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Some Morpho-Physiological Characters as Indicators of Water Deficit Tolerance in some Bread Wheat Genotypes

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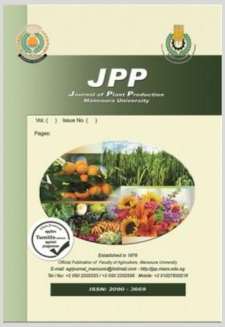

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ABSTRACT

Wheat (*Triticum aestivum* L.) represents a fundamental cereal crop in Egypt. In the context of ongoing climate change and escalating population growth, enhancing wheat resilience to abiotic stresses, particularly drought, has become imperative for maintaining stable and sustainable yields. This research was undertaken at the El-Gemmeiza Research Station to investigate the responses of diverse bread wheat genotypes to soil water deficit stress, utilizing selected morphological and physiological traits as evaluation criteria. The experimental design followed Randomized Complete Block Design (RCBD) with three replications. Ten wheat genotypes were assessed under two irrigation regimes: (1) well-watered conditions and (2) water-deficit conditions. The results indicated that water deficit stress significantly influenced all measured traits. However, genotypic variability exerted a more pronounced effect on the observed morphological and physiological responses. Genotypes such as Gemmeiza 12, Misr 3, Misr 1, Giza 171, Sids 14, and Line 3 exhibited superior adaptability under drought stress. These genotypes maintained relatively higher values in grain yield, total chlorophyll content (Chl a+b), osmotic potential, shoot dry matter accumulation, and water use efficiency, suggesting enhanced drought tolerance mechanisms. The identified morpho-physiological traits proved to be reliable indicators for screening drought-tolerant wheat genotypes. Furthermore, selection efficiency can be significantly improved when multiple complementary traits are evaluated in combination rather than in isolation. To support breeding efforts targeting drought tolerance, it is crucial to validate the stability and expression of these traits across diverse environmental conditions.

Keywords: Wheat, water deficit, morpho-physiological characters and drought tolerance index

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally, cultivated across a wide range of elevations by smallholder farmers. However, drought is one of the most critical abiotic stresses in arid and semi-arid regions, significantly contributing to poverty and food insecurity (Dereje *et al*., 2007). Globally, drought can reduce crop yield and productivity by up to 70% (Lum *et al*., 2014). As the global population continues to grow, improving crop productivity is essential to meet rising food demands.

Drought stress adversely affects plant growth and development, leading to a substantial decline in agricultural output. Water deficiency triggers significant alterations in plant physiological functions (Chaves *et al*., 2002 and Osakabe *et al*., 2014). Plant responses to drought are complex, involving morphological, physiological, and metabolic changes that depend on environmental unpredictability and interactions with other biotic and abiotic factors (Sangtarash, 2010 and Lum *et al*., 2014). The degree of drought tolerance varies widely among plant species and genotypes (Chaves *et al*., 2002 and Osakabe *et al*., 2014). Some plants exhibit adaptive strategies such as changes in root architecture, stomatal regulation, and osmotic adjustment to cope with water stress (Osakabe *et al*., 2014 and Basu *et al*., 2016).

Several factors influence plant responses to drought, including developmental stage, stress intensity and duration, and genetic background (Beltrano & Marta, 2008). Plants with limited drought tolerance may suffer from severe functional damage and tissue loss as stress severity increases (Sangtarash, 2010). To mitigate these impacts, drought-tolerant cultivars have been developed through conventional breeding approaches (Gemechu *et al*., 2017 and Lamaoui *et al*., 2018). Screening existing wheat cultivars for drought tolerance remains a practical strategy to identify genotypes capable of maintaining productivity under limited water conditions (Marmar *et al*., 2013 and Kacem *et al*., 2017).

Adaptive responses to water scarcity include morphological, physiological, and biochemical modifications, such as alterations in growth rate, stomatal conductance, osmotic potential, and antioxidant defenses (Kozlowski & Pallardy, 2002 and Duan *et al*., 2007). Drought stress typically increases the biosynthesis of compatible solutes like proline and soluble sugars compared to plants grown under optimal conditions (Nazar *et al*., 2015). According to Manuchehri and Salehi (2014), drought also enhances the accumulation of antioxidants and scavenging enzyme activity, helping to mitigate the effects of reactive oxygen species. Genotypes with greater biochemical resilience under drought tend to sustain higher yields and contribute significantly to food security in dryland areas (Basu *et al*., 2016).

The intensification of drought stress, driven by global climate change, poses a growing threat to agricultural productivity (Fang & Xiong, 2015 and Senapati *et al*., 2019). Enhancing drought tolerance by exploiting the genetic variability present within wheat germplasm represents a key

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approach to improving crop performance in semi-arid regions (Mwadzingeni *et al*., 2016 and Wasaya *et al*., 2021). Drought stress induces a wide range of morphological and physiological alterations in plants, which highlights the need for focused breeding strategies and optimized agronomic practices to mitigate its adverse impacts (Shalaby *et al*., 2020; Shehab-Eldeen & Farhat, 2020; Mu *et al*., 2021; Morsy *et al*., 2021; Nehe *et al*., 2021 and Wasaya *et al*., 2021)

At the physiological scale, drought stress commonly leads to significant declines in both relative water content and total chlorophyll concentration (Wasaya *et al*., 2021). Despite these negative impacts, drought tolerance is fundamentally characterized by a genotype's ability to sustain acceptable levels of productivity under water-limited conditions (Al-Naggar *et al*., 2020; Shehab-Eldeen & Farhat, 2020; El Gataa *et al*., 2021; Morsy *et al*., 2021 and Nehe *et al*., 2021)

Therefore, the objective of this study was to assess the effects of water deficit on selected morpho-physiological traits in a set of Egyptian bread wheat genotypes and to identify key indicators associated with drought tolerance, which can support the selection of resilient cultivars under water-limited conditions.

MATERIALS AND METHODS

Plant Materials and Structure of Experimental Design

This study was carried out on clay soil at the Gemmeiza Agricultural Research Station Farm, Egypt (latitude 31°07′N, longitude 30°48′E). Ten Egyptian bread wheat cultivars and lines were chosen because they represent a broad genetic diversity, including widely grown high-yielding cultivars and promising breeding lines. They also exhibit variation in their response to water availability, disease resistance, and agronomic traits, which makes them suitable for assessing tolerance to water deficit and identifying potential parents for future wheat improvement programs in Egypt (listed in Table 1) were evaluated under two irrigation regimes using the flooded irrigation method: a normal irrigation treatment (five irrigations including planting irrigation) and a water deficit treatment (a single irrigation applied 45 days after planting irrigation to coincide with the critical crown root initiation and tillering stage, ensuring proper establishment under water deficit conditions). The experiments were initiated on November 25th and November 15th for the 2020/2021 and 2021/2022 growing seasons, respectively.

