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

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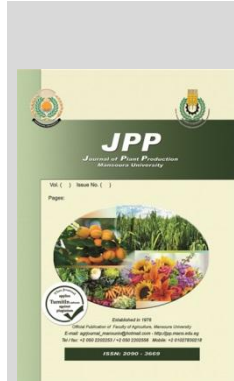


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#### ABSTRACT

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



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#### 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 (Kozłowski & 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 (Mwadingeni *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 25<sup>th</sup> and November 15<sup>th</sup> for the 2020/2021 and 2021/2022 growing seasons, respectively.

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

| Genotypes   | Pedigree                                                                                     | Origin |
|-------------|----------------------------------------------------------------------------------------------|--------|
| Misir 1     | OASIS/KAUZ//4*BCN/3/2*PASTOR                                                                 | Egypt  |
| Misir 3     | ROHF 07*2/KIRITI                                                                             | Egypt  |
| Misir 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//GOURMIA-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/AESQUARROSA(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° 2020/2021 |      | AT C° 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 (m<sup>3</sup> fed<sup>-1</sup>) 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<sup>3</sup> fed<sup>-1</sup>)

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<sup>3</sup> fed<sup>-1</sup> 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<sup>3</sup> sec<sup>-1</sup>.

C = coefficient of discharge ranged from 0.6 up to 0.8.

A = cross-sectional area of the orifice, cm<sup>2</sup>.

g = acceleration of gravity, 981 cm sec<sup>-2</sup>.

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<sup>-2</sup>, GS = No. of grains spike<sup>-1</sup>, GW = 1000-grains weight (g) and GY = grain yield (Ardeb feddan<sup>-1</sup>).

**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:

$$\text{Chlorophyll a} = 12.64 \times A_{664} - 2.99 \times A_{647} = \mu\text{g/l}$$

$$\text{Chlorophyll b} = 23.26 \times A_{647} - 5.6 \times A_{664} = \mu\text{g/l}$$

$$\text{Chlorophyll a+b} = 7.04 \times A_{664} + 20.27 \times A_{647} = \mu\text{g/l}$$

**Where:** A<sub>664</sub> is the reading at 664 nm, A<sub>647</sub> is the reading at 647 nm

The concentration of chlorophyll contents was then expressed as (μg ml<sup>-1</sup>).

**Determination of osmotic potential**

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:

$$\text{RWC (\%)} = [(FW - DW) / (TW - DW)] \times 100$$

**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<sub>t</sub> = total dry weight of all plant leaves (g)

dwt<sub>a</sub> = dry weight of a known measured leaf area (g)

A = measured area of leaves used for determining dwt<sub>a</sub> (cm<sup>2</sup>)

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<sub>d</sub> = mean yield under drought (water stress) conditions,

• Y<sub>p</sub> = mean yield under normal (well-watered) conditions,

• D = drought intensity = 1 - (mean Y<sub>d</sub> of all genotypes / mean Y<sub>p</sub> 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  $\times$  genotype interaction was not significant for GW and osmotic potential (OP); the

water treatment  $\times$  genotype interaction was not significant for plant height, leaf area index (LAI), and SDM; and the three-way interaction (season  $\times$  water treatment  $\times$  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 $\times$ W            | 1   | 0.095**  | <.001*** | <.001*** | 0.118    | 0.868    |
| S $\times$ G            | 9   | <.001*** | <.001*** | <.001*** | 0.129    | <.001*** |
| W $\times$ G            | 9   | 0.11     | 0.005**  | <.001*** | 0.04*    | <.001*** |
| S $\times$ W $\times$ 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 $\times$ W            | 1   | <.001*** | 0.03*    | 0.099    | 0.048*   | 0.134    |
| S $\times$ G            | 9   | <.001*** | 0.669    | <.001*** | 0.04*    | <.001*** |
| W $\times$ G            | 9   | <.001*** | <.001*** | 0.032*   | 0.497    | 0.174    |
| S $\times$ W $\times$ 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  $\mu bar$  in Line 2 to -12.23  $\mu bar$  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  $\mu\text{g ml}^{-1}$  in Misr 4 (first season) and 6.96  $\mu\text{g ml}^{-1}$  in Line 1 (second season) to 10.58  $\mu\text{g ml}^{-1}$  in Sids 14 and 10.33  $\mu\text{g ml}^{-1}$  in Line 2 during the first and second seasons, respectively.

