P-ISSN: 3009 – 7487
E-ISSN: 3009 – 7886

JOURNAL OF PLANT AND FOOD SCIENCES

June 2025

Simulating the Impacts of Heat Waves and Water Stress on Wheat Crop

Osman, S. M.[1], Abou-Shleel, S. M.[1*], El- Mohandes, M. A.[1] and Kheireldin, K. A.[2]

(1) Environment and Bio-Agric. Dept., Fac. of Agric., Al-Azhar Univ., Nasr city, Cairo, Egypt

(2) National Water Research Center (NWRC), Cairo, Egypt

*** Corresponding author:** Abou-Shleel, S. M. **E-mail:** s_masoud_2006@azhar.edu.eg

https://orcid.org/0000-0003-2690-9127

Received: Received: 31*st* January 2025; in revised form: 31*st* January 2025/ Accepted: 10*th* April 2025/ Published: 1*st* June 2025

DOI: 10.21608/jpfs.2025.356997.1023

ABSTRACT

Wheat is one of the most important crops in the world and is a major source of food for millions of people. However, due to climate change, increasing temperatures and water stress are affecting wheat production worldwide, leading to reduced yield and quality. Egypt is one of the countries that depend on wheat imports, and the impact of environmental stress on wheat production can have significant impact on food security. This study aimed to simulate the impact of heat and water stress on productivity and quality of wheat crops. Field experiments were conducted during two successive seasons 2019/2020 and 2020/2021. The experimental farm of Environment and Bio-Agriculture Dept., Faculty of Agriculture-Cairo, Al-Azhar University. The experimental treatments were distributed in a split-split plot design, the water stress treatments (irrigated and unirrigated) were presented in the main plot, the wheat cultivars (Misr1, Misr2 and Giza 168) were presented in sub-plot, and the heat wave treatments (flowering, maturity and both flowering and maturity stages) were distributed in sub-sub-plot. The results showed that the yield components (spike length, grain weight, and yield/feddan) in all tested cultivars were affected under conditions of heat and water stress. The results also indicated that heat and water stress had a significant effect on the chemical composition of wheat varieties which led to a decrease in their content of protein, total carbohydrates, and gluten, which had a negative impact on the yield quality. Exposing plants to heat waves and water stress led to an increase in their proline content.

Keywords: Wheat, heat stress, water scarcity, productivity, grain quality, proline, Egypt.

INTRODUCTION

Wheat is a major cereal crop, accounting for providing about one-half of the total calorie intake and two-fifths of the protein consumed worldwide (Erenstein *et al.*, 2022). Egypt is the largest wheat importer in the world. However, it is the largest wheat producer in the Middle East and North Africa region (Abdalla *et al.*, 2023). According to the FAO (2022)**,** wheat is the first most important cereal crop in Egypt, accounting for around 20% of the country's total cereal production. Wheat yield in Egypt is relatively high per feddan compared to other countries, however, the country is heavily dependent on imports to meet its domestic demand for wheat (Abdelaal and Thilmany, 2019). However, according to the 4*th*

Intergovernmental Panel on Climate Change (IPCC) report, wheat production is threatened by climate change due to extreme weather events such as heat waves, sandstorms, and rainfall fluctuation, which is likely to disappear wheat crops from Africa by the 2080s (IPCC, 2007). Both heat waves and water stress can cause significant damage to wheat crop leading to a reduction in yield and quality, which will have severe consequences on food security globally (Akter and Rafiqul, 2017) and in Egypt (Elsayed *et al.*, 2021). Studies have shown that rising temperatures can reduce global wheat production (Asseng *et al.*, 2015). Heat stress can damage wheat embryos and endosperm cells through oxidative stress-mediated reactive oxygen species generation (Poudel and Poudel, 2020). Inadequate water supply can also impact wheat productivity (Elahi *et al.*, 2022), where water scarcity caused a significant impact on crop productivity in Egypt (Ouda and Zohry, 2016). However, climate change poses a significant threat to wheat production in Egypt as rising temperatures and water scarcity affected crop yield (Hatfield and Prueger, 2015).

