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Yield Stability Analysis of Some Promising Barley Genotypes under Different Environmental Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

To mitigate the impact of climate change on barley production, adaptation strategies are crucial including developing and promoting drought-tolerant barley genotypes that can withstand higher temperatures. This study aimed to evaluate twenty different barley genotypes under different conditions, specifically normal, heat stress, and rain-fed conditions during 2019/2020 and 2020/2021 growing seasons. This study was conducted as part of breeding programs aimed at developing agricultural genotypes that can adapt to changing environments. The experiment involved evaluating the performance of the twenty barley genotypes at three different locations: Sakha for the normal condition, New Valley Station for the heat stress condition, and Marsa Matruh for the rain-fed condition. The analysis of variance showed that there were significant differences in grain yield among the different genotypes and locations, as well as the interaction between genotypes and locations. This indicates that the genotypes responded differently to the different locations, and further analysis is needed to determine their stability. The average grain yield ranged from 9.9 to

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16.0 arddab fad^{-1} (Faddan=4200m^2) for Giza 135 and Line 5, respectively, across all three locations in both seasons, this shows that there is variation among the genotypes. Considering GGE biplot and stability analyses, Giza 126, Giza 2000, Giza 134, Giza 137, Giza 138, Line1, Line 2, Line 3, Line 4 and Line 5 showed the best performances, suggesting their adaptation to a wide range of environments. This suggests that these genotypes perform well in relation to the linear component of the genotype-by-environment interaction. Overall, this information can be used by plant breeders to select genotypes that are not only high-yielding but also stable across different environments.

Keywords: Barley; heat stress; drought; stability analysis; yield components; genetic resources.

1. INTRODUCTION

Barley (*Hordeum vulgare*, L.) is one of the major winter cereal crops in Egypt and arid and semi-arid Mediterranean region. It is primarily grown in rain-fed regions where there is a limited water supply, such as in the North West Coastal region and North Sinai. Also, it could be grown in irrigated poor saline affected soil. Additionally, it has been grown on both new and old reclaimed lands.

Future projections of climate change suggest that the Mediterranean region will experience increased heat and drought, leading to severe yield reductions [1]. Both heat and drought stresses during reproductive development have negative effects on yield. Higher temperatures can damage reproductive organs and accelerate senescence rates, further reducing yield [2]. Limited soil moisture negatively affects crop growth and stomatal conductance. Low soil water content leads to close stomata, reduce photosynthesis, low intercellular CO_2 concentration, and lower biomass [3].

Drought and heat stresses are the two of main factors that have serious and adverse effects on agricultural production worldwide [4,5]. High temperatures and drought significantly harm the grown crops [6,7]. Barley cultivars developed for such stressed regions should therefore be tolerant to drought and stable under difficult conditions. It is possible to identify barley genotypes with high yield potential under severe difficulties with high yield stability [8,9,10]. The growth and production of important agricultural species, particularly cereals, are commonly hampered by a biotic stresses like high temperatures and limited water supply. Since high temperatures are frequently accompanied by a high need to water. Cereal breeding programs concentrate on creating cultivars that are resistant to stress [11]. Crop growth and productivity are affected by many biotic and abiotic stresses [12,13]. Heat stress and drought can contribute to severe grain losses [14]. Global crop productivity is seriously threatened by heat stress [15]. The accumulation of carbohydrates needed for grain growth is impeded by high temperatures. Furthermore, heat stress before blooming results in sterility and reduction in grains formation.

GGE biplot methodology is a statistical tool used to analyze genotype by environment interactions in plant breeding. It helps in identifying genotypes that have high yield and stability across different environments. The genotypes with high PC1 scores have high mean yield, indicating that they perform well in terms of yield across environments. On the other hand, genotypes with low PC2 scores have stable yield, meaning that their performance is consistent across different environments [16].

Therefore, this study aimed to evaluate the adaptability and performance of twenty barley genotypes in different locations and seasons, taking into account factors such as irrigation, heat stress, and rain-fed conditions.

2. MATERIALS AND METHODS

2.1 Plant Materials

Twenty spring six-rowed barley genotypes, including five promising lines, ten covered local varieties, and five hulls local varieties, were used in the study. Table 1 provides the names and pedigrees of the twenty genotypes. This study was conducted during 2019/20 and 2020/21 growing seasons. The first experiment took place at Sakha Agricultural Research Station, where barley was irrigated three times according to the normal irrigation schedule. The second experiment was conducted in the New Valley (Dakhla Oasis), which is known as a heat stress condition. The third experiment was carried out in Marsa Matruh (Barrani), where the barley was grown under rain-fed conditions.

