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The Effect of Antitranspirants on Physiological Aspects and Yield of Wheat Crop under Varied Irrigation Levels

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THE ANTICIPATED consequences of climate change include adverse effects on numerous agricultural ecosystems and diminished water resources, which are projected to result in a decline in the yield of significant food crops such as wheat. Hence, the prioritization of crop research is the development of crop types capable of sustaining or enhancing yields while minimizing water usage. Hence, it is imperative to employ a technique aimed at mitigating the plant's water loss by transpiration, with one such approach being the utilization of antitranspirants. The current investigation involved a field in a split split-plot design experiment aimed at comprehending the effects of antitranspirants on the physiological and yield attributes of wheat cultivars (*Triticum aestivum* L.) under varying irrigation levels. The present investigation encompassed three different irrigation treatments, namely 100%, 80%, and 60% of the recommended irrigation levels, applied at rates of 5476, 4381, and 3285 m^3 ha^{-1}, respectively. Additionally, three distinct wheat cultivars, namely Sids 14, Giza 171, and Sakha 95, were included in the study. Furthermore, four treatments consisting of kaolin at a concentration of 5%, potassium sulphate at a concentration of 200 mg L^{-1}, paraffine at a concentration of 6%, and a control treatment involving water spray were also incorporated. The physiological parameters that were assessed included total chlorophyll, membrane stability index, relative water content, stomatal density, and transpiration intensity. The growth and yield parameters were documented subsequent to the crop's harvest. The findings of the study indicate that exposing wheat cultivars to prescribed irrigation resulted in notable enhancements in the examined feature, as compared to alternative irrigation treatments. The application of antitranspirants resulted in notable enhancements in the observed characteristics across all cultivars when subjected to irrigation intensities of 80% and 100%. Furthermore, the three wheat cultivars exhibited varying responses under the three irrigation regimens, as well as in the presence or absence of foliar spray application of antitranspirants.

Keywords: Antitranspirants; Irrigation; Yield; Wheat cultivars.

1. Introduction

The fundamental objectives of Egypt's present policies and development plans are around attaining self-sufficiency in primary crops while concurrently fostering the sustainable utilization of land and water resources. Due to the effects of climate change, there is less water available in Egypt for agricultural production (El-Sherpiny, 2023). In order to increase water consumption efficiency, a lot of focus is placed on water management for dry circumstances based on plant physiology (Abdelhalem, 2022). The crop known as wheat (*Triticum aestivum* L.), a member of the Poaceae (Gramineae) family, holds significant importance as a primary and strategic cereal crop for a majority of the global population (Abdelaal and Thilmany, 2019). According to the Food and Agriculture Organization (FAO, 2022), wheat holds significant importance as the primary grain and the greatest cultivated crop in terms of land area in Egypt. In the context of Egypt, wheat accounts for approximately 10% of the overall value of agricultural production and approximately 20% of all agricultural imports (GASC, 2020). The quantity of wheat production in Egypt in 2021 amounted to approximately 9 million metric tonnes, reflecting a growth rate of 1.12% compared to previous years

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(FAO, 2022). This increase in wheat cultivation aims to reduce reliance on wheat imports.

The escalating global population has placed significant strain on freshwater resources, as they face mounting pressure to satisfy the expanding need for food. On a global scale, the agricultural sector stands as the primary consumer of irrigation, utilizing over 70% of the world's freshwater resources (Ouda et al., 2021). Hence, it can be concluded that the scarcity of water resources in arid and semi-arid regions has adverse implications for both food and water security (Ding et al., 2021). Over a prolonged period and in the presence of water scarcity, farmers will have limitations in their ability to provide crops with the necessary amount of irrigation water. Hence, it is of utmost significance to regulate the water loss from the plant, as the majority of water absorbed by the roots (with approximately 98% of it) is subsequently released into the atmosphere by transpiration through stomatal pores located on the leaf epidermis. The phenomenon of rapid urbanization and industrialization has resulted in an escalated demand for limited freshwater resources in order to adequately address the expanding requirements of food production. Two direct remedies to this difficulty may be identified which are the effective use of irrigation technology and the adoption of alternate water sources (Hassanli et al., 2010). Hence, it is imperative to employ a strategy that mitigates water loss by transpiration in plants, with one such approach being the utilization of antitranspirants. Antitranspirants aid in mitigating these losses to a certain degree. The application of antitranspirants in cereal crops plays a crucial function, since they are recognized for their ability to retain water in the soil. This characteristic aids in mitigating water stress and substantially enhancing the water holding capacity.

Antitranspirants refer to chemical substances that are administered to plant leaves with the intention of mitigating water loss (transpiration) and alleviating water stress in plants (Ghazi et al. 2023). This is achieved by increasing the resistance of the leaves to the diffusion of water vapor, without significantly impacting crucial plant processes such as growth and photosynthesis (Abdullah et al. 2015). Antitranspirants can be classified into three distinct categories based on their mechanism of action. The first category is the stomatal closing type, which reduces transpiration losses by increasing the leaf resistance to water vapor transfer through the covering of stomata. The second category is the film-forming type, which creates an external physical barrier outside the stomatal opening to slow down the escape of water vapor. The third category is the reflecting type, which reduces water losses by reflecting a significant amount of radiation, this reduction in radiation leads to a decline in leaf temperature and vapor pressure gradient from the leaf to the atmosphere, ultimately reducing the rate of transpiration. This mechanism enables plants to better withstand drought conditions (Conde et al., 2016; Guleria and Shweta, 2020; Mphande et al., 2021; Elmasry and Al-Maracy, 2023). The regulation of stomatal aperture plays a crucial role in maintaining leaf temperature, facilitating water evaporation, and enabling gas exchange, is achieved through precise control of osmotic pressure within the guard cells, these processes are vital for the survival and growth of plants (Acharya and Assmann, 2009). Stomata participate in providing a carbon source for photosynthetic reactions. Whereas the coinciding transpiration of water are crucial for the absorption of nutrients from the soil into the plant's structure. However, it should be noted that excessive water loss from plants during periods of drought-induced stress can have detrimental consequences, perhaps leading to the death of the plant (Eisele et al., 2016).

The primary aims of this investigation were: (i) to evaluate the most effective irrigation level when antitranspirants are applied to wheat cultivars in order to minimize the amount of irrigation water required, (ii) to examine the impact of applying various antitranspirants on plants to reduce transpiration, and (iii) to determine the interaction between the three factors under investigation on physiological characteristics, yield, and yield components in wheat cultivars.

2. Materials and methods

2.1 Experimental location

The field experiment was conducted over two consecutive winter seasons 2020/2021 and 2021/2022, at the Shandaweel Agricultural Research Station located in the Sohag Governorate of Egypt. The geographical coordinates of the research station are around 24.54° N latitude and 32.94° E longitude. The experiment commenced on December 1st, 2020, during the first season, and on November 23rd, 2021, during the second season.

2.2 Experimental design and treatments

The soil was partitioned into individual plots, each measuring 10.5 square meters, with a gap of 1.5 meters between neighboring plots. The study employed a split split-plot design, and three replications were conducted in each season. In the main plots, three different levels of water regimes were assigned, namely I1 (100% of the prescribed amount), I2 (80% of the recommended amount), and I3 (60% of the recommended amount) at rates of 5476, 4381, and 3285 m^3 ha^{-1}, respectively, water was supplied from a pump outlet to the plots by using plastic pipes, and a water meter was used to measure the amount of applied water. Three different wheat cultivars (V1: Sids 14, V2: Giza 171, and V3: Sakha 95) were assigned to the subplots, while four treatments (T0: control, T2: kaolin 5%, T3:

potassium sulphate 200 mg/L, and T4: paraffin 6%) were assigned to the sub-subplots. The wheat plants in each subplot were sprayed twice, using a dorsal sprayer, at 40 and 55 days after sowing. Kaolin, an aluminosilicate clay mineral with the chemical formula $Al_4Si_4O_{10}$ $(OH)_8$, is well recognized as a non-toxic substance. It exhibits reflecting properties and acts as an antitranspirant by effectively lowering leaf temperature and reducing the rate of transpiration. This characteristic has been documented in several studies (Cantore et al., 2009; Abdallah et al., 2019). Potassium is a chemical element with the symbol K and atomic number 19. It is This particular type of stomatal closure is considered one of the three crucial macronutrients and plays a significant role in regulating crop productivity. It affects the water balance and growth of crops by maintaining turgor, regulating transpiration, and controlling stomatal activity (Mfilinge et al., 2014; Itelima et al., 2018). Paraffin, a film-forming antitranspirant, serves to mitigate water loss from plant leaves, this substance is characterized by its transparency, colorlessness, little odour, and oily consistency, it mostly consists of saturated hydrocarbons obtained from petroleum (Khalel, 2015).

2.3 Soil sampling and measurements

A soil sample was collected from the surface layer (0-30 cm) before planting and during plant bed preparation. The sample was then analyzed for mechanical and physiochemical parameters using the Sparks et al. (2020) method. The results of the analysis are presented in Table 1. The air temperature data for Sohag Governorate was obtained from the Central Laboratory for Agricultural Meteorology, Ministry of Agriculture - Egypt and is displayed in Table 2.

Soil preparation involves the application of mineral fertilizers and other agricultural practices to wheat, as per the recommendations provided by the Agriculture Research Centre.

Table 1: Some chemical and physical properties of field soil for the 2020-2021 and 2021/2022 seasons.

Item	2020/21	2021/22	Item	2020/21	2021/22
pH (1:2.5)	7.80	7.80	**Soluble Cations (cmol kg^{-1})**		
EC (1:5, dS m^{-1})	0.21	0.22	**Ca^{2+}**	0.80	0.52
Organic matter (%)	0.61	0.72	**Mg^{2+}**	0.40	0.49
Particles size distribution%			**Na^+**	0.75	0.79
Sand%	23.90	26.20	**K^+**	0.34	0.33
Silt%	38.60	35.30	**Soluble Anions (cmol kg^{-1})**		
Clay%	37.50	38.50	**HCO_3^-**	1.20	0.93
Texture class	Clay loam	Clay loam	**Cl^-**	0.65	0.80
Soil water content %			**SO_4^{2-}**	0.40	0.30
Saturation point (SP) (%)	52.00	54.00	**Available Macro-Nutrients (mg kg^{-1})**		
Field capacity (FC) (%)	25.44	25.58	**N**	51.00	58.00
Wilting point (WP) (%)	12.84	12.91	**P**	14.30	17.00
bulk density (BD) (g/cm^3)	1.43	1.48	**K**	363.33	385.00

Table 2: Meteorological data of Sohag Governorate at 2020/2021 and 2021/2022 seasons.