Asseng *et al.* (2015) estimated that the global wheat production could decline by 6% for every 1°C increase in temperature. Furthermore, Zhao *et al.* (2017) revealed that wheat yields have plateaued or even decreased in many regions due to heat stress. This is particularly true for regions such as South Asia, North Africa, and the Middle East where the temperature is expected to rise in the coming years due to climate change (Hoegh-Guldberg *et al.*, 2018). According to several studies, wheat is most sensitive to high temperatures during the reproductive phase, particularly during the flowering and grain filling stages, high temperatures during these stages can lead to reduced grain yield, poor grain quality, and decreased biomass production (Ullah *et al.*, 2022). As well as increase the incidence of diseases and pests (Shahin *et al., 2020*). Several studies have demonstrated the importance of proline accumulation in mitigating the negative effects of heat stress. Nazir *et al.* (2021) indicated that wheat plants exposed to high temperature stress exhibited increased proline accumulation, which was positively correlated with the plant's ability to maintain photosynthetic activity and grain yield. Similarly, (Abou Gabal, 2014) reported that wheat plants under heat stress conditions showed relatively higher value of proline content for heat tolerant cultivars such as Giza 168. The impact of heat stress on wheat production varies depending on the intensity and duration as well as the developmental stage of the plant. According to (Yadav *et al.*, 2022), heat stress during the vegetative phase can lead to reduced plant height, tillering, and biomass accumulation, while heat stress during the reproductive phase can lead to reduced grain yield, grain weight, and harvest index. (Lu *et al.*, 2019) found that heat stress during the grain filling stage can lead to decreased starch accumulation, which can result in reduced grain yield and quality.

On the other hand, (Farooq *et al*., 2014) claimed that water stress could reduce wheat yields by 1–30% especially if exposed to drought post anthesis while prolonged mild drought at flowering and grain filling reduced the grain yields by 58–92% in some regions.

In the recent study, in (2023) they estimated that global wheat production could decline by 17% by 2050 due to water stress (Farooq *et al.*, 2023). This is particularly true for countries where water availability is already limited such as Egypt. In addition, water stress during the vegetative phase can lead to reduced plant height, biomass production, and tillering, while water stress during the reproductive phase can lead to reduced grain yield and quality (Zhang *et al.*, 2018). The water stress on wheat production depends on the severity and duration of the stress, as well as the developmental stage of the plant. According to Ozturk *et al.* (2022), mild water stress during the vegetative phase can have a positive impact on wheat yield by promoting root growth and increasing water use efficiency. However, severe water stress during any stage of growth can have a negative impact on wheat yield and quality. The Egyptian government has implemented various policies and initiatives to support wheat production in the country, including providing subsidies for inputs such as fertilizers and seeds and investing in irrigation infrastructure (FAO and EBRD, 2015). In that context, the objectives of the current investigation were to study the integrated effects of heat waves (extreme weather events) and water stress on the yield, and quality of some wheat Egyptian cultivars.

MATERIALS AND METHODS

Open field experiment was carried out on wheat crop (*Triticum aestivum* L.) at the experimental farm of Environment and Bio-Agriculture Dept., Faculty of Agriculture-Cairo, Al-Azhar University, Nasr City, Cairo, Egypt; during two growing seasons of 2019/2020 and 2020/2021 under semi-automated control environmental chambers conditions of heat waves and water stress treatments. The site is located at (30°03'12.2"N 31°19'05.4"E) as shown in Fig. (1).

Fig. (1). Experimental site and location

1. Experimental design:

The experimental treatments were distributed in a split-split plot design, the water stress treatments irrigated (positive control) and unirrigated (negative control) during heat waves were in the main plot, whereas wheat cultivars (Misr1, Misr2 and Giza 168) were in sub-plot, and the heat waves treatments during growth plant stages (flowering, maturity and both flowering and maturity) were distributed in sub-sub-plot, as shown in Fig. (2).

