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Growth, Physiological Performance and Yield Traits Responses in Bread Wheat Cultivars under Drought, Sprinkler Irrigation and Potassium Levels Conditions

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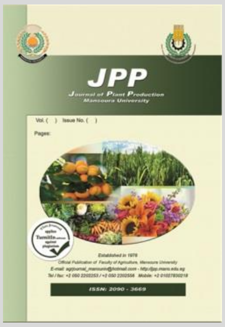

ABSTRACT

Water scarcity is a major obstacle to wheat output in the context of climate change, particularly in dry and semi-arid areas. A field experiment was conducted at the Ismailia Agricultural Research Station in Egypt during the two consecutive seasons of 2020/2021 and 2021/2022 to examine the effects of potassium levels on growth traits, physiological performance, as well as yield and yield attributes of droughted bread wheat cultivars. Four potassium levels (0, 24, 48, and 72 kg K_2O/fed) were applied to two wheat cultivars, Sakha 95 and Giza 171, under both drought and well irrigated circumstances. The acquired data proved that the plant water relations, membrane properties, photosynthetic pigments, and nutrient uptake were all significantly impacted by the drought exposure, which in turn affected yield and yield attributes. The exogenous potassium application, notably at 72 kg K_2O/fed, seems to lessen the negative effects of dryness on all growth metrics and photosynthetic pigments in both cultivars, especially Sakha 95. Moreover, all potassium levels, especially 72 kg K_2O/fed, improved leaf turgidity by raising relative water content, lowering saturation drought, and so enhancing yield and yield components in both cultivars, particularly Sakha 95.

***Keywords**:* Wheat, Drought, Potassium, Growth, yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is grown extensively over much of the world (Ahmad *et al.*, 2020). Global wheat production is estimated to be 763.3 million metric tons annually (FAOSTAT, 2023). By 2050, there would be a 60% increase in the demand for wheat, according to (Miransari and Smith, 2019). Drought reduces wheat productivity (El-Sabagh *et al.*, 2021). Egypt is one of the world's largest consumers of wheat, importing more over 22 million tons year (USDA, 2023). Its protein content gives the human diet more energy than any other grain crop (Ahmad *et al.*, 2020). According to Ahmad *et al.* (2022), the grain has 69% carbohydrates, 9.4% protein, 2.5% fat, and 1.8% fiber. In the field, wheat plants are regularly subjected to a range of biotic and abiotic stressors, which negatively impact their development, growth, and production (Chowdhury *et al.*, 2021).

Drought is one of the primary environmental variables affecting crop development and productivity (Waraich *et al.* 2020) due to its effects on essential processes and the structure of cells and tissues at every stage of growth (Wahab *et al.*, 2022). Drought has a detrimental effect on the morphological and physiological characteristics of plants, such as plant height, leaf area, leaf relative water content, leaf drought, membrane stability and chlorophyll content (Ghanem and Al-Farouk, 2024). In addition, drought, as an abiotic stressor, negatively impacts stressed wheat plants' morphophysiological traits (Duvnjak *et al.*, 2023), plant-water relations (Ahmad *et al.*, 2022), and yield criteria (Ali *et al.*, 2023) significantly. Plants suffering from drought exhibit a range of physiological and molecular abnormalities (Ahmad *et al.*, 2022). Because of the reduction in synthesis and the presence of pigments necessary for photosynthesis, it hinders plants' ability to use light and photosynthesis (Siddique *et al.*, 2016). Dryness induces oxidative stress in plants, which leads to anomalies in their physiological and biochemical functions and, eventually, cell suicide (Duvnjak *et al.*, 2023). Photosynthesis is one of the most impacted processes because dryness closes stomata, which reduces the amount of CO_2 available in a stepwise manner.

Potassium is a key inorganic osmoprotectant solute that helps plants tolerate drought (Basu *et al.*, 2021). The osmoprotectant solutes promote the capacity of cells to preserve water without interfering with their normal metabolic processes (Basu *et al.*, 2022). These osmoprotectants' primary roles include scavenging reactive oxygen species (ROS), controlling enzyme activity, balancing ionic transport across the cell membrane, and halting membrane disintegration (Elhakem, 2019). Moreover, these osmolytes maintain the physiological functioning of plants, which is thought to be the primary means by which plants adjust to stressful environments (Basu *et al.*, 2021). Thus, the goal of the current study was to examine how potassium level supplementation affected

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the physiological function, yield, and growth characteristics of bread wheat cultivars that had been affected by drought.

MATERIALS AND METHODS

Plant growth conditions

At the Ismailia Agricultural Research Station farm in the Ismailia Governorate (Lat. 30° 35' 30" N, Long. 32° 14' 50" E, 10 m above sea level), Egypt, a field experiment using sprinkler irrigation was conducted over the course of two consecutive seasons, 2020/2021 and 2021/2022. With three replications, the study was set up in an randomized complete block design (RCBD) in split-split plot arrangement. Distributed among the main, sub, and sub-subplots were the irrigation treatment, wheat cultivars, and potassium treatments, respectively. Each plot area was 7.2 m^2; 3 m in long, 2.4 m in wide, and 20 cm apart. The two wheat cultivars used in the experiment were Sakha 95 and Giza 171. The Wheat Research Department, Field Crops Research Institute, Agricultural Research Center, Egypt provided the pedigree and source of the wheat grains (Table 1).

Table 1. Origin, pedigree, and history of selection of the wheat cultivars under study.

Cultivar	Pedigree and History of selection	Origin
Sakha 95	PASTOR//SITE/MO/3/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/4/WBLL1 CMA01Y00158°-040POY-040M-030ZIM-040SY26M- 04-OM-OY-OSY-OS	Egypt
Giza 171	SAKHA93 /GEMMEIZA 9 S.6-1GZ- 4GZ- 1GZ- 2GZ-0S	Egypt

Two irrigation treatments are done once germination is finished: watering every two days for well-watered plants and every four days for drought-prone plants. During the tillering stage, two equal doses of K were given every ten days at four different levels: 0, 24, 48, and 72 kg K_2O/fed. Phosphorus and nitrogen fertilizers were given to the plants in accordance with the prescribed dosages for seedbed preparation: thirty kg of P_2O_5/fed was administered, and 120 kg of N/fed was added in five equal doses. Ten samples from each treatment were gathered at the heading stage in order to evaluate the growth parameters. In addition, three samples were obtained for biochemical examination from each therapy. After gathering data, mean values for the two seasons were computed.

Growth parameters:

Flag leaf area = Length X Breadth X 0.75 (Quarrie and Jones, 1979).

Specific leaf area = leaf area / Dry mass (Beadle, 1993).

Leaf area index = Leaf area per plant / Ground area covered by the plant (Beadle, 1993).

Degree of succulence = water amount / Leaf area (Delf, 1912).

Shoot density = Dry Mass / Length (Arduini *et al.,* 1994).

Shoot distribution = Fresh Mass / Length (Arduini *et al.,* 1994).

Estimation of relative water content (RWC).

The RWC of flag leaves was estimated by the method of Schonfeld *et al.* (1988).

Estimation of the saturation water deficit (SWD). S

WD was estimated according to Schonfeld *et al.* (1988) method.

Estimation of water use efficiency for grains (WUEG):

WUEG was estimated according to Stanhill (1987) method.

Estimation of membrane stability index (MSI):

MSI was estimated according to Sairam *et al.* (2002) method with some modifications.

Estimation of membrane leakage (ML):

ML was measured by using Vahala *et al.* (2003) method.

Estimation of chlorophylls and carotenoids:

A method established by Jichtenthaler and Buschmann (2001) for measuring chlorophylls and carotenoids.

Nutrients uptake:

The plant shoot with spike samples taken at heading, plant, shoot samples without grains, and grain samples taken at harvest were dried in an oven at 75 °C and the total K, total N, and total P content were estimated according to (Yang *et al.*, 2011).

Yield Analysis:

Heading date (days), Maturity date (days,) Plant height (cm), Spike length (cm), Spike weight (g), Number of spikes/m^2, Number of grains/spikes, Hundred kernels weight (g), Biological yield (t/fed), Grain yield (t/fed), Harvest index, and Straw yield (t/fed).

Soil Analysis:

Before sowing the plant, soil was sampled with an auger to determine the soil chemical and physical characteristics. To be analysed, soil samples were packed in plastic bags, marked with tags, and delivered to the soil and water testing laboratory. Details of several physiochemical characteristics are provided in Table 2. Climatic conditions: air temperature (ºC) and relative humidity % (RH) were daily recorded and their monthly mean values were calculated (Table 3).

Table 2. Soil physiochemical parameters before sowing of wheat crop season.

Parameters	2020/2021	2021/2022
Mechanical Analysis		
Sand (%)	89.20	88.80
Clay (%)	3.78	3.98
Silt (%)	7.02	7.22
Texture grade	Sandy	Sandy
Chemical Analysis		
pH (1:25)	7.89	7.90
EC (dS/m)	0.4	0.41
Organic C (%)	0.27	0.29
CaCO3	0.32	0.33
Soluble anion meq/100g soil		
CO_3^{2-}	-	-
HCO_3^-	0.5	0.53
Cl^-	1.92	1.93
SO_4^{2-}	1.45	1.45
Soluble cation meq/100g soil		
Ca^{2+}	1.22	1.23
Mg^{2+}	0.63	0.65
Na^+	1.84	1.84
K^+	0.18	0.19
Available N, P, K (ppm)		
N	20	20.2
P	4.5	4.6
K	57.18	57.21

Table 3. Climatic conditions of the experimental site during both wheat growing seasons. T_{max}: Maximum air temperature (ºC), T_{min}: Minimum air temperature (ºC), Tavr: Average air temperature (ºC), Relative Humidity: RH.

Season	2020/2021			2021/2022			2020/2021	2021/2022
Parameter / Month	**T_{min}**	**T_{max}**	**Tavr**	**T_{min}**	**T_{max}**	**Tavr**	**RH**	
November	16.37	23.57	19.79	17.57	26.67	22.12	61.5	62.9
December	11.36	22.44	17.22	10.41	19.24	14.825	59.7	64.9
January	9.82	21.2	16.7	6.82	15.7	11.26	63.3	67.3
February	11.67	22.06	16.33	9.87	19.96	14.915	61.97	64.07
March	11.1	23.7	18.2	9.6	21.69	15.645	59.9	53.7
April	13.09	29.6	21.86	14.49	31.4	22.945	44.9	40.6
May	17.10	32.2	24.65	15.9	28.4	22.15	39.9	44.9

Statistical analysis.

Data were treated by analysis of variance (ANOVA) and different letters revealed remarkable variations among means of treatments at $p \leq 0.05$ in accordance with the version 6.311 of CoHort/CoStat software.

RESULTS AND DISCUSSION

Drought is a significant environmental stressor which restricts plant productivity and yield. Plants respond to drought in different ways; morpho physiologically and biochemically (Ghanem and Al-Farouk, 2024). In this investigation, stressed as well as unstressed wheat cultivars were subjected to different potassium levels to evaluate the interactive influences of these factors on crop parameters related to growth, metabolism, nutrient acquisition, development, and productivity as a function of an injurious growth condition. The parameters assessed responded to the experimental factors in a triple, double, or non-interactive manner. As shown in Table 2, the soil of the experimental site before both wheat sowing seasons suffers from nutrient deficiencies which exert a nutritional problem for wheat grain yield and grain nutritional quality. Moreover, Table 3 clarified the climatic conditions of the experimental site during both wheat growing seasons.