Osmotic potential (OP) ranged from -15.02  $\mu\text{bar}$  in Line 2 during the first season and -14.05  $\mu\text{bar}$  in the same genotype during the second season, to -12.16  $\mu\text{bar}$  in Sids 14 and -11.77  $\mu\text{bar}$  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  $\text{m}^2 \text{m}^{-2}$  in the first season and 2.14  $\text{m}^2 \text{m}^{-2}$  in the second season for Line 1, whereas Misr 3 recorded the highest LAI values of 2.97 and 2.92  $\text{m}^2 \text{m}^{-2}$  in the first and second seasons, respectively.

Shoot dry matter (SDM) ranged from 1.83  $\text{kg m}^{-2}$  in Misr 1 and 5.84  $\text{kg m}^{-2}$  in Misr 4, to peak values of 3.01  $\text{kg m}^{-2}$  in Line 3 and 10.58  $\text{kg m}^{-2}$  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  $\times$  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   |
| Misir 1     | 13.87 | 2.24 | -11.89 | -15.99 | 79.84 | 72.56 | 3.87 | 1.31 | 2.34 | 2.11 |
| Misir 3     | 13.28 | 3.13 | -12.32 | -12.14 | 81.53 | 73.07 | 4.18 | 1.71 | 2.87 | 2.44 |
| Misir 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  $\mu g ml^{-1}$ ) and peaked in Sids 14 (16.45  $\mu g ml^{-1}$ ) and Sakha 95 (3.33  $\mu g ml^{-1}$ ) under well-watered and water deficit conditions, respectively.

Osmotic potential ranged from -13.65  $\mu bar$  in Line 2 and -15.99  $\mu bar$  in Gemmeiza 12 to -11.04  $\mu bar$  in Sids 14 and -12.14  $\mu bar$  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    |
| Misir 1     | 115   | 113 | 111   | 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 |
| Misir 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 |
| Misir 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   |
| Misir 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 |
| Misir 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 |
| Misir 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  | WW | 112 | 575.2 | 66.00 | 58.24 | 32.32 | 13.06 | -12.62 | 84.64 | 3.62 | 2.75 |
|        | WD | 109 | 460.7 | 55.70 | 53.31 | 27.45 | 2.40  | -14.59 | 75.63 | 1.37 | 2.44 |
| 21-22  | WW | 113 | 429.7 | 49.33 | 49.74 | 29.31 | 15.06 | -11.63 | 79.74 | 3.90 | 2.92 |
|        | WD | 111 | 404.3 | 45.10 | 46.44 | 24.54 | 2.84  | -14.42 | 73.68 | 1.42 | 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. Misir 3 demonstrated the lowest reduction in No. of spikes m<sup>-2</sup>, 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, Misir 1, Misir 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, Misir 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  |
|-------------|------|-------|-------|-------|-------|---------|-------|-------|-------|-------|------|
| Misir 1     | 1.75 | 18.81 | 17.87 | 3.33  | 10.00 | 83.85   | 34.48 | 9.12  | 66.15 | 9.83  | 0.64 |
| Misir 3     | 1.80 | 7.32  | 7.25  | 11.38 | 9.19  | 76.43   | 1.48  | 10.38 | 59.09 | 14.98 | 0.59 |
| Misir 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<sup>3</sup>/feddan and 199.5 m<sup>3</sup>/feddan in the first and second seasons, respectively. Under deficit irrigation, the total applied water reached 915.2 m<sup>3</sup>/feddan during 2020/2021 and 1004.5 m<sup>3</sup>/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<sup>-1</sup> (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<sup>-2</sup>, 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.