Item		Months corresponding from sowing to harvest period							
	Season	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**
Average daily maximum temp.	**2020/2021**	36.71	25.07	24.45	23	24.25	29.52	34.2	39.68
	2021/2022	36.77	32.1	23.61	20.87	25.25	28.32	39.93	40.29
Average daily minimum temp.	**2020/2021**	22.39	14	12.1	9.81	9.86	13.97	20.6	27
	2021/2022	21.29	17.7	10.81	7.71	9.11	11.58	21.5	23.87
Cumulative monthly rainfall (mm)	**2020/2021**	0	0	0	0	0	0	0	0
	2021/2022	0	0	0	0	0	0	0	0
Radiation (MJ/m^2/day)	**2020/2021**	11:02	10:18	10:08	10:10	11:04	11:43	12:30	13:08
	2021/2022	11:30:16	10:48:47	10:27:42	10:39:00	11:14:31	12:00:30	12:48:47	13:29:17

The data presented in this study were collected at a specific time point of 65 days after sowing, throughout the agricultural seasons.

2.4 Physiological measurements

1. Chlorophyll (SPAD unit): According to Minolta (1989), ten plants from each treatment were chosen at random, and SPAD readings were taken from the flag leaves using a chlorophyll meter (SPAD-502, Minolta, Japan).

2. Relative Water Content (RWC%): Samples of flag leaves were taken to figure out the RWC. The leaves were put in plastic bags and taken to the lab as soon as possible to keep as much water from evaporating as possible. The samples were also

weighed as fresh weight (FW) right away. They were then cut into 2-cm pieces and floated for 4 hours on pure water. The leaf plates were quickly blotted to get rid of the water on the surface, and then they were weighed to get the turgid weight (TW). The leaf plates were dried in an oven at 60°C for 24 hours, and then the dry weight (DW) was measured. Barrs (1968) gave the method that was used to figure out the RWC:

$$RWC(\%) = [(FW - DW)/(TW - DW)]x100$$

3. Membrane stability index (%): The electrical conductivity of leaf ions leaching in double-distilled water was used to figure out the MSI. Two sets of test tubes with 10 mL of double-distilled water and 0.1 g of leaf samples were used. One set was left at 40 °C for 30 minutes, and the other set was put in a boiling water bath at 100 °C for 15 minutes. Their electrical conductivities, C1 and C2, were recorded with an EC meter (JENWAY Model 4520 Conductivity meter), as Hesse (1998) explained. The following method was used to figure out the membrane stability index:

$$MSI(\%) = [1 - (C1/C2)]x100$$

4. Opening Stomatal number (mm^{-2}): After taking a sample, the stomatal number on the center of the adaxial side (upper surface) of the flag leaves of five plants was carefully marked (smeared) with a thin layer of nail polish. When the film was dry, it was peeled off the leaf surface, put on a glass slide, and then covered right away with a cover slip. Under a photomicroscope with a 10X objective lens and objective and eyepiece micrometers (Optika, B-190-TB, Italy), the number of open stomata per view was counted. The average number of stomata in 5 different view areas was found, and stomatal density was described as the number of stomata per millimeter square (stomata No./mm^2) of leaf surface.

5. Transpiration intensity (mg cm^{-2} min^{-1}): It was measured using Dzung et al.'s (2011) method. Each plot had ten plants, and three leaves from each plant were taken and kept in the plant's condition. After 30, 60, 90, and 120 minutes, the weight of the leaves was measured by weighing them. The intensity of transpiration was determined as follows:

$$I= (W0 - Wt)\, S^{-1}\, t^{-1}$$

Where I: is an intensity of transpiration (unit: mg cm^{-2} min^{-1}); S: is the leaf area (cm^2); W0: is the weight of the leaves after cutting; Wt: is the weight of the leaves after t min in the plant's condition. The average of intensity of transpiration was found by taking the mean of four times and analyzing them.

2.5 Post harvesting measurements

In each season, the height of the plant, the number of days to 50% heading (in days), the number of spikes per m^2, the grain yield (t ha^{-1}), the weight of 1000 kernels (gr), and the number of kernels per spike were measured. Each of the 36 treatments was tested in three replicates. For determine the previous measurements, a certain amount of wheat plants were taken from each replicate.

2.6 Statistical analyses

The obtained data were subjected to analysis of variance (ANOVA) according to Snedecor and Cochran (1989) using the MSTAT-C software version 2.1. The means of the various factors were compared by use Duncan's Multiple Range Test (Duncan, 1955).

3. Results

The current study was conducted to examine the physiological and yield characteristics of three wheat cultivars subjected to varying irrigation rates and treated with different types of antitranspirants.

3.1 ***Irrigation effect***

The findings presented in Table 3 indicate that there were statistically significant variations seen among the three irrigation levels for all the attributes examined. The leaf chlorophyll content, membrane stability index, and relative water content exhibited the highest mean values when subjected to 100% irrigation level in both seasons. Conversely, the lowest values were found when subjected to a 60% irrigation level. In relation to the stomatal density examined in this study, it was observed that the density of open stomata significantly increased as the irrigation level decreased up to 60% (with values of 38.50 and 37.06 stomata mm^{-2} in the first and second seasons, respectively). Conversely, the lower mean value for stomatal opening was observed under the 80% irrigation level (with values of 35.47 and 33.86 stomata mm^{-2} in the first and second seasons, respectively), during both seasons. The transpiration intensity was found to be higher at a 60% irrigation level, with values of 0.196 mg cm^{-2} min^{-1} and 0.184 mg cm^{-2} min^{-1} in the first and second seasons, respectively. Conversely, the lowest transpiration intensity was recorded at an 80% irrigation level, with values of 0.127 mg cm^{-2} min^{-1} and 0.122 mg cm^{-2} min^{-1} in the first and second seasons, respectively. The findings shown in Table 4 demonstrate the impact of different irrigation levels on the yield component of wheat crop. The results of the study indicate that irrigation with 100% resulted in the greatest values for yield and its components in both seasons. This irrigation level shown a considerable superiority over all other irrigation levels.

3.2 ***Cultivars effect***

The findings shown in Table 3 indicate the presence of statistically significant variations across the three cultivars examined in this study, namely Sids 14, Giza 171, and Sakha 95, across all the attributes investigated. In both the 2020/21 and 2021/22 seasons, Sids 14 exhibited the highest recorded values for leaf chlorophyll content (LCC) at 45.06 and 45.18 SPAD unit, membrane stability index (MSI) at 85.15 and 85.72%, and relative water content (RWC) at 85.73 and 85.55%, respectively. The data presented in Table 3 indicates that the three cultivars under investigation exhibited significant differences in terms of stomatal density and transpiration rate during both seasons. Specifically, the Giza 171 cultivar demonstrated significantly lower numbers of opening stomata (34.19 and 33.06 stomata mm^{-2}) and transpiration intensity (0.120 and 0.114 mg cm^{-2} min^{-1}) in the first and second seasons, respectively. Table 4 illustrates notable disparities in yield components among different cultivars. Specifically, Giza 171 was the earliest cultivar while the latest cultivar was Sids 14, in both seasons. The Sids 14 cultivar demonstrated superior performance in terms of plant height, with average measurements of 120.92 cm and 123.56 cm in the first and second seasons, respectively. In comparison, the Giza 171 and Sakha 95 cultivars exhibited lower plant heights over the same periods. On the contrary, it can be observed that Giza 171 cultivars exhibit elevated spike number per square meter and 1000-kernel weight in both seasons. Conversely, Sakha 95 cultivars demonstrate superior spike number per square meter, and number of kernels per spike in both seasons. Furthermore, there were no significant differences among the three cultivars in grain yield in the 1st season.

3.3 *Antitranspirants effect*

The analysis of the data presented in Table 3 indicates that the use of antitranspirant resulted in a statistically significant rise in physiological parameters when compared to the control. According to the data shown in Table 3, it was seen that the application of paraffin resulted in the greatest leaf chlorophyll content (LCC) values, with recorded measurements of 44.77 and 44.65 SPAD units in both seasons, respectively. Also, spraying of K_2SO_4 attained the highest LCC (44.63 and 44.47 SPAD units in both seasons, respectively). The highest observed values for MSI were achieved through the application of paraffin (80.50% and 82.02% in both seasons, respectively) and kaolin (82.27% in 2nd seasons, respectively). Similarly, the highest mean values for RWC were recorded when paraffin (81.72% and 83.00% in both seasons, respectively) and kaolin (81.78% in 1st seasons, respectively) were applied. These results were compared to a control group, and no significant differences were found between these treatments. The data shown in Table 3 indicates that the application of antitranspirants had a substantial impact on the number of open stomata in both seasons. Specifically, kaolin demonstrated a lower value for the number of open stomata (35.12 and 32.59 stomata mm^{-2}) and transpiration intensity (0.139 and 0.132 mg cm^{-2} min^{-1}) in both seasons, respectively. Additionally, the use of antitranspirant spray shown a notable impact on crop output and its many components. Specifically, the application of kaolin spray exhibited the highest average values in terms of plant height, grain yield, and number of kernels per spike across both seasons. In comparison to the control treatment, which involved the application of water alone, the lowest mean of these features was seen. Also, in the first season only, the application of paraffin spray demonstrated a statistically significant improvement in all features as compared to the control group. While, spraying K_2SO_4 increased most of the traits of yield components in both seasons.