Effects of drought and K addition on the shoot growth vigor.

The acquired data made it clear that all parameters related to shoot growth, biomass, number of tillers, length, density, and distribution, were noticeably reduced by drought (Table 4). These outcomes agreed with the conclusion reported by Basu *et al.* (2022). According to Munns (2002), the findings support his theory that the stress of reduced water absorption by the plant causes a sharp decline in growth rate and a range of metabolic changes similar to those brought on by drought, which in turn causes the negative effect of drought on shoot growth. Furthermore, Tawfik *et al.* (2006) suggest that a decrease in shoot growth during a drought may be caused by a reduction in photosynthesis in conjunction with issues with protein synthesis, mineral uptake, and/or glucose metabolism.

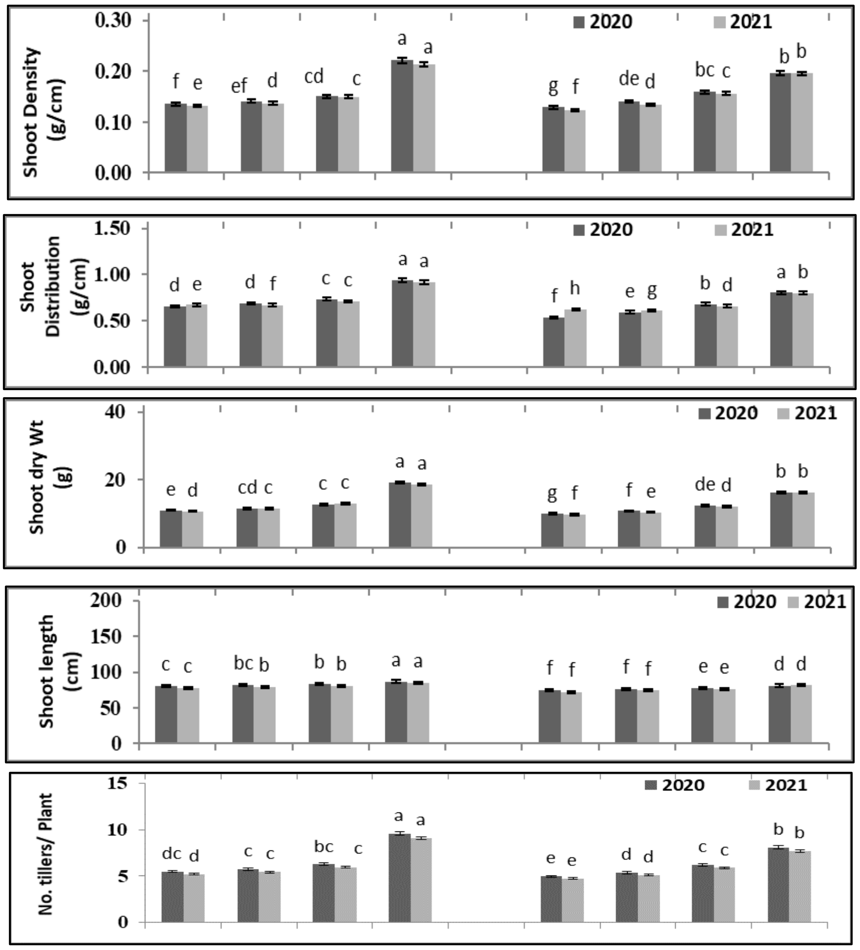
Table 4. The impact of water treatment, wheat cultivars, potassium treatments, and their interaction on shoot growth vigor at heading. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

Traits	No. tillers/ plant		Shoot length (cm)		Shoot fresh Wt (g)		Shoot dry Wt (g)		Shoot Distribution (g/cm)		Shoot Density (g/cm)	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
A. Irrigation												
Well-watered	6.75	6.42	83.15	80.66	62.94	60.71	13.51	13.40	0.76	0.74	0.16	0.16
Droughted	3.73	3.54	66.75	66.24	50.49	48.91	10.46	10.12	0.71	0.69	0.15	0.14
F test	**	**	**	**	**	**	**	**	*	**	**	**
B. Cultivar												
Giza 171	4.34	4.12	66.97	65.94	47.34	45.47	10.55	10.12	0.66	0.68	0.15	0.14
Sakha 95	6.15	5.84	72.83	70.97 a	53.16	50.81	10.88	10.53	0.81	0.76	0.16	0.15
F test	**	**	**	**	**	**	*	*	**	**	*	**
C. K levels kg K_2O/fed												
K0	4.16^d	3.95^d	71.80^d	69.34^d	46.44^d	44.48^d	9.76^d	9.38^d	0.61^d	0.64^c	0.13^d	0.12^d
K1	4.73^c	4.49^c	72.78^c	70.87^c	49.89^c	47.72^c	10.93^c	10.64^c	0.64^c	0.64^c	0.14^c	0.14^c
K2	5.18^b	4.92^b	75.75^b	74.53^b	56.91^b	54.64^b	11.87^b	11.88^b	0.76^b	0.70^b	0.15^b	0.15^b
K3	6.95^a	6.60^a	79.47^a	79.06^a	73.62^a	72.39^a	15.39^a	15.15^a	0.93^a	0.90^a	0.19^a	0.18^a
F test	**	**	**	**	**	**	**	**	**	**	**	**
D. Interactions												
A X B	**	**	**	*	ns	ns	ns	ns	ns	ns	ns	ns
A X C	**	**	*	**	**	**	**	**	**	**	**	**
B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

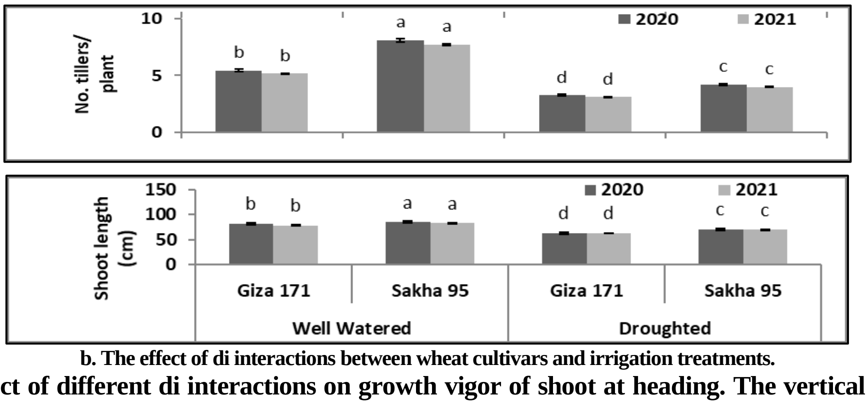
Regarding the parameters for shoot growth, wheat cultivars varied greatly as well; Sakha 95 recorded higher values than Giza 171. Thus, genetic variations amongst wheat cultivars could be the cause of these discrepancies. According to this research, there may be a detectable degree of genetic diversity that is particularly crucial for adaptability and flexibility in a variety of environmental settings. Additionally, the significant primary impacts of the genotypes and their interactions with environments were confirmed by Ghanem and Gebrel (2024), showing that these genotypes have genes with changeable additives that look unstable and tend to rank differently depending on the environment.

The fact that stress can impair a plant's capacity to absorb water and cause a sharp decline in growth rate, in addition to a variety of metabolic alterations similar to those brought on by drought conditions, may help to explain the hazardous effect of drought on shoot growth (Elhakem, 2019). Moreover, a decrease in photosynthesis, along with disruptions in protein synthesis, carbohydrate metabolism, and/or mineral uptake, could be the cause of the decline in shoot growth during a drought (Ahmad *et al.,* 2022). Furthermore, it is commonly known that a drought may inhibit plant growth by reducing the amount of leaf area (Table 4).

Graded potassium levels had a substantial impact on all aspects of shoot growth, with the level of 72 kg K2O/fed having the greatest effects on shoot biomass, number of tillers, shoot length, density, and distribution (Table 4). So, prolonged leaf photosynthesis, postponed leaf senescence, and improved vegetative growth in wheat plants may be the cause of the growth metrics' improvement with K addition (Swetha *et al.,* 2017). There was no triple interaction effect of irrigation, cultivar, and K treatment on all shoot growth parameters (Table 4). The interaction between irrigation and K levels showed a remarkable impact on all shoot growth parameters; this was shown in Figure 1a. The combination of irrigation and K treatments from the well watering treatment and 72 kg K2O/fed recorded the highest values of number of tillers, shoot biomass, shoot length, shoot density, and distribution (Figure 1, a). Furthermore, the combination between wheat cultivars and treatments under drought had a remarkable influence on shoot length and tiller number (Figure 1, b).



a. The impact of di interactions between levels of potassium and irrigation.



b. The effect of di interactions between wheat cultivars and irrigation treatments.

Figure 1. The effect of different di interactions on growth vigor of shoot at heading. The vertical bars showed the standard error of the mean (n=10). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

Impact of drought and K treatment on the flag leaves growth vigor.

The acquired data proved that the degree of succulence, leaf area, leaf biomass, and leaf specific area were all significantly reduced by drought (Table 5). This can be understood by seeing that reduced water absorption leads to less water content in the developing leaves, as showed by less succulence, greater SWD, and less RWC (Table 6). The findings of this investigation support the theory put forth by Ghanem *et al.* (2019), which postulates that a decrease in growth may be an adaptive characteristic that helps plants endure drought by storing the energy and nutrients needed for shoot and leaf growth into molecules that act as barriers to the process of drying out. Furthermore, Sakha 95 greatly outperformed Giza171 in terms of flag leaf growth requirements. Usually, wheat uses its flag leaves as its primary photosynthetic organ, especially as the grain is filling. According to Aldesuquy *et al.* (2012), specific area, leaf area index, and degree of succulence are crucial adaptation indicators for stress tolerance. Furthermore, slower growth and development brought on by osmotic stress could account for the observed decrease in leaf growth, according to Shani and Ben-Gal (2005) along with suppression of photosynthesis either from direct impacts of stress on the photosynthetic machinery or secondary effects resulting from a reduction in sink capacity (Moradi and Ismail, 2007).