## REFERENCES

- Al-Naggar A. M. M., Abdel-Shafi M.A., El-Shal M.H., Anany A.H. (2020). Evaluation of Egyptian wheat landraces (*Triticum aestivum* L.) for drought tolerance, agronomic, grain yield and quality traits. Plant Archives Vol. Supplement 20, 3487-3504
- Basu S., Ramegowda V., Kumar A., and Pereira A., (2016). Plant adaptation to drought stress," F1000 Report, 5: 1–10.
- Beltrano J. and Marta G. R., (2008). Improved tolerance of wheat plants (*Triticum aestivum* L.) to drought stress and rewatering by the arbuscular mycorrhizal fungus *Glomus claroideum*: effect on growth and cell membrane stability," Journal of Brazilian Social Plant Physiology, 7: 569–572.
- Chaves M. M., Pereira J. S., Maroco J. *et al.*, (2002). How plants cope with water stress in the field? Photosynthesis and growth. Annals of Botany. 89 (7): 907–916. Cheikh M'hamed ,H.; Rezig M. and Ben Naceur M.(2015). Water use efficiency of durum wheat (*Triticum durum* Desf) under deficit irrigation journal of Agricultural Science; 7 (8):238-249.
- Chen S.; Sun, H.; Shao. L. and Zhang X. (2014). Performance of winter wheat under different irrigation regimes associated with weather conditions in the North China Plain. AJCS 8(4):550-557.
- Dehnavi M.M., Zarei T., Khajeeyan R., Merajipoor M. (2017). drought and salinity impact on bread wheat in a hydroponic culture: a physiological comparison. Journal of Plant Physiology and Breeding. 7(1): 61-74.

- Dereje A., Maru B., Diress T. and Mitiku H., (2007). Transplanting sorghum as a means of ensuring food security in low rainfall sorghum growing areas of northern Ethiopia. Drylands Coordination Group, DCG report; no. 48.
- Din A., Ahmad M., Watto F.M., Ahmed S., Ali I., Shah M.K.N. (2020). Drought tolerance screening in thirty common wheat (*Triticum aestivum* L.) genotypes. Sarhad Journal of Agriculture 35 (1): 168-177.
- Dolferus R., Powell N., Ji X., Ravash R., Edlington J., Oliver S., Dongen J.V., Shiran B. (2013). The physiology of reproductive-stage abiotic stress tolerance in cereals. In: Rout G. R. and A. B. Das eds. Molecular stress physiology of plants. New Delhi, India, Springer: 193-216.
- Duan B., Yang Y., Lu Y., Korpelainen H., Berninger F. and Li C. (2007). Interactions between water deficit, ABA, and provenances in *Picea asperata*. Journal of Experimental Botany, vol. 58, no. 11, pp. 3025–3036.
- El Gataa Z, El Hanafi S, Basheer F, Kehel Z, bouhouch Y, El Messoadi K, Eddakir K, Ladraa N, Samir K, Tadesse W (2021). Genome wide association study of grain yield and yield related traits in spring bread wheat (*Triticum aestivum* L.) under drought and heat conditions in three different locations. Journal of Crop Science and Biotechnology: 1-13.
- Ehdaie B., Alloush G.A., Waines J.G. (2008). Genotypic variation in linear rate of grain growth and contribution of stem reserves to grain yield in wheat. Field Crops Res. 106: 34-43.
- Farhat W.Z.E., Shehab-Eldeen M.T., Khedr R.A. (2020). Agronomic and physiological studies on some exotic and local bread wheat genotypes under saline soil conditions in north delta region. Egypt. J. Plant Breed. 24(2): 465-491
- Fang Y., Xiong L. (2015). General mechanisms of drought response and their application in drought resistance improvement in plants. Cell Mol. Life Sci., 72(4): 673-689.
- Fischer R.A. and Maurer R (1978). Drought resistance in spring wheat cultivars I. Grain yield responses. Aust. J. Agric. Res., 29:897-912.
- Gemechu K., Endashaw B., Muhammad I., Kifle D., and Getinet A., (2017). Challenges associated with crop breeding for adaptation to drought-prone environments. Ethiopian Journal of Agricultural Science, vol. 27, no. 1, pp. 1–4.
- Hamed, H.C.M.; Rezig M. and Naceur. M.B. (2015). Water use efficiency of durum wheat (*Triticum durum* Desf) under deficit irrigation. Journal of Agricultural Sciences 7: 238-249.
- Hussin S. A. E. (2007). Mechanisms of salt tolerance in the halophytes *Atriplex nummularia* Lindl. and *Atriplex leucoclada* Boiss. Ph.D. thesis, Gottfried Wilhelm Leibniz Universität Hannover, Niedersachsen, Germany.
- Kacem N. S., Delporte F., Muhovski Y., Djekoun A. and Watillon B. (2017). In vitro screening of durum wheat against water- stress mediated through polyethylene glycol. Journal of Genetic Engineering and Biotechnology, vol. 15, no. 1, pp. 239–247.
- Khayatnezhad M., Gholamin R. (2021). The effect of drought stress on the superoxide dismutase and chlorophyll content in durum wheat genotypes. Adv. Life Sci., 8: 119-123.
- Koyro H. W. (2003). Study of potential cash crop halophytes in a quick check system: Determination of the threshold of salinity tolerance and the ecophysiological demands. In: Lieth H., Mochtchenko M. (eds) Cash Crop Halophytes: Recent Studies. Tasks for Vegetation Science, vol 38. Springer, Dordrecht. doi: 10.1007/978- 94-017 -0211-9 -1.
- Kozłowski T. T. and Pallardy S. G. (2002). Acclimation and adaptive responses of woody plants to environmental stresses,” The Botanical Review, vol. 68, no. 2, pp. 270–334.
- Lamaoui M., Jemo M., Datla R. and Bekkaoui F., (2018). Heat and drought stresses in crops and approaches for their mitigation,” Frontiers in Chemistry, vol. 6, p. 26.
- Leilah A.A. and Al-Khateeb S.A. (2005). Statistical analysis of wheat yield under drought conditions. J. Arid Environ., 61: 483-496.
- Levene H. (1960). Robust test for equality of variances. Contributions to probability and statistics, 278-292. Stanford University Press, Palo Alto, vol. 2: 278-292.
- Lichtenthaler H. K. and Wellburn A. R. (1983). Determination of Total Carotenoids and Chlorophylls a and b of Leaf Extracts in Different Solvents. Biochemical Society Transactions, 11, 591-603.
- Lum M., Hanafi M., Rafii Y., and Akmar A. (2014). Effect of drought stress on growth, proline and antioxidant enzyme activities of upland rice. Journal of Animal & Plant Science, vol. 24, pp. 1487–1493.
- Mahamed, M.B.; Sarobol, E.D.; Hordofa, T.; Kaewrueng S. and Verawudh. J. (2011). Effects of soil moisture depletion at different growth stages on yield and water use efficiency of bread wheat grown in semiarid conditions in Ethiopia. Kasetsart Journal Natural Science 45: 201-208.
- Manuchehri R. and Salehi H. (2014). Physiological and biochemical changes of common bermudagrass (*Cynodon dactylon* Pers.) under combined salinity and deficit irrigation stresses,” South African Journal of Botany, vol. 92, pp. 83–88.
- Marmar A., Baenziger S. and Dweikat I. (2013). Preliminary screening for water stress tolerance and genetic diversity in wheat (*Triticum aestivum* L.) cultivars from Sudan,” Journal of Genetic Engineering and Biotechnology, vol. 11, no. 2, pp. 87–94.
- Michael C. Jensen (1978). Some Anomalous Evidence Regarding Market Efficiency, Journal of Financial Economics, Vol. 6, Nos. 2/3 pp 95-101.
- Microsoft EXCEL (2016). Computer user’s guide.
- Morsy S. M., Elbasyoni I. S., Abdallah A. M., Baenziger P. S. (2021). Imposing water deficit on modern and wild wheat collections to identify drought-resilient genotypes. Journal of Agronomy and Crop Science 00: 1-14.
- Mu Q., Cai H., Sun S., Wen S., Xu J., Dong M., Saddique Q. (2021). The physiological response of winter wheat under short-term drought conditions and the sensitivity of different indices to soil water changes. Agricultural Water Management 243:106475.