Table 1. Names and pedigrees of the studied wheat genotypes.

Genotypes	Pedigree	Origin
Misr 1	OASIS/SKAUZ//4*BCN/3/2*PASTOR	Egypt
Misr 3	ROHF 07*2/KIRITI	Egypt
Misr 4	NS732/HER/3/PRL/SARA//TSI/VEE 5/6/FRET 2/5/WHEAR/SOKOLL	Egypt
Giza 171	SAKHA93/GEMMEIZA9	Egypt
Gemmeiza 12	OTUS/3/SARA/THB//VEE	Egypt
Sakha 95	PASTOR//SITE/MO/3/CHEN/AEGILOPS/SQUARROSA(TAUS)//BCN/4/WBLL1	Egypt
Sids 14	BOW"S"/VEE"S"//BOW"S"/TSI/3/BANI SUEF 1	Egypt
Line 1	SIDS1/ATTILA//GOUMRIA-17	Egypt
Line 2	QUAIU/5/FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ	Egypt
Line 3	FRET2*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ*2/5/BOW/URES//2*WEAVER/3/CROC_1/AE.SQUARROSA(213)//POG	Egypt

***Source: Wheat Research Department**

A randomized complete block design (RCBD) with three replications was used to evaluate the genotypes under each water treatment independently. Each plot consisted of six rows, each four meters long, with row spacing 20 cm. To minimize lateral movement of irrigation water, each trial was isolated within a 5-meter-wide buffer zone. The experimental site was located near the main irrigation ditch, and groundwater levels were regularly monitored during irrigation operations.

All agronomic practices, except for irrigation, followed the recommendations of the Wheat Research Department for the Delta region of Egypt. In both growing seasons, maize was the preceding crop. Meteorological data and irrigation water amounts for the two seasons were obtained from the Gemmeiza meteorological station and are presented in Tables 2 and 3.

Table 2. Monthly averages of air temperature (°C), relative humidity (%), total rainfall (mm), and sunshine duration (hours) recorded during the 2020/2021 and 2021/2022 winter growing seasons at El-Gemmeiza Research Station.

Month	AT C^{O} 2020/2021		AT C^{O} 2021/2022		RH %		Rainfall (mm)		Sun hours (hr.)	
	Max.	Min.	Max.	Min.	20/21	21/22	20/21	21/22	20/21	21/22
November	24	16	28	16	64	62	11.2	03.6	181	264
December	22	13	21	12	62	63	02.4	18.2	291	190
January	21	11	18	8	64	64	02.1	09.6	293	220
February	22	10	21	8	66	63	14.5	11.7	212	196
March	24	11	22	8	59	59	00.3	04.4	315	234
April	30	14	33	14	49	46	00.5	00.0	323	309
May	36	19	34	17	44	48	00.0	00.0	372	348

*** Source: https://www.worldweatheronline.com/tanta-weather-averages/al-gharbiyah/eg.aspx**

Table 3. Volume of irrigation water applied (m³ fed⁻¹) during the wheat growing seasons of 2020/2021 and 2021/2022.

Supplied water	2020/2021		2021/2022	
	WW	WD	WW	WD
Planting irrigation	445.2		385.6	
Second irrigation	320.5		289.7	
Remaining irrigations	1138.8	-	1108.7	-
Total irrigation	1904.3	765.5	1784.0	675.3
Rainfall	130.2		199.5	
Total of water	2034.5	895.7	1983.5	874.8

***WW= Well-watered and WD=Water deficit.**

Applied Irrigation Water (AIW, m^3 fed^{-1})

Table 3 shows the amount of irrigation water applied during each irrigation and seasonally. The lowest seasonal water applied values were reported under Water deficit (WD), with 895.7 and 874.8 m^3 fed^{-1} in 2020/2021 and 2021/2022, respectively. The values decreased by 44.02 and 44.1 % in 2020/2021 and 2021/2022, respectively. The volume of water applied was calculated using the equation described by Michael (1978) as follows:

$$Q = CA\sqrt{2gh}$$

Where:

Q =water discharged through the orifice, $cm^3 sec^{-1}$.
C =coefficient of discharge ranged from 0.6 up to 0.8.
A =cross-sectional area of the orifice, cm^2.
g =acceleration of gravity, 981 cm sec^{-2}.
h =pressure head causing discharge through the orifice, cm.

Effective rainfall (Rfe)

Effective rainfall (Rfe) was computed as rainfall multiply by 0.7 (Novica, 1979).

Evaluation of morphological characters

Agronomic data were recorded on PH = plant height (cm), SM = No. of spikes m^{-2}, GS = No. of grains $spike^{-1}$, GW = 1000-grains weight (g) and GY = grain yield (Ardeb $feddan^{-1}$).

Evaluation of physiological characters

At the heading stage, five flag leaves were randomly sampled from each plot to evaluate physiological characteristics.

Determination of Total Chlorophyll Content (TCC)

Total chlorophyll content was extracted and determined following the method of Lichtenthaler and Wellburn (1983) as follows:

Two leaf discs (0.8 mm in diameter) were taken from the most fully developed leaf, and pigments were extracted using 6 mL of N, N-dimethylformamide. The absorbance of the extract was then measured spectrophotometrically at wavelengths of 664 and 647 nm to quantify chlorophyll a and b, respectively.

Chlorophyll a and b were calculated using the following formula:

Chlorophyll a = 12.64 X A664 – 2.99 X A647 = µg/l
Chlorophyll b =23.26 X A647 – 5.6 X A664 = µg/l
Chlorophyll a+b =7.04 X A664 +20.27 X A664= µg/l

Where: A664 is the reading at 664 nm, A647 is the reading at 647 nm

The concentration of chlorophyll contents was then expressed as (µg ml^{-1}).

Determination of osmotic potential (OP)

Leaf osmotic potential was determined according to the method described by Hussin (2007). Measurements were based on the freeze point depression technique using an osmometer (Osmomat 030, Genotec GMBH, Berlin). A 300 mOsmol NaCl solution served as the calibration standard, with calibration verified after every ten measurements. The obtained osmotic values were subsequently converted into pressure units (MPa) using a conversion table as outlined by Koyro (2003).