Table 5. The impact of water treatment, wheat cultivars, potassium treatments, and their interaction on growth vigor of flag leaves at heading. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

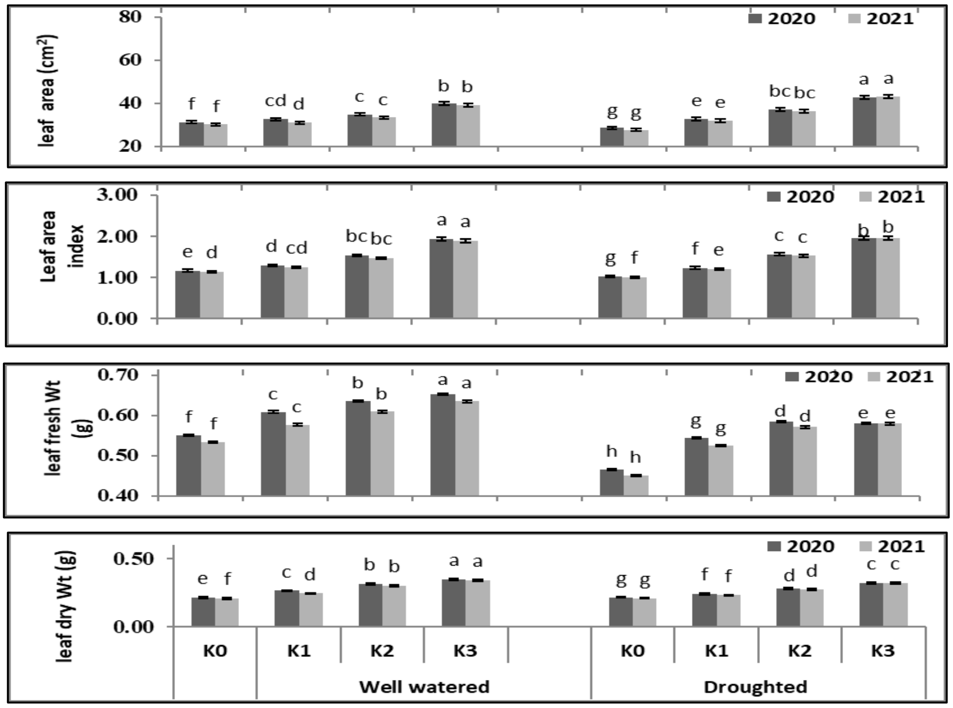
Traits	leaf fresh Wt (g)		leaf dry Wt (g)		leaf area (cm^2)		Leaf area index		Specific leaf area (cm^2/mg)		Dgree of Succulence (g/cm)	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
A. Irrigation												
Well-watered	0.61	0.59	0.28	0.27	34.53	33.29	1.48	1.43	0.21	0.21	0.015	0.016
Droughted	0.42	0.41	0.21	0.21	25.45	24.96	1.12	1.10	0.20	0.20	0.011	0.01
F test	*	**	**	**	*	**	**	**	*	*	*	**
B. Cultivar												
Giza 171	0.42	0.40	0.21	0.20	24.32	23.63	1.07	1.11	0.19	0.19	0.012	0.012
Sakha 95	0.49	0.47	0.23	0.22	30.24	34.63	1.21	1.41	0.21	0.21	0.013	0.015
F test	**	**	**	**	**	**	**	**	**	**	*	**
C. K levels kg K_2O/fed												
K0	0.44^{d}	0.43^{d}	0.19^{d}	0.18^{d}	25.00^{d}	24.39^{d}	0.95^{d}	0.95^{d}	0.19^{d}	0.185^{d}	0.011^{d}	0.010^{d}
K1	0.51^{c}	0.48^{c}	0.23^{c}	0.22^{c}	28.48^{c}	27.03^{c}	1.15^{c}	1.09^{c}	0.20^{c}	0.195^{c}	0.012^{c}	0.011^{c}
K2	0.54^{b}	0.52^{b}	0.27^{b}	0.26^{b}	31.14^{b}	30.02^{b}	1.41^{b}	1.36^{b}	0.21^{b}	0.20^{b}	0.013^{b}	0.013^{b}
K3	0.57^{a}	0.57^{a}	0.30^{a}	0.30^{a}	35.35^{a}	35.30^{a}	1.68^{a}	1.66^{a}	0.23^{a}	0.22^{a}	0.014^{a}	0.014^{a}
F test	**	**	**	**	**	**	**	**	**	**	**	**
D. Interactions												
A X B	**	**	ns	ns	**	**	ns	ns	ns	ns	ns	ns
A X C	**	**	**	**	**	**	**	**	ns	ns	ns	ns
B X C	ns	ns	ns	ns	**	**	**	**	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 6. The impact of wheat cultivars, water treatments, potassium treatments, and their interaction on ML% and MSI%, RWC%, SWD%, and WUEG. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. ML: membrane leakage; MSI: membrane stability index; RWC: relative water content; SWD: saturation water deficit; WUEG: water use efficiency of grains; K0:0; K1: 24; K2: 48; K3: 72.

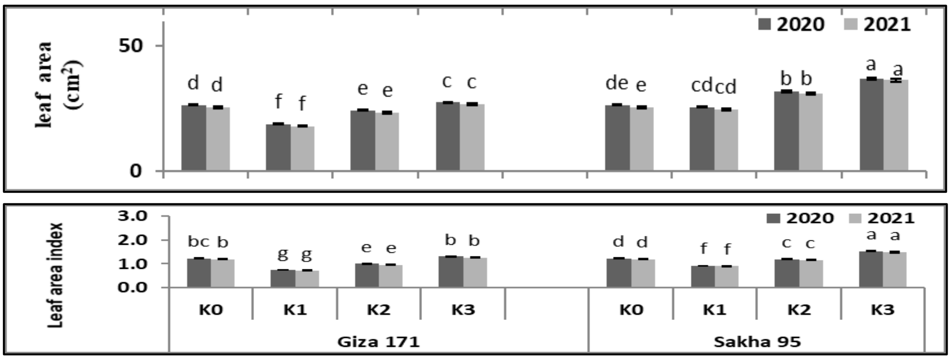
Traits	ML (%)		MSI (%)		RWC (%)		SWD (%)		WUEG (kg/m^3)	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
A. Irrigation										
Well-watered	2.56	2.54	59.16	58.08	80.09	77.31	19.91	22.69	2.12	2.05
Droughted	4.62	4.37	48.03	46.82	72.46	69.04	27.53	30.96	1.59	1.54
F test	**	**	**	**	*	*	*	*	**	**
B. Cultivar										
Giza 171	4.81	4.58	43.70	42.07	75.14	72.03	24.59	27.97	1.61	1.54
Sakha 95	4.22	4.03	44.25	43.55	77.40	74.32	22.86	25.68	1.82	1.75
F test	**ns**	**	**	*	*	*	*	*	**	**
C. K levels kg K_2O/fed										
K0	4.5^{a}	4.41^{a}	37.82^{d}	36.30^{d}	70.46^{d}	67.28^{d}	29.53^{a}	32.72^{a}	1.66^{d}	1.59^{d}
K1	4.05^{b}	4.00^{b}	38.77^{c}	39.08^{c}	73.99^{c}	70.39^{c}	26.01^{b}	29.60^{b}	1.78^{c}	1.69^{c}
K2	3.27^{c}	3.11^{d}	59.62^{b}	57.28^{b}	79.92^{b}	76.06^{b}	20.08^{c}	23.94^{c}	1.89^{b}	1.83^{b}
K3	2.45^{d}	2.31^{c}	78.17^{a}	77.14^{a}	81.02^{a}	79.22^{a}	18.98^{d}	20.78^{d}	2.09^{a}	2.06^{a}
F test	**	**	**	**	**	**	**	**	**	**
D. Interactions										
A X B	ns	ns	**	**	ns	ns	ns	ns	ns	ns
A X C	**	**	**	**	**	**	**	**	**	**
B X C	ns	ns	**	**	ns	ns	ns	ns	**	**
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

In general, potassium application specifically, at 72 kg K2O/fed seemed to be the most successful method of preventing the negative effects of drought on all of the flag leaf's growth metrics (Table 5). Raising potassium levels may have contributed to an increase in the quantity of cellular components, primarily protoplasm, which in turn led to a rise in leaf area and the leaf area index. Furthermore, it is likely that K's beneficial effects stem from its capacity to improve RWC (Table 6), as well as the uptake of nutrients and translocation of total leaf protein in wheat plants and through the transpiration stream. The present findings are consistent with that showed by Baque *et al.* (2006).

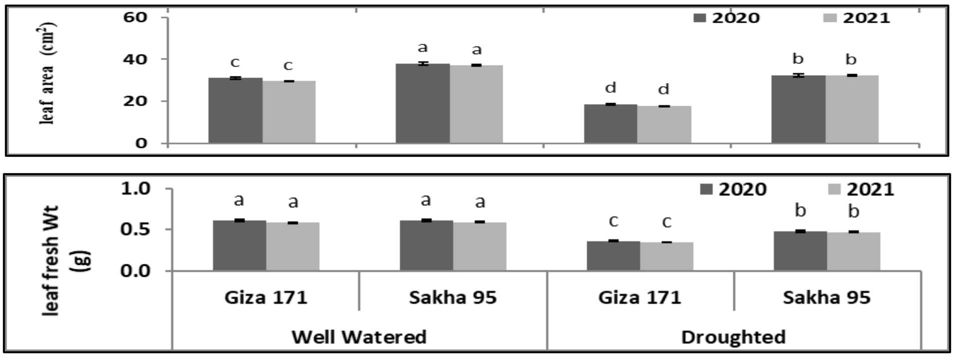
Table 5 shows that there was no tri-interaction effect of irrigation, cultivars, and K treatment on nearly all of the metrics related to flag leaf growth in wheat plants at heading. Irrigation and k treatments had an interaction effect on every flag leaf development criterion (Figure 2, a). The maximum values of flag leaf area, leaf area index, specific leaf area, and fresh and dry weight were obtained when watering and K level were combined at a level of 72 kg K_2O/fed (Figure 2, a). Otherwise, the combination of drought and zero K level treatment resulted in the lowest values of the aforementioned parameters being observed. Additionally, wheat cultivars and k treatments had an interaction effect on the leaf area index and flag leaf area (Figure 2, b). Furthermore, leaf area and leaf fresh weight were significantly affected by the combination of wheat cultivars and irrigation treatments (Figure 2, c).



a. The impact of di- interaction between K treatments, and irrigation.



b. The effect of di- interaction between wheat cultivars, and K treatments.

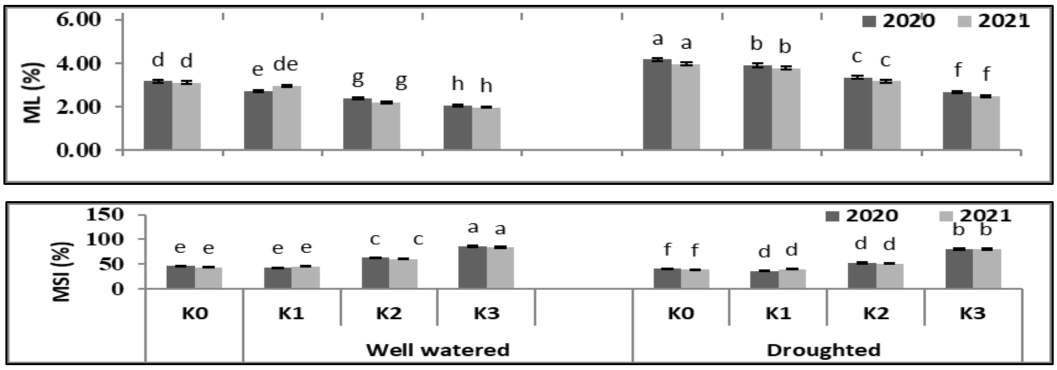


c. The impact of di- interaction between wheat cultivars and irrigation treatments.