Table 1. Name and pedigrees of the studied barley genotypes

No.	Genotype	Pedigree/Cross Name
1	Giza 123	Giza 117 // FAO86
2	Giza 124	Giza 117 / Bahteem 52 // Giza 118 / FAO 86
3	Giza 125	Giza 117 / Bahteem 52 // Giza 118 / FAO 86
4	Giza 126	BaladiBahteem / SD729-por12762-Bc
5	Giza 2000	Cr366-13-1/Giza121
6	Giza 129	Deir Alla 106/Cel // As46/Aths*2
7	Giza 130	"Comp.cross"229 // Bco.Mr./ DZ0231 /3 / Deir Alla106
8	Giza 131	CM67-B/CENTENO // CAM- B /3/ ROW906.73 /4 / GLORIA-BAR / COME-B/5/ FALCON –BAR /6/ LINO
9	Giza 132	Rihane-05 // As46/Aths*2" Aths / Lignee686
10	Giza 133	Carbo/Gustoe
11	Giza 134	Alanda-01/4/ WI 2291/3/Api/CM67 // L2966-69
12	Giza 135	ZARZA/BERMEJO/4/DS4931 // GLORIA-BAR/COPAL/3/SEN/5/AYAROS
13	Giza 136	PLAISANT /7/ CLN-B/LIGEE640/3/S.P-B // GLORIA-BAR/COME-B/5/FALCON-BAR/6/ LINO CLN-B/A/S.P-B /LIGNEE640/3/S.P-B // GLORIA- BAR/COME-B/5/FALCON-BAR/6/LINO
14	Giza 137	Giza 118 /4/ Rhn-03/3/Mr25-//Att//Mari/Aths*3-02
15	Giza 138	Acsad1164 /3/ Mari / Aths*2 // M-Att-73-337-1/5/Aths / lignee686 /3/ Deir Alla 106// Sv.Asa / Attiki /4/Cen / Bglo."S"
16	Line 1	Giza 123 /3/ Aths / Lignee 686 // ACSAD 618
17	Line 2	C.C. 89 //5/ACSAD 1182 /4/Arr /ESP// Alger/Ceres 361-1-1
18	Line 3	ACSAD 1182 /4/Arr/ ESP// Alger/Ceres 362-1-1/3/WI/5/ Aths/ Lignee 686 // ACSAD 618
19	Line 4	Alanda / Hamra // Alanda-01
20	Line 5	Giza 123 / Giza 132

The meteorological data for the two growing seasons are given in Tables 2 and 3. The temperature at Sakha site during the two growing seasons ranged from 9 to 28 degrees, at New Valley site ranged from 9 to 32 degrees, while at Marsa Matruh site, the temperature ranged from 11 to 24. New Vally's geographical location and climate pattern characterize with no rainfall and low relative humidity compared with the other sites, while Sakha received 77.7 (323.82m^3/feddan) and 51.4 mm (215.88m^3/feddan) of rainfall in the first and second seasons, respectively. On the other hand, Marsa Matruh, had 108.86 mm (457.12m^3/feddan) of rainfall in the first season and 116.82 mm (490.64m^3/feddan) in the second season.

For each experiment, the grains were manually drilled at the recommended seeding rate of 50 kg per feddan. The plot area for each experiment was 4.2 m^2, consisting of six rows that were 3.5 m long. Each experiment was replicated three times and set up in a randomized complete block design (RCBD). In both seasons, sowing was done as recommended on mid of December at Sakha and in the mid of November at both the New Valley and Marsa Matruh. Data collected for plant height (cm), spike length (cm), number of spikes m^{-2}, number of grains spike^{-1}, and grain yield (ardab fed^{-1}) for each plot on a random sample for each genotype.

2.2 Statistical Analysis

The analysis of variance (ANOVA) was conducted independently for each environment. A combined analysis of variance was performed using the mean data for every parameter. According to the methods described in Gomez and Gomez [17], homogeneity tests of variances were determined.

The stability parameters were calculated based on Eberhart and Russell's work from [18]. Regarding the site mean yield, the genotype is regarded as more adapted to favorable and unfavorable environments, respectively, if the regression coefficient (bi) is significantly more or less than one. The genotype is regarded as stable for all contexts if (bi) does not differ considerably from one. The t-test was used to test the hypothesis that any regression coefficient does not deviate from unity using the regression's standard error. The mean squares of the deviation from regression for each genotype served as the second stability metric. The residual from the combined analysis of variance was utilized as a pooled error to assess the S^2di values in the regression analysis of variance. An important F-value would suggest that there was a large difference between the S^2d and zero. With this model, the sums of squares attributable to environments and genotype x environments (linear) and deviations from the regression model are provided, along with the necessary analysis of variance.

The GGE biplot is a graphical tool used in multivariate analysis to visualize the relationships between genotypes and environments. It was developed by Yan et al. [18], based on a specific formula is used to calculate the coordinates of genotypes and environments in the biplot, allowing for the visualization of their interactions and performance.