- Mwadingeni L., Shimelis H., Dube E., Laing M. D., Tsilo T. J. (2016). Breeding wheat for drought tolerance: Progress and technologies. J. Integr. Agric. 15: 935-943.
- Nazar R., Umar S., Khan N. A. and Sareer O. (2015). Salicylic acid supplementation improves photosynthesis and growth in mustard through changes in proline accumulation and ethylene formation under drought stress. South African Journal of Botany, vol. 98, pp. 84-94.
- Nehe A. S., Foulkes M. J., Ozturk I., Rasheed A., York L., Kefauver S. C., Ozdemir F., Morgounov A. (2021). Root and canopy traits and adaptability genes explain drought tolerance responses in winter wheat. PLoS One 16 (4): e0242472.
- Novica, V. (1979). Irrigation of agriculture crops. Fac. Agric. Press, Novi sad Yugoslavia.
- Onyemaobi I., Liu H., Siddique K.H., Yan G. (2017). Both male and female malfunction contributes to yield reduction under water stress during meiosis in bread wheat. Frontiers in Plant Science, 7: 2071.
- Osakabe Y., Osakabe K., Shinozaki K. and Tran L. S. P. (2014). Response of plants to water stress," Frontiers in Plant Science, vol. 5, no. 86, pp. 1-8.
- Payne R. W., Murray D. A., Harding S. A. (2017). An introduction to the GenStat command language. Hemel Hempstead, UK: VSN International.
- Rhoads F. M. and M. E. Bloodworth (1964). Area measurement of cotton leaf by dry weight method, Agronomy J. 56(5):520-525.
- Salemi, H.; Soom, M. A. M.; Lee, T. S.; Mousavi, S. F; Ganji, A. and Kamil Yusoff, M. (2011). Application of Aqua Crop model in deficit irrigation management of winter wheat in arid region. African Journal of Agricultural Research 610:2204-2215.
- Sangtarash M. H. (2010). Responses of different wheat genotypes to drought stress applied at different growth stages. Pakistan Journal of Biological Sciences, 13 (3): 114-119.
- Schonfeld M., Johnson R., Carver B. and Mornhinweg D. (1988). Water relations in winter wheat as drought resistance indicators," Crop Science, 28: 536-541.
- Senapati N., Stratonovitch P., Paul M.J., Semenov M.A. (2019). Drought tolerance during reproductive development is important for increasing wheat yield potential under climate change in Europe. J. Exp. Bot. 70: 2549-2560.
- Shalaby E., Galall E., Ali M., Amro A., El Ramly A. (2020). Growth and yield responses of ten wheat (*Triticum aestivum* L) genotypes to drought. SVU- International Journal of Agricultural Sciences 2: 1-17.
- Shehab-Eldeen M. T. and Farhat W. Z. E. (2020). Response of some exotic bread wheat genotypes to reduced irrigation in north Delta region of Egypt. Egypt. J. Plant Breed., 24 (4): 793-815.
- Sun, H.Y.; Liu, C.M.; Zhang, X.Y.; Shen, Y.Q. and Zhang, Y.J. (2006). Effects of irrigation on water balance, yield and WUE of winter wheat in the North China Plain. Agric. Water Manage., 48: 151-167.
- Steel R. G. D., Torrie J. H., Dicky D. A. (1997). Principles and procedures of statistics, A biometrical approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York, 352-358.
- Wasaya A., Manzoor S., Yasir T. A., Sarwar N., Mubeen K., Ismail I. A., Raza A., Rehman A., Hossain A., El Sabagh A. (2021). Evaluation of fourteen bread wheat (*Triticum aestivum* L.) genotypes by observing gas exchange parameters, relative water and chlorophyll content, and yield attributes under drought stress. Sustainability 13: 1-15.
- Yang J., Zhang J., Wang Z., Zhu Q., Liu L. (2001). Water deficit induced senescence and its relationship to the remobilization of pre-stored carbon in wheat during grain filling. Agron. J., 93: 196-206.
- Zhao W., Liu L., Shen Q., Yang J., Han X., Tian F., Wu J. (2020). Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. Water 12(8): 21-27.