Determination of Relative Water Content (RWC)

Relative water content (RWC) was determined for a fully expanded leaf from each pot following the procedure outlined by Schonfeld *et al.* (1988). Five leaves per pot were excised at the base of the petiole and immediately placed in polyethylene plastic bags before being transported to the laboratory. Upon arrival, fresh weight (FW) was recorded using a sensitive balance (precision ±0.01 g). The leaves were then immersed in distilled water for 24 hours at room temperature to obtain the turgid weight (TW). After saturation, the leaves were gently blotted with tissue paper to remove surface moisture. Subsequently, dry weight (DW) was measured after oven-drying the leaves at 70 °C for 24 hours. RWC was calculated using the following formula:

RWC (%) = [(FW – DW) / (TW – DW)] × 100

Where: FW, DW, and TW are the fresh weight, dry weight, and turgor weight, respectively.

Determination of leaf area index (LAI)

Leaf Area Index (LAI) is defined as the ratio of the total leaf surface area of a plant to the ground area it occupies. Leaf area was estimated using the dry weight method described by Rhoads and Bloodworth (1964), according to the following equation:

$$LA = (Tdw_t \times A) / dwt_a$$

Where:

Tdw_t = total dry weight of all plant leaves (g)
dwt_a = dry weight of a known measured leaf area (g)
A = measured area of leaves used for determining dwt_a (cm^2)

This method allows for the indirect estimation of leaf area by establishing a proportional relationship between dry weight and area in a representative leaf sample.

Determination of Shoot dry matter (SDM)

At the sampling date (*i.e.*, at the end of the stress period), a uniform 25 cm length from one row of each plot was collected above ground. The plant samples were immediately weighed to determine fresh weight, then oven-dried at 70 °C until a constant weight was reached. The dried plant material was then ground and stored for subsequent chemical analysis.

Stress susceptibility index (SSI)

The Stress Susceptibility Index (SSI) was calculated according to the method proposed by Fischer and Maurer (1978) using the following formula:

$$SSI = 1 - (Y_d / Y_p) / D$$

Where:

- **Y_d = mean yield under drought (water stress) conditions,**
- **Y_p = mean yield under normal (well-watered) conditions,**
- **D = drought intensity = 1 − (mean Y_d of all genotypes/mean Y_p of all genotypes)**

Data Analysis

Analysis of variance was conducted based on a randomized complete block design (RCBD). A combined analysis across the two water treatments and two seasons was performed, and the assumption of error variance homogeneity was not rejected, as verified by Levene's test (Levene, 1960). Mean comparisons were carried out using the Least Significant Difference (LSD) test at the 0.05 probability level, following the method described by Steel *et al.* (1997). While the seasons exhibited variability, the effects of water treatments and genotypes were found to be consistent. In addition, a Spearman rank correlation analysis was conducted to assess relationships among traits. All statistical analyses were performed using Microsoft Excel (2016) and GenStat version 18 (Payne *et al.*, 2017).

RESULTS AND DISCUSSION

Results

Analysis of variance

Tables 4 and 5 present the analysis of variance for the studied traits across seasons and water treatments. The mean squares for the effects of seasons, water treatments, and genotypes were significant or highly significant ($P < 0.05$ or $P \leq 0.01$) for all evaluated traits. These results indicate that both seasonal and irrigation conditions influenced trait performance, and there was adequate genetic variability among the tested genotypes.

The interaction effects among seasons, water treatments, and genotypes were significant for all traits, with some exceptions. Specifically, the season × water treatment interaction was not significant for grain weight (GW), grain yield (GY), relative water content (RWC), and shoot dry matter (SDM). Likewise, the season × genotype interaction was not significant for GW and osmotic potential (OP); the water treatment × genotype interaction was not significant for plant height, leaf area index (LAI), and SDM; and the three-way interaction (season × water treatment × genotype) was not significant for plant height, GW, RWC, LAI, and SDM.

Table 4. Analysis of variance (ANOVA) for morphological traits of wheat as influenced by growing seasons, irrigation treatments, and genotypes.

SOV	d.f	PH	SM	GS	GW	GY
Seasons (S)	1	0.002**	<.001***	<.001***	<.001***	<.001***
Water treatment (W)	1	<.001***	<.001***	<.001***	<.001***	<.001***
Genotypes (G)	9	<.001***	<.001***	<.001***	<.001***	<.001***
S x W	1	0.095**	<.001***	<.001***	0.118	0.868
S x G	9	<.001***	<.001***	<.001***	0.129	<.001***
W x G	9	0.11	0.005**	<.001***	0.04*	<.001***
S x W x G	9	0.866	<.001***	<.001***	0.383	0.001**

NS: not significant at $p \leq 0.05$; *: significant at $p \leq 0.05$; **: highly significant at $p \leq 0.01$; ***: very highly significant at $p \leq 0.001$.

Table 5. Analysis of variance (ANOVA) for physiological traits of wheat as affected by growing seasons, irrigation regimes, and genotypes under study.

SOV	d.f	TCC	OP	RWC	LAI	SDM
Seasons (S)	1	<.001***	0.002**	<.001***	0.004**	0.026*
Water treatment (W)	1	<.001***	<.001***	<.001***	<.001***	<.001***
Genotypes (G)	9	<.001***	<.001***	<.001***	<.001***	<.001***
S x W	1	<.001***	0.03*	0.099	0.048*	0.134
S x G	9	<.001***	0.669	<.001***	0.04*	<.001***
W x G	9	<.001***	<.001***	0.032*	0.497	0.174
S x W x G	9	0.001**	0.022*	0.688	0.236	0.379

NS: not significant at $p \leq 0.05$; *: significant at $p \leq 0.05$; **: highly significant at $p \leq 0.01$; ***: very highly significant at $p \leq 0.001$

Mean Performance

Table 6 summarizes the average values of the evaluated traits across both growing seasons and irrigation regimes. Plant height exhibited a range from 97 cm in Line 1 to 116 cm in both Sakha 95 and Giza 171. The No. of spikes m^{-2} (SM) was lowest in Line 1 (438.3) and highest in Misr 1 (493.8).