Table 2. Maximum and minimum temperatures during 2019/2020 and 2020/2021 growing seasons at Sakha, New Valley and Marsa Matruh locations

Month	Sakha				New Valley				Marsa Matruh			
	2019-2020		2020-2021		2019-2020		2020-2021		2019-2020		2020-2021	
	Max	mini	max	mini	Max	mini	max	mini	max	mini	max	mini
Nov.	26	18	24	16	28	16	24	13	24	18	21	17
Dec.	20	13	22	13	21	10	23	12	19	15	19	14
Jan.	17	9	21	12	18	7	22	10	15	11	18	13
Feb.	19	10	21	11	22	9	23	10	17	12	17	12
Mar.	22	12	22	11	28	14	28	14	19	13	18	13
Apr.	26	14	28	14	32	18	23	18	21	14	22	15

Table 3. Applied irrigation (m3/ha), rainfall amounts and relative humidity (%) during the two growing seasons at Sakha, New Valley and Marsa Matruh locations

Month	Rain-fed (mm)					
	Sakha		New Valley		Marsa Matruh	
	2019-2020	2020-2021	2019-2020	2020-2021	2019-2020	2020-2021
Nov	-	15.40	-	-	15.20	29.37
Dec	15.10	2.40	-	-	20.22	13.65
Jan	12.50	5.60	-	-	20.1	18.25
Feb	11.40	26.20	0.80	-	17.22	15.05
Mar	35.20	1.60	-	-	35.72	40.20
Apr	2.90	0.20	-	-	0.40	0.30
Total amount of rainfed (M^3/feddan)	**323.82**	**215.88**	**3.36**	**-**	**457.12**	**490.64**
Total amount of irrigation (M^3/feddan)	**1017.66**	**1240.44**	**1620.15**	**1747.11**	**-**	**-**
Total amount of applied water (M^3/feddan)	**1341.48**	**1456.32**	**1623.51**	**1647.11**	**457.12**	**490.64**
Month	**Relative humidity (%)**					
	Sakha		**New Valley**		**Marsa Matruh**	
	2019-2020	**2020-2021**	**2019-2020**	**2020-2021**	**2019-2020**	**2020-2021**
Nov	60	64	33	46	67	63
Dec	64	64	45	40	61	65
Jan	72	67	46	38	62	67
Feb	72	69	39	33	63	68
Mar	65	62	27	25	60	64
Apr	63	53	21	16	55	64

1 feddan=1.038 acres (0.42 ha).

3. RESULTS AND DISCUSSION

The results in Table 4 indicate that there were significant differences in all traits between different years, locations, and genotypes. The interaction effects between genotypes and locations, as well as between years and locations, were highly significant for all studied traits. The interaction between genotypes and years was highly significant for spike length and grain yield. Furthermore, the interaction effects between genotypes, years, and locations were highly significant for plant height, spike length, and grain yield.

3.1 Seasons and Locations Effect

Data of the first season at Sakha and New Valley had higher mean values for all studied characters compared to the second season. This could be attributed to the lower mean air temperature in the first year. These findings are consistent with previous studies conducted by Talukder et al. [19] and Agwa et al. [20]. On the other hand, the second season at Marsa Matruh had higher mean values for all studied characters compared to the first year. This could be due to the lower mean rainfall in the first year. Among the three locations, Sakha had the highest values for all characters, followed by New Valley, while the third location had the lowest values.

The variations in the attributes were mostly influenced by environmental factors, as indicated by the overall mean squares. These results are in agreement with those reported by many researchers in their studies [21, 22, 23, 24, 25, 20].

3.2 Effectiveness of Genotypes

The effectiveness of genotypes is influenced by various factors, including environment, and genetic variation. In stable environments, genotypes that are well adapted to the prevailing conditions are generally more effective. However, in changing or unpredictable environments, genotypes with high genetic diversity may be more effective as they have a higher chance of possessing traits that are advantageous in different conditions.

Data presented in Table 5 show that, overall location and years the commercial cultivar Giza 126, Giza 2000, Giza 134, Giza 137, and Giza138 were superior in grain yield and yield-related traits, also the new five promising lines showed good behavior especially Line 5, which had the highest number of spikes m^{-2}, and the highest grain yield per faddan, while Giza129 and Giza135 had the lowest values of grain yield per faddan.

The average plant height ranged from 87 cm for Giza129 (the shortest genotype) to 112.2 cm for Line 1, where Line1, Line2, Line5, and Giza137 recorded highest plant height values. The average spike length ranged from 5.4 cm for Giza133 to 9.3 cm for Giza138. Line5 had the highest number of spikes^{-1} (363.4), while Giza135 had the lowest number of spikes^{-1} (226.3). The number of grains spike^{-1} ranged from 49.6 for Giza133 to 62.8 for Giza138. The average grain yield ranged from 9.9 ardab fed^{-1} for Giza135 to 16.0 ardab fed^{-1} for Line5. These results were consistent across all three locations and seasons (Table 5).