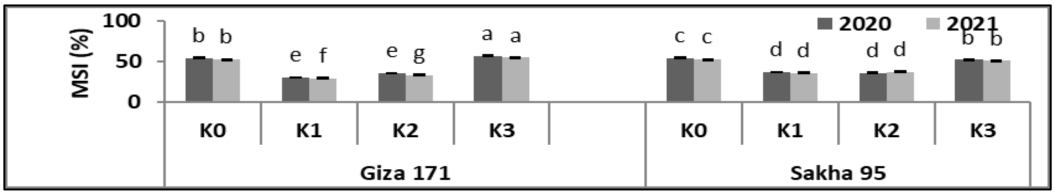
Figure 2. The effect of different di- interaction on growth vigor of flag leaf at heading. The vertical bars showed the standard error of the mean (n=10). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

Impact of drought and K supplementation on membrane leakage (ML) and membrane stability index (MSI).

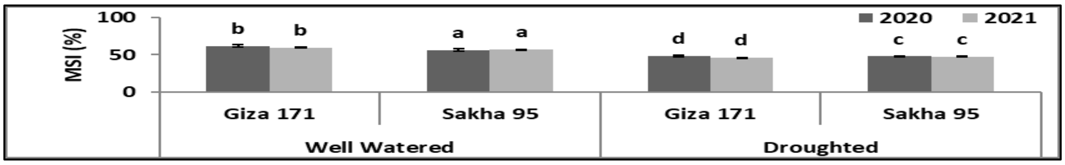
One of the primary biological targets for various stress types is the cell membrane (Zayed *et al.,* 2023). The degree of damage to the membrane shows how resilient the plant is to external factors like drought (Ahmad *et al.*, 2023). In the present study, dryness led to a notable increase in ML and a notable decrease in MSI of wheat plants (Table 6). Furthermore, wheat cultivars showed significant variations with respect to MSI and ML, recording more MSI in Sakha 95 than in Giza 171. This agreed with Zayed *et al.* (2023) findings. Drought is known to increase the production of free radicals, which then triggers the lipid peroxidation of biomembranes, causing cells to spill their contents, quickly dehydrate, and die (Basu *et al.,* 2021). Conversely, K application recorded a significant decrease in ML with a marked increase in MSI, especially at 72 kg K_2O/fed. There was no triple interaction effect of irrigation, cultivars, and K treatment on MSI (Table 6), while there was a tri-interaction in ML (Figure 3, d). The combination of wheat cultivars and K treatment significantly affected MSI, as Figure 3b illustrates. Additionally, there was an interaction effect on the membrane stability index between wheat cultivars and irrigation (Figure 3, c). Furthermore, irrigation and K treatment had an interaction impact on MSI and ML (Figure 3, a). Conversely, the highest MSI values were obtained when irrigation was combined with K treatments that is, 72 kg of K_2O/fed and well watering treatment.



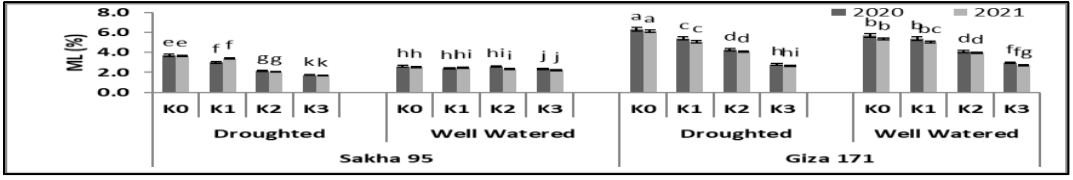
a. The effect of di- interactions between K treatments and irrigation on ML% and MSI%.



b. The effect of di- interactions between K treatments and wheat cultivars on MSI%.



c. The impact of di- interactions between wheat cultivars, and irrigation treatments on MSI%.



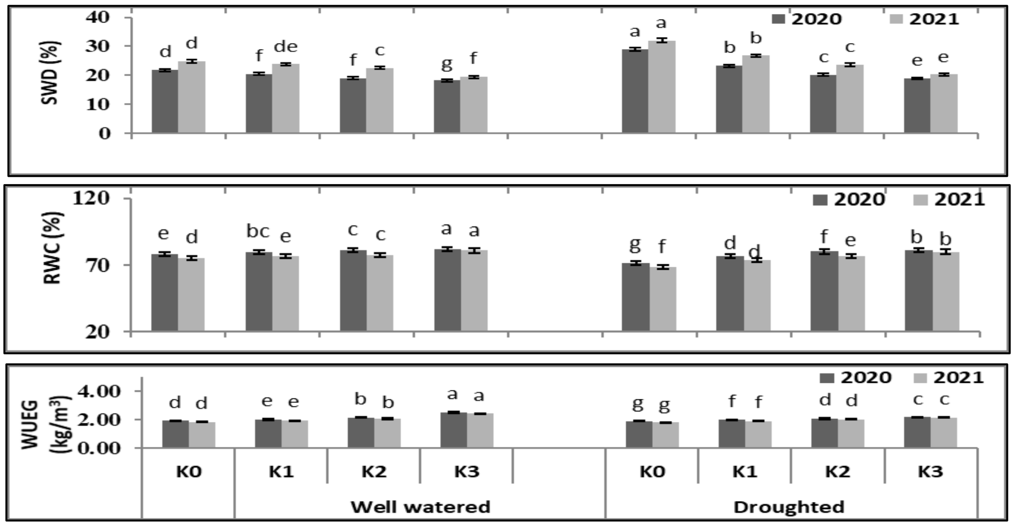
d. The tri- interaction effect of irrigation (watered v. droughted), cultivars (Giza 171 v. Sakha 95), and K treatment (K0, K1, K2 and K3) on ML.

Figure 3. The effect of different di- and tri- interactions on ML% and MSI% at heading. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. ML: membrane leakage; MSI: membrane stability index; K0:0; K1: 24; K2: 48; K3: 72.

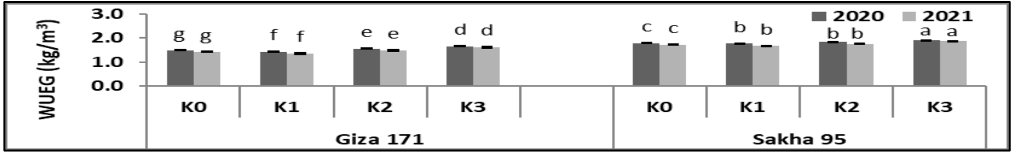
Response of water relations to drought and K application.

Water scarcity was found to be one of the most important factors in both predicting and regulating plant performance (Ahmad *et al.*, 2023). To achieve maximum growth with optimal water availability, it is vitally important for plants to increase WUE (Elhakem, 2020). In the present study, Table 6 showed that compared to untreated plants; drought induced an additional reduction in RWC%, WUEG and a marked increase in SWD during heading. As a result, there was a clear loss in practically every attribute of the shoot and flag leaf that was linked to the observed decrease in RWC and WUEG and the rise in SWD (Tables 4 & 5). These outcomes corroborated those of Aldesuquy *et al.* (2018a), who demonstrated that drought-exposed wheat plants considerably reduced the RWC. Water loss and cultivar-to-cultivar variations in water intake may be connected to the decrease in RWC in leaves. Furthermore, there were notable differences across cultivars in terms of RWC, WUEG, and SWD; Sakha 95 recorded higher levels of RWC, WUEG, and SWD than did Giza 171. The aforementioned findings on the water status of plant cells supported Sakha 95's superiority over Giza171.

Alternatively, the detrimental effects of drought were lessened to promote leaf turgidity by external K supplementation up to a rate of 72 kg K_2O/fed; in comparison to control plants, each of these treatments resulted in a noteworthy increase in RWC and a significant drop ($p \leq 0.05$) in SWD. K treatment increased RWC and decreased SWD to improve drought tolerance. By using soil moisture more effectively than plants lacking in K, K supplementation increased crop tolerance to drought conditions (Table 6). The control treatment, which applied to no potassium, recorded the lowest values of RWC and WUEG, while the increased potassium level exerted the greatest values of both. Similar findings were obtained by Umar (2006), who reported that K treatment improved RWC of plants in both normal and drought circumstances. Regarding RWC, WUEG, and SWD, there was no triple interaction effect of irrigation, cultivars, and K treatment (Table 6). In contrast, WUEG and WUEG were significantly affected by the combination of wheat cultivars and K treatment (Figure 4, b). Furthermore, as Figure 4a illustrates, there was an interaction impact between irrigation and K treatment on RWC, WUEG, and SWD. The highest values of RWC and WUEG were obtained when K treatments at 72 kg K_2O/fed and well watering treatment were combined (Figure 4, a). Furthermore, the combination of drought and zero K level resulted in the lowest values of the aforementioned features being reported.



a. The impact of di- interactions between irrigation and K treatment on RWC%, SWD%, and WUEG.



b. The effect of di- interactions between wheat cultivars and K treatment on WUEG.

Figure 4. The effect of different di- interactions on RWC%, SWD%, and WUEG of wheat cultivars at heading. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. RWC: relative water content; SWD: saturation water deficit; WUEG: water use efficiency of grains; K0:0; K1: 24; K2: 48; K3: 72.

Effects of drought and K treatment on photosynthetic pigments.

The present findings in Table 7 made it abundantly clear that the drought significantly reduced the pigment content of flag leaves (Chl a, Chl b, Chl a+b, Chl a/b, and total pigment). In the meantime, stressed wheat plants produced more carotenoids. Consequently, the decrease can be linked to the speed at which drought causes plant flag leaf senescence and, so, pigment deterioration. Carotenoids can also be used for photoprotection by quenching the triplet state of chlorophyll, light harvesting through singlet state energy transfer, scavenging singlet oxygen, preserving the structural integrity of plastids, and dissipating surplus energy (Elhakem, 2019). Additionally, cultivars differed greatly in terms of the pigment content of flag leaves; Sakha 95 had higher levels of total pigment, Chl a, Chl a+b, and Chl a/b, but lower levels of Chl b than Giza 171. The results obtained were consistent with the findings published by Aldesuquy *et al.* (2018b).

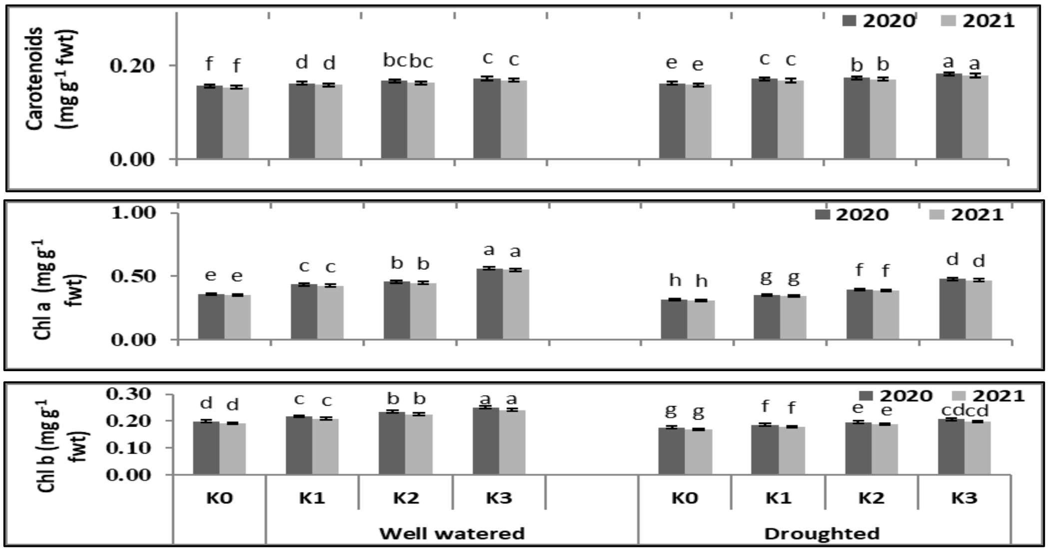
The pigments of wheat plants in the two seasons are greatly impacted by different K fertilizer amounts. The pigment content (chl a, chl b, Chl a+b, Chl a/b, carotenoids, as well as total pigment) in the flag leaves of the two cultivates improved with K treatment, especially at 72 kg K_2O/fed (Table 7). These findings aligned with research conducted by Wei *et al* (2013).