Table 3. Mean values of the physiological characters as affected by irrigation levels, wheat cultivars and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

Season	2020/2021					2021/2022				
Traits	LCC	MSI	RWC	SD	I	LCC	MSI	RWC	SD	I
Treatments					Irrigation					
100%	44.86 a	82.09 a	83.49 a	36.93 b	0.152 b	45.19 a	82.42 a	83.08 a	35.78 b	0.145 b
80%	43.83 ab	78.32 b	80.69 b	35.47 c	0.127 c	43.63 b	79.88 b	80.15 b	33.86 c	0.122 c
60%	42.39 b	74.37 c	74.36 c	38.50 a	0.196 a	41.85 c	75.50 c	75.23 c	37.06 a	0.184 a
F test	*	**	**	**	**	**	**	**	**	**
					Cultivars					
Sids 14	45.06 a	85.15 a	85.73 a	39.36 a	0.154 b	45.18 a	85.72 a	85.55 a	37.31 a	0.147 b
Giza 171	42.70 b	76.57 b	78.34 b	34.19 c	0.120 c	42.95 b	78.31 b	78.57 b	33.06 c	0.114 c
Sakha 95	43.33 b	73.06 c	74.46 c	37.35 b	0.201 a	42.53 c	73.77 c	74.33 c	36.33 b	0.189 a
F test	**	**	**	**	**	**	**	**	**	**
					Foliar application					
Control	41.62 c	74.22 d	74.40 c	39.01 a	0.185 a	41.21 c	73.71 c	72.63 d	37.85 a	0.173 a
Kaolin	43.75 b	80.19 b	81.78 a	35.12 c	0.139 c	43.89 b	82.27 a	82.23 b	32.59 d	0.132 d
K_2SO_4	44.63 a	78.12 c	80.15 b	36.62 b	0.153 b	44.47 a	79.07 b	80.10 c	35.63 c	0.144 c
Paraffine	44.77 a	80.50 a	81.72 a	37.12 b	0.156 b	44.65 a	82.02 a	83.00 a	36.19 b	0.151 b
F test	**	**	**	**	**	**	**	**	**	**

- LCC: leaf chlorophyll content (SPAD unit), MSI: membrane stability index (%), RWC: relative water content (%), SD: stomatal density (stomata No. mm^{-2}), I: intensity of transpiration (mg cm^{-2} min^{-1}).
- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Table 4. Mean values of yield and its components as affected by irrigation levels, wheat cultivars and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

Season	2020/2021						2021/2022					
Traits	Days to 50% heading	Plant height (cm)	Spikes No./ m^2	Grain yield (t/ha)	1000 Kernel wt. (g)	No. kernels /spike	Days to 50% heading	Plant height (cm)	Spikes No./ m^2	Grain yield (t/ha)	1000 Kernel wt. (g)	No. kernels /spike
Treatments	**Irrigation levels**											
100%	95.58 a	120.03 a	411.61 a	7.963 a	53.18 a	57.47 a	98.33 a	121.44 a	426.92 a	8.584 a	54.99 a	61.41 a
80%	92.83 b	115.69 b	397.25 b	6.952 b	50.04 b	55.46 ab	95.97 b	116.83 b	409.67 b	7.640 b	52.87 b	59.20 b
60%	92.33 b	112.58 c	372.44 c	5.780 c	45.43 c	52.00 b	96.17 b	114.42 c	390.31 c	6.055 c	47.06 c	53.30 c
F test	**	**	**	**	**	**	**	**	**	**	**	**
	Cultivars											
Sids 14	95.61 a	120.92 a	389.50 b	6.843 a	47.72 c	54.15 b	98.97 a	123.56 a	405.42 b	7.395 ab	49.62 c	56.61 b
Giza 171	91.61 c	112.14 c	395.83 a	6.742 b	50.99 a	53.27 b	94.89 c	113.94 b	411.08 a	7.162 b	53.54 a	56.52 b
Sakha 95	93.53 b	115.25 b	395.97 a	7.110 a	49.94 b	57.51 a	96.61 b	115.19 b	410.39 a	7.721 a	51.75 b	60.78 a
F test	**	**	**	NS	**	**	**	**	*	**	**	**
	Foliar application											
Control	92.19 c	112.85 b	384.67 c	6.209 c	46.75 c	52.28 c	96.11 b	114.19 b	399.78 c	6.769 b	48.93 c	55.34 c
Kaolin	93.59 b	117.07 a	394.04 b	7.126 ab	48.89 b	57.44 a	97.15 a	118.89 a	408.33 b	7.679 a	51.32 b	60.83 a
K_2SO_4	94.30 a	117.59 a	399.74 a	6.975 b	50.96 a	54.61 b	97.33 a	118.89 a	416.15 a	7.536 a	52.86 a	57.67 b
Paraffine	94.26 a	116.89 a	396.63 ab	7.282 a	51.60 a	55.58 ab	96.70 ab	118.30 a	411.59 b	7.722 a	53.43 a	58.04 b
F test	**	**	**	**	**	**	**	**	**	**	**	**

- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

3.4 *Interaction between irrigation and cultivars*

Table (5) shows that chlorophyll content was not significant in the 1st season, Sids 14 cultivar had the highest average LCC values under 100% irrigation (46.77 SPAD unit) in the 2nd season. Sids 14 had the highest MSI% under 100% irrigation (89.02 and 87.85%, in the two seasons, respectively) whereas Sakha 93 had the lowest. Also, Sids 14 cultivar had the highest RWC values at 100% (89.77 and 90.14% in the two seasons). Table 4 showed a substantial difference in stomatal openings and transpiration intensity across the three irrigation levels and wheat cultivars. Cultivated Giza 171 under the irrigation level of 80% had fewer opening stomata (32.64 and 31.25 stomata mm^{-2}, in 1st and 2nd seasons, respectively) and lower transpiration intensity (0.099 and 0.097 mg cm^{-2} min^{-1}, respectively).

Table 6 shows how Sids 14, Giza 171, and Sakha 93 wheat cultivars responded to irrigation. This data shows that irrigation levels and cultivars do not significantly differ in days to 50% heading and plant height, in the 1st season, and in spikes no/m^2, and number of kernels/spike in the second seasons, respectively. Table 6 shows that Sakha 95 and Sids 14 had the maximum grain yields with 100% irrigation (8.314 and 8.117 t/ha in the 1st season and 8.920 and 8.741 t/ha in the 2nd season). The recommended water level yielded the heaviest 1000-kernel in Giza 171 (45.15 and 56.17 g) and Sakha 95 (53.94 and 55.22 g) in the 1st and 2nd seasons, respectively. However, all cultivars with 60% irrigation exhibited the lowest yield traits during the two growing seasons.

Table 5: Mean values of the physiological characters as affected by the interaction between irrigation levels and cultivars, in 2020/21 and 2021/22 seasons.

Irri.	Season / Traits / Cultivars	2020/2021 LCC	MSI	RWC	SD	I	2021/2022 LCC	MSI	RWC	SD	I
100%	**Sids 14**	46.18 a	89.02 a	89.77 a	39.46 b	0.163 d	46.77 a	87.85 a	90.14 a	37.75 a	0.154 d
	Giza 171	44.08 c	81.94 c	83.06 c	33.53 e	0.116 f	44.26 c	84.11 c	82.82 c	32.83 e	0.114 f
	Sakha 95	44.31 bc	75.32 e	77.63 e	37.78 c	0.176 c	44.54 c	75.31 f	76.28 f	36.75 b	0.166 c
80%	**Sids 14**	45.65 ab	85.52 b	88.07 b	38.06 c	0.115 f	45.93 b	86.86 b	86.67 b	35.83 c	0.114 f
	Giza 171	42.47 de	75.03 e	79.06 d	32.64 f	0.099 g	42.86 d	77.14 e	79.11 e	31.25 f	0.097 g
	Sakha 95	43.38 cd	74.40 f	74.94 f	35.72 d	0.167 d	42.11 e	75.64 f	74.65 g	34.50 d	0.154 d
60%	**Sids 14**	43.34 cd	80.89 d	79.37 d	40.57 a	0.184 b	42.85 d	82.46 d	79.85 d	38.33 a	0.173 b
	Giza 171	41.54 e	72.75 g	72.90 g	36.38 d	0.144 e	41.74 e	73.68 g	73.79 h	35.08 d	0.132 e
	Sakha 95	42.29 de	69.46 h	70.83 h	38.54 c	0.259 a	40.96 f	70.36 h	72.06 i	37.75 a	0.246 a
F test		NS	**	**	**	**	**	**	**	**	**

- Irri: irrigation levels, LCC: leaf chlorophyll content (SPAD unit), MSI: membrane stability index (%), RWC: relative water content (%), SD: stomatal density (stomata No. mm^{-2}), I: intensity of transpiration (mg cm^{-2} min^{-1}).
- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Table 6: Mean values of yield and its components as affected by the interaction between irrigation levels and cultivars, in 2020/21 and 2021/22 seasons.

Irri.	Season / Traits	2020/2021 Days to 50% heading	2020/2021 Plant height (cm)	2020/2021 Spikes No./ m^2	2020/2021 Grain yield (t/ha)	2020/2021 1000 Kernel wt. (g)	2020/2021 No. kernels /spike	2021/2022 Days to 50% heading	2021/2022 Plant height (cm)	2021/2022 Spikes No./ m^2	2021/2022 Grain yield (t/ha)	2021/2022 1000 Kernel wt. (g)	2021/2022 No. kernels /spike
100%	Sids 14	97.58 a	125.50 a	408.33 b-c	8.117 a	51.46 b	57.66 ab	100.75 a	129.42 a	422.17 b	8.741 ab	53.58 cd	61.40 a-c
	Giza 171	93.83 cd	115.42 c	412.17 ab	7.456 b	54.15 a	54.05 b-d	96.08 cd	117.33 cd	427.58 ab	8.092 c	56.17 a	58.53 b-d
	Sakha 95	95.33 b	119.17 b	414.33 a	8.314 a	53.94 a	60.70 a	98.17 b	117.58 cd	431.00 a	8.920 a	55.22 ab	64.31 a
80%	Sids 14	94.33 bc	119.17 b	391.75 d	6.935 bc	48.11 c	56.14 b-d	98.00 b	121.50 b	406.50 c	7.700 c	51.05 e	58.78 b-d
	Giza 171	91.33 e	112.25 d	397.17d	6.687 cd	51.20 b	53.31 cd	94.75 ef	113.08 e	410.50 c	7.034 d	54.52 bc	56.78 cd
	Sakha 95	92.83 d	115.67 c	402.83 c	7.233 bc	50.82 b	56.94 bc	95.17 de	115.92 d	412.00 c	8.186 bc	53.02 d	62.05 ab
60%	Sids 14	94.92 bc	118.08 bc	368.42 f	5.477 e	43.61 e	48.64 e	98.17 b	119.75 bc	387.58 e	5.745 f	44.23 h	49.66 e
	Giza 171	89.67 f	108.75 e	378.17 e	6.082 de	47.61 c	52.47 d	93.83 f	111.42 e	395.17 d	6.360 e	49.94 f	54.24 d
	Sakha 95	92.42 de	110.92 de	370.75 f	5.782 e	45.06 d	54.89 b-d	96.50 c	112.08 e	388.17 e	6.060 ef	47.00 g	56.00 d
F test		NS	NS	*	*	*	*	*	*	NS	**	**	NS

- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

3.5 *Interaction between irrigation and antitranspirants*

The impact of various antitranspirants applied to the leaves on the growth parameters of wheat plants under varying watering conditions was demonstrated in Table 7. The results clearly indicate that there was a substantial impact on plant growth measurements when considering the combined effects of additional irrigation and antitranspirant treatments, as compared to the control. The morphological parameters (LCC, MSI, and RWC) of plants were seen to significantly decrease when exposed to a 60% irrigation level in the soil, in comparison to plants growing under 80% or 100% irrigation levels. There was no observed significant impact on chlorophyll content during the first season. However, in the second season, the application of potassium sulphate (46.22 SPAD unit) to wheat plants resulted in a significantly greater chlorophyll content under 100% irrigation level. Similarly, the use of paraffin spray also exhibited a similar tendency, with a chlorophyll content of 46.47 SPAD unit. The most elevated values for the membrane stability index (MSI) were seen when the irrigation level was maintained at 100% and paired with the application of paraffin (85.01% in the 2020/21 season) or kaolin (86.56% in the 2021/22 season). In relation to the relative water content (RWC), the most elevated values were observed when subjected to 100% irrigation levels combined with the application of paraffin (86.97% and 87.01% in the seasons 2020/21 and 2021/22, respectively). Statistically significant disparities in stomatal density and transpiration rate were observed among the three irrigation levels and the use of antitranspirants, as indicated in Table 7, across both seasons. A notable reduction in stomatal density was observed when using kaolin spray in conjunction with irrigation at either 100% (34.57 mm^{-2}, in the seasons 2020/21) or 80% (34.00 and 31.00 mm^{-2}, in the seasons 2020/21 and 2021/22, respectively). Moreover, a notable reduction in transpiration intensity of 80% water level was seen when kaolin was applied via spraying, resulting in transpiration rates of 0.111 and 0.105 mg cm^{-2} min^{-1} during the 2020/21 and 2021/22 seasons, respectively. Table 8 presents the impact of the interaction between irrigation levels and antitranspirants on the yield components of a wheat crop. The interaction between irrigation level at 100% and the application of kaolin spray resulted in the tallest plant heights observed in the first and second seasons, measuring 121.33 cm and 124.22 cm, respectively. The interaction between 100% irrigation and the use of antitranspirants (kaolin, K_2SO_4, or paraffin) resulted in the best grain yield, which was significantly superior to most other interactions. While the other yield component was non-significant under varied levels of irrigation and different type of anti-transpiration, during both seasons.

Table 7: Mean values of the physiological characters as affected by the interaction between irrigation levels and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

Irri.	Season / Traits / Treat.	2020/2021 LCC	MSI	RWC	SD	I	2021/2022 LCC	MSI	RWC	SD	I
100%	**Control**	42.48 e-g	77.39 f	78.02 e	39.91 a	0.192 c	42.62 ef	76.60 g	76.18 g	39.00 a	0.180 c
	Kaolin	45.19 ab	84.30 b	86.02 b	34.57 d	0.128 g	45.45 b	86.56 a	86.15 b	32.33 g	0.124 g
	K_2SO_4	46.14 a	81.67 c	82.94 c	36.52 c	0.149 e	46.22 a	81.40 d	82.98 c	35.33 d	0.134 f
	Paraffine	45.62 ab	85.01 a	86.97 a	36.69 c	0.139 f	46.47 a	85.12 b	87.01 a	36.44 c	0.141 e
80%	**Control**	41.67 gh	75.08 h	75.99 g	38.41 b	0.148 e	41.40 g	74.52 i	73.35 h	37.67 b	0.143 e
	Kaolin	43.90 cd	80.02 d	82.47 c	34.00 d	0.111 i	44.02 d	82.13 c	82.91 c	31.00 h	0.105 i
	K_2SO_4	44.52 bc	78.02 e	81.58 d	34.75 d	0.119 h	44.40 cd	80.52 e	80.89 d	33.67 f	0.113 h
	Paraffine	45.24 ab	80.13 d	82.73 c	34.73 d	0.130 g	44.70 c	82.37 c	83.44 c	33.11 f	0.125 g
60%	**Control**	40.72 h	70.18 j	69.21 h	38.70 b	0.215 a	39.61 h	70.01 j	68.35 i	36.89 c	0.196 a
	Kaolin	42.16 fg	76.25 g	76.85 f	36.78 c	0.178 d	42.20 f	78.12 f	77.62 f	34.44 e	0.167 d
	K_2SO_4	43.23 d-f	74.68 i	75.94 g	38.57 b	0.192 c	42.78 e	75.28 h	76.41 g	37.89 b	0.185 bc
	Paraffine	43.46 c-e	76.35 g	75.46 g	39.95 a	0.199 b	42.80 e	78.58 f	78.56 e	39.00 a	0.187 b
F test		**NS**	**	**	**	**	**	**	**	**	**

- Irri: irrigation levels, LCC: leaf chlorophyll content (SPAD unit), MSI: membrane stability index (%), RWC: relative water content (%), SD: stomatal density (stomata No. mm^{-2}), I: intensity of transpiration (mg cm^{-2} min^{-1}).
- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Table 8: Mean values of yield and its components as affected by the interaction between irrigation levels and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

Irri.	Season / Traits / Treats.	2020/2021 Days to 50% heading	Plant height (cm)	Spikes No./ m^2	Grain yield (t/ha)	1000 Kernel wt. (g)	No. kernels /spike	2021/2022 Days to 50% heading	Plant height (cm)	Spikes No./ m^2	Grain yield (t/ha)	1000 Kernel wt. (g)	No. kernels /spike
100%	**Control**	94.44 b	117.67 b	404.22 bc	7.171 cd	50.51 cd	53.83 cd	97.56 cd	119.78 bc	417.78 b	7.448 c	52.22 d	57.55 b-d
	Kaolin	95.44 a	121.33 a	412.22 ab	8.125 ab	51.98 bc	60.04 a	98.89 ab	124.22 a	427.22 a	9.241 a	54.33 c	67.60 a
	K_2SO_4	96.33 a	120.67 a	415.11 a	8.040 b	54.79 a	57.52 a-c	99.22 a	120.89 b	432.67 a	8.850 a	56.56 ab	60.63 b
	Paraffine	96.11 a	120.44 a	414.89 a	8.514 a	55.44 a	58.48 ab	97.67 bc	120.89 b	430.00 a	8.797 a	56.84 a	59.88 bc
80%	**Control**	91.56 e	113.89 d	389.44 de	6.098 e	46.93 e	51.58 d	95.78 ef	112.78 f	401.22 d	7.329 c	50.00 e	56.10 c-e
	Kaolin	93.11 cd	116.56 bc	396.56 cd	7.541 c	49.23 d	61.14 a	96.22 d-f	118.00 b-d	408.33 c	7.607 bc	52.14 d	60.57 b
	K_2SO_4	93.44 c	117.33 bc	402.89 c	6.971 d	51.46 bc	54.33 b-d	95.78 ef	119.11 b-d	416.56 b	7.488 c	54.15 c	60.01 bc
	Paraffine	93.22 c	115.00 cd	400.11 c	7.197 cd	52.53 b	54.80 b-d	96.11 ef	117.44 cd	412.56 bc	8.136 b	55.18 bc	60.14 bc
60%	**Control**	90.56 f	107.00 e	360.33 g	5.357 f	42.80 f	51.42 d	95.00 f	110.00 g	380.33 f	5.530 e	44.57 g	52.36 e
	Kaolin	92.22 de	113.33 d	373.33 f	5.714 ef	45.46 e	51.14 d	96.33 c-f	114.44 ef	389.44 e	6.189 d	47.50 f	54.34 de
	K_2SO_4	93.11 cd	114.78 cd	381.22 ef	5.913 e	46.63 e	51.97 d	97.00 c-e	116.67 de	399.22 d	6.271 d	47.88 f	52.38 e
	Paraffine	93.44 c	115.22 ecd	374.89 f	6.136 e	46.82 e	53.47 cd	96.33 c-f	116.56 de	392.22 e	6.231 d	48.27 f	54.11 de
F test		**NS**	**	**NS**	*	**NS**	**NS**	**NS**	*	**NS**	**	**NS**	*

- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

3.6 *Interaction between cultivars and antitranspirants*

The findings presented in Table 9 demonstrate that there was a substantial interaction between the different cultivars and the application of antitranspirants. This interaction was observed to have a high level of significance across all the attributes that were evaluated, in both seasons. The cultivar Sids 14 exhibited the highest LCC values when treated with K_2SO_4 (46.03 and 46.11 SPAD unit) or paraffin (45.48 and 46.04 SPAD unit) during the growing seasons of 2020/21 and 2021/22, respectively. Cultivated the cultivar Sids 14, when treated with kaolin spray, demonstrates the greatest mean values for both MSI (88.21% and 88.89% in both seasons) and RWC (88.44% and 88.80% in both seasons, respectively). Additionally, the application of paraffin on Sids 14 resulted in significantly elevated relative water content (RWC) levels, 89.30% for 2^{nd} seasons. The results presented in Table 9 demonstrate the impact of antitranspirant spray on the stomatal opening response in different wheat cultivars. Specifically, the Giza 171 cultivar treated with kaolin spray exhibited a considerably lower stomatal density of 31.69 and 30.33 stomata mm^{-2} in the 2020/21 and 2021/22 seasons, respectively. Similarly, the Giza 171 cultivar treated with paraffin spray showed a significantly lower stomatal density of 32.51 stomata mm^{-2} in the first season. The transpiration intensity of Giza 171 was found to be lowest when treated with paraffin (0.100 and 0.099 mg cm^{-2} min^{-1}, during both seasons, respectively) or kaolin (0.111 and 0.104 mg cm^{-2} min^{-1}) throughout the second seasons.

The results presented in Table 10 demonstrate the impact of the interaction between irrigation levels and antitranspirants on yield and its components, seen in both seasons. No statistically significant differences were seen among all interactions in terms of plant height, spike number per square meter, and 1000-kernel weight in both seasons. The interaction between cultivars and foliar spray of antitranspirant did not have a significant effect on grain output in the second season. However, in the first season, all cultivars demonstrated a higher yield when treated with any of the antitranspirants. The highest grain yield (7.422 t/ha) is observed when Giza 171 is combined with paraffine spraying. Additionally, cultivated Sids 14 shows a high yield when sprayed with either kaolin (7.289 t/ha) or paraffine (7.231 t/ha). Similarly, sprayed Sakha 95 exhibits a high yield when treated with kaolin (7.368 t/ha), K_2SO_4 (7.368 t/ha), or paraffine (7.194 t/ha). The highest mean number of kernels per spike, measuring 63.95 and 63.46 g, was observed in the second season for the combination of Sakha 95 with the application of kaolin and K_2SO_4, respectively. Similarly, the interaction between Sids 14 and the spraying of kaolin resulted in a mean kernel weight of 60.17 g in the second season.