## بعض الصفات المورفوفسيولوجية كدلائل لتحمل نقص الماء في بعض التراكيب الوراثية لقمح الخبز عبد الفتاح محمد عبد الفتاح ناجي<sup>١</sup>، وائل محمد عبد الحليم غانم<sup>١</sup>، ياسمين إسماعيل محمود عثمان<sup>٢</sup> ومحمود إبراهيم بدوي<sup>٣</sup>

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### الملخص

أجريت هذه الدراسة في محطة البحوث الزراعية بالجميزة بهدف تقييم قدرة بعض التراكيب الوراثية لقمح الخبز على تحمل نقص مياه الري، وذلك من خلال دراسة مجموعة من الصفات المورفولوجية والفسولوجية. تم تنفيذ التجربة خلال موسمي ٢٠٢١/٢٠٢٠ و ٢٠٢٢/٢٠٢١ 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 أثر بشكل معنوي على جميع الصفات المدروسة، في حين اختلفت التراكيب الوراثية فيما بينها بصورة واضحة في الصفات المورفولوجية للقمح. وقد تميزت الأصناف: جميزة ١٢، مصر ٣، مصر ١، جميزة 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 المورفوفسيولوجية مؤشرات وأداة في اختيار أصناف القمح المحتملة 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 تحمل الإجهاد المائي، بما يساهم في تعزيز إنتاجية القمح في البيئات الجافة وشبه الجافة.