For No. of grains $spike^{-1}$, Sakha 95 showed the minimum value at 49.42, while Line 3 recorded the highest at 63.58 grains. The 1000-grains weight varied from 48.33 g in Line 3 to 55.65 g in Giza 171. The highest grain yield was obtained in Sakha 95, reaching 32.21 Ardeb $feddan^{-1}$, whereas the lowest yield was observed in Line 1 at 22.57 Ardeb $feddan^{-1}$.

In terms of physiological parameters, total chlorophyll content ranged between 6.74 $\mu g\ ml^{-1}$ in Line 1 and 9.69 $\mu g\ ml^{-1}$ in Sids 14. Osmotic potential values spanned from -14.54 µbar in Line 2 to -12.23 µbar in Misr 3. Relative water content (RWC) varied from 69.92% in Gemmeiza 12 to 83.75% in Misr 4. Leaf area index (LAI) showed its lowest value in Line 1 (2.04 $m^2\ m^{-2}$) and peaked in Misr 3 (2.94 $m^2\ m^{-2}$). Regarding shoot dry matter (SDM), the values ranged from 2.23 $kg\ m^{-2}$ in Misr 1 to 2.88 $kg\ m^{-2}$ in Line 2.

Table 6. Mean values of the assessed traits in the studied genotypes of wheat averaged as combined over seasons and water conditions.

Genotypes	PH	SM	GS	GW	GY	TCC	OP	RWC	LAI	SDM
Misr 1	113	493.8	50.08	51.69	26.50	8.05	-13.94	76.20	2.59	2.23
Misr 3	110	450.4	55.42	51.73	29.70	8.21	-12.23	77.30	2.94	2.65
Misr 4	108	470.4	53.58	53.43	30.23	6.94	-12.40	83.75	2.84	2.60
Giza 171	116	456.7	57.33	55.65	30.96	7.76	-13.20	81.27	2.36	2.59
Gemmeiza 12	109	471.7	51.67	50.28	26.87	9.52	-14.15	69.92	2.62	2.62
Sakha 95	116	475.0	49.42	52.74	32.21	9.22	-13.57	78.02	2.57	2.83
Sids 14	115	476.7	52.00	51.09	26.48	9.69	-12.26	75.07	2.39	2.64
Line 1	97	438.3	49.92	49.40	22.57	6.74	-13.45	80.47	2.04	2.59
Line 2	116	477.1	57.33	54.98	29.32	8.79	-14.54	78.68	2.83	2.88
Line 3	113	464.6	63.58	48.33	29.21	8.51	-13.41	83.53	2.60	2.81
Minimum	97	438.3	49.42	48.33	22.57	6.74	-14.54	69.92	2.04	2.23
Maximum	116	493.8	63.58	55.65	32.21	9.69	-12.23	83.75	2.94	2.88
Mean	111	467.5	54.03	51.93	28.41	8.34	-13.32	78.42	2.58	2.64
LSD	1.50	17.28	2.49	2.31	1.21	0.86	0.82	3.93	0.25	0.10

Interaction Effects Between Seasons and Genotypes

Tables 7 and 8 display the average values of the assessed traits under different water treatments across both seasons. Plant height varied from 96 cm in Line 1 to 115 cm in Line 2 during the first season, and from 99 cm in Line 1 to 117 cm in Line 2 during the second season.

The No of spikes m^{-2} ranged from 482.5 (Line 1) and 393.3 (Line 3) to 555 (Misr 1) and 438.3 (Sakha 95) in the first and second seasons, respectively.

No. of grains $spike^{-1}$ ranged between 49.00 (Sakha 95) and 75.33 (Line 3) in the first season, while in the second season, the values ranged from 39.83 (Misr 1) to 57.50 (Giza 171). The lowest 1000-grain weight was recorded in Line 3 across both seasons (52.80 g and 43.87 g), whereas Giza 171 showed the highest values (59.60 g and 51.70 g) in the respective seasons.

Grain yield ranged from 21.27 and 23.87 Ardeb $feddan^{-1}$ in Line 1 to 33.27 and 31.16 Ardeb $feddan^{-1}$ in Sakha

95 during the first and second seasons, respectively.

In terms of physiological traits, total chlorophyll content spanned from 5.84 µg ml^{-1} in Misr 4 (first season) and 6.96 µg ml^{-1} in Line 1 (second season) to 10.58 µg ml^{-1} in Sids 14 and 10.33 µg ml^{-1} in Line 2 during the first and second seasons, respectively.

Osmotic potential (OP) ranged from -15.02 µbar in Line 2 during the first season and -14.05 µbar in the same genotype during the second season, to -12.16 µbar in Sids 14 and -11.77 µbar in Misr 4 across the two seasons, respectively. Relative water content (RWC) showed its lowest values in Gemmeiza 12 (71.52%) and Misr 1 (66.26%), while the highest RWC was observed in Line 3 (86.76%) and Misr 4 (83.24%) over the two seasons.

Leaf area index (LAI) ranged between 1.94 m² m^{-2} in the first season and 2.14 m² m^{-2} in the second season for Line 1, whereas Misr 3 recorded the highest LAI values of 2.97 and 2.92 m² m^{-2} in the first and second seasons, respectively.

Shoot dry matter (SDM) ranged from 1.83 kg m^{-2} in Misr 1 and 5.84 kg m^{-2} in Misr 4, to peak values of 3.01 kg m^{-2} in Line 3 and 10.58 kg m^{-2} in Sids 14 during the first and second growing seasons, respectively.

Table 7. Mean performance of plant height and yield traits of wheat combined across seasons and genotypes under integrated irrigation conditions.

Genotypes	PH		SM		GS		GW		GY	
	20/21	21/22	20/21	21/22	20/21	21/22	20/21	21/22	20/21	21/22
Misr 1	114	112	555.0	432.5	60.33	39.83	55.17	48.20	28.45	24.55
Misr 3	111	109	499.2	401.7	61.33	49.50	55.81	47.65	30.92	28.49
Misr 4	107	109	539.2	401.7	58.00	49.17	58.21	48.65	33.19	27.27
Giza 171	114	117	490.0	423.3	57.17	57.50	59.60	51.70	31.83	30.09
Gemmeiza 12	109	109	523.3	420.0	57.50	45.83	53.24	47.32	28.75	24.99
Sakha 95	114	117	511.7	438.3	49.00	49.83	54.65	50.83	33.27	31.16
Sids 14	115	116	520.0	433.3	63.17	40.83	53.98	48.20	29.09	23.87
Line 1	96	99	482.5	394.2	58.50	41.33	54.81	43.99	21.27	23.87
Line 2	115	117	522.5	431.7	68.17	46.50	59.47	50.49	31.32	27.32
Line 3	112	114	535.8	393.3	75.33	51.83	52.80	43.87	30.76	27.66
LSD	2.1		12.27		3.52		3.27		1.72	

Table 8. Mean values of physiological traits of wheat for the season × genotype interaction under combined over water conditions.

