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Comparative Performance and Stability of Some Durum Wheat Genotypes under Heat Stress

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Abstract

The present study was conducted to select high-yielding, heat-tolerant genotypes with potential for cultivation in climate-stressed environments. Twenty-five durum wheat lines were evaluated for heat tolerance under two sowing dates (November 25th and December 25th). Five agronomic traits were evaluated, *i.e.* spike length, no. of spikes per plant, 1000-grain weight, biological yield per plant and grain yield under timely and late sowing dates. The results showed that sowing dates, genotypes and their interaction significantly influenced all agronomic traits. Based on the results obtained from the Eberhart & Russell and principal components, Line No. 15 was identified as superior genotype under diverse environmental conditions. Moreover, Lines No. 13 and 14 were regarded as comparatively superior under stress conditions (heat stress), while Lines No. 20 and 24 demonstrated superior performance under favorable environmental conditions (timely sowing date) according to Eberhart & Russell and principal components. Consequently, these findings may be valuable for breeding programs aimed at developing high-yielding, stable genotypes for these environmental conditions.

Key words: *Triticum durum*, stability, principal component, agronomic traits, heat stress.

INTRODUCTION

Durum wheat (*Triticum durum*), a monocotyledonous annual within the *Poaceae* family, ranks as the second most cultivated wheat species after common wheat (*Triticum aestivum*). It is contributes approximately 10% to international wheat production (Adamski et al. 2020). Wheat serves as a critical global cereal crop, playing essential roles in food security, animal feed, and biofuel production. As a primary dietary staple for over 35% of the world's population, it provides more calories and protein than any other crop, particularly in low- and middle-income countries (D'souza and Jolliffe 2012).

Among abiotic factors, drought and heat are the primary constraints limiting durum wheat production (Chaouachi et al. 2024). Various environmental stressors, particularly high temperatures, frequently result in substantial yield reductions in durum wheat (Pequeno et al. 2021). This stress is projected to intensify under future climate change scenarios, primarily driven by projected increases in global temperatures. According to the Intergovernmental Panel on Climate Change (IPCC, 2023). Heat and drought stresses exert significant detrimental effects on wheat growth and yield globally, with individual yield reductions reaching up to 60 and 40%, respectively; however, their combined occurrence can result in even more pronounced and severe yield losses (Sareen et al. 2023).

Developing robust wheat varieties that can adapt to challenging climatic conditions has become a central objective in crop breeding programs (Posch et al. 2019). Yield stability is influenced by plant traits such as resistance or tolerance to environmental stresses. Enhancing productivity and maintaining stability under both optimal and adverse conditions is crucial to satisfy the increasing global food demand. (Basu et al., 2017). Stable performance of durum wheat genotypes for key economic traits across diverse environments is a primary breeding objective. Yield stability is commonly assessed through multi-environment trials using the joint linear regression method of Eberhart and Russell (1966), which identifies cultivars with high and consistent yield across environments. Principal component analysis (PCA), a multivariate statistical method, can transform several possibly correlated variables into a smaller number of variables and explains the variation among genotypes.

This study aimed to assess the performance of different genotypes at high temperatures to select high-yielding, heat-tolerant genotypes with potential for cultivation in climate-stressed environments, and identify critical agronomic traits that confer heat tolerance.

MATERIALS AND METHODS

Field experiments:

Two experiments were carried out in 2023/24 and 2024/25 growing seasons, under open field conditions in The Research Farm of Faculty of Agriculture, Sohag University, Egypt. Twenty five durum wheat genotypes were planted in 25th November as the timely sowing date in Upper Egypt, control sowing date, and in 25th of December as the late sowing date (stress condition). These genotypes are released by Plant Genetic Resources Conservation Unit, USDA, ARS, Griffin, Georgia, USA.

The experimental design was a randomized complete block with three replicates for each treatment. Each experimental plot consisted of two rows, spaced with 20 cm, and each row was two meters in length with a space of 10 cm between plants within each row and this plot was converted to ton per hectare. The experimental farm's newly reclaimed soil exhibited a sandy clay loam texture from 0 - 30 cm and sandy loam from 30 - 45 cm depth. All wheat agronomic practices were conducted according to recommended guidelines. At harvesting, guarded plants were excluded and measurements were performed on 10 plants for each replication, and spike length (cm), number of spikes/plant, 1000-grain weight (g), biological yield/plant (g) and grain yield (ton/ha) were recorded. Climate conditions and soil characteristics at the experimental site are shown in Tables 1 and 2.