Table 9: Mean values of the physiological characters as affected by the interaction between cultivars and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

Cultivars	Season / Traits / Treats	2020/2021 LCC	2020/2021 MSI	2020/2021 RWC	2020/2021 SD	2020/2021 I	2021/2022 LCC	2021/2022 MSI	2021/2022 RWC	2021/2022 SD	2021/2022 I
Sids 14	**Control**	44.17 cd	79.75 d	81.18 d	44.01 a	0.183 d	43.53 cd	79.81 f	79.14 e	43.44 a	0.173 c
	Kaolin	44.56 bc	88.21 a	88.44 a	36.66 e	0.130 h	45.04 b	88.89 a	88.80 a	32.56 h	0.129 g
	K_2SO_4	46.03 a	85.31 c	85.63 c	38.25 c	0.145 g	46.11 a	86.44 c	84.98 b	37.11 cd	0.139 f
	Paraffine	45.48 ab	87.31 b	87.69 b	38.53 c	0.158 f	46.04 a	87.74 b	89.30 a	36.11 e	0.148 e
Giza 171	**Control**	39.31 f	72.77 j	72.63 i	37.91 cd	0.147 g	39.12 g	72.45 k	71.25 h	36.67 de	0.140 f
	Kaolin	43.78 cd	78.11 f	80.93 de	31.69 g	0.111 j	43.69 cd	81.85 d	81.09 d	30.33 i	0.104 i
	K_2SO_4	43.64 cd	76.37 g	79.36 f	34.64 f	0.121 i	44.04 c	77.66 g	79.36 e	32.33 h	0.114 h
	Paraffine	44.06 cd	79.02 e	80.44 e	32.51 g	0.100 k	44.96 b	81.27 e	82.59 c	32.89 gh	0.099 i
Sakha 95	**Control**	41.39 e	70.14 k	69.39 j	35.10 f	0.224 a	40.98 f	68.88 l	67.48 i	33.44 g	0.206 a
	Kaolin	42.91 d	74.25 i	75.97 h	37.00 de	0.176 e	42.95 e	76.07 i	76.78 f	34.89 f	0.163 d
	K_2SO_4	44.22 c	72.69 j	75.47 h	36.95 de	0.193 c	43.25 de	73.09 j	75.95 g	37.44 c	0.179 b
	Paraffine	44.79 bc	75.16 h	77.02 g	40.33 b	0.210 b	42.96 e	77.05 h	77.12 f	39.56 b	0.206 a
F test		**	**	**	**	**	**	**	**	**	**

- LCC: leaf chlorophyll content (SPAD unit), MSI: membrane stability index (%), RWC: relative water content (%), SD: stomatal density (stomata No. mm^{-2}), I: intensity of transpiration (mg cm^{-2} min^{-1}).
- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Table 10: Mean values of yield and its components as affected by the interaction between cultivars and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

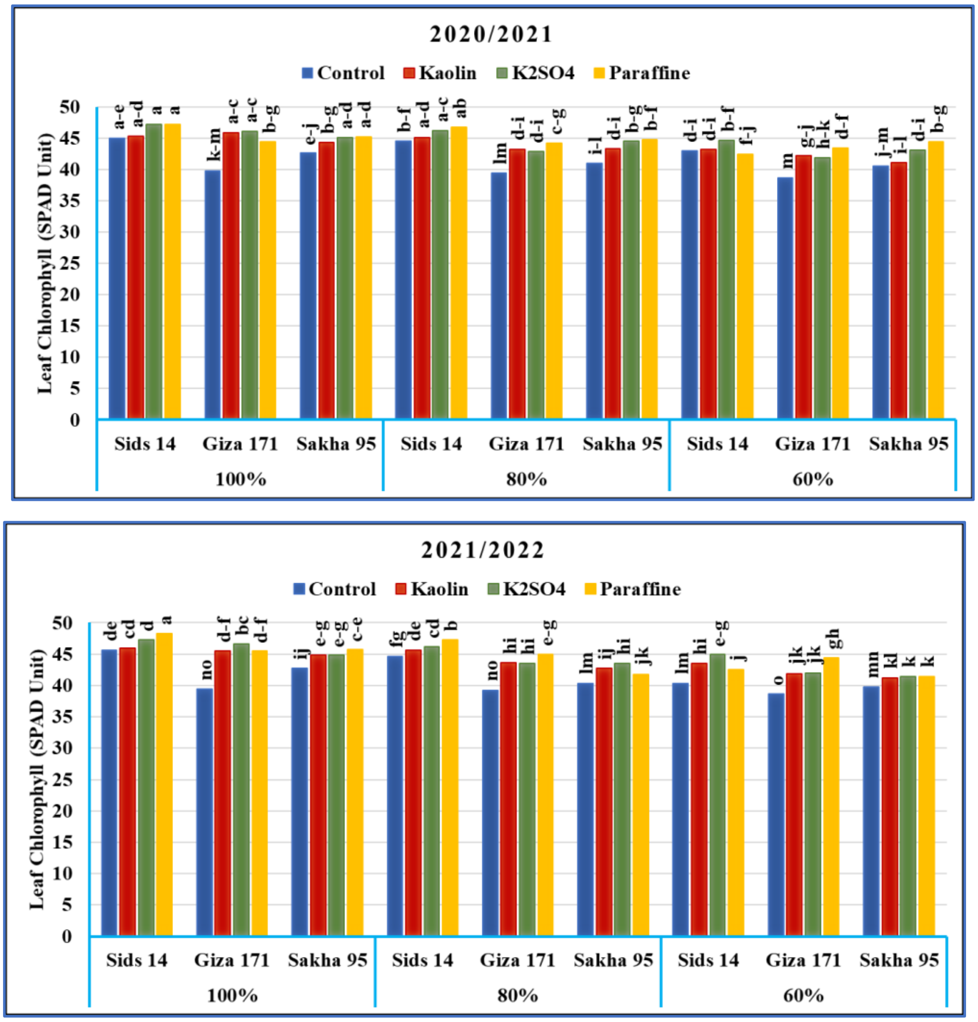
Cultivars	Season / Traits / Treats.	2020/2021 Days to 50% heading	2020/2021 Plant height (cm)	2020/2021 Spikes No./ m^2	2020/2021 Grain yield (t/ha)	2020/2021 1000 Kernel wt. (g)	2020/2021 No. kernels /spike	2021/2022 Days to 50% heading	2021/2022 Plant height (cm)	2021/2022 Spikes No./ m^2	2021/2022 Grain yield (t/ha)	2021/2022 1000 Kernel wt. (g)	2021/2022 No. kernels /spike
Sids 14	**Control**	94.33 cd	117.78 b	379.00 d	6.059 e	44.91 f	50.43 f	97.78 bc	120.89 b	396.11 f	6.509 d	47.22 e	54.05 f
	Kaolin	95.22 bc	121.56 a	388.44 bc	7.289 a	47.32 e	59.00 ab	99.33 a	124.33 a	405.22 de	7.713 ab	49.22 d	60.17 a-c
	K_2SO_4	97.11 a	122.00 a	397.22 ab	6.793 b-d	48.75 c-e	53.05 d-f	99.89 a	125.00 a	413.22 a-c	7.581 ab	50.61 cd	55.07 ef
	Paraffine	95.78 b	122.33 a	393.33 a-c	7.231 ab	49.92 c	54.11 c-f	98.89 ab	124.00 a	407.11 c-e	7.779 ab	51.42 bc	57.16 c-f
Giza 171	**Control**	89.67 h	108.67 f	388.44 bc	6.059 e	48.05 de	51.10 ef	94.44 f	109.44 e	401.22 ef	6.628 cd	50.45 cd	55.85 d-f
	Kaolin	91.44 g	112.56 de	394.44 a-c	6.722 cd	49.90 c	53.21 d-f	95.11 ef	114.89 cd	410.00 b-d	7.337 ab	52.54 b	58.48 c-e
	K_2SO_4	92.33 fg	114.00 de	402.78 a	6.764 b-d	52.59 ab	52.51 d-f	94.44 f	115.33 c	419.33 a	7.210 bc	55.18 a	54.48 ef
	Paraffine	93.00 ef	113.33 de	397.67 ab	7.422 a	53.40 a	56.28 a-d	95.56 ef	116.11 c	413.78 a-c	7.474 ab	56.01 a	57.26 c-f
Sakha 95	**Control**	92.56 ef	112.11 e	386.56 cd	6.508 d	47.28 e	55.30 b-e	96.11 de	112.22 d	402.00 ef	7.170 bc	49.12 d	56.12 c-f
	Kaolin	94.11 d	117.11 bc	399.22 a	7.368 a	49.45 cd	60.12 a	97.00 cd	117.44 c	409.78 b-d	7.987 a	52.21 b	63.85 a
	K_2SO_4	93.44 de	116.78 bc	399.22 a	7.368 a	51.54 b	58.26 a-c	97.67 bc	116.33 c	415.89 ab	7.819 ab	52.79 b	63.46 ab
	Paraffine	94.00 d	115.00 cd	398.89 a	7.194 a-c	51.47 b	56.36 a-d	95.67 ef	114.78 cd	413.89 a-c	7.911 a	52.86 b	59.71 b-d
F test		**	NS	NS	*	NS	NS	*	NS	NS	NS	NS	*

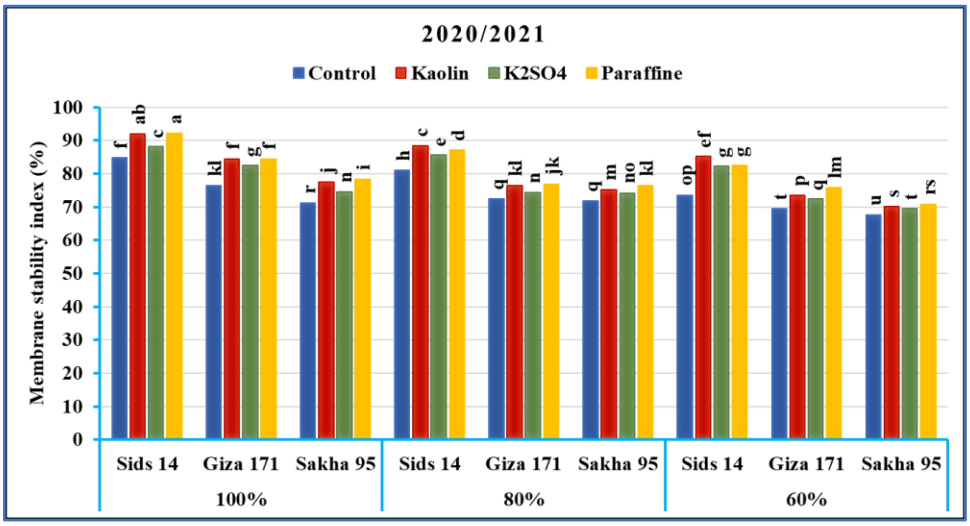
- *, **, and NS stand for significant, highly significant, and not significant, respectively.
- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