On the other hand, Giza 129 had the lowest mean values at the Sakha location in both seasons and at Marsa Matruh location in the second season. Additionally, Giza 133 was the shortest genotype in the first season. At the New Valley location, both Giza 124 and Giza 135 were the shortest genotypes in both seasons**.**

Table 4. The combined analyses of variance over two seasons and three locations

S.o.v	d.f.	plant height (cm)	spike length (cm)	number of spikes m^{-2}	no. of grains spike^{-1}	Grain yield (arddab fad^{-1})
Years (Y)	1	466.43**	5.16**	5944.36**	300.08**	39.54**
Location (L)	2	135365.41**	404.14**	825171.03**	35509.19**	6311.95**
Y x L	2	1649.48**	26.79**	6342.32**	588.98**	37.55**
Error	9	12.07	0.22	351.33	21.93	0.81
Genotypes (G)	19	725.50**	13.18**	28436.36**	190.87**	44.81**
G x Y	19	7.15	0.46**	81.10	17.37	0.89**
G x L	38	104.43**	2.54**	6243.12**	34.64**	4.08**
G x Y x L	38	11.89**	0.46**	111.06	10.17	0.68**
Errors	227	5.00	0.18	129.20	12.30	0.25

Table 5. Mean of grain yield and its related traits of the studied barley genotypes over the two seasons and three locations

Item	plant height (cm)	spike length (cm)	number of spikes m^{-2}	number of grains $spike^{-1}$	Grain yield (ardab fad^{-1})
Season					
First season	97.5	7.8	291.7	55.5	12.5
Second season	99.8	8.0	299.5	57.4	13.2
L.S.D 0.05	0.96	0.19	6.95	1.11	0.33
Locations					
Sakha	122.5	9.3	360.4	70.1	18.0
New Valley	113.3	8.6	324.5	62.2	16.0
Marsa Matruh	60.3	5.8	201.8	37.1	4.5
Mean overall	98.68	7.92	295.57	56.44	12.85
L.S.D 0.05	6.42	0.87	34.62	8.17	1.66
Genotypes					
Giza 123	101.5	8.0	321.3	56.4	13.4
Giza 124	94.6	7.3	254.3	55.6	11.8
Giza 125	92.1	7.4	273.9	54.0	11.4
Giza 126	101.4	8.2	311.9	54.3	13.8
Giza 2000	102	8.0	312.5	57.5	13.8
Giza 129	87	7.6	244.5	55.1	10.8
Giza 130	100	7.5	259.8	54.2	11.3
Giza 131	96.5	7.4	250.5	53.4	11.3
Giza 132	97.5	8.6	263.6	61.8	12.6
Giza 133	89.7	5.4	287.9	49.6	12.1
Giza 134	93.4	7.9	333.7	60.1	14.1
Giza 135	88.5	8.4	226.3	54.2	9.9
Giza 136	101.6	8.1	250.2	56.3	10.8
Giza 137	112.2	9.2	312.1	61.4	13.8
Giza 138	99.9	9.3	330.7	62.8	14.4
Line 1	107	8.2	330.6	57.3	14.0
Line 2	104.2	7.8	338.2	56.5	13.9
Line 3	100.4	7.2	307.2	53.2	13.6
Line 4	100.6	8.0	338.8	56.9	14.1
Line 5	103.6	9.0	363.4	58.1	16.0
L.S.D 0.05	3.64	0.69	18.52	5.72	0.81

Comparing barley plants grown under stress treatments to those grown under normal conditions, it was observed that the tallest plants were developed under normal conditions. This suggests that lower crop growth rates and a decrease in relative water content may be responsible for the decrease in plant height under stress conditions (Table 6). These findings are in agreement with the results of the previous research conducted by Farhat [26], Bagheri and Abad [27], Samarah et al. [28], Vaezi et al. [29], El-Shawy et al. [25], and Agwa et al. [20].

The results in Table 7 showed that Giza 137 and Line 5 had the highest spike length values among the twenty barley genotypes at all locations in both seasons. While, Giza 133 was the lowest in this trait. In terms of the number of spikes^{-2}, Line1, had the highest values at Sakha location in both seasons, followed by Line4 and Line5 in the first season and Line2, Line4 and Line5 in the second season Line5 had the highest values at the New Valley location followed by Line2 in both growing seasons, while Line1 had the highest values at Marsa Matruh location followed by Giza2000 and Giza126 in both seasons. Giza135 had the lowest values at Sakha and New Valley locations in both seasons, while Giza129 had the lowest values at Marsa Matruh location in both seasons (Table 8).