Table 1. Mean of meteorological data of the growing seasons 2023/24 and 2024/25.

Factor	Month						
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Temperature (^oC)							
Max. Temp. (^oC) S_1	36.90	31.39	28.73	29.79	35.91	42.43	44.87
Min. Temp. (^oC) S_1	10.28	7.51	2.95	2.64	8.52	13.22	15.32
Max. Temp. (^oC) S_2	32.02	29.68	31.34	28.72	38.15	44.51	47.09
Min. Temp. (^oC) S_2	7.27	4.39	6.25	3.97	7.53	11.13	14.71
Relative humidity (%)							
Relative humidity (%) S_1	40.15	52.84	46.62	45.59	28.85	23.25	20.39
Relative humidity (%) S_2	45.66	46.89	45.34	40.35	29.66	22.11	20.27
Source:https://power.larc.nasa.gov/data-access-viewer							

S_1: first season and S_2: second season.

Table 2. Physical and chemical properties of the experimental soil.

Physical properties						
Depth (cm)	Bulk density (Mg m^{-3})		Field capacity (%)	Permanent wilting Point (%)	Available water (%)	Soil texture
0-15	1.35		23	13	10	Sandy clay loam
15-30	1.28		20	11	9	Sandy clay loam
Chemical properties						
ECe (dS/m)	Soil pH	Organic matter %	Ca CO3 %	Exchangeable potassium (ppm)	Available nitrogen (ppm)	Available phosphorus (ppm)
2.65	7.91	1.40	3.18	68.00	57.50	18.00

Statistical analyses

The combined analysis of variance was performed on the recorded data of all the studied traits of the 25 durum wheat genotypes over all environments according to Gomez and Gomez (1984). The joint regression coefficient (b_i) and deviation from regression (S^2d_i) were estimated by using Eberhart and Russell's model (1966). INDOSTAT software version 9.2 was used to perform the principal component analysis.

RESULT AND DISCUSSION

Analysis of variance:

The combined analysis of variance (ANOVA) for sowing dates, genotypes and their interactions on all measured traits is presented in Table 3, highlighting the influence of environmental conditions and genetic variability on the expression of yield and its components. Mean squares for sowing dates were highly significant across all traits, reflecting substantial environmental differences. Similarly, genotype effects were highly significant, demonstrating significant genetic diversity. Furthermore, the significant genotype-by-sowing date interaction indicates differential genotype responses to sowing dates for all assessed traits.

Performance of the evaluated genotypes under timely and late sowing date:

The performance of evaluated wheat genotypes displayed significant variations for all evaluated traits under timely and late sowing date conditions (Table 4 and Fig. 1). The average spike length in the two years ranged from 5.50 cm for line No. 20 in late sowing date condition to 12.00 cm for line No. 10 in timely sowing date condition. Heat stress resulted in a significant reduction in spike length by 30.10% compared to timely sowing date condition (Table 4 and Fig. 1A). For number of spikes/plant, the average across all tested genotypes was 5.93 spikes/plant with a range from 4.50 for lines No. 3 and 5 under late sowing date to 9.50 spikes/plant for line No. 20 under timely sowing date condition. There was a reduction in number of spikes/plant of approximately 21.79% caused by heat conditions when compared with timely sowing date condition (Table 4 and Fig. 1B). Under timely sowing date condition, the average 1000-grain yield was 42.13 g with a range from 31.95 to 49.08 g for lines No. 18 and 22, respectively. Meanwhile, 1000-grain yield of the different genotypes under late sowing date ranged from 22.38 for line No. 17 to 33.53 for line No. 15 with an average of 28.64 g (Table 4 and Fig 1C). Biological yield/plant was reduced by 58.18% due to heat stress conditions (Table 4 and Fig. 1D). Furthermore, the study found significant differences in grain yield among the tested wheat genotypes under two conditions (Table 4 and Fig. 1E).

On Average for overall tested genotypes, grain yield (ton/ha) was reduced from 7.69 ton/ha in timely sowing date conditions to 4.47 ton/ha in late sowing date conditions, representing a 41.96% reduction under late sowing date conditions. The highest grain yield was obtained from lines No. 22, 4 and 25 with 10, 9.10 and 8.98 ton/ha respectively under timely sowing date. Meanwhile, Lines No. 8, 16 and 14 with 7.44, 6.59 and 5.96 ton/ha produced the highest grain yield under late sowing date conditions (Table 4 and Fig. 1E).

