (Figure 1). This analysis elaborated best performing genotypes based on their yield performance and stability in multiple environments. Figure 2 represents the probable relationship between the locations where the regions were graded on diversity basis and evaluated the high performing genotypes at superior locations. There are four groups in the PCA biplot graph constructed by plotting the first two interaction principal component axes IPCA1 and IPCA2 (Figure 1). Although more than two principal component axes were applied by some researchers in their stability analysis (Nachit *et al*., 1992). A biplot is constructed by using genotypic and environmental scores of the first two interaction principle component axes (Vargas and Crossa, 2000). Using more than two interaction component axes could create disturbance and complications (Kaya *et al*., 2002). So mostly first two interaction principal component axes IPCA1 and IPCA2 are graphically interpreted. In the present study, the sum of the first two interaction principal component axes (IPCA1 and IPCA2) is 35.52% of total GEI, which took part in construction of the biplot to distinguish the adaptation of various cultivars in the diversity of environments. Genotypic main effects are illustrated at (IPCA1) horizontal axis in biplot analysis, while G×E interaction (IPCA2) is shown by vertical axis, which is considered as the main principle component for instability of genotypes (Yan and Tinker, 2006). The graph (Figure 1) presents 19.07% of 1PCA1 of the GEI sum of squares, while IPCA2 and IPCA3 contributes 16.46% and 15.65% sum of squares of GEI. First eight interaction principal component axes (IPCA 1-8) accounts for 95.33% of total GEI, which is greater than the contributing effects of genotypes.

The yield performance and stability of various genotypes could be interpreted by their position from center of origin and the angle between genotype vector and environment. So those genotypes had more stability and less environmental changes that were falling near to the origin. On the other hand, if the angle between genotype vector and environment is less than 90^o then this means that the genotype performed best in that specific environment and vice versa. If the angle is equal to 90^o then performance of the genotype is near to mean.

The environments were divided into four groups according to their position in four partitions in biplot graph (Figure 2). First group included E4 (Larkana) and E9 (Sakrand) while E2 (DI Khan), E3 (Faisalabad) and E8 (Tarnab) were kept in the second coordinate. At the same time third coordinate consisted of E1 (BAARI), E6 (RAARI BWP) and E7 (Serai Naurang). There existed only one environment in last group which was E5 (NARC). Genotype which lied on axis in positive side resulted in higher production. There was greater contribution of yield performance of genotypes 15 and 40 in E5 and E7 respectively in G×E interaction. E1 was best adaptable for genotypes 1, 20 and 40, while E2 was best suitable for the adaptability of genotypes 18, 20 and 34. On the other hand, genotype 26, 27 and 47 could be more adaptable in environment E3, E4 and E5 which showed high performance of genotypes 31 and 15. E6 proved to be favorable environment for genotypes 41, 34 and 20. Genotype 8 showed high production in environment E8. In addition to this, the adaptability of genotypes 50, 48 and 46 was more in environment E9. Environment E9 showed lower contribution of yield for all genotypes as compared to other environments.

Genotypes exhibited zero interaction with environment that occupied the center of origin of biplot. They were showing general adaptation with different means of grain yield. The genotypes 9, 47, 42, 19, 5, 4 and 7 had position toward the center of biplot and fell in this category by showing more stability and less response to environment. However low and average yielding genotypes had stable yield that does not benefit from the favorable environments (Hill *et al*., 1998). Among these genotypes, 9, 47 showed high stability among all other genotypes.

It was concluded that environment E5, E8 and genotypes 24 and 43 could be used as selection criteria for better yield performance of wheat genotypes.