Table 6. Averages of plant height (cm) for studied barley genotypes at three locations throughout 2019/2020 and 2020/2021 seasons

Genotypes	First season			Second season		
	Sakha	New Valley	Marsa Matruh	Sakha	New Valley	Marsa Matruh
Giza 123	121.7	114.8	60.0	127.3	121.3	63.7
Giza 124	115.0	99.5	60.5	123.3	105.5	63.6
Giza 125	110.0	100.2	56.0	122.3	105.3	59.0
Giza 126	116.5	110.3	61.0	127.0	122.7	70.6
Giza 2000	120.3	111.0	65.0	128.0	116.6	71.4
Giza 129	104.0	100.0	47.0	110.0	109.9	50.9
Giza 130	123.3	111.3	56.0	126.7	120.3	62.3
Giza 131	122.5	110.7	46.6	128.0	115.6	55.9
Giza 132	115.0	102.4	65.0	120.3	112.0	70.0
Giza 133	114.5	100.1	37.6	122.0	110.9	53.2
Giza 134	110.5	107.3	51.0	118.0	113.4	60.3
Giza 135	111.5	99.5	46.0	115.3	105.5	53.0
Giza 136	125.0	119.2	53.6	131.7	122.8	57.3
Giza 137	131.0	125.0	73.7	137.0	130.3	76.4
Giza 138	118.5	115.0	60.0	122.0	121.0	62.6
Line 1	125.5	120.8	66.3	129.7	127.2	72.4
Line 2	128.7	112.1	62.7	133.7	118.8	69.0
Line 3	125.0	110.6	57.7	129.7	115.4	64.0
Line 4	125.5	111.0	54.1	130.3	119.0	63.4
Line 5	124.0	115.5	62.7	129.3	121.3	69.0
LSD 0.05	2.77	2.36	4.15	3.18	2.43	5.90

Table 7. Spike length averages (cm) for studied barley genotypes at three locations throughout 2019/2020 and 2020/2021 seasons

Genotypes	First season			Second season		
	Sakha	New Valley	Marsa Matruh	Sakha	New Valley	Marsa Matruh
Giza 123	9.17	8.67	5.10	9.83	9.33	5.90
Giza 124	8.33	8.17	4.10	9.33	8.67	4.90
Giza 125	8.17	7.83	5.10	8.67	8.50	5.90
Giza 126	9.00	8.00	6.21	9.67	9.00	7.13
Giza 2000	8.83	8.17	5.90	9.33	9.17	6.50
Giza 129	9.67	7.80	4.10	10.50	8.00	5.67
Giza 130	9.67	7.50	5.10	9.70	7.70	5.90
Giza 131	9.53	7.50	5.10	9.70	7.50	5.90
Giza 132	9.67	8.83	6.10	10.83	9.00	6.90
Giza 133	5.53	5.53	4.00	6.67	5.83	4.33
Giza 134	8.67	8.67	5.21	8.83	9.17	6.79
Giza 135	9.33	8.20	5.10	9.83	10.33	5.90
Giza 136	9.33	8.00	5.10	9.50	10.50	5.90
Giza 137	10.67	10.17	6.76	12.67	12.33	7.60
Giza 138	10.33	9.30	6.10	11.67	10.50	7.00
Line 1	9.67	8.00	6.10	10.33	8.33	6.90
Line 2	8.50	8.43	5.10	9.83	9.18	5.90
Line 3	7.50	7.18	5.10	7.67	8.00	6.90
Line 4	8.00	8.09	6.10	9.50	9.33	6.89
Line 5	10.33	10.00	6.54	11.33	10.61	6.55
L.S.D 0.05	0.8	0.7	0.26	0.95	0.72	0.5

Table 8. Number of spikes m^{-2} averages for the studied barley genotypes at three locations throughout 2019/2020 and 2020/2021 seasons

Genotypes	First season			Second season		
	Sakha	New Valley	Marsa Matruh	Sakha	New Valley	Marsa Matruh
Giza 123	388.0	374.2	183.0	406.0	379.8	196.7
Giza 124	285.0	258.3	186.0	324.0	279.2	193.3
Giza 125	333.3	287.0	187.2	350.7	290.5	194.7
Giza 126	366.0	334.9	221.9	381.0	342.1	225.4
Giza 2000	341.7	359.6	223.8	351.7	365.5	232.8
Giza 129	316.0	244.3	160.3	326.0	255.8	164.7
Giza 130	300.0	263.3	180.3	352.7	267.7	194.7
Giza 131	320.3	249.4	169.5	333.7	254.6	175.5
Giza 132	326.0	261.1	185.5	344.0	271.0	193.9
Giza 133	359.0	270.6	208.0	392.0	279.4	218.7
Giza 134	396.7	359.9	223.0	428.0	364.6	230.2
Giza 135	252.0	219.0	194.0	272.7	224.4	196.0
Giza 136	277.0	279.6	177.6	296.0	286.4	184.4
Giza 137	339.0	379.0	198.8	359.7	388.4	207.9
Giza 138	374.7	383.6	216.8	397.3	391.0	221.0
Line 1	423.5	319.5	225.2	448.3	325.5	241.5
Line 2	378.0	407.8	194.7	424.7	420.2	203.8
Line 3	395.0	330.0	190.7	400.0	334.0	193.6
Line 4	413.0	371.4	217.3	420.3	390.6	220.0
Line 5	400.0	451.9	218.3	425.0	463.4	222.1
L.S.D 0.05	24.58	18.6	12.02	28.63	8.93	10.3