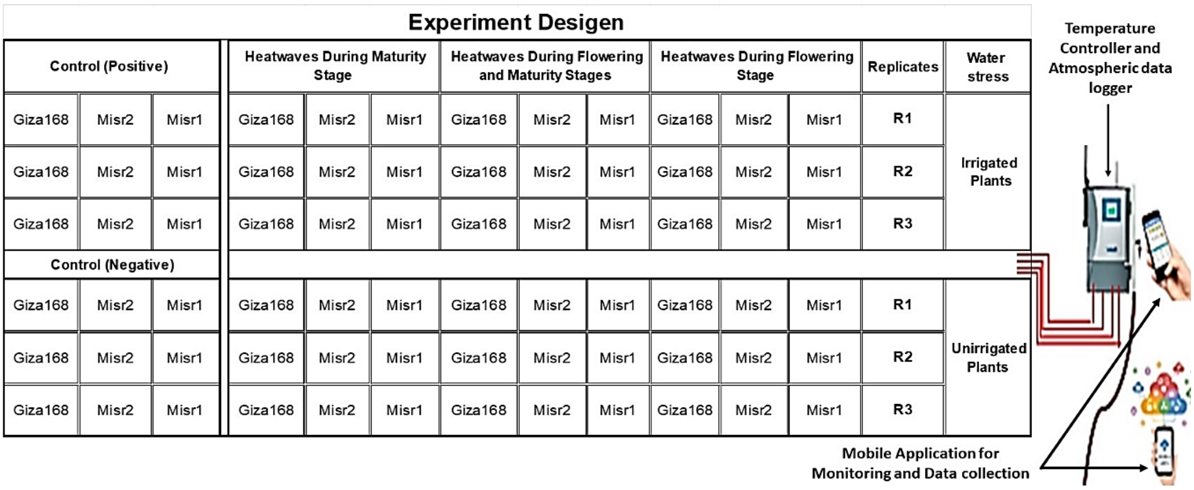

Fig. (2). Experimental design

2. Greenhouse preparation and sowing seeds:

In both seasons, wheat seed cultivars were kindly obtained from Field Crops Research Institute (FCRI), Agricultural Research Center (ARC), Ministry of Agriculture and Land Reclamation, Cairo, Egypt. The agricultural practices were implemented based on the recommendations of ARC. Grains of each crop were sown at the proper recommended seeding rate at suitable soil depth. Wheat grains were sowed on 19^{th} November in both growing seasons (2019/2020 and 2020/2021).

The growth conditions were like practices applied in the open field except during flowering and maturity stages; heat waves were applied under a semi-automated greenhouse, which was previously designed to simulate heat waves conditions. The greenhouse was covered with transparent plastic (200 microns) during the heat waves periods which was applied according to Zadoks *et al.* (1974) during the flowering stage (50% of flowering plants) and maturity stage (50% of matured grains).

The components of the heat wave smart system used in the experiment were rented from the Tomatiki company, as shown in Fig. (3)., 1) the heater, which was used to raise the air temperature inside the greenhouse to 5°C higher than outside the greenhouse, during heat wave treatments, according to De Boeck *et al.* (2011); 2) the temperature controller (model name: THA300C ATMOSPHERE CONTROL), which was used to control the temperature inside the greenhouse during heat wave treatments, as it controls the switching off and on of the "Tubular Heaters" upon a temperature preset point. This device accurately measures temperature and saves collected data on the cloud for further downloading and analysis; 3) dataloggers were used for weather data acquisition from inside and outside the greenhouse and stored to be double-checked with data on the cloud, and 4) temperature sensors are components that directly translate physical temperature into digital information. Likewise, humidity sensors can measure atmospheric moisture levels and translate them into digital information.

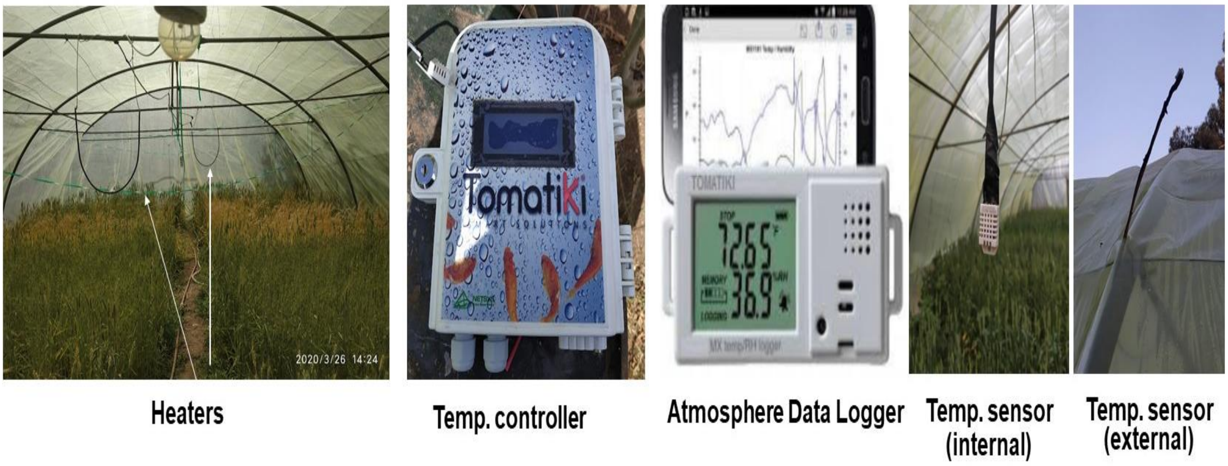

Fig. (3). Components of the heat wave smart system

The air temperature increase was estimated to be 5 ºC above the average temperature of the open air in the area for more than five days according to Frich *et al.* (2002) heat wave Duration Index (HWDI) is that a heat wave occurs "when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by five °C", the normal period being 1961–1990 according to the World Meteorological Organization (WMO) (Encyclopedia, 2022). Air temperature increased by using heaters under the greenhouse; the temperature was controlled by using a thermostat that switched off the heaters when the air temperature inside the greenhouse increased by five °C above the outside air temperature. Air temperature during the two growing seasons and periods of heat waves are presented in Table (1). The air temperature data were recorded using a portable digital weather station.