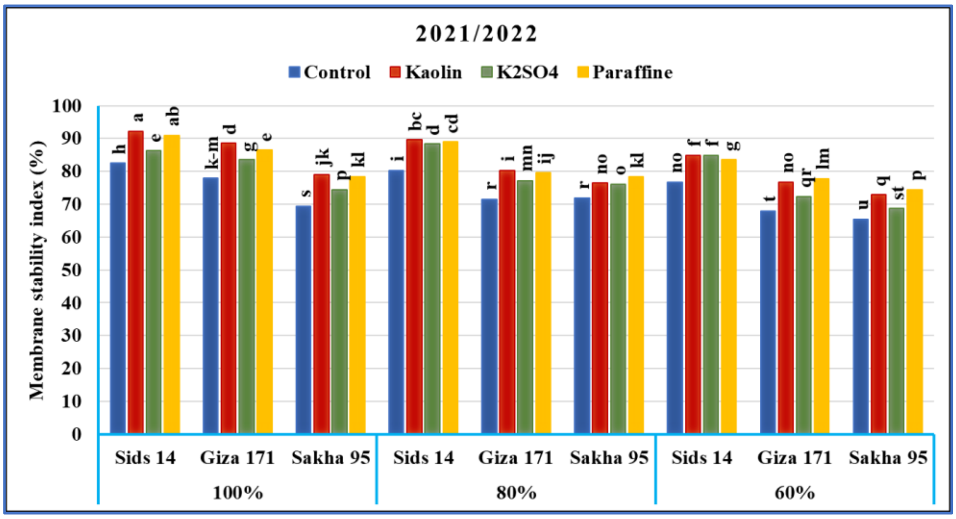
3.7 *Interaction between irrigation, cultivars and antitranspirants cultivars*

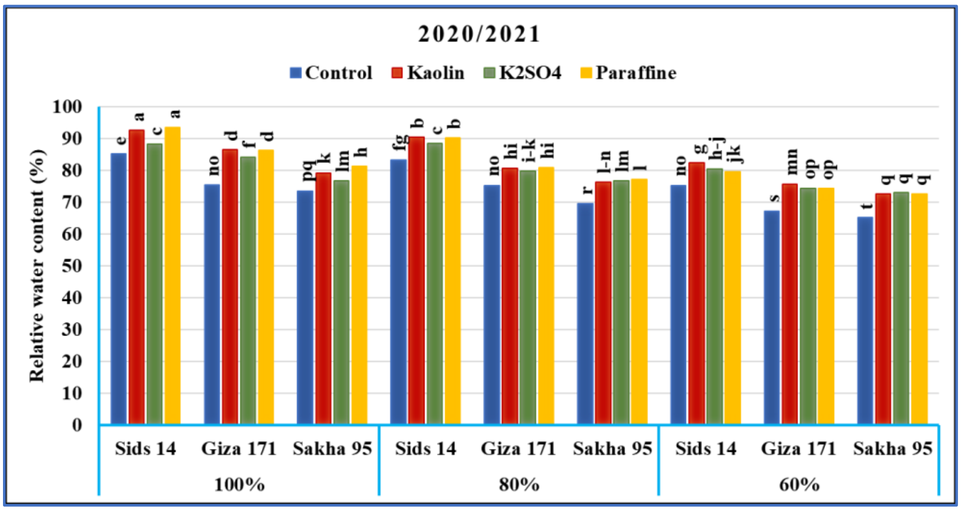
Concerning the effect of interaction between irrigation levels, cultivars and different antitranspirant types (Table 11). Non-ssignificant differences between the irrigation levels and three tested wheat cultivars among antitranspirants spraying were detected in chlorophyll content in the 1st season (Table 11). While Sids 14 cultivar significantly enjoyed higher LCC (48.23, in the 2nd season) under 100% irrigation level and spraying with paraffine oil. Data of MSI% illustrate that the cultivars Sids 14 grown under normal irrigation (100%) showed the highest values of MSI% in the leaves with applying kaolin (91.85 and 92.19%) or paraffine (92.23 and 90.98%), in both seasons. Data in Figure 1 estimated that cultivars differed significantly in RWC% of plant over irrigation levels and spraying treatments. Sids 14 cultivar spraying with kaolin (92.46 and 93.99%) or paraffine (93.40 and 95.13%) under 100% irrigation level significantly exhibited higher RWC, in both seasons, respectively. In the present work, the application of kaolin or paraffine to Giza 171 under 80 or 100% irrigation levels induced significant decrease in the stomata opening at upper epidermis as compared with the corresponding control at 60% irrigation level in both seasons as shown in Table 11. Data in table 11 show significant differences between the three irrigation levels, three tested wheat cultivars and different antitranspirant types were detected in intensity of transpiration, under irrigation level of 100%, spraying Giza 171 with paraffine recorded the lowest values for intensity of transpiration (0.068 and 0.083 mg cm^{-2} min^{-1} in 1st and 2nd seasons, respectively), while under 80%, Giza 171 sprayed with kaolin (0.081 mg cm^{-2} min^{-1}) or paraffine (0.082 mg cm^{-2} min^{-1}) recorded lowest values of intensity of transpiration in 2nd season. The interaction between each of the tested antitranspirant (kaolin and paraffine) under irrigation treatment (100%) under the same cultivar had not reached the level of significance in either season.

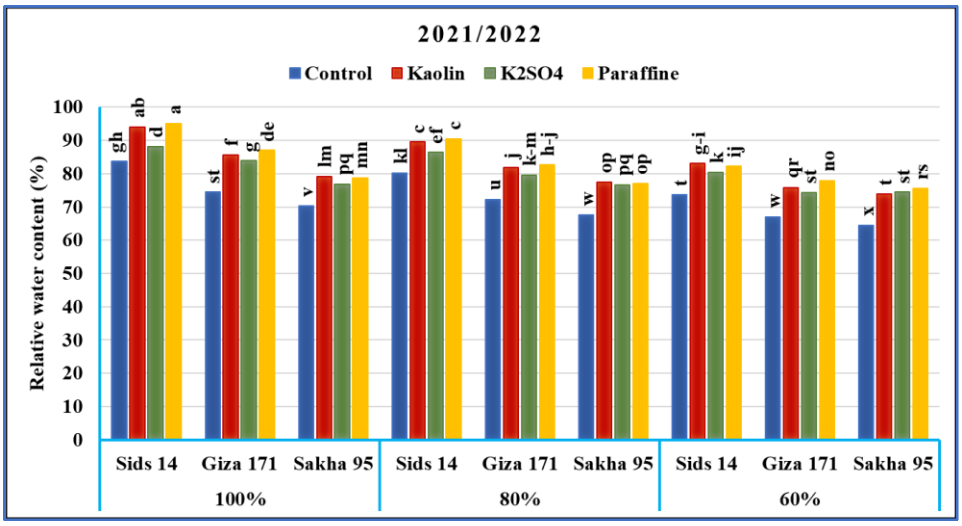
Figure 2 revealed the effect of interaction between irrigation levels, cultivars and different antitranspirant types on yield and its components. It was noticed there were no significant differences between the rate of irrigation, cultivars and different antitranspirant types in all yield characters, in both seasons.

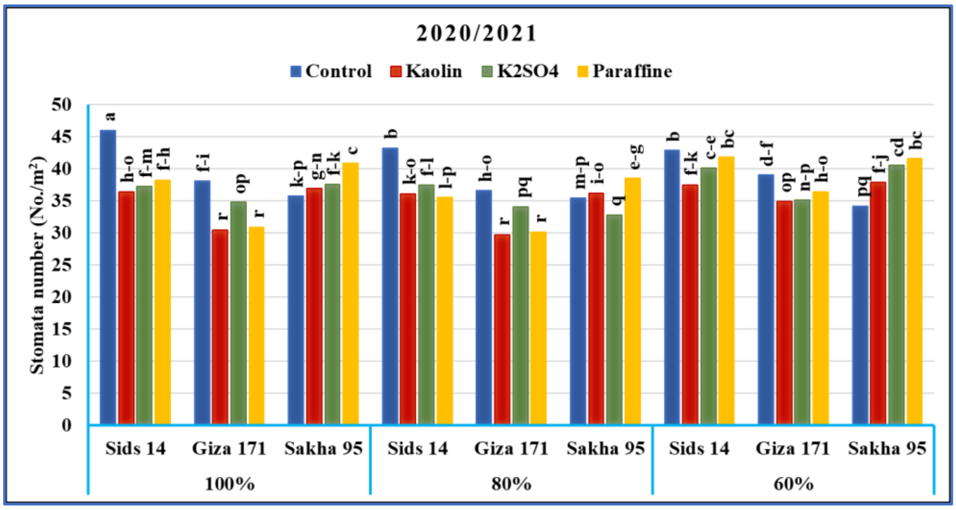


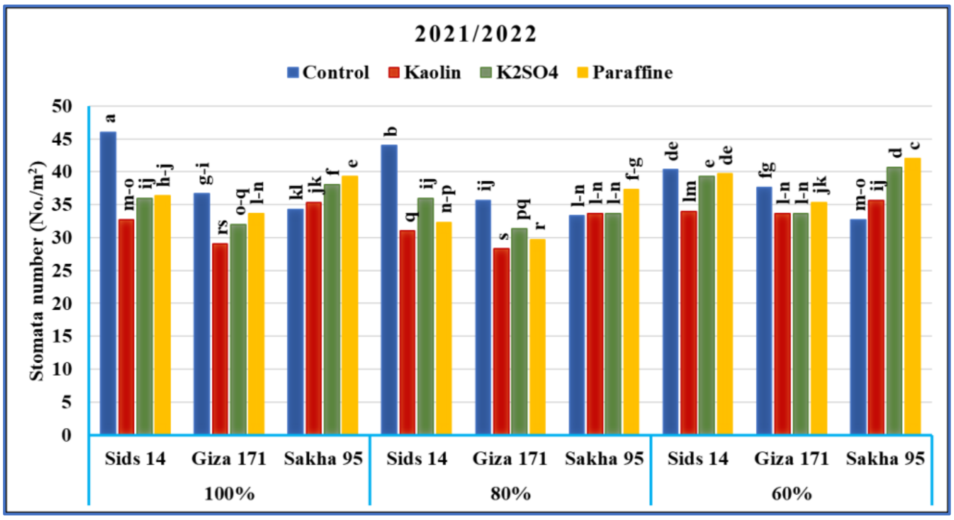

2020/2021
Control
Kaolin
K2SO4
Paraffine
Membrane stability index (%)
100
90
80
70
60
50
40
30
20
10
0
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
100%
80%
60%