Genotypes	TCC		OP		RWC		LAI		SDM	
	20/21	21/22	20/21	21/22	20/21	21/22	20/21	21/22	20/21	21/22
Misr 1	6.03	10.08	-14.24	-13.65	86.14	66.26	2.44	2.74	1.83	6.03
Misr 3	7.89	8.52	-12.19	-12.27	76.33	78.27	2.97	2.92	2.67	7.89
Misr 4	5.84	8.04	-13.02	-11.77	84.27	83.24	2.77	2.92	2.50	5.84
Giza 171	6.08	9.43	-13.31	-13.08	84.02	78.53	2.06	2.66	2.65	6.08
Gemmeiza 12	9.42	9.62	-14.74	-13.56	71.52	68.32	2.63	2.61	2.60	9.42
Sakha 95	9.44	9.00	-13.75	-13.40	78.03	78.01	2.73	2.41	2.79	9.44
Sids 14	10.58	8.79	-12.16	-12.37	74.50	75.65	2.17	2.61	2.64	10.58
Line 1	6.51	6.96	-13.82	-13.09	81.27	79.67	1.94	2.14	2.29	6.51
Line 2	7.25	10.33	-15.02	-14.05	78.51	78.85	2.76	2.90	2.94	7.25
Line 3	8.26	8.76	-13.81	-13.02	86.76	80.30	2.49	2.71	3.01	8.26
LSD	0.32		NS		4.59		0.28		0.26	

Interaction Effects of Water Stress and Wheat Genotypes

Tables 9 and 10 display the average values of the measured traits for each genotype under both irrigation regimes, pooled across the two seasons. Plant height varied from 98 cm and 96 cm in Line 1 to a maximum of 118 cm in Sids 14 under well-watered conditions and 115 cm in Sakha 95 under water deficit conditions.

Table 9. Mean performance of selected morpho-physiological characteristics of wheat varieties under well-watered and water deficit conditions combined over seasons.

Genotypes	PH		SM		GS		GW		GY	
	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD
Misr 1	114	112	545.0	442.5	55.00	45.17	52.56	50.81	27.89	25.10
Misr 3	111	109	467.5	433.3	57.50	53.33	54.85	48.61	31.13	28.27
Misr 4	110	107	494.2	446.7	55.50	51.67	55.34	51.53	34.25	26.21
Giza 171	118	114	481.7	431.7	58.00	56.67	57.38	53.92	32.66	29.26
Gemmeiza 12	110	108	507.5	435.8	57.00	46.33	51.83	48.73	28.09	25.65
Sakha 95	116	115	515.0	435.0	54.00	44.83	54.65	50.82	36.10	28.33
Sids 14	118	113	517.5	435.8	53.17	50.83	55.16	47.02	28.02	24.94
Line 1	98	96	473.3	403.3	57.50	42.33	51.15	47.65	26.22	18.92
Line 2	118	114	522.5	431.7	63.17	51.50	58.47	51.49	32.45	26.18
Line 3	114	112	500.0	429.2	65.83	61.33	48.49	48.18	31.33	27.09
Mean	114	112	545.0	442.5	55.00	45.17	52.56	50.81	27.89	25.10
LSD	2.1		24.4		3.52		3.27		1.72	

Table 10. Mean performance of selected morpho-physiological characteristics of wheat varieties under well-watered and water deficit conditions combined over seasons.

Genotypes	TCC		OP		RWC		LAI		SDM	
	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD
Misr 1	13.87	2.24	-11.89	-15.99	79.84	72.56	3.87	1.31	2.34	2.11
Misr 3	13.28	3.13	-12.32	-12.14	81.53	73.07	4.18	1.71	2.87	2.44
Misr 4	11.56	2.31	-11.15	-13.64	84.08	83.42	4.06	1.62	2.83	2.36
Giza 171	13.06	2.46	-12.91	-13.49	86.39	76.16	3.41	1.30	2.73	2.44
Gemmeiza 12	16.03	3.01	-12.31	-15.99	76.04	63.81	3.82	1.42	2.73	2.51
Sakha 95	15.11	3.33	-11.65	-15.49	78.15	77.89	3.70	1.44	2.98	2.69
Sids 14	16.45	2.93	-11.04	-13.49	80.29	69.86	3.45	1.32	2.70	2.58
Line 1	11.46	2.02	-11.84	-15.06	84.45	76.48	3.15	0.93	2.87	2.31
Line 2	15.03	2.55	-13.65	-15.42	84.26	73.10	4.10	1.57	3.23	2.53
Line 3	14.78	2.23	-12.49	-14.33	86.86	80.20	3.88	1.32	3.03	2.59
Mean	13.87	2.24	-11.89	-15.99	79.84	72.56	3.87	1.31	2.34	2.11
LSD	1.22		1.15		5.55		0.35		0.28	

No. of spikes m^{-2} ranged from 467.5 in Misr 3 and 403.3 in Line 1 to 545 in Misr 1 and 446.7 in Misr 4 under optimal and limited irrigation, respectively.

No. of grains $spike^{-1}$ ranged from 53.17 (Sids 14) and 42.33 (Line 1) to 65.83 and 61.33 in Line 3 under the well-watered and water-stressed conditions, respectively. The lightest 1000-grain weights were observed in Line 3 (48.49 g) and Sids 14 (47.02 g), while the heaviest were found in Line 2 (58.47 g) and Giza 171 (53.92 g) under the same respective conditions.

Grain yield ranged from 26.22 and 18.92 Ardeb $feddan^{-1}$ in Line 1 to 36.10 Ardeb $feddan^{-1}$ in Sakha 95 and 26.26 Ardeb $feddan^{-1}$ in Giza 171 under well-watered and deficit irrigation, respectively. Total chlorophyll content (a + b) was lowest in Line 1 (11.46 and 2.02 µg ml^{-1}) and peaked in Sids 14 (16.45 µg ml^{-1}) and Sakha 95 (3.33 µg ml^{-1}) under well-watered and water deficit conditions, respectively.