The decrease in the number of spikes/m^2 in Marsa Matrouh could be attributed to heat stress and harsh rainfed conditions, which affected water absorption and photosynthetic efficiency. Additionally, the death of new tillers and a decline in the number of primal spikes could have contributed to the decrease in assimilates translocate to new developing tillers. These findings are in agreement with previous studies conducted by Farhat [26], Bagheri and Abad [27], Samarah et al. [28], Vaezi et al. [29], El-Shawy et al. [25], and Agwa et al. [20].

Concerning number of grains spike^{-1}, Giza 138 performed the best at the Sakha location in both seasons (Table 9). It was followed by Giza 137, Giza 134 and Giza 132, which also performed well at all locations in both seasons. On the other hand, Giza 133 had the lowest values at Sakha and New Valley locations in both seasons, while Giza 129 had the lowest values at the Matruh location in both seasons. The number of grains spike^{-1}, or fertility, is influenced by water availability during the early vegetative phase and shooting stage. These findings are consistent with previous studies conducted by Bagheri and Abad [27], Samarah et al. [28], Vaezi et al. [29], El-Shawy et al. [25], Agwa et al. [20] and El-Mantawy et al. [30]

For grain yield, Line 5 had the highest grain yield per faddan averages at all locations in both seasons (Table 10). Giza 138 and Giza 2000 also performed well at Sakha in both seasons. Giza 138, Giza 134 and Giza 2000 performed well at Sakha and New Valley locations. At Marsa Matruh location, Giza 137 and Line1 had relatively high grain yields in both seasons.

On the other hand, Giza 135 had the lowest grain yields at Sakha and New Valley locations in both seasons. Giza129 poorly performed at Marsa Matruh location in both seasons.

The study also highlights the negative impact of higher temperatures and dryness on grain yield. Heat stress can lead to severe grain losses and hinder the accumulation of carbohydrates needed for grain filling. Heat stress before flowering can result in sterility and reduced output. The results are supported by those obtained by Hall [15], Cattivelli et al. [14], El-Shawy et al. [25], Agwa et al., [20], Mansour and Aboulila [30] and El-Mantawy et al. [31].

Table 9. Number of grains spike^{-1} averages for studied barley genotypes at three locations throughout 2019/2020 and 2020/2021 seasons

genotypes	First season			Second season		
	Sakha	**New Valley**	**Marsa Matruh**	**Sakha**	**New Valley**	**Marsa Matruh**
Giza 123	64	56	37	75	68	39
Giza 124	68	64	32	69	66	35
Giza 125	66	57	33	68	64	37
Giza 126	66	53	38	67	63	39
Giza 2000	70	60	36	72	68	40
Giza 129	66	60	31	74	66	34
Giza 130	68	56	36	69	58	38
Giza 131	68	56	33	70	57	36
Giza 132	72	68	41	76	69	45
Giza 133	58	47	36	66	53	37
Giza 134	72	66	38	74	71	42
Giza 135	66	54	33	72	60	41
Giza 136	68	58	36	72	66	38
Giza 137	72	69	40	76	72	42
Giza 138	78	64	38	80	75	42
Line 1	69	63	38	70	65	39
Line 2	68	62	35	69	64	41
Line 3	66	58	32	68	60	36
Line 4	70	62	35	72	66	36
Line 5	70	60	35	78	67	39
L.S.D 0.05	6.1	5.5	6.5	7.6	3.9	4.3

Table 10. Mean grain yield (ardab fad^{-1}) averages for the studied barley genotypes at three locations throughout 2019/2020 and 2020/2021 seasons

genotypes	First season			Second season		
	Sakha	**New Valley**	**Marsa Matruh**	**Sakha**	**New Valley**	**Marsa Matruh**
Giza 123	17.26	16.46	4.19	21.00	16.82	4.48
Giza 124	16.42	13.58	3.68	17.14	15.71	4.16
Giza 125	15.98	12.95	4.05	16.59	13.85	5.23
Giza 126	17.47	15.75	4.82	20.74	18.21	6.04
Giza 2000	18.88	17.43	4.65	22.18	18.28	5.04
Giza 129	15.09	14.18	1.77	16.22	14.88	2.56
Giza 130	15.08	14.26	3.45	16.16	15.16	3.75
Giza 131	15.50	14.25	3.26	16.29	15.08	3.32
Giza 132	16.20	15.75	4.52	17.39	15.92	5.53
Giza 133	16.07	14.97	4.44	16.87	15.19	4.89
Giza 134	18.33	17.08	4.83	20.96	18.42	5.11
Giza 135	14.35	11.47	2.02	16.10	12.74	2.81
Giza 136	15.52	12.39	3.79	16.63	12.85	3.83
Giza 137	17.99	16.46	5.37	19.52	17.67	5.75
Giza 138	19.13	17.58	4.99	21.06	18.59	5.20
Line 1	17.59	17.03	5.27	20.17	18.02	5.82
Line 2	18.03	17.14	4.85	19.37	17.67	5.57
Line 3	17.95	16.79	4.49	18.70	17.59	5.68
Line 4	18.86	15.97	4.59	19.52	17.47	5.44
Line 5	21.54	19.42	6.04	22.28	20.52	6.48
L.S.D 0.05	1.1	0.8	0.3	1.2	0.6	0.5