Table 1. Yield component of multiple genotypes evaluated under different environments

Source	DF	SS	MSS	F Value	Pr> F	% G×E Explained	Cumulative
L	8	1028147315	1.29E+08	391.6	<.0001	65.9	
Rep*L	9	43244187	4804910	14.6	<.0001		
Block (L*Rep)	72	123268999	1712069	5.2	<.0001		
Entry	49	36810602	751237	2.3	<.0001	2.4	
L*Entry	392	207434535	529170	1.6	<.0001	13.3	
IPCA 1						19.1	19.1
IPCA 2						16.5	35.5
IPCA 3						15.7	51.2
IPCA 4						11.1	62.3
IPCA 5						10.3	72.6
IPCA 6						8.5	81.1
IPCA 7						8.0	89.1
IPCA 8						6.2	95.3
IPCA 9						4.7	100.0
Error	369	121097182	328177				
Total	899	1560002821					

Table 2. Average yield Kg/ha^{-1} of multiple genotypes evaluated under different environments

Genotype	BAARI E1	DI Khan E2	FSD E3	Larkana E4	NARC E5	RARI BWP E6	Serai Naurang E7	Taranb E8	WRI Sakrand E9	Mean
1	5512.0	2053.5	3405.0	3463.5	4939.0	2778.0	4414.0	5539.0	2400.0	3833.8
2	4097.0	2821.5	2969.5	3556.5	5026.0	2333.0	3361.0	4830.5	2333.0	3480.9
3	3443.0	2733.0	3273.5	3523.0	5184.0	1666.5	4253.0	5209.5	2333.5	3513.2
4	3553.5	1986.5	3244.5	3578.5	5117.5	1667.0	4528.0	5608.5	2000.0	3476.0
5	4752.0	2649.5	3292.5	3565.0	5193.5	1389.0	3966.5	5141.5	2333.5	3587.0
6	3282.0	2788.5	3420.0	3572.5	6097.5	1611.5	4050.0	6041.5	2500.0	3707.1
7	4354.5	2431.5	3348.0	3482.5	6085.0	2278.0	3689.0	5627.5	2400.0	3744.0
8	3376.5	2168.5	3691.0	3538.0	6393.0	1722.0	3333.5	6119.5	2667.0	3667.7
9	5011.5	2112.5	3320.0	3557.5	5554.5	1500.0	3208.5	5375.0	2600.0	3582.2
10	3987.0	1362.0	3428.0	3520.5	5714.5	2805.5	3722.0	5164.0	2167.0	3541.2
11	4318.0	2435.0	3063.5	3521.5	5956.0	1555.5	2344.5	4476.5	2000.0	3296.7
12	4362.5	2090.0	3280.5	3575.0	4601.5	2778.0	3252.5	4228.0	2433.0	3400.1
13	3184.0	2326.5	3688.5	3463.5	5305.5	1944.5	3369.5	3023.5	1667.0	3108.1
14	3684.0	2401.5	2987.0	3620.0	4524.0	1305.5	4188.5	4619.5	2000.0	3258.9
15	4663.0	1933.5	3422.0	1848.5	7033.0	1667.0	3415.0	4555.5	2033.5	3396.8
16	4647.5	2153.5	3041.0	3511.5	6124.0	2833.5	3786.0	4422.0	2300.0	3646.6
17	3394.0	2813.5	3308.0	3344.5	5556.0	2500.0	3716.5	4883.5	2316.5	3536.9
18	3626.5	4003.5	3549.0	3425.0	6171.0	2722.0	3569.5	4498.5	2100.0	3740.6
19	3996.5	2373.5	3193.5	3540.0	5145.0	1388.5	4203.0	4827.5	2366.5	3448.2
20	5403.5	3905.0	3442.5	3361.5	5356.0	3055.5	3683.0	4579.0	2200.0	3887.3
21	2763.5	2335.0	2986.5	3593.5	4960.0	2222.0	5033.5	4587.5	2166.5	3405.3
22	3059.0	2565.0	3440.5	3516.5	5012.0	1722.5	3503.0	2540.0	2267.0	3069.5
23	3681.0	2768.0	3436.0	3458.5	6072.0	1555.5	4297.0	3614.0	2300.0	3464.7
24	4515.5	2783.5	3724.0	4979.0	5225.0	2833.5	4375.0	5089.0	2333.0	3984.2
25	4041.5	2590.0	3586.0	3539.0	5297.5	1389.0	3319.5	4737.5	1833.5	3370.3
26	3749.0	2783.0	3980.0	3577.0	5591.0	1778.0	3744.5	6011.0	2316.5	3725.6
27	4365.0	2306.5	3945.0	3372.0	5065.0	1667.0	3941.5	4007.0	2833.5	3500.3
28	3026.0	2333.0	3709.0	4310.0	5394.5	1722.0	2908.0	4132.0	2300.0	3314.9
29	4462.5	2440.0	3535.0	4291.5	5446.5	2222.0	4533.5	4969.5	2266.5	3796.3
30	3674.0	2310.0	3843.0	4990.0	5656.0	2055.5	2894.5	5118.0	2500.0	3671.2
31	4085.5	2033.5	2891.0	5125.0	5741.5	1833.5	3783.5	4613.5	2300.0	3600.8
32	3081.5	2943.0	3218.5	3475.0	4954.5	1500.0	3919.5	4955.5	2200.0	3360.8
33	5099.5	1620.0	2723.0	3376.5	5182.5	2222.0	4561.0	3929.0	2366.5	3453.3
34	4164.0	3261.5	3217.5	3505.5	5051.0	3061.0	4283.0	5280.5	2200.0	3780.4
35	3876.0	2416.5	3272.5	3603.5	4328.0	1666.5	4488.5	4853.0	1983.5	3387.6
36	4301.5	2458.5	3714.5	3382.0	5996.0	2667.0	4722.5	4345.5	2500.0	3787.5
37	3518.0	1508.0	3221.0	3500.0	5765.5	1555.5	3473.5	3703.0	2367.0	3179.1
38	4611.0	2167.0	3320.0	1940.5	6117.5	2222.0	3305.5	4399.0	1833.5	3324.0
39	4087.5	1391.5	3698.0	1890.5	6312.0	2167.0	4375.0	4592.0	2166.5	3408.9
40	5345.5	1520.0	3324.0	3494.0	6262.5	2333.0	6769.0	3892.0	2367.0	3923.0
41	3765.5	1905.0	2788.5	5050.0	5565.5	3166.5	5044.5	4154.0	2333.0	3752.5