According to Gnanasundari *et al.* (2018), current data clearly indicate that K demand rises during droughts in order to preserve photosynthetic pigments and shield chloroplasts from oxidative damage. Also, Chloroplasts lose a lot of K when there is a drought, which further slows down photosynthesis and increases ROS generation Gnanasundari *et al.* (2018).

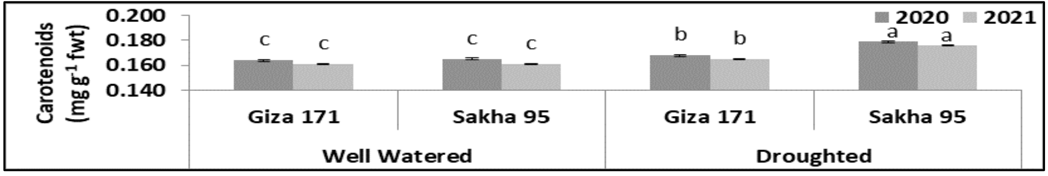
Furthermore, no triple interaction impact was observed between irrigation, cultivars, and K treatment on total pigment, carotenoids, chl a, chl b, chl a+b, and chl a/b (Table 7). On the other hand, carotenoids were significantly affected by the combination of wheat cultivars and drought treatment (Figure 5, b). Furthermore, the correlation between potassium levels and water treatment proved to be beneficial in boosting pigment content during drought conditions (Figure 5, a). The highest values of chl a and chl b were obtained with the K treatment at a level of 72 kg K_2O/fed in conjunction with well watering (Figure 5, a). Furthermore, the combination of zero potassium level and drought treatment resulted in the lowest values of the aforementioned features being reported. Furthermore, under drought conditions and 72 kg K_2O/fed treatment, the maximum value of carotenoids was produced (Figure 5, a).

Table 7. The impact of wheat cultivars, water treatment, potassium treatments, and their interaction on plant pigments at heading. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

Traits	Chl a (mg g^{-1} fwt)		Chl b (mg g^{-1} fwt)		Carotenoids (mg g^{-1} fwt)		Chl a+b		Chl a/b		Total pigments (mg g^{-1} fwt)	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
					A. Irrigation							
Well-watered	0.454	0.445	0.226	0.216	0.164	0.161	0.680	0.661	2.03	2.05	0.890	0.828
Droughted	0.330	0.324	0.194	0.186	0.173	0.170	0.524	0.510	1.73	1.75	0.735	0.674
F test	*	**	**	**	*	*	**	**	*	*	*	**
					B. Cultivar							
Giza 171	0.385	0.378	0.191	0.184	0.166	0.162	0.577	0.561	1.73	1.74	0.789	0.724
Sakha 95	0.398	0.391	0.228	0.219	0.172	0.169	0.627	0.609	2.03	2.04	0.835	0.778
F test	*	**	**	**	**	**	**	**	**	**	**	**
					C. K levels kg K_2O/fed							
K0	0.335^{d}	$0.\ 329^{d}$	0.193^{d}	0.221^{d}	0.160^{d}	0.156^{d}	0.529^{d}	0.514^{d}	1.74^{d}	1.76^{d}	0.725^{d}	0.672^{d}
K1	0.355^{c}	0.348^{c}	0.200^{c}	0.207^{c}	0.167^{c}	0.163^{c}	0.556^{c}	0.540^{c}	1.79^{c}	1.81^{c}	0.761^{c}	0.702^{c}
K2	0.398^{b}	0.390^{b}	0.216^{b}	$0.192^{\ b}$	0.171^{b}	0.168^{b}	0.614^{b}	0.597^{b}	1.87^{b}	1.89^{b}	$0.827^{\ b}$	0.765^{b}
K3	0.482^{a}	0.420^{a}	0.230^{a}	$0.186^{\ a}$	0.178^{a}	0.175^{a}	$0.711^{\ a}$	0.627^{a}	2.12^{a}	2.14^{a}	0.939^{a}	0.868^{a}
F test	**	**	**	**	**	**	**	**	**	**	**	**
					D. Interactions							
A X B	ns	ns	ns	ns	**	**	ns	ns	ns	ns	ns	ns
A X C	**	**	**	**	**	*	ns	ns	ns	ns	**	**
B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns



a. The impact of di- interactions between K treatments, and irrigation on Chl b, Chl a, and carotenoids.



b. The effect of di- interactions between wheat cultivars and irrigation treatment on carotenoids.

Figure 5. The effect of different di- interactions on Chl a, Chl b, and carotenoids of wheat cultivars at heading. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. Chl: Chlorophyll; K0: 0 kg K_2O/fed; K1: 24 kg K_2O/fed; K2: 48 kg K_2O/fed; K3: 72 kg K_2O/fed.

Effects of drought and K application on nutrients uptake and Total Protein.

Data in Table 8 showed that drought increased total nutrients uptake (K, P, and K) and protein content in wheat flag leaves at heading. These results contradict the results of earlier research of Ahmad *et al.* (2022) and Ghanem and Al-Farouk (2024). Moreover, Sakha 95 significantly surpassed Giza171 concerning nutrient uptake and total protein in both seasons of study. Furthermore, potassium application up to 72 kg K_2O/fed recorded the largest total nutrients uptake and total protein contents in wheat flag leaves at the heading.

The increase in N, K, and P uptake could result from improved use of applied N, K, and P in the condition of enough potassium in different stages of wheat growth, which encouraged improved dry matter production and root growth, resulting in an improvement in phosphorus content and uptake. Furthermore, this increase could have resulted in vigorous growth (Tables 3,4) and higher photosynthetic pigments (Table 7) that led to better uptake of N throughout the wheat growth period. In this regard, Kumar *et al.* (2015) showed that because applied potassium has a synergistic effect and facilitates the translocation of other nutrients, there is an increase in the uptake of other nutrients like nitrogen and phosphorus with increasing potassium application levels. Furthermore, the increase in protein may result from stimulating the synthesis of stress protein, which is the wheat cells' response to stress.

There was no tri-interaction effect between irrigation, cultivars and K treatment on the uptake of nutrients and total protein concentrations at heading, as Table 8 demonstrates. On the other hand, there was an interaction between wheat cultivars and irrigation for K uptake (Figure 6, b). Additionally, cultivars and K treatment had a substantial interaction effect on K absorption (Figure 6, c). Furthermore, the coupling of K levels and water treatment seemed to validate the beneficial impact of potassium on the uptake of nutrients and total protein contents during drought conditions (Figure 6, a). The highest values of total protein and nutrient absorption were obtained when potassium treatments and drought were combined at a rate of 72 kg K_2O/fed (Figure 6, a). Otherwise, the combination of a well-watered treatment and a zero potassium level was observed to yield the smallest levels of the aforementioned features.

Response of plant phenology to drought and K treatment.

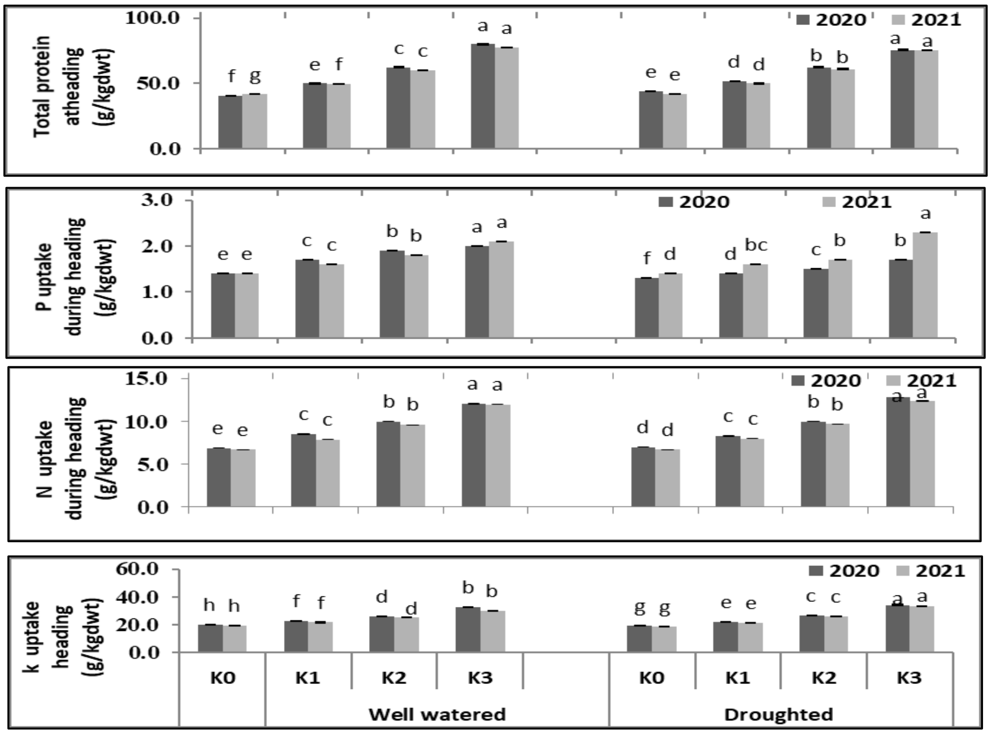
The length of a wheat genotype's phenological development is a critical characteristic for estimating grain output in any given environment (Motzo and Giunta, 2017). Aldesuquy *et al.* (2012) claimed that by reducing the detrimental effects of environmental pressures through shorter growth periods and balancing resource consumption, particularly moisture, the length of the growth phase interacts with phenological development to boost grain output. The number of days to heading and days to maturity was drastically lowered by dryness because it shortened plant leaf life and sped up senescence (Table 9). Days to heading and days to maturity may have decreased as a result of photosynthetic pigment depletion (Table 7), which eventually led to early plant maturity by causing early senescence during drought. Drought accelerated the growth stage and led to a notable reduction in the number of days to heading, as claimed by Ghanem and Al-Farouk (2024). The cultivars' days to heading and maturity varied greatly across them. When it came to the cultivars' performance, Sakha 95 outperformed Giza 171 in terms of days to heading and maturity.

Days to heading and maturity were greatly impacted and improved by different levels of K. Given that K application increased leaf growth and delayed leaf senescence by increasing leaf pigment, 72 kg K2O/fed appeared to be the most efficient quantity of supplementation in mitigating the negative effects of dryness on days to heading and maturity (Tables 5, 6). According to Gnanasundari *et al.* (2018), the strategy of escaping the drought is a characteristic of early heading and maturity.