3.3 Grain Yield Stability Analysis

Table 11 show the parametric stability analysis for grain yield, according to Eberhart and Russell (1966). The genotypes with a regression coefficient (bi) near 1.0 and a regression deviation (s^2d) close to zero indicate average stability. These genotypes are generally adaptable and linked to high mean yield. On the other hand, genotypes with low yield are considered to have poor environmental adaptation. A regression coefficient (bi) greater than 1.0 indicates high sensitivity to environmental changes, while a coefficient below 1.0 suggests greater adaptability to a low-productive environment.

Among the genotypes listed, Giza 2000, Giza 134, Giza 137, Giza 138, and Line5 exhibited high grain yields, regression coefficients (bi) around 1.0, and (s^2d) values close to zero, which indicates their high adaptability and stability. On the other hand, genotypes Giza 131 and Giza 133 displayed regression coefficients (bi) below 1.0, indicating stronger resilience to environmental changes and above-average stability. This suggests their specificity in adapting to low-yielding conditions.

The range of regression coefficients obtained, from 0.86 to 1.17, suggests that different genotypes respond differently to different environments. Overall, genotypes with high mean yield and regression coefficients (bi) close to 1.0 are generally considered adaptable and stable, similar to the findings of Gebremedhin [32], Elakhdar et al. [33], Mansour et al. [34] and El-Shawy et al. [25], Mansour and Aboulila [30] and El-Mantawy et al. [31].

Cluster analysis based on all studied traits under all environments during 2019/2020 and 2020/2021 seasons were performed (Fig. 1). In this analysis two main clusters were appeared. The first main cluster contained desired performance genotypes, which separated to two branches, the first branch contained Line 4, Line 5, Giza 134 and Giza138 the most desired performance. Also the second branch included Giza 123, Giza 126, Giza 133, Giza 2000, Line 1, Line 2 and Line 3 where sowed a medium performance. The lowest adaptability potential genotypes were found in the second main cluster. Cluster analysis has been used for description of the diversity based on similar characteristics [35, 25].

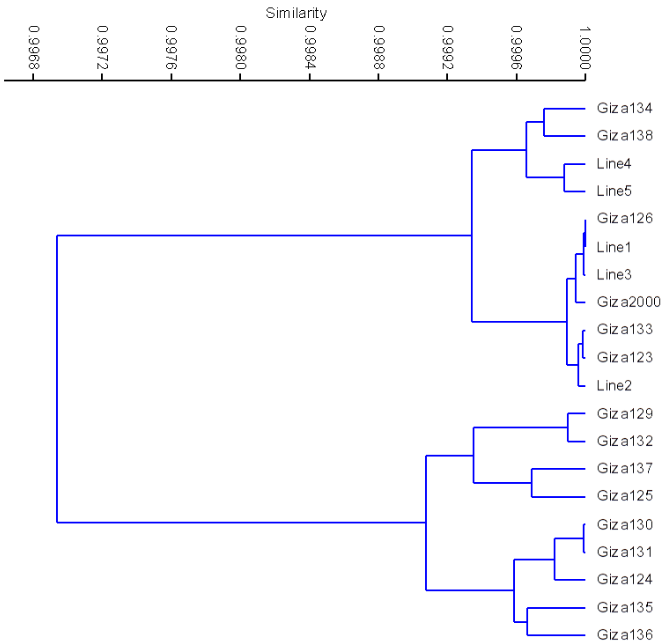

Fig. 1. Cluster analysis of twenty barley genotypes evaluated at three environments (normal, rain-fed conditions and heat stress) based on all studied traits during 2019/2020 and 2020/2021 seasons

Table 11. Mean grain yield stability parameters of the studied barley genotypes over two seasons and three locations