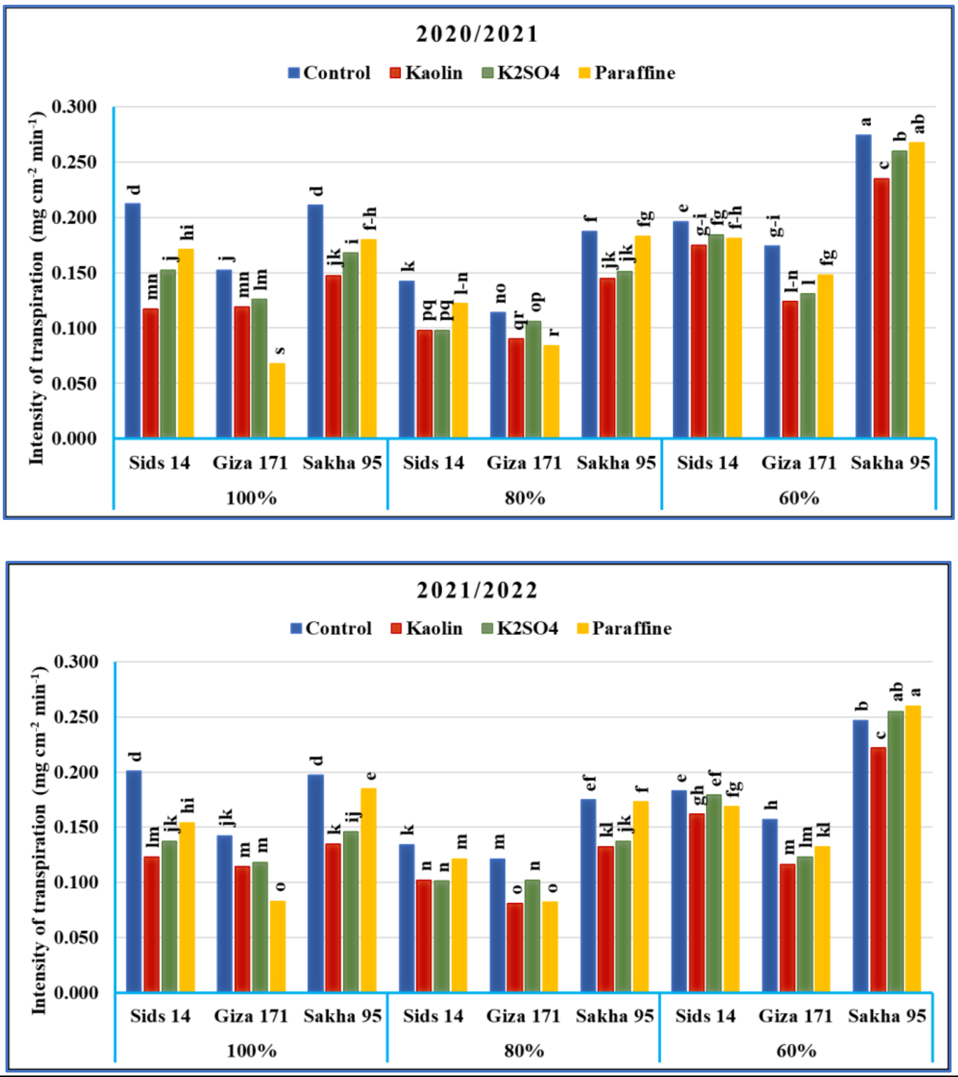

2021/2022
Control
Kaolin
K2SO4
Paraffine
Membrane stability index (%)
100
90
80
70
60
50
40
30
20
10
0
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
100%
80%
60%


2020/2021
Control
Kaolin
K2SO4
Paraffine
Relative water content (%)
100
90
80
70
60
50
40
30
20
10
0
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
Sids 14
Giza 171
Sakha 95
100%
80%
60%


2021/2022
Control Kaolin K2SO4 Paraffine
Relative water content (%)
Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95
100% 80% 60%

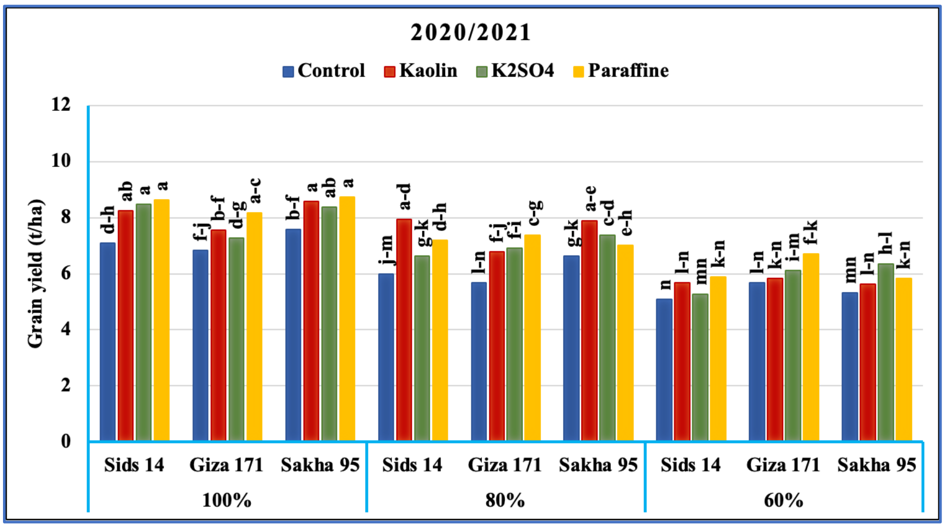

2020/2021
Control Kaolin K2SO4 Paraffine
Stomata number (No./m²)
Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95
100% 80% 60%

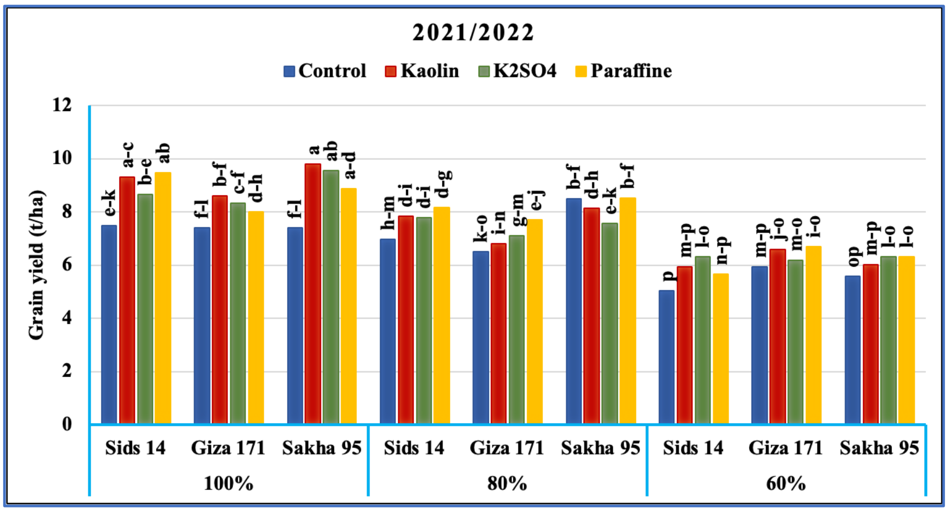

2021/2022
Control Kaolin K2SO4 Paraffine
Stomata number (No./m²)
Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95 Sids 14 Giza 171 Sakha 95
100% 80% 60%



- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Fig. 1. Histograms shows the mean values of physiological characters as affected by the interaction between irrigation levels, cultivars, and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.





- Duncan's Multiple Range Test indicates; There are no significant differences among the means for any factor specified by the same letter inside the same column at the 5% level.

Fig. 2. Histograms shows the mean values of yield as affected by the interaction between irrigation levels, cultivars, and foliar spray of antitranspirants, in 2020/21 and 2021/22 seasons.

4. Discussion

The highly significant differences between seasons for all studied traits can be attributed to the varied in temperature during both seasons (Table 2). When plants were watered at a 60% level in 2020–2021 and 202–2022, the chlorophyll in the leaves, the membrane stability index, and the relative amount of water in the leaves all went down greatly (Table 3). The decrease in LCC, MSI, and RWC may have been caused by tissue water loss, which stopped cells from dividing and growing, or by a drop in the activity of elongating meristematic tissues, which led to a drop in photosynthetic pigments like chlorophyll content and, in turn, a drop in the efficiency of photosynthesis (Abdallah et al., 2019). Research by Yaseen et al. (2020) showed that drought stress had significant adverse effects on growth and yield parameters, also it can cause more reactive oxygen species (ROS) to be made, which breaks down proteins and membranes and slows down photosynthesis (El-Bassiouny et al. 2022). Other studies confirmed these results. Also, it could be caused by a decrease in soil moisture and the plant's water status, which slowed down the rate at which nutrients were taken up from the soil and slowed down photosynthesis (Khalel, 2015), which slowed down cell division and elongation, which in turn slowed down enzyme activity and hormone production (Yasin, 1992).

When there is enough water in the root zone, more photosynthate can be moved from the leaves to the grain, leading to a higher yield character value. On the other hand, plants with less water had lighter grain, which Sarwar et al. (2010) think may have been caused by a lack of nutrients in the soil solution. Wajid et al. (2002) showed that irrigation had a big effect on the output and reported similar results. There may be big differences between genotypes in terms of physiological traits and yield components because genotypes have different genes.

Table 3 shows that foliar applications of antitranspirants like kaolin, K_2SO_4, and paraffine led to significant increases in growth criteria (LCC, RWC, and MSI%) compared to the control treatment in both seasons, as well as a decrease in the number of stomata that opened and the amount of transpiration. The antitranspirant spray also had a big effect on the yield and the parts of the yield. In both seasons, the kaolin spray had the best mean values for plant height, grain production, and the number of seeds per spike (Table 4). Kaolin acts as a radiation-reflecting compound that lowers leaf temperature, this decreases transpiration rate more than photosynthesis in plants grown in high levels of solar radiation (Nakano and Uehara, 1996), which keeps more water in the plant's tissues. This could help the plant's metabolism, physiological processes, photosynthetic rate, carbohydrate metabolism, and many other things. Cantore et al. (2009) looked at the effects of kaolin on different types of wheat and found that it gradually lowers plant stress, which is important for plant growth and crop quality. Segura-Monroy et al. (2015) also found that kaolin made *Physalis peruviana* L. seedlings grow taller and weigh more when they were dry.