Table 3. Mean squares for studied traits under sowing dates.

S.O.V	d.f	Mean squares				
		SL	**NS**	**GW**	**BY**	**GY**
Years (Y)	1	3.63**	122.88**	301.87**	99.95**	70.48**
Rep/Y	4	2.89	2.08	26.57	6.89	1.48
Sowing dates (S)	1	563.07**	159.87**	13654.58**	196708.35**	780.52**
Y × S	1	34.68**	1.03	162.29**	347390**	17.49**
Error a	4	0.185	1.07	9.00	5.04	1.60
Genotypes (G)	24	7.54**	9.50**	81.34**	2703.19**	12.27**
Y × C	24	4.29**	3.91**	10.16**	546.41**	4.77**
Y × S	24	2.82**	2.28**	55.31**	1615.63**	3.98**
Y × C × S	24	1.96**	1.59**	5.75**	336.77**	1.31**
Error b	192	0.337	0.332	1.67	20.62	0.221

** Significant at 0.01 level of probability, respectively. SL: spike length, NS: number of spikes/plant, GW: 1000- grain weight, BY: biological yield/plant, GY: grain yield.

Table 4. Estimation of average, minimum (Min), maximum (Max), reduction (%), CV% and heritabilities (h^2) of studied traits under timely and late sowing dates.

Treatment		SL	NS	GW	BY	GY
Timely sowing date	**Min**	7.25	5.50	31.95	52.78	5.31
	Max	12.00	9.50	49.08	124.8	10.00
	Average	**9.37**	**7.59**	**42.13**	**79.55**	**7.69**
Late sowing date	**Min**	5.50	4.50	22.38	19.26	2.71
	Max	8.00	7.83	33.53	50.28	7.44
	Average	**6.55**	**5.93**	**28.64**	**33.27**	**4.47**
	Reduction %	30.10	21.79	32.02	58.18	41.96
CV (%)		11.29	12.59	7.65	11.6	13.53
h^2 (%)		57.32	46.71	84.10	97.02	51.85

SL: spike length, NS: number of spikes/plant, GW: 1000-grain weight, BY: biological yield/plant, GY: grain yield, CV: coefficient of variation and h^2: broad sense heritability %.