Genotype	Mean (ardab fed^{-1})	b_i	S^2d
Giza 123	13.37	1.097	0.622
Giza 124	11.78	0.950	0.28
Giza 125	11.44	0.830	0.546
Giza 126	13.84	1.025	0.668
Giza 2000	13.76	1.068	0.151
Giza 129	10.76	1.025	0.272
Giza 130	11.31	0.919	0.210
Giza 131	11.28	0.954	0.189
Giza 132	12.55	0.898	0.246
Giza 133	12.07	0.885	0.123
Giza 134	14.12	1.104	0.131
Giza 135	9.94	0.922	0.558
Giza 136	10.84	0.860	0.884
Giza 137	13.79	0.990	0.022
Giza 138	14.43	1.122	0.033
Line 1	13.98	1.015	0.206
Line 2	13.87	1.034	0.263
Line 3	13.64	1.016	0.554
Line 4	14.09	1.115	1.043
Line 5	16.05	1.171	0.186

bi = coffiecient of regression and S^2d = deviation from regression

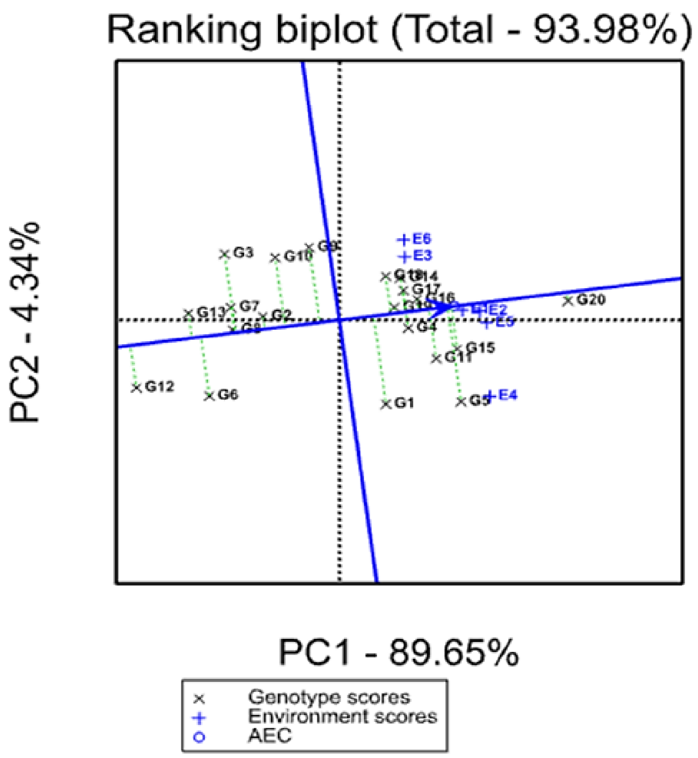

Fig. 2. GGE genotypes ranking for yield stability performance over the three environments. E1 and E4 are environmental codes for the environments under irrigated conditions (Sakha), E2 and E5 are environmental codes for the environments under heat stress conditions (New Valley), E3 and E6 are environmental codes for the environments under rain-fed conditions (Marsa Matruh) in 2019/2020 and 2020/2021 seasons, respectively

The GGE biplot analysis for the performance of the studied barley genotypes is shown in Fig. 2. G2 (Giza 124), G3 (Giza 125), G6 (Giza 129), G7 (Giza 130), G8 (Giza 131), G9 (Giza 132), G10 (Giza 133), G12 (Giza 135) and G13 (Giza 136) located on the left side of the ordinate line had yields less than mean yield (Fig. 2). The genotypes on the right side of the line have yield performance greater than mean yield and according to this genotypes, G1 (Giza 123), G4 (Giza 126), G5 (Giza 2000), G11 (Giza 134), G14 (Giza 137), G15 (Giza 138), G16 (Line1), G17 (Line 2), G18 (Lin 3), G19 (Line 4) and G20 (Line 5) gave mean yields which were higher than grand mean 12.8 (ardab fad^{-1}). Considering simultaneously yield and stability, genotype Giza 134, Giza 138, Line1, Line 2, Lin 3, Line 4 and Line 5 showed the best performances, suggesting their adaptation to a wide range of environments. For instance, genotype Giza 124, Giza 130, Giza 131 and Giza 136 were more stable as well as low yielding. By considering both the mean yield and stability across environments, the best genotype can be identified as the one with the highest yield and stability.

4. CONCLUSION

The combination of reduced water availability and extreme heat as a result due to climate change can negatively impact plant growth, leading to decreased crop production. This could have serious implications for food security and economic stability. Adaptation strategies, such as implementing efficient irrigation systems and promoting drought-tolerant genotypes, will be crucial to mitigate the potential impacts of climate change on agriculture.

In order to develop barley genotypes that are more adapted to abiotic stresses such as drought and heat stress, it is crucial to study the stability of grain yield under such conditions. In this study, the performance of twenty barley genotypes were evaluated under normal, heat stress and drought conditions. Various yield components were measured, including grain yield, spike length, number of grains spike^{-1}, and number of spikes m^{-2}. Giza 2000, Giza 134, Giza 137, Giza 138, and Line 5 had high grain yield as a compared with other genotypes, these genotypes showed consistent and high performance in different environments.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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