Osmotic potential ranged from -13.65 µbar in Line 2 and -15.99 µbar in Gemmeiza 12 to -11.04 µbar in Sids 14 and -12.14 µbar in Misr 3, under well-watered and stressed irrigation, respectively. Relative water content (RWC) ranged from 76.04% in Gemmeiza 12 and 63.81% in the same genotype, to 86.86% in Line 3 and 83.42% in Misr 4 under respective irrigation levels.

Leaf area index (LAI) recorded its lowest values in Line 1 (3.15 and 0.93 $m^2\ m^{-2}$) and its highest in Misr 3 (4.18 and 1.71 $m^2\ m^{-2}$) under normal and water-limited conditions, respectively. Shoot dry matter ranged from 2.34 and 2.11 kg m^{-2} in Misr 1 to 3.23 kg m^{-2} in Line 2 and 2.69 kg m^{-2} in Sakha 95 under the respective water regimes.

The effect of season, water treatments and genotypes interaction

The mean performance of the studied traits across the interaction of seasons, irrigation treatments, and genotypes with significant differences is presented in Tables 11 and 12.

The lowest No. of spikes m^{-2} was recorded for Line 3 under water deficit conditions during the second season, whereas the highest number was observed for Misr 1 under well-watered conditions in the first season. Regarding the No. of grains $spike^{-1}$, Misr 1 recorded the lowest values under water deficit in the second season, while Line 2 exhibited the highest values under well-watered conditions in the first season.

In terms of grain yield, the lowest value was obtained from Line 1 under water deficit during the first season, whereas Sakha 95 achieved the highest yield under well-watered conditions in the same season. Concerning physiological traits, total chlorophyll content reached its minimum in Misr 1 under water deficit during the first season, while the highest content was noted in Sids 14 under well-watered conditions in the first season. Finally, osmotic potential recorded its lowest value in Misr 1 under water deficit in the first season, while the highest value was observed in Sids 14 under well-watered conditions in the second season.

Effects of Environmental Season, Irrigation Conditions, and Their Interaction on Morphophysiological Traits

Table 13 presents the mean values for seasons, water treatments, and their interaction across all studied genotypes. The mean performance of all genotypes for the evaluated traits was significantly higher in the 2020-21 season compared to the 2021-22 season, as shown in Tables 4 and 5.

Table 11. Interaction effects of seasons, irrigation levels, and genotypes on plant height and yield-contributing traits of wheat.

Genotypes	PH				SM				GS				GW				GY			
	20-21		21-22		20-21		21-22		20-21		21-22		20-21		21-22		20-21		21-22	
	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD
Misr 1	115	113	113	111	621.7	488.3	468.3	396.7	66.00	54.67	44.00	35.67	55.61	54.73	49.50	46.90	29.24	27.65	26.54	22.56
Misr 3	112	110	109	108	556.7	441.7	378.3	425.0	65.00	57.67	50.00	49.00	58.83	52.78	50.87	44.44	31.73	30.10	30.53	26.44
Misr 4	108	106	111	108	578.3	500.0	410.0	393.3	60.00	56.00	51.00	47.33	60.04	56.39	50.64	46.66	37.29	29.09	31.21	23.33
Giza 171	116	111	119	116	541.7	438.3	421.7	425.0	58.00	56.33	58.00	57.00	62.96	56.25	51.80	51.60	33.52	30.14	31.79	28.39
Gemmeiza 12	111	108	110	109	590.0	456.7	425.0	415.0	61.67	53.33	52.33	39.33	53.65	52.82	50.00	44.63	31.19	26.31	24.99	24.99
Sakha 95	115	114	117	117	583.3	440.0	446.7	430.0	55.00	43.00	53.00	46.67	57.70	51.60	51.61	50.04	37.88	28.66	34.32	28.00
Sids 14	118	111	118	114	573.3	466.7	461.7	405.0	64.33	62.00	42.00	39.67	58.46	49.51	51.87	44.54	30.66	27.51	25.38	22.36
Line 1	97	95	100	98	540.0	425.0	406.7	381.7	72.00	45.00	43.00	39.67	57.08	52.54	45.22	42.75	25.90	16.64	26.54	21.19
Line 2	118	112	118	115	586.7	458.3	458.3	405.0	79.33	57.00	47.00	46.00	63.81	55.13	53.14	47.84	34.28	28.35	30.62	24.01
Line 3	113	111	115	113	580.0	491.7	420.0	366.7	78.67	72.00	53.00	50.67	54.27	51.32	42.71	45.03	31.46	30.06	31.21	24.11
LSD	3.00				34.56				4.98				4.63				2.43			

Table 12. Physiological traits of wheat as affected by the combined effects of seasons, water regimes, and genotypes.

Genotypes	TCC				OP				RWC				LAI				SDM			
	20-21		21-22		20-21		21-22		20-21		21-22		20-21		21-22		20-21		21-22	
	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD	WW	WD
Misr 1	10.58	1.48	17.16	2.99	-12.27	-16.20	-11.52	-15.77	88.05	84.23	71.63	60.88	3.53	1.36	4.22	1.26	1.86	1.80	2.83	2.42
Misr 3	12.43	3.35	14.14	2.91	-13.07	-11.31	-11.57	-12.97	80.67	72.00	82.39	74.15	4.17	1.77	4.19	1.65	2.97	2.37	2.77	2.51
Misr 4	9.81	1.86	13.31	2.77	-11.04	-15.00	-11.25	-12.29	85.63	82.90	82.53	83.95	3.93	1.61	4.19	1.64	2.68	2.33	2.99	2.40
Giza 171	10.19	1.97	15.92	2.95	-13.81	-12.81	-12.00	-14.16	90.16	77.88	82.61	74.44	3.07	1.04	3.75	1.57	2.74	2.56	2.73	2.33
Gemmeiza12	16.25	2.60	15.82	3.42	-13.44	-16.03	-11.17	-15.95	78.27	64.78	73.81	62.84	3.63	1.62	4.00	1.22	2.62	2.57	2.85	2.44
Sakha 95	15.14	3.73	15.08	2.93	-11.89	-15.60	-11.41	-15.38	78.38	77.67	77.92	78.10	3.79	1.66	3.60	1.22	2.91	2.68	3.05	2.69
Sids 14	17.55	3.62	15.35	2.24	-11.09	-13.23	-10.99	-13.74	82.05	66.95	78.53	72.76	3.22	1.11	3.69	1.52	2.65	2.63	2.75	2.53
Line 1	11.40	1.62	11.51	2.41	-12.37	-15.26	-11.31	-14.86	86.85	75.68	82.06	77.28	3.17	0.72	3.14	1.14	2.41	2.16	3.34	2.46
Line 2	12.78	1.72	17.28	3.39	-14.32	-15.73	-12.99	-15.12	86.22	70.81	82.30	75.39	3.87	1.65	4.32	1.48	3.36	2.52	3.10	2.54
Line 3	14.50	2.01	15.07	2.45	-12.88	-14.74	-12.11	-13.93	90.12	83.41	83.60	77.00	3.84	1.13	3.92	1.50	3.26	2.76	2.80	2.41
LSD	1.73				1.63				7.86				0.50				0.40			

Table 13. Mean performance of the studied traits of wheat as affected by seasons, irrigation regimes, and their interaction.