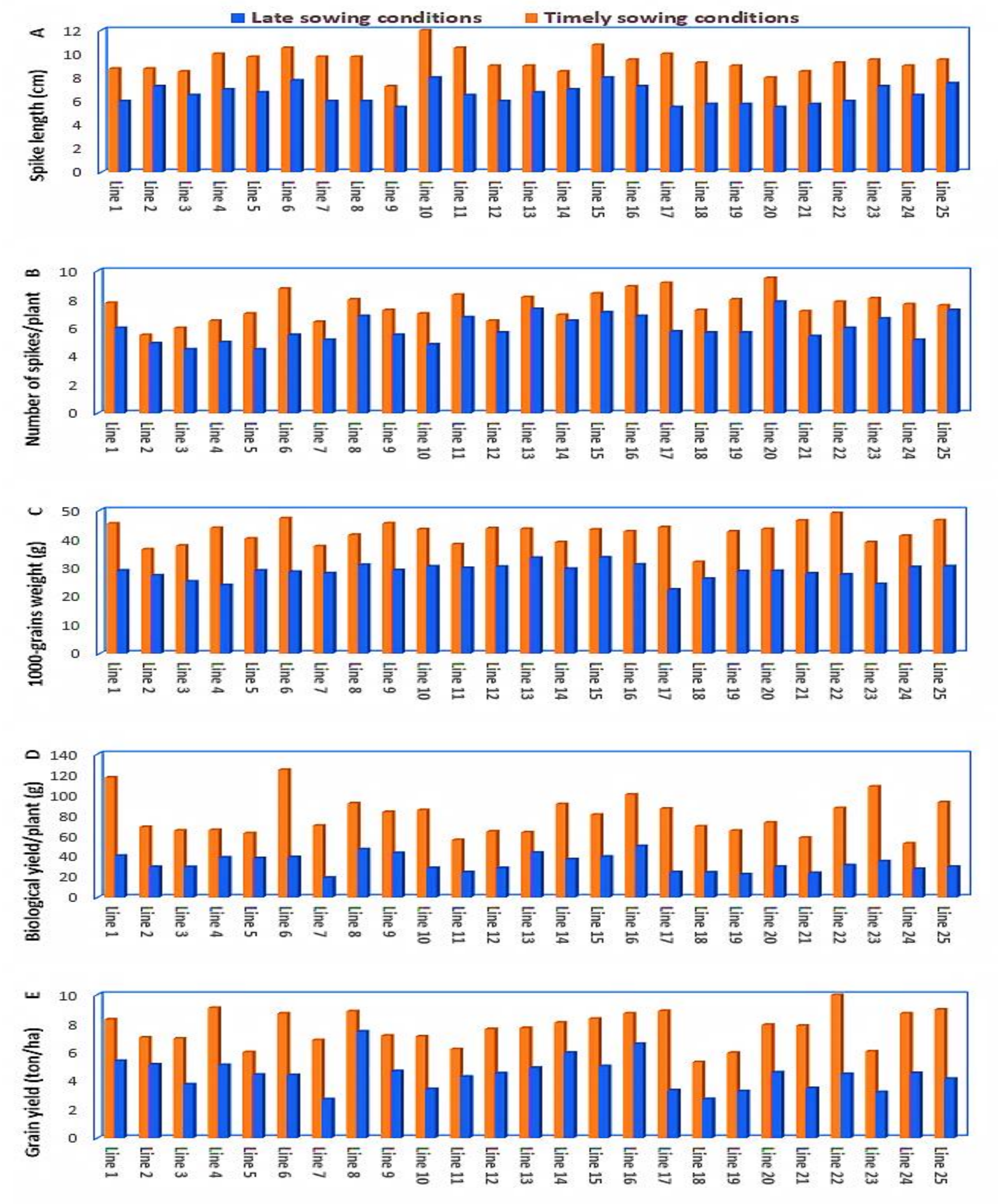
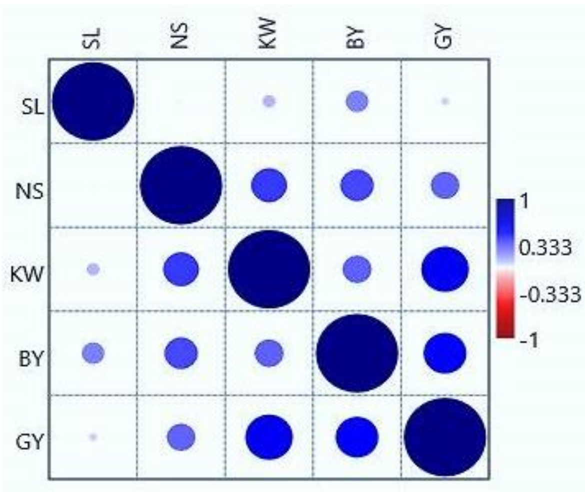


Figure 1. Performance of the 25 durum wheat genotypes for spike length (A), no. of spikes/plant (B), 1000-grain weight (C); biological yield/plant (D) and grain yield (E).

Correlation matrix:

Correlation matrix (Figure 2) showed that grain yield was highly significant and positively associated with 1000-grain weight followed by



biological yield, while yield was positive but non-significant with spike length.

Figure 2. Correlation between SL: spike length, NS: number of spikes/plant, KW: 1000-grain weight, BY: biological yield/plant and GY: grain yield.

Stability parameters:

The studied wheat genotypes appeared to have a wide range of variability in average grain yield across environments conditions (sowing dates and years). According to Eberhart and Russell (1966), four lines No. 3, 10, 15 and 19 were stable over all the studied environments because the regression coefficient (b_i) of these cultivars close to one and the deviation from regression (S^2d_i) was insignificant, one of them (Line No. 15) showed a high mean when compared with the overall mean of genotypes (Table 5 and Fig. 3). Moreover, Lines No. 5, 11, 13, 14, 18 and 23 were stable and exhibited low average response to different environments (b_i<1.0), they were considered relatively better in stressed environments, two of them (Lines No. 13 and 14) indicated a high mean when compared with grand mean. Meanwhile, Lines No. 7, 20, 21 and 24 performed consistently better in favorable environment (b_i>1), one of them (Line No. 20) showed a high mean when compared with grand mean. (Table 5). These results are in agreement with those reported by Josephides et al. (2007), Mohammadi and Amri (2007), Mohamed and Said (2014), Subira et al. (2015), Knapp et al. (2017), Said et al. (2020), Ibrahim and Said (2020), Lozada et al. (2020), Mohammadi et al. (2020) and Kyratzis et al. (2022).