42	3467.5	2116.5	3193.0	3515.0	5750.5	2778.0	3683.5	4446.0	2316.5	3474.1
43	4474.5	2140.0	3786.0	3399.0	5649.5	2889.0	5347.0	5719.0	2433.5	3981.9
44	3093.5	1959.5	2622.0	3478.5	6120.0	2500.0	4825.0	4584.5	2366.5	3505.5
45	4368.0	2618.5	3100.5	3339.0	5042.5	1944.5	4408.0	3835.0	2400.0	3450.7
46	4144.0	3085.0	3158.5	3576.5	4812.0	1833.0	3580.5	4651.5	2833.5	3519.4
47	3652.0	2533.5	3916.0	3351.5	5556.0	2444.0	4647.0	4836.0	2650.0	3731.8
48	5168.0	2202.0	2817.0	3526.5	4479.0	1833.5	5244.5	3369.5	2883.0	3502.6
49	3834.0	2087.0	3289.0	3374.0	4811.0	1778.0	4761.5	4507.0	2500.0	3437.9
50	5051.5	2733.0	3202.0	3546.0	4777.5	2833.5	3295.5	4119.5	3100.0	3628.7
	4063.5	2389.1	3340.5	3552.9	5461.4	2117.9	4022.4	4647.2	2327.3	**3546.9**

Table 3. Mean performance of environment

Locations	Mean	t Grouping
NARC	5461	A
Tarnab	4647	B
BAARI	4063	C
Serai Naurang	4022	C
Larkana	3553	D
Fsd	3341	E
D.I. Khan	2389	F
WRI-Skd	2327	F
RARI-Bhp	2118	G

Figure 1. Biplot analysis showing performance of 50 genotypes in multiple locations of Pakistan