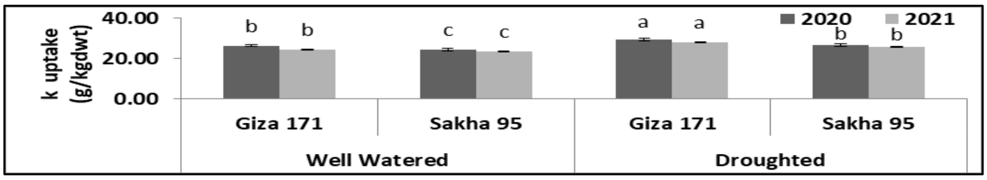
Furthermore, there was no triple interaction effect on days to maturity and head that resulted from irrigation, cultivars, and K treatment (Table 9). On the other hand, the combination of K levels and water treatment seemed to validate the beneficial impact of K on rasping plant phenology during drought (Figure 7, a). The highest values of days to heading and maturity were obtained when well watering was combined with K treatment at a level of 72 kg K_2O/fed (Figure 7, a). Additionally, the interaction between the drought treatment and the zero K level showed the lowest values of the aforementioned features (Figure 7, a).

Table 8. The impact of wheat cultivars, water treatment, potassium treatments (0, 24, 48, and 72 kg K_2O/fed), and their interaction on N P K uptake, and total protein of wheat flag leaves at heading. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. N: nitrogen; P: phosphorus; K: potassium; K0:0; K1: 24; K2: 48; K3: 72.

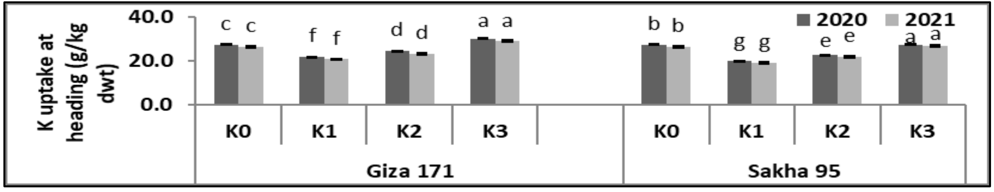
Traits	**N uptake (g/kg dwt)**		**P uptake (g/kg dwt)**		**k uptake (g/kg dwt)**		**Total protein (g/kg dwt)**	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
A. Irrigation								
Well-watered	9.5	9.13	1.81	1.73	24.9	24.1	59.6	57.1
Droughted	10.6	10.32	2.37	2.3	27.8	27	66.5	64.5
F test	*	*	**	**	*	**	*	*
B. Cultivar								
Giza 171	9.1	8.76	1.86	1.79	25.4	24.8	56.8	54.7
Sakha 95	9.5	9.08	2.19	2.09	27.3	26.3	59.3	56.7
F test	**	**	**	**	*	**	**	**
C. K levels kg K_2O/fed								
K0	07.3^{d}	7.05^{d}	1.67^{d}	1.61^{d}	21.0^{d}	20.3^{d}	45.9^{d}	44.1^{d}
K1	08.6^{c}	8.11^{c}	1.89^{c}	1.77^{c}	23.5^{c}	22.4^{c}	53.9^{c}	50.7^{c}
K2	10.4^{b}	10.02^{b}	2.22^{b}	2.13^{b}	28.1^{b}	27.0^{b}	65.1^{b}	62.6^{b}
K3	14.0^{a}	13.73^{a}	2.58^{a}	2.55^{a}	33.0^{a}	32.7^{a}	87.4^{a}	85.8^{a}
F test	**	**	**	**	**	**	**	**
D. Interactions								
A X B	ns	ns	ns	ns	*	*	ns	ns
A X C	**	**	**	**	**	**	**	**
B X C	ns	ns	ns	ns	*	**	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns



a. The impact of di- interactions between irrigation and K treatment on NPK uptake and total protein.



b. The impact of di- interactions between irrigation and wheat cultivars on K uptake .

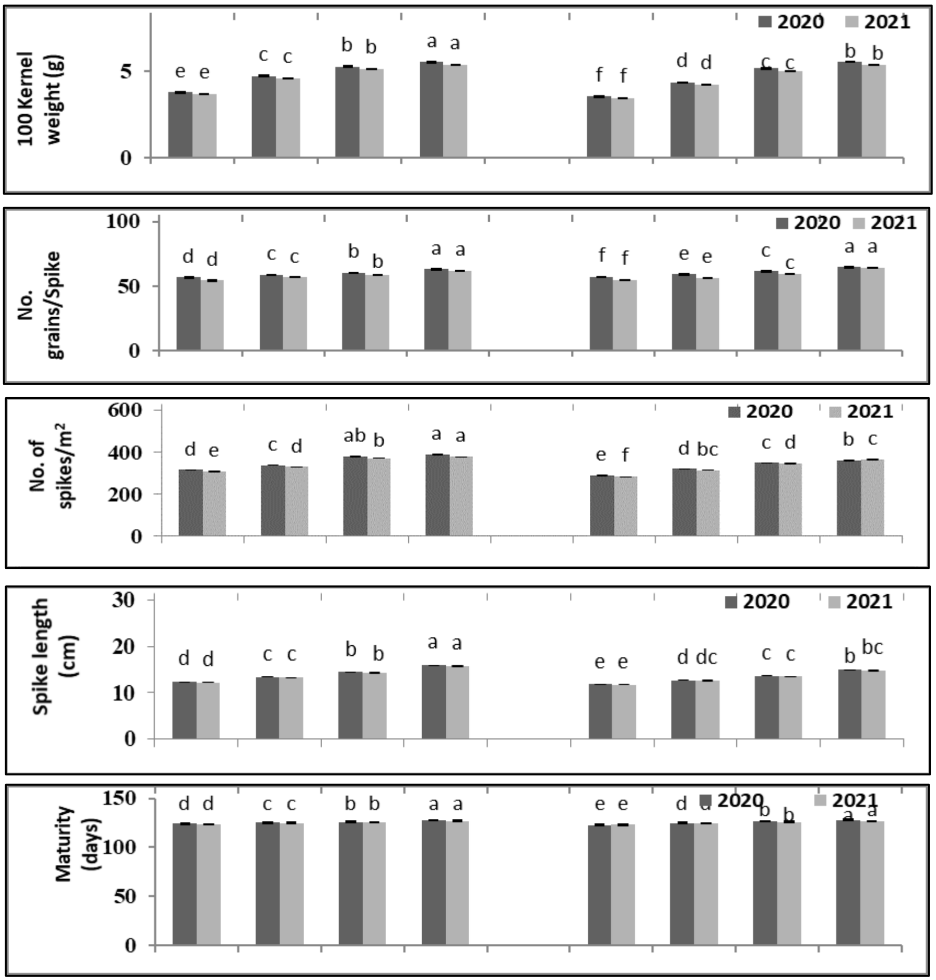


c. The impact of di- interactions between cultivars and K treatment on K uptake.

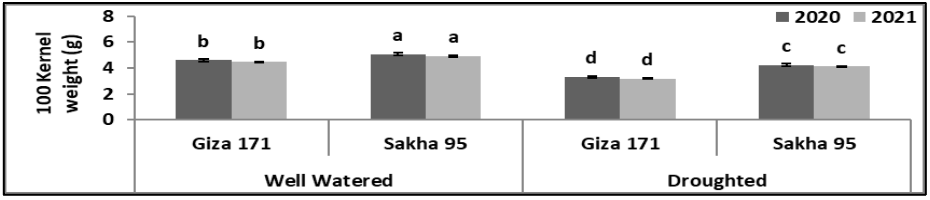
Figure 6. The effect of different di- interactions on N P K uptake and total protein of wheat cultivars at heading. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. N: nitrogen; P: phosphorus; K: potassium; K0:0; K1: 24; K2: 48; K3: 72.

Table 9. The impact of wheat cultivars, water treatment, potassium, and their interaction on days to heading, days to maturity, No. of spikes/m^2, spike weight, and spike length of wheat plants. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

Traits	Heading (days)		Maturity (days)		No. of spikes/m^2		Spike length (cm)		Spike weight (g)	
Season	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
A. Irrigation										
Well-watered watered	71.75	70.78	125.75	125.33	355.50 a	346.7	14.00	13.86	5.77	5.72
Droughted	69.13	68.12	123.13	121.75	284.25 b	282.12	10.78	10.67	4.30	4.29
F test	*	*	*	*	**	**	*	*	*	*
B. Cultivar										
Giza 171	69.42	68.44	123.42	122.17	310.3	301.93	11.53	11.41	4.61	4.60
Sakha 95	71.46	70.45	125.46	124.92	329.4	326.94	13.25	13.12	5.47	5.41
F test	**	**	**	**	**	**	**	**	*	*
C. K levels kg K_2O/fed										
K0	68.15^{d}	67.20^{d}	122.15^{d}	121.69^{d}	286.9^{d}	278.46^{d}	10.61^{d}	10.50^{d}	3.90^{d}	3.87^{d}
K1	69.82^{c}	68.86^{c}	123.82^{c}	123.00^{c}	305.7^{c}	300.26^{c}	11.51^{c}	11.39^{c}	4.34^{c}	4.32^{c}
K2	71.33^{b}	70.33^{b}	125.33^{b}	124.33^{b}	338.6^{b}	332.45^{b}	12.85^{b}	12.72^{b}	5.46^{b}	5.47^{b}
K3	72.58^{a}	71.54^{a}	126.58^{a}	125.25^{a}	349.7^{a}	348.40^{a}	14.65^{a}	14.50 ^{a}	6.45^{a}	6.41^{a}
F test	**	**	**	**	**	**	**	**	**	**
D. Interactions										
A X B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X C	**	**	**	*	**	**	*	*	ns	ns
B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns



a. The impact of di- interactions between K treatments, and irrigation on heading, maturity, spike length, No. of spikes/m^2, 100 Kernel weight, and spike weight.



b. The impact of di- interactions between wheat cultivars, and irrigation on 100 Kernel weight.

Figure 7. The effect of different di- interactions on heading, maturity, spike length, 100 Kernel weight, spike weight, and No. of spikes/m^2 of wheat cultivars. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$ K0:0; K1: 24; K2: 48; K3: 72.

Responses of yield and yield components to drought and K treatments.

Grain production is the primary selection criterion for drought resilience and is considered the most important economic trait of crops (Ali *et al.,* 2023). Drought significantly reduced wheat plant yield and yield attributes (plant height, main spike weight, spike length, number of spikelets, 100 kernel weight, number of grains per spike, grain yield, straw yield, biological yield, and harvest index), as indicated by Tables 9 and 10. These results were in line with what Ahmad *et al.* (2022) stated. Furthermore, leaf abscission, which may result in plant shoot weight loss (Tables 4 and 5) and lower biological yield, may be the reason of the fall in the harvest index during dry conditions. Reduced relative turgidity brought on by turgor damage and protoplasm desiccation could be the cause of the plant height drop. Inadequate photosynthetic pigments (Table 7) or earlier spike emergence since spikelets/spikes determine earlier spike emergence could be the reason of the lower number of spikelets/spikes. In addition, the low number of spikelets per spike and spike length during a drought may contribute to the decrease in grain number. The plant experienced a reduction in 100-grain weight due to ineffective and disturbed nitrogen uptake and reduced photosynthetic transformation, which accelerated maturity and resulted in dried kernels.