K_2SO_4 stimulates the guard cells that circle the stomata pore, which is a chemical compound (metabolic substance) that stops the stomata from opening all the way (Anjum et al., 2011), because of this, plant leaves don't lose water vapour. MacRobbie (2006) showed that stomata open when a lot of potassium accumulating in guard cells, mostly in the vacuole. To make enough turgor for the stomata to open.

Most of antitranspirants are sticky, like waxes, oils that have been mixed with water, strong alcohol, silicon, and plastic. The benefit of antitranspirants is that they improve the plant's water potential by reducing soil water loss. At this time, plant growth depends more on the plant's water status than on photosynthesis (Khalel, 2015). This study found that liquid paraffin boosted the relative amount of water while decreasing the rate of transpiration. This effect may be caused by the substance's ability to partly close stomata, which slows down transpiration and stops water loss through stomata with a waxy layer on top. Abdallah (1996) also talked about the same results. Khalil (2006) found that, compared to the control treatment, all antitranspirants (film-forming, metabolic, and reflecting compounds) increased the growth of sesame (*Sesamum indicum*) plants by a large amount.

Table 5 shows that the physiological character values of all cultivars decreased when they were stressed by drought compared to when they were watered as suggested. Based on the results in Table 4, Sids 14 and Giza 171 did better than Sakha 95 in most ways when watering treatments were used. On the other hand, Sids 14 did better than other cultivars when watered at three different amounts.

Based on the information in Table 6, when irrigation was used, all types grew taller and produced more. This could be because different types have different genetic traits and help plants grow better when there are enough nutrients and no moisture stress (Sarwar et al. 2010). Which was that wheat production went up as irrigation levels increased (Wajid et al., 2002). On the other hand, when all types were watered at a rate of 60% during the two growing seasons, the yield component values were the lowest. Dencic et al. (2000) came to similar conclusions. They found that different wheat cultivars had number. kernels per spike that were more subject to drought stress.

Table 7 showed the link between the amount of watering and antiperspirants. The interaction between irrigation levels (100% and 80%) and foliar spray of liquid paraffin or kaolin gave the highest values of LCC, RWC, and MSI and the lowest number of open stomata and intensity of transpiration, this interaction was significantly better than all the other interactions. The waxy substance keeps the cells from drying out and keeps the plant from losing water by partially closing the stomata and slowing down the rate of transpiration, this the beneficial effects of spraying liquid paraffin on a significant increase in physiological characteristics (Davenport, 1977; Khalel, 2015), it helps keep the soil moist and keeps the rate of biological processes, especially photosynthesis, steady, which is demonstrated in the best growth and crop yield (Abdallah, 1996). Abdallah et al. (1996) and Abdel-Nasser and El-Gamal (1996) both said that antitranspirants affect plant growth by increasing the plant's water potential at a time when growth depends more on water than on photosynthesis. This growth spurt will lead to a healthy leaf area, which will help photosynthesis (Ibrahim et al., 1993). Khalel (2015) also came to the same conclusions. Tanaka and Tsuji (1980) found that K is important for the production of photosynthetic pigment because it stops the breakdown of newly made Chl and the production of δ-aminolevulinic acid synthase. These results show that K^+ treatment affects how well wheat plants can deal with water stress by making it easier for them to make pigments that are used in photosynthesis.

The results are shown in Table 8, which shows how the antitranspirant foliar spray affected the yield factors of wheat plants that were watered at different rates. Spraying liquid wax on the plants makes them produce more. Because the stomata partially close, which helps the plant grow well and gives it more growth characteristics, it may be because these antitranspirant chemicals help plants lose less water through transpiration (Abdallah, 1996) when compared to treating water, this is shown by a rise in crop growth. Abdallah et al. (2019) showed that putting an antitranspirant on the leaves causes a covering layer to form on the surface, which slows down the rate of transpiration. Also, it keeps more water in plant tissues, which is good for the plant's metabolism and rate of photosynthesis. It also helps move photosynthesis away from the plant's leaves, which is important for the best growth, yield, and quality of the plant (Cantore et al., 2009). El Shafei et al. (2023) found that the foliar application of potassium either in the forms of K_2SO_4 or K_2SiO_3 at the different tested concentrations increased the grain production of wheat per unit of water use. Another study suggests that spraying K-silicate has the potential to alleviate the negative effects of drought stress on sugar beet yield grown in calcareous soils (Ali et al. 2019).

When anti-transpirant was put on plants, the plants lost a lot less water. This fits with what Abdullah et al. (2015) said about how the anti-transpirant stops plants from sweating, making it harder for water vapour to move through the stomata. The relative water content (RWC%) shows how much water is in the leaf tissue. The membrane stability index (MSI%) shows what percentage of the leaf tissues of the three wheat types have been damaged by the different ways they are watered. These two measures can be used to evaluate a cultivar tolerance for a lack of water. The relative water content and cell membrane stability index were very different between the three irrigation levels, the three wheat cultivars studied, and the different types of antitranspirants. The decrease in MSI may be attributed to cell membrane integrity damage caused by less water and drought (Shaukat et al., 2021).

In general, the antitranspirant agents raised the LCC, MSI%, and RWC% of the three cultivars under each level of irrigation by a large amount compared to the non-sprayed group. These results were the same with those by Abdelkader et al. (2010). The larger flag leaf area of the Sids 14 cultivar may be why it is better in LCC, MSI, and RWC of flag leaf. This shows that the flag leaf has more green cells and more chlorophyll. This could be because of the effect of the flag leaf area (Figure 1), which helps photosynthesis and the build-up of dry matter. Abd El-Rady (2022) found that, Sids 14 had higher values of LCC, MSI, and RWC under various environmental conditions than other genotypes.

Since stomata control both the loss of water vapour and the intake of carbon dioxide, you would expect that the rate of transpiration would also slow down. In fact, compared to the control plants that were not treated with antitranspirants, the antitranspirant treatments greatly reduced the number of open stomata and the intensity of transpiration in plants that were watered at different levels. But only the Giza 171 type that was sprayed with paraffine or kaolin showed a decrease in the number of stomata that opened and the amount of transpiration intensity. According to the study by Bertolino et al. (2019), the different numbers of stomata may be caused by genetic differences or growing in different environments. Mphande et al. (2021) reported that ABA signalling controls the closing of stomata as one of the first ways plants adapt to less water in the soil. Reduced transpiration can be duplicated in the field by using antitranspirants as a way to deal with drought (Buckley, 2019). Potassium is needed for plants to grow. It is also important for the activities of enzymes, for stomata to open and close, and for photosynthesis (Golldack et al., 2003). Abdelaziz and Abdeldaym (2018) showed that spray potassium rates made cucumbers grow much more quickly. Potassium is important for a plant's growth, its ability to make food through photosynthesis, its ability to use water efficiently, and its role in making metabolic chemicals. In the form of a water emulsion, kaolin, which makes a thin film on leaves and hardens when exposed to sunlight, can be used as a foliar anti-transpirant. This film is very strong and has a lot of flexibility. A film like this makes it harder for water to leave a plant by lowering the amount of water lost through evaporation, improving the plant's water status, and stopping leaves from falling off and drying out. Faralli et al. (2016) say that it is considered a safe resource for the environment. Rosati et al. (2006) found that putting kaolin on the leaves of plants makes them healthier and more productive. It also lessens the bad effects of water stress on photosynthesis in almond or walnut trees. Dinis et al. (2018) found that the bad effects of water stress are also lessened by higher photochemical reflectance and photosynthetic pigments. Xiang et al. (2022) and Mphande et al. (2023) say that paraffine is helpful because it seems to form a film that works as a physical waterproof barrier over stomata and reduces water loss through transpiration.

The results of yield and yield components (Figure 2) showed that there were no significant differences between cultivars, types of antitranspirants, and irrigation rates in terms of yield in either season. This study examined the relationship between antitranspirant use and irrigation levels in numerous wheat cultivars. Antitranspirants' ability to conserve water and sustain wheat crop yield was our study's key goal. However, our analysis found no statistically significant crop performance differences due to this interaction. Our study's lack of statistical significance suggests that antitranspirants may reduce wheat growing water use under the conditions we evaluated. Antitranspirants in agriculture regulate plant height, reduce lodging, and improve crop management. In locations with limited water supply, conservation measures are crucial. The potential for water saving and economic crop productivity underpinned our research. Our data do not show a significant interaction impact, but they do suggest that antitranspirants do not reduce wheat production at the irrigation levels tested. The ability of wheat plants to adapt to many environmental conditions may explain the lack of a significant interaction. Wheat's physiological processes can adapt to water availability, which may help reduce antitranspirant effects on crop growth. In addition, our analysis showed that wheat economic productivity was steady regardless of irrigation. This shows that wheat growing with antitranspirants may be economically viable. A new review by Mphande et al. (2020) says that antitranspirants can help many types of crops do better when they are stressed by drought. In this study, yield improvements were seen in most cases, and the antitranspirants had little or no effect. One possible explanation is that the anti-transpirant effect of reducing water loss also reduces ABA biosynthesis and, in turn, its effects on photosynthesis, reproductive development, or other metabolic processes. (Kondhare et al., 2015) found that abiotic pressures like drought and high temperature are among the things that affect growth and development of spikes, which in turn affects yield.

Conclusion

Based on the above results, it can be said that irrigation level of 60% (Drought stress) had a negative impact on all studied traits, while the recommended irrigation was superior in all traits under study. Also, application of antitranspirants like kaolin, K_2SO_4, and paraffine with different irrigation rates increased LCC, MSI, RWC, and yield components for the studied cultivars and decreased the harmful effects of low irrigation levels under the same conditions at Sohag governorate, Egypt, during the winter seasons. Antitranspirants are agricultural products that are put on leaves to stop plants from losing water through evaporation. This makes the plant's water situation better. With the suggested irrigation and spraying treatments, it could be said that the wheat cultivar Sids 14 was much better than Giza 171 and Sakha 95 in terms of chlorophyll content, plant height, and membrane stability index there was stable and outperformed. At the same time, the differences between the three types were not big enough to matter in terms of yield. The current study suggested that kaolin may improve plant physiology, which led to a higher yield and could be safe for the environment. Potassium is a necessary nutrient that controls some biochemical and physiological responses in plants. The use of waxing-type antitranspirants (liquid paraffin) helped improve the plant's water status and cut down on water loss through transpiration. It means that antitranspirants can be used to make up for the lack of water in dry and semi-arid areas. They can also help plants grow and produce more when they are under water stress.

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