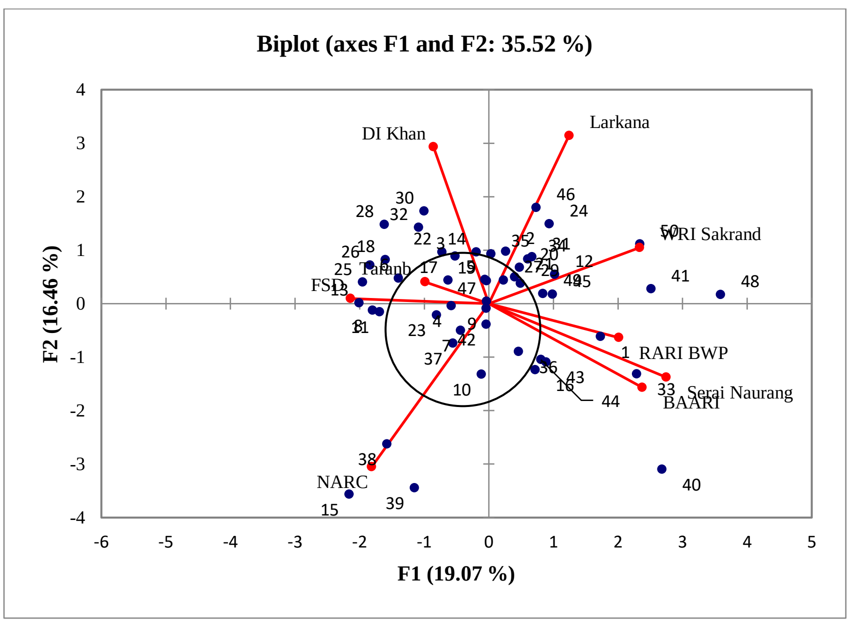
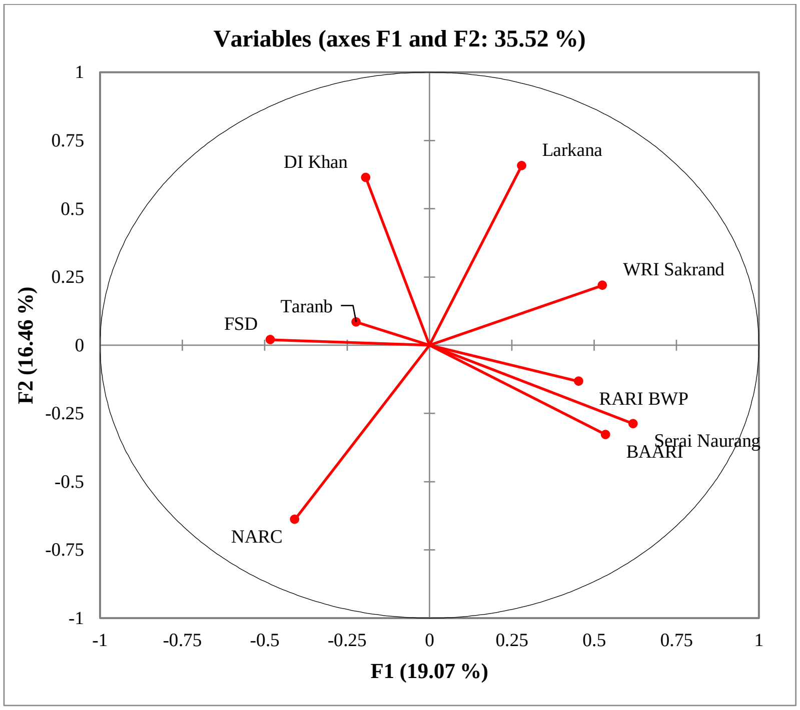


Figure 2. Probable relationship between the locations where the regions were graded on diversity basis



CONCLUSION

Based on the Analysis of Variance (ANOVA) results, it appears that there are significant differences ($P \leq 0.05$) among the tested genotypes. Additionally, PCA biplot analysis revealed that the variation in yield performance is attributed to different factors: 65.90% due to the environment (E), 2.35% due to genotype (G), and 13.29% due to the interaction between genotype and environment (G×E).

Specifically, genotypes 24 and 43 demonstrated consistent high yield and adaptability across all ten locations, indicating their strong performance. Other genotypes exhibited location-specific performance.

Furthermore, all the genotypes exhibited better adaptability in environments E5 and E8. So these locations were suggested favorable for wheat cultivation.

In conclusion, it is recommended to consider using environment E5, E8, and genotypes 24 and 43 as selection criteria for developing high-yielding and stable wheat cultivars, as they showed promising performance across multiple locations and environmental conditions.

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