Concerning wheat cultivars, during both research seasons, there were notable and substantial variations between the two wheat cultivars in terms of all yield variables that were assessed as well as the yield and harvest index. Sakha 95 yielded the highest values of assessed yield and yield contributions, indicating a significant improvement over Giza171 in terms of yield and yield attribute in both seasons. The decrease in growth criteria (Tables 4,5), plant water relations (Table 6), membrane properties (Table 6), photosynthetic pigment (Table 7), and nutrient uptake (Table 8) can be ascribed to the reduction in grain production of stressed wheat plants.

Data from Tables 9 and 10 demonstrated that the application of K increased the fertilizer K gradually and significantly increased the yield and yield attributes that were up to the higher K level of 72 kg K_2O/fed. This had a significant and positive effect on the yield and yield attributed in the first and second seasons, respectively. The highest yield and yield attribute values were obtained at the potassium level indicated later. The crop absorbed the added nutrients with ease, which increased the production because K was transferred to the plant and increased the yield that was credited.

According to our determinations, the reason for this yield increase under K treatment may be attributed to the flag leaf and prolific shoot growth (Tables 4,5), improved membrane properties (Table 6), improved photosynthetic pigment (Table 7), and improved nutrient uptake (Table 8). Furthermore, the transfer of potassium nutrients from the soil to the plant, whether enough or excess, was the cause of this increase in grain yield with K treatment (Table 8).

Furthermore, because potassium was necessary for the osmotic adjustment (stomatal opening) of plants during drought circumstances, wheat showed a similar reaction to the rise in the number of spikelets that resulted from the exogenous injection of K. Conversely, cultivars, irrigation, and K treatment tri-interaction significantly impacted grain production (Figure 8, d). When Sakha 95 was well-watered and received 72 kg of K_2O/fed, the maximum grain yield values were recorded (Figure 8d). Furthermore, there was an interaction between wheat cultivars and irrigation in terms of grain production and 100 kernel weight (Figures 7, b & 8, b). There was a di-interaction effect between irrigation and K treatments on spike length, spike weight, the number of spikes/m^2, and 100 kernel weight (Figure 7, a). Conversely, as indicated in (Tables 8,9), there was no interaction impact between cultivars and k treatment on the number of spikes/m^2, spike length, spike weight, biological yield, straw yield, and harvest index. Furthermore, irrigation and K treatments had an interaction effect on harvest index, grain yield, straw yield, and biological yield (Figure 8, a). Additionally, there was a significant interaction effect of cultivars and K treatment on grain yield as shown in Figure 8, c. The highest values of grain yield, biological yield, straw yield, and harvest index were obtained with the combination of well watering treatment and K treatments at 72 kg K_2O/fed. Also, all yield components were produced under well-watered conditions and 72 kg K_2O/fed (Figures 7,a & 8, a). If not, the combination of the drought treatment and the zero potassium level resulted in the lowest values of the aforementioned features.

Effects of drought and K supplementation on nutrients uptake in grains and straw.

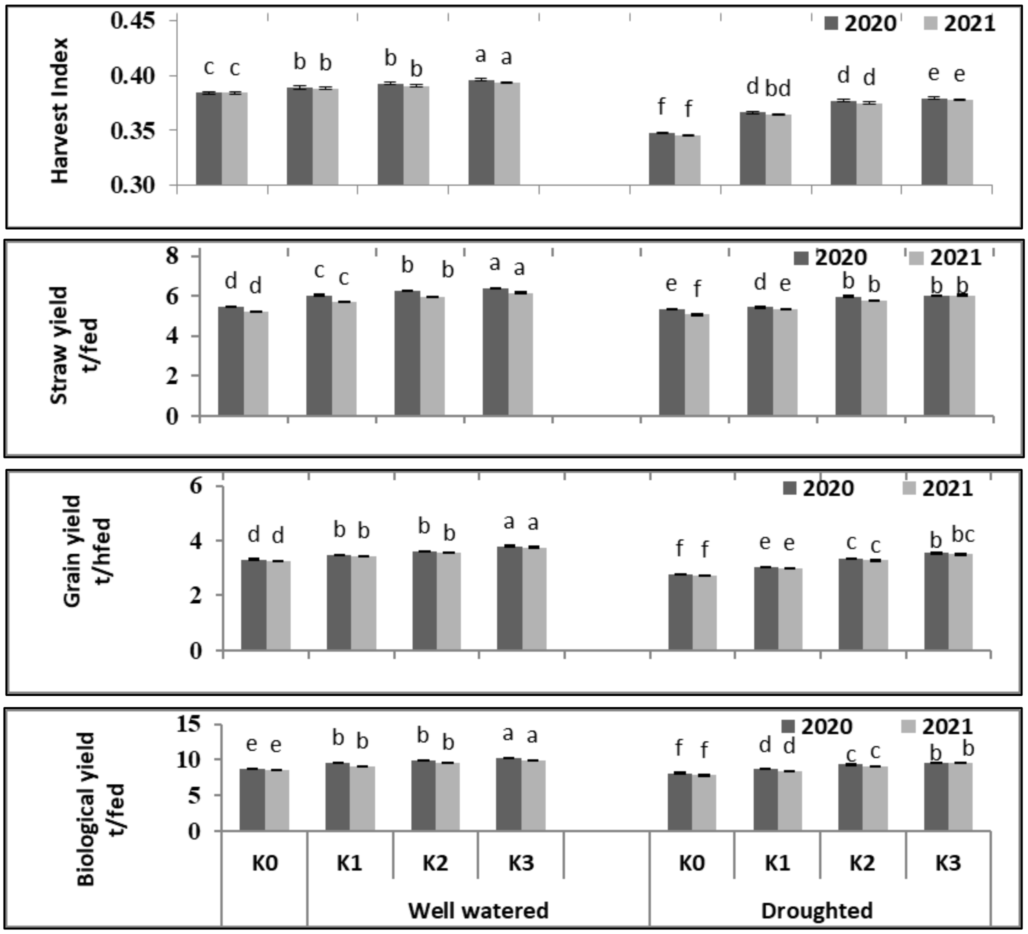
The concentration of N, K, and P uptake in the grains and straw of stressed wheat cultivars rose throughout the drought, as shown by our data in Table 11. The outcomes aligned with the findings of Ahmad *et al.* (2022) and Ghanem and Al-Farouk (2024). The intake of N, P, and K in wheat grains and straw varied considerably amongst cultivars as well; Sakha 95 recorded higher levels of uptake than Giza 171. According to the latest data, wheat grain and straw's ability to absorb N, P, and K improved as potassium application levels increased. This resulted from the potassium's synergistic effect and the translocation of other nutrients (Kumar *et al.*, 2015).

Furthermore, there was no triple interaction impact on K, P, and N uptake between irrigation, cultivars, and K treatment (Table 11). On the uptake of K, P, and N, however, there was a noteworthy interaction effect between irrigation and K treatment. Furthermore, the combination of drought and K treatment at the amount of 72 kg K_2O/fed application resulted in the maximum values of K, P, and N uptake in wheat grains and straw (Figure 9). Conversely, the combination of zero K level and well watering treatment produced the lowest values of the aforementioned features (Figure 9).

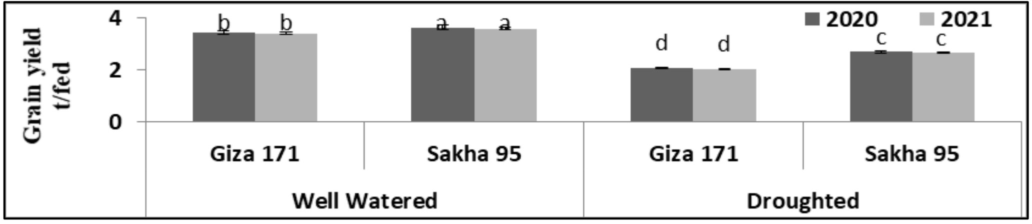
Overall, the findings demonstrated that applying K might reduce the effects of drought and increase grain output by enhancing bread wheat's shoot and flag leaf growth, plant-water relationship, membrane properties, and nutrient uptake efficiency. All the aforementioned characteristics were shown to rise in both wheat cultivars as the K rate rose from 0 > 24 > 48 > 72 kg K_2O/fed. Both stressed and unstressed wheat plants of the two cultivars under graded amounts of potassium fertilizer outperformed control plants during the wheat growth phase. Our results imply that maintaining a high yield during a drought requires improving the plant K status.

Table 10. The impact of water treatment, wheat cultivars, potassium treatments, and their interaction on 100 kernel weight, grain number/spike, grain yield, biological yield, harvest index, and straw yield of wheat plants. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. K0:0; K1: 24; K2: 48; K3: 72.

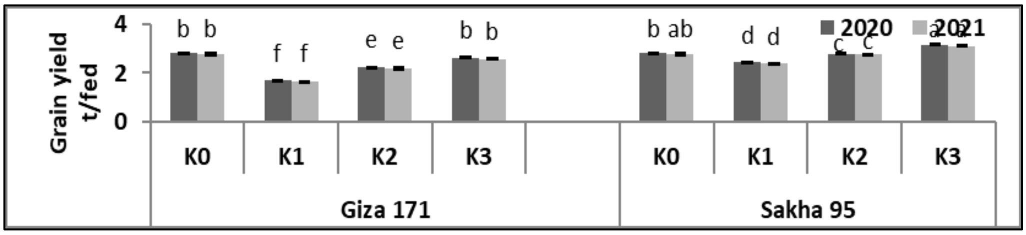
Traits	No. grains/Spike		100 Kernel weight (g)		Biological yield (t/fed)		Grain yield t/fed		Straw yield (t/fed)		Harvest Index	
Season	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
A. Irrigation												
Well-watered	59.46	57.73	4.83	4.68	9.57	9.21	3.55	3.5	6.02	5.76	0.390	0.389
Droughted	54.41	52.00	3.76	3.64	7.1	6.88	2.38	2.33	4.69	4.55	0.331	0.328
F test	*	*	*	*	**	**	**	**	**	**	**	**
B. Cultivar												
Giza 171	53.44	54.83	3.94	3.83	7.09	6.81	2.33	2.71	4.74	4.52	0.354	0.351
Sakha 95	60.43	58.54	4.65	4.51	8.14	7.86	2.79	3.12	5.31	5.02	0.367	0.366
F test	**	**	*	*	**	**	**	**	**	**	**	**
C. K levels kg K_2O/fed												
K0	53.48^{d}	50.52^{d}	3.03^{d}	2.94^{d}	7.37^{d}	7.10^{d}	2.50^{d}	2.52^{d}	4.87^{d}	4.69^{d}	0.342^{d}	0.341^{d}
K1	55.60^{c}	52.96^{c}	3.99^{c}	3.87^{c}	8.25^{c}	7.84^{c}	2.85^{c}	2.75^{c}	5.32^{c}	5.12^{c}	0.356^{c}	0.354^{c}
K2	57.62^{b}	55.88^{b}	4.89^{b}	4.75^{b}	8.71^{b}	8.39^{b}	3.12^{b}	3.07^{b}	5.59^{b}	5.38^{b}	0.370^{b}	0.367^{b}
K3	61.22^{a}	60.31^{a}	5.33^{a}	5.17^{a}	9.01^{a}	8.89^{a}	3.41^{a}	3.36^{a}	5.67^{a}	5.53^{a}	0.376^{a}	0.372^{a}
F test	**	**	**	**	**	**	**	**	**	**	**	**
D. Interactions												
A X B	ns	ns	*	*	ns	ns	**	**	ns	ns	*	*
A X C	*	**	**	**	**	**	**	**	*	**	**	**
B X C	ns	ns	ns	ns	ns	ns	**	**	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	**	**	ns	ns	ns	ns