		PH	SM	GS	GW	GY	TCC	OP	RWC	LAI	SDM
20-21		111	517.9	60.85	55.77	29.88	7.73	-13.60	80.13	2.49	2.59
21-22		112	417.0	47.22	48.09	26.93	8.95	-13.02	76.71	2.66	2.70
F test		**	***	***	***	***	***	**	***	**	*
WW		113	502.4	57.67	53.99	30.81	14.06	-12.13	82.19	3.76	2.83
WD		110	432.5	50.40	49.88	26.00	2.62	-14.50	74.66	1.39	2.46
F test		***	***	***	***	***	***	***	***	***	***
20-21	112	575.2	66.00	58.24	32.32	13.06	-12.62	84.64	3.62	2.75	2.75
	109	460.7	55.70	53.31	27.45	2.40	-14.59	75.63	1.37	2.44	2.44
21-22	113	429.7	49.33	49.74	29.31	15.06	-11.63	79.74	3.90	2.92	2.92
	111	404.3	45.10	46.44	24.54	2.84	-14.42	73.68	1.42	2.47	2.47
LSD		1	10.93	0.56	NS	NS	0.54	0.51	NS	0.16	NS

Reduction % and Stress Susceptibility Index (SSI)

The percentage reduction in the measured traits due to water deficit is presented in Table 14. Among all genotypes, Gemmeiza 12 exhibited the smallest reduction in grain yield, suggesting superior stability under drought conditions. Misr 3 demonstrated the lowest reduction in No. of spikes m^{-2}, total chlorophyll content (chlorophyll a + b), osmotic potential (OP), and leaf area index (LAI), highlighting its physiological adaptability to water stress.

In contrast, Sakha 95 showed the least reduction in plant height and relative water content (RWC), indicating a degree of resilience in structural and hydration-related traits. Furthermore, Line 3 recorded the smallest decrease in 1000-grains weight, suggesting a capacity to maintain grain filling under stress.

Grain yield data under well-watered and water-deficit conditions were used to compute the Stress Susceptibility Index (SSI), as shown in Table 11. An SSI value less than 1 indicates tolerance, values close to or around 1 suggest moderate tolerance or sensitivity, and values above 1 signify sensitivity to water stress. Averaging across the two growing seasons, Misr 1, Misr 3, Giza 171, Gemmeiza 12, Sids 14, and Line 3 consistently displayed SSI values below 1, classifying them as drought-tolerant genotypes. On the other hand, Misr 4, Line 1, Sakha 95 and Line 2 exhibited SSI values above 1, indicating a higher sensitivity to water shortage.

Notably, the drought-tolerant genotypes also recorded favorable levels in key traits such as 1000-grains weight, grain yield, total chlorophyll content, osmotic potential, and shoot dry matter, traits that are essential indicators of physiological performance under water-limited conditions.

Table 14. The reduction % under drought conditions for all studied traits of wheat genotypes, and grain yield-based Stress Susceptibility Index (SSI) values for the tested genotypes.

Genotypes	PH	SM	GS	GW	GY	TCC a+b	OP	RWC	LAI	SDM	SSI
Misr 1	1.75	18.81	17.87	3.33	10.00	83.85	34.48	9.12	66.15	9.83	0.64
Misr 3	1.80	7.32	7.25	11.38	9.19	76.43	1.48	10.38	59.09	14.98	0.59
Misr 4	2.73	9.61	6.90	6.88	23.47	80.02	22.33	0.78	60.10	16.61	1.50
Giza 171	3.39	10.38	2.29	6.03	10.41	81.16	4.49	11.84	61.88	10.62	0.67
Gemmeiza 12	1.82	14.13	18.72	5.98	8.69	81.22	29.89	16.08	62.83	8.06	0.56
Sakha 95	0.86	15.53	16.98	7.01	21.52	77.96	32.96	0.33	61.08	9.73	1.38
Sids 14	4.24	15.79	4.40	14.76	10.99	82.19	22.19	12.99	61.74	4.44	0.70
Line 1	2.04	14.79	26.38	6.84	27.84	82.37	27.20	9.44	70.48	19.51	1.78
Line 2	3.39	17.38	18.47	11.94	19.32	83.03	12.97	13.24	61.71	21.67	1.24
Line 3	1.75	14.16	6.84	0.64	13.53	84.91	14.73	7.67	65.98	14.52	0.87
Mean	2.38	13.79	12.61	7.48	15.50	81.32	20.27	9.19	63.10	13.00	

Discussion

Throughout this investigation, the examined wheat genotypes experienced extended drought stress lasting nearly 130 days, beginning at the elongation stage and continuing through to harvest. Recorded rainfall contributed 130.2 m^3/feddan and 199.5 m^3/feddan in the first and second seasons, respectively. Under deficit irrigation, the total applied water reached 915.2 m^3/feddan during 2020/2021 and 1004.5 m^3/feddan in 2021/2022, indicating a reduction of 47.5% and 48.6%, respectively, compared to the well-watered treatment. These contrasting irrigation levels facilitated an effective evaluation of genotype responses under both adequate and limited water availability.

Meteorological data (Table 2) indicated typical winter conditions at El-Gemmeiza, with moderate temperatures, relatively stable relative humidity, limited rainfall, and a gradual increase in sunshine duration towards the end of the season. These conditions, particularly the low rainfall and rising temperatures, likely intensified water deficit stress, thereby differentiating the wheat genotypes in their tolerance to drought.