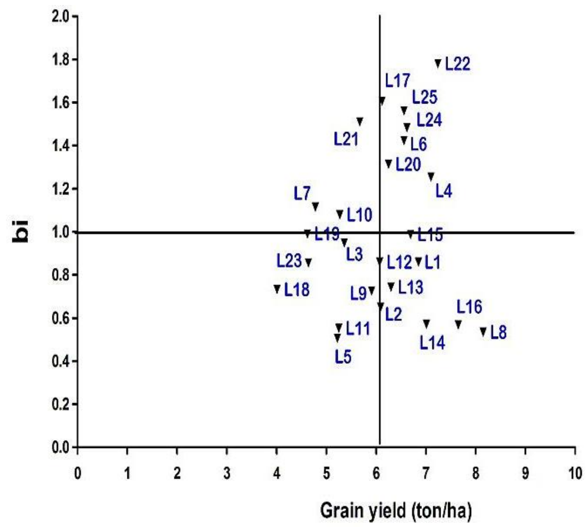


Figure 3. Present graphically the relationships between the stability parameters (b_i) and its mean performance of each genotype for yield.

Principle components analysis:

Table 6 and Fig.4 show the analyzed components of the different environments. Firstly; two components represented the total percentage of data variation (100%). The first component accounted for 75.87%, while the second component achieved 24.13% of the total changes in the dataset of the timely and late sowing date conditions. Durum wheat genotypes were classified into four groups based on biplots of PC1 vs. PC2 (Fig. 4). According to biplot analysis, the correlation coefficients between the timely and late sowing date environments with 25 durum wheat genotypes for grain yield trait were positive and highly significant (r = 0.74 and 0.67 respectively). However, line No.15 was located between these environments for grain yield trait (Stable genotype over environments). Moreover, lines No. 1, 8, 13, 14 and 16 were located near late sowing date environment for this trait (Stable genotypes over stress environment). Meanwhile, lines No. 4, 6, 20, 22 and 24 were located near timely sowing date environment for yield trait (Stable genotypes for these conditions).

Table 5. Mean performance and stability parameters of genotypes for yield (ton/ha).

Genotypes	Environments					Stability parameters	
	E_1	E_2	E_3	E_4	Mean	b_i	S^2d_i
L1	8.51	8.07	5.70	5.10	6.85	0.86	345.00**
L2	7.69	6.36	5.93	4.38	6.09	0.65	261.95*
L3	7.18	6.74	4.05	3.46	5.36	0.95	190.78
L4	9.84	8.36	5.83	4.38	7.10	1.25	375.68**
L5	6.19	5.83	5.08	3.79	5.22	0.51	178.36
L6	10.11	7.32	5.35	3.48	6.56	1.42	313.11**
L7	6.60	7.08	2.27	3.15	4.78	1.11	142.15
L8	9.73	8.59	7.5	6.79	8.15	0.72	511.92**
L9	7.41	6.90	4.63	4.71	5.91	0.73	244.00*
L10	7.09	7.12	4.08	2.78	5.27	1.08	182.91
L11	6.28	6.16	4.31	4.28	5.25	0.55	181.45
L12	8.18	7.05	3.38	5.67	6.07	0.86	261.79*
L13	7.35	8.02	4.79	5.03	6.30	0.74	224.48
L14	7.82	8.31	5.99	5.94	7.01	0.57	225.28
L15	8.68	8.00	5.27	4.80	6.69	0.99	226.70
L16	8.38	9.05	6.63	6.56	7.65	0.57	445.14**
L17	9.49	8.28	3.02	3.69	6.12	1.61	265.71*
L18	5.80	4.81	1.92	3.52	4.01	0.73	84.63
L19	7.51	4.41	4.36	2.20	4.62	0.99	129.60
L20	10.75	5.77	5.07	3.41	6.25	1.43	243.84
L21	9.60	6.12	4.92	2.06	5.67	1.51	221.84
L22	11.57	8.43	5.37	3.61	7.24	1.78	393.00**
L23	6.58	5.55	3.18	3.26	4.64	0.86	129.87
L24	8.90	8.52	5.69	3.39	6.62	1.48	218.97
L25	10.11	7.84	5.28	3.00	6.56	1.56	312.76**
Mean	**8.29**	**7.12**	**4.81**	**4.10**	**6.08**		

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 6. Variances and correlations of PC1 and PC2 with the grain yield of 25 wheat genotypes under timely and late sowing date conditions.