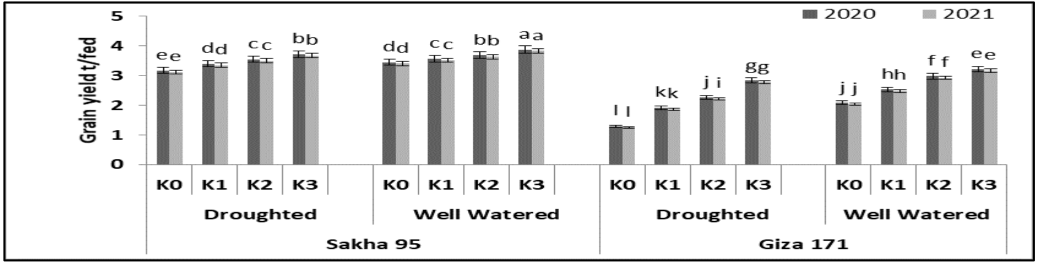
a. The impact of di- interactions between K treatments, and irrigation on grain yield, biological yield, harvest index, and straw yield.



b. The impact of di- interactions between wheat cultivars, and irrigation on grain yield.



c. The effect of di- interactions between wheat cultivars and K treatments on grain yield.



d. The tri- interaction effect of irrigation (watered v. droughted), cultivars (Giza 171 v. Sakha 95) and K treatments on grain yield.

Figure 8. The effect of different di- and tri- interactions on grain yield, biological yield, harvest index, and straw yield of wheat plants. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at p ≤ 0.05. K0:0; K1: 24; K2: 48; K3: 72.

Table 11. The impact of wheat cultivars, water treatments, and potassium treatments (0, 24, 48, and 72 kg K_2O/fed), and their interaction on NPK uptake in straw, and grain of wheat cultivars. Different letters reveal remarkable differences between treatments at $p \leq 0.05$. N: nitrogen; P: phosphorus; K: potassium; K0:0; K1: 24; K2: 48; K3: 72.

Traits	k grain (g/kg dwt)		K straw (g/kg dwt)		N grain (g/kg dwt)		N straw (g/kg dwt)		P grain (g/kg dwt)		P straw (g/kg dwt)	
Season	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
A. Irrigation												
Well-watered	3.17	3.01	18.1	19	25.3	12.2	2	1.95	3.5	3.44	0.177	0.21
Droughted	3.5	3.38	20.3	21	29.3	14.9	2.4	2.41	3.7	3.77	0.189	0.41
F test	**	**	**	**	*	**	*	**	**	*	*	**
B. Cultivar												
Giza 171	3.19	3.1	18.6	19.1	27.1	13.09	1.9	1.83	3.35	3.3	0.168	0.19
Sakha 95	3.48	3.28	19.7	20.9	27.6	13.51	2.18	2.1	3.96	3.87	0.198	0.22
F test	**	**	**	**	ns	*	**	**	**	**	**	**
C. K levels kg K_2O/fed												
K0	2.60^d	2.54^d	15.2^d	15.8^d	24.0^d	23.0^d	1.45^d	1.40^d	3.32^d	3.23^d	0.21^d	0.23^d
K1	2.93^c	2.79^c	16.8^c	17.6^c	26.2^c	25.1^c	1.76^c	1.61^c	3.38^c	3.30^c	0.190^c	0.21^c
K2	3.51^b	3.37^b	20.2^b	21.1^b	28.5^b	27.5^b	2.66^b	2.56^b	3.80^b	3.66^b	0.169^b	0.19^b
K3	4.26^a	4.09^a	24.5^a	25.8^a	$37.^a$	30.8^a	3.20^a	3.16^a	4.14^a	4.14^a	0.165^a	0.18^a
F test	**	**	**	**	**	**	**	**	**	**	**	**
D. Interactions												
A X B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X C	**	**	**	**	*	*	**	**	*	*	*	*
B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
A X B X C	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

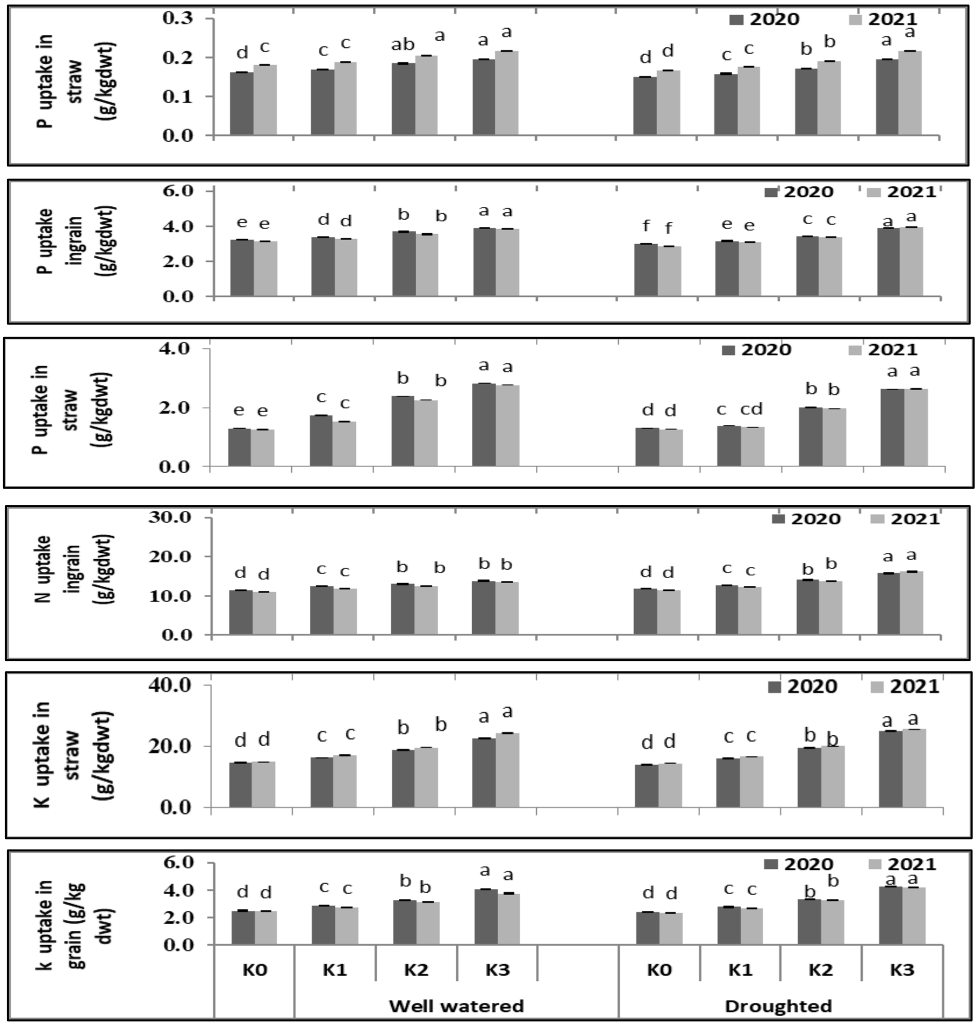


Figure 9. The impact of di- interactions between irrigation and K treatments on NPK uptake in straw, and grain of wheat cultivars. The vertical bars showed the standard error of the mean (n=3). Different letters reveal remarkable differences between treatments at $p \leq 0.05$. N: nitrogen; P: phosphorus; K: potassium; K0:0; K1: 24; K2: 48; K3: 72.

CONCLUSION

The application of potassium under drought, particularly at 72 kg K2O/fed, was found to be efficient in minimizing the reduction in yield and its components through improving all morpho-physiological and nutrient uptake performances of bread wheat and making it possible to control practice. Consequently, the application of potassium at 72 kg K2O/fed can be an adaptive technique to deal with drought by increasing wheat plants tolerance and ameliorating the effects of drought to get a very beneficial yield with a small and insignificant reduction, which was a fact under current and similar conditions.

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النمو والأداء الفسيولوجي واستجابات صفات المحصول في أصناف قمح الخبز تحت ظروف الجفاف، الري بالرش ومستويات البوتاسيوم

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الملخص

في ظل ظروف التغير المناخي، وخاصة في البلدان الجافة وشبه القاحلة، تشكل ندرة المياه تحديا هاما لمحصول القمح. ولذلك أجريت تجربة حقلية خلال موسمين متتاليين (٢٠٢١/٢٠٢٠) و (٢٠٢٢/٢٠٢١) بمحطة البحوث الزراعية بالإسماعيلية ، مصر لدراسة تأثير مستويات البوتاسيوم على صفات النمو والأداء الفسيولوجي وكذلك المحصول وصفاته لقمح الخبز تحت ظروف الجفاف، تم استخدام صنفين من القمح (جيزة ١٧١ وسخا ٩٥) وأربعة مستويات من البوتاسيوم (٠، ٢٤ كجم K_2O/ فدان، ٤٨ كجم K_2O /فدان و ٧٢ كجم K_2O /فدان) ومعدلين ري. وقد أوضحت النتائج أن التعرض للجفاف كان له تأثيرا سلبيا واضحًا على نمو الفروع ونمو أوراق العلم والعلاقات المائية للنبات بالإضافة إلى نقص ملحوظ فى محتوى الكلوروفيل بالأوراق، تقليل معامل الثبات النسبي للأغشية البلازمية وزيادة معدل تسريبها للأيونات والتى تؤدى فى النهاية إلى إنخفاض المحصول ومكوناته. وقد كان الصنف سخا ٩٥ متفوقا فى جميع صفاته المورفولوجية والفسيولوجية تحت الدراسة وكذلك فى المحصول ومكوناته عن نظيره الصنف جيزة ١٧١. من ناحية أخرى ، كما يبدو أن جميع مستويات البوتاسيوم وبخاصة ٧٢ كجم من K_2O /فدان يخفف من التأثير الضار للجفاف على نباتات القمح المجهدة وذلك من خلال تحسين جميع الصفات المورفولوجية والفسيولوجية للساق والأوراق، وزيادة المحتوى المائي النسبي وتقليل نقص التشبع المائي، وزيادة المحتوى الكلوروفيللي، وزيادة معامل الثبات النسبي للأغشية البلازمية وتقليل معدل تسريبها للأيونات والتي تؤدي في النهاية إلى تعظيم الإنتاجية وتحقيق العائد الاقتصادي المرجو. نستنتج من خلال هذه الدراسة، أن استخدام أسمدة البوتاسيوم يمكن أن يكون تقنية تكيفية للتعامل مع الإجهاد المائى عن طريق زيادة تحمل النباتات وتخفيف آثار الجفاف على نمو وإنتاجية نباتات القمح.