The analysis of variance revealed significant interactions between seasons, water treatments, and genotypes, underscoring the critical role of genotype-by-environment interactions. Different genotypes exhibited varied responses to irrigation levels across seasons, which proved essential in identifying drought-resilient entries. These findings support previous research (e.g., Shalaby *et al*., 2020 and Morsy *et al*., 2021), which highlighted the necessity of testing genotypes under contrasting water regimes to effectively select for drought tolerance.

Superior performance during the first growing season can likely be attributed to more favorable environmental conditions, such as higher solar radiation and optimal temperatures, factors known to enhance wheat development (Farhat *et al*., 2020 and Shehab-Eldeen & Farhat, 2020).

Drought stress significantly reduced all measured traits, especially grain yield, which showed substantial declines mainly due to reductions in grain number and weight. These yield components are known to be sensitive to stress-induced floret abortion (Dolferus *et al*., 2013) and reproductive failure (Onyemaobi *et al*., 2017). Likewise, studies by Zhao *et al*. (2020) have shown that drought conditions shorten the grain-filling period, reducing the accumulation of dry matter in the kernels.

Reduced grain yield was also linked to decreased spike density (Leilah & Al-Khateeb, 2005) and a lower No. of grains spike^{-1} (Ehdaie *et al*., 2008). These results mirror yield decline patterns reported by Al-Naggar *et al*. (2020), Shalaby *et al*. (2020), and Nehe *et al*. (2021), reinforcing the consistency of drought impacts across environments.

Relative water content (RWC) proved to be a reliable indicator of drought resistance, as drought-tolerant genotypes maintained higher RWC levels, thereby supporting physiological activity and biomass production, a finding consistent with Dehnavi *et al*. (2017), Din *et al*. (2020), and Wasaya *et al*. (2021).

Chlorophyll content, a proxy for photosynthetic efficiency, also declined under water-limited conditions. This reduction is likely due to oxidative stress damaging the chloroplasts, as previously noted by Shalaby *et al*. (2020) and Khayatnezhad & Gholamin (2021). Decreased chlorophyll content typically leads to reduced photosynthesis and visible leaf chlorosis (Yang *et al*., 2001).

According to the Stress Susceptibility Index (SSI), the genotypes Gemmeiza 12, Misr 3, Misr 1, Giza 171, Sids 14, and Line 3 exhibited strong drought tolerance. These genotypes consistently outperformed others in terms of spikes m^{-2}, 1000-grains weight, chlorophyll content, osmotic potential, and final grain yield under water stress.

In conclusion, the study revealed substantial genotypic variation in drought response. Gemmeiza 12 emerged as the most drought-tolerant genotype, followed by Misr 3, Misr 1, Giza 171, Sids 14, and Line 3. Conversely, Line 1 exhibited the highest sensitivity to drought, with Misr 4, Sakha 95, and Line 2 also showing lower resilience. These results align with earlier studies (Sun *et al*., 2006; Salemi *et al*., 2011; Chen *et al*., 2014 and Cheikh M'hamed *et al*., 2015).

Interestingly, findings by Mahamed *et al*. (2011) and Hamed *et al*. (2015) indicate that over-irrigation may actually decrease water use efficiency (WUE), reinforcing the necessity of optimizing irrigation management in wheat cropping systems, particularly under water-scarce conditions.

CONCLUSION

Water shortage had a substantial influence on all evaluated variables, but genotypes had a greater impact on wheat morphological and physiological treatments. This study found that the varieties Gemmeiza 12, Misr 3, Misr 1, Giza 171, Sids 14 and Line 3 were suitable for cultivation under water scarcity situations. Grain yield, total chlorophyll content, OP, and SDM all show high values. Overall, these morpho-physiological characteristics can effectively identify tolerant wheat cultivars in water-limited situations. Using multiple qualities can improve selection effectiveness compared to relying just on one trait. The identified features for selecting tolerant wheat cultivars for specific areas should be tested under various environmental situations to address water deficit issues. The findings of this study can also extend useable diversity in wheat yield enhancement, which is critical in selecting suitable wheat varieties as well as desired parents for the breeding program to generate wheat types resistant to drought stress situations.

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بعض الصفات المورفو-فسيولوجية كدلائل لتحمل نقص الماء في بعض التراكيب الوراثية لقمح الخبز

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الملخص

أُجريت هذه الدراسة في محطة البحوث الزراعية بالجميزة بهدف تقييم قدرة بعض التراكيب الوراثية لقمح الخبز على تحمّل نقص مياه الري، وذلك من خلال دراسة مجموعة من الصفات المورفولوجية والفسيولوجية. تم تنفيذ التجربة خلال موسمي ٢٠٢١/٢٠٢٠ و٢٠٢٢/٢٠٢١ باستخدام تصميم القطاعات الكاملة العشوائية (RCBD) بثلاث مكررات. شملت الدراسة عشرة تراكيب وراثية من القمح تمت زراعتها في تجربتين منفصلتين: الأولى تحت ظروف الري الجيد (١٠٠٪ من السعة الحقلية)، والثانية تحت ظروف نقص المياه (٣٠٪ من السعة الحقلية). أظهرت النتائج أن الإجهاد المائي أثّر بشكل معنوي على جميع الصفات المدروسة، في حين اختلفت التراكيب الوراثية فيما بينها بصورة واضحة في الصفات المورفوفسيولوجية للقمح. وقد تميزت الأصناف: جميزة ١٢، مصر ٣، مصر ١، جيزة ١٧١، سدس ١٤، وسلالة ٣ بأداء جيد تحت ظروف نقص المياه، حيث سجلت أعلى القيم في محصول الحبوب، ومحتوى الكلوروفيل الكلي، والضغط الأسموزي، والمادة الجافة للساق .بشكل عام، تُعد هذه الصفات المورفو-فسيولوجية مؤشرات واعدة في اختيار أصناف القمح المتحملة للإجهاد المائي. كما أن فاعلية الانتخاب تزداد عند الاعتماد على أكثر من صفة مجتمعة بدلاً من الاعتماد على صفة واحدة فقط. توصي الدراسة باستخدام هذه المؤشرات لتحديد الأصناف المناسبة للزراعة في المناطق ذات الموارد المائية المحدودة والظروف البيئية المتغيرة. بالإضافة إلى ذلك، يمكن الاستفادة من التنوع الوراثي المكتشف في هذه التراكيب لتطوير برامج تربية تهدف إلى استنباط أصناف قمح ذات قدرة عالية على تحمّل الإجهاد المائي، بما يسهم في تعزيز إنتاجية القمح في البيئات الجافة وشبه الجافة.