Component	Eigenvalue	% Variance	Timely sowing	Late sowing
PC 1	2.07	75.86	0.74	0.67
PC 2	0.66	24.13	-0.66	0.74

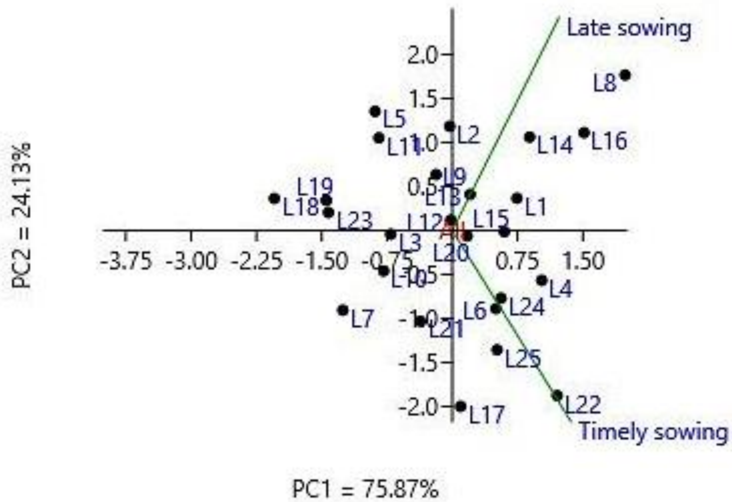


Figure 4. Biplot diagram based on first two principal components (PCA1, PCA2) axes of the 25 durum wheat genotypes according to mean measured of grain yield trait under two environments.

CONCLUSION

Characterizing the stability of 25 durum wheat genotypes yield performance under different environments (Two growing seasons and two sowing dates) according to Eberhart and Russell (1966) and principal components analysis revealed that line No. 15 was identified as superior genotype under diverse environmental conditions. Moreover, lines No. 13 and 14 were regarded as comparatively superior under stress conditions (heat stress). Meanwhile, lines No. 20 and 24 demonstrated superior performance under favorable environmental conditions (timely sowing date). The findings of this study enabled the identification of genotypes that exhibit both high performance and stability in yield under these conditions. This knowledge is essential for refining plant breeding strategies and guiding variety recommendations for farmers.

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الملخص العربي

مقارنة أداء وثبات بعض التراكيب الوراثية لقمح المكرونة تحت الإجهاد الحراري

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أُجريت هذه الدراسة لانتخاب التراكيب الوراثية في قمح المكرونة الثابتة وراثيا والعالية المحصول تحت الظروف العادية والاجهاد الحراري باستخدام تحليلى الثبات تبعاً لايبرهارت وراسيل (1966) وتحليل المكونات الاساسية. حيث قُيِّمت خمسة وعشرون سلالة من قمح المكرونة لتحملها للحرارة في موعدي زراعة (25 نوفمبر و25 ديسمبر) وذلك بمزرعة كلية الزراعة-جامعة سوهاج-محافظة سوهاج-مصر. وتم دراسة الصفات المحصولية التالية: طول السنبلة، وعدد السنابل في النبات، ووزن الألف حبة، والمحصول البيولوجي للنبات، ومحصول الحبوب. أظهر تحليل التباين للصفات تحت الدراسة تباينًا كبيرًا بين مواعيد الزراعة والتركيب الوراثية لقمح المكرونة وتفاعلاتها، مما يشير إلى أنها تباينت في استجاباتها للبيئات المتنوعة. كما أظهرت النتائج بناء على تحليل إيبرهارت وراسل والمكونات الرئيسية، تفوق السلالة رقم 15 تحت الظروف البيئية المختلفة لإظهارها أداءً عاليًا لمحصول الحبوب (طن/للهكتار) عبر هذه البيئات عند مقارنتها بالمتوسط العام للسلالات بجانب معايير الثبات المقبولة (b_i بالقرب من واحد، S^2d_i غير معنوية، ايضا أظهر تحليل المكونات الرئيسية ان السلالة رقم 15 موجودة بالقرب من البيئات المدروسة لصفة المحصول (كتركيب وراثي ثابت عبر البيئات المختلفة). ايضا بناء علي تحليل إيبرهارت وراسل والمكونات الرئيسية اعتُبرت السلالتان رقم 13 ، 14 أفضل نسبيًا تحت ظروف بيئات الإجهاد الحراري. بينما، أظهرت السلالتان رقم 20 ، 24 أداءً أفضل تحت بيئات الزراعة العادية. لذلك، يُمكن استخدام هذه السلالات في برامج التربية لتحسين صنف ثابت وراثيا وعالي المحصول في ظل هذه الظروف البيئية مستقبلًا.