Table (1). Average air temperature and heat waves during the two wheat-growing seasons.

Month	Air temp. (°C)			The temperature during heat waves		
	Max.	Min.	Avg.	Max.	Min.	Avg.
First season 2019/2020						
Nov. 2019	24.3	13.8	19.1			
Dec. 2019	22.3	9.7	16.0			
Jan. 2020	18.8	6.5	12.6			
Feb. 2020	19.0	7.7	13.3	24.0	12.7	18.3
March 2020	22.7	11.7	17.2	27.7	16.7	22.2
April 2020	25.6	13.7	19.7			
Mean	**22.1**	**10.5**	**16.3**			
Second season 2020/2021						
Nov. 2020	24.8	14.4	19.6			
Dec. 2020	20.4	8.3	14.4			
Jan. 2020	18.4	6.3	12.4			
Feb. 2021	22.5	6.7	14.6	27.5	11.7	19.6
March 2021	23.7	11.6	17.6	28.7	16.6	22.6
April 2021	30.0	19.2	24.6			
Mean	**23.3**	**11.1**	**17.2**			

3. Measured characteristics:

Yield and yield components data estimated at harvesting included spike length, biological crop, one hundred grain weight, and yield/ feddan. Spike length (cm) was measured at harvesting as an average length of 10 spikes taken randomly from the middle of each plot. Biological crop (g/m^2) was measured at harvesting as the sum of plants from one meter in three replicates of each plot.

4. Chemical analysis:

A quantitative estimation for the values of chemical composition of wheat grains (*i.e.*, carbohydrates, protein, fiber, fat, and gluten) from each sample of the studied wheat cultivars was achieved at wavelength region from ~750nm to2500nm of the electromagnetic spectrum, using Near-InfraRed (NIR) Spectroscopy apparatus, model DA1650, manufactured by FOSS Corporation. The estimation of the biochemical composition was done at the Central Laboratory, Faculty of Agriculture-Cairo, Al-Azhar University. Proline was extracted and estimated in µmolg−1 fresh weight of leaves according to Bates *et al.* (1973). The estimation of proline was determined at the Laboratory of Agriculture and Biological Dept., National Research Center, Dokki, Giza, Egypt.

5. Statistical analysis:

Analysis of the variance of the obtained data from each attribute was computed using the Minitab Computer Program. The Duncan's New Multiple Range test at 5% level of probability was used to test the significance of differences among mean values of treatments (Steel *et al.*, 1997)**.**

RESULTS AND DISCUSSION

1. Effect of heat waves and water stress on wheat productivity:

1.1. Spike length and biological yield:

Data presented in Table (2) showed that there was no significant difference between cultivars; Misr1 and Giza 168 in terms of the weight of 100 grains whereas they showed significant difference when compared with cultivar; Misr2. The effect of wheat cultivars on biological yield indicated that there was no significant difference with the same highest value being recorded by both Misr1 and Misr2 compared to Giza 168. The impact of heat waves on both yield parameters showed that the control treatment recorded the highest significant values compared to heat waves exposed to treatments where the lowest recorded values were observed when the plants exposed to heat waves during F & M stages. In addition, grains weight and biological yield of irrigated cultivars increased significantly compared with non-irrigated ones.

Regarding the interaction between cultivars and heat waves, the obtained results indicated that Misr1 without treatment (positive control) gave the highest spike length and biological yield, while Giza 168 heat waves exposed plants during F & M stages detected the lowest value for both characteristics. The mutual interaction effects between the heat waves and water stress indicated that there was no significant difference detected on spike length. The unirrigated plants exposed to heat waves during F & M stages recorded the highest significant biological yield while the irrigated plants exposed to heat waves during flowering stage detected the lowest value. The mutual interaction effects between cultivars and water stress on spike length and biological yield showed that Giza 168 cultivar was negatively and significantly affected by water stress compared to other cultivars. As for the interaction among wheat cultivars, heat waves and water stress treatments, the obtained data showed that Misr1 plants with negative control recorded the highest spike length and biological yield, while irrigated Giza 168 plants that exposed to heat waves during F & M stages recorded the lowest spike length, and the lowest biological yield was recorded with unirrigated Giza 168 plants that exposed to heat waves during maturity stage.

These results could be attributed to high temperatures during the growing season that reduce photosynthesis, respiration, and enzyme activity, which in turn reduces the growth and development of wheat plants (Hasanuzzaman *et al.*, 2013). In addition, the impact of heat stress on wheat spike length may be due to changes in cell division and elongation rates (Shenoda *et al.*, 2021). In Egypt, heat waves and water stress are major factors affecting wheat spike length during the reproductive phase of growth. A study conducted by (Shalaby *et al.*, 2020) showed that wheat spike length was significantly reduced under water stress conditions. Water stress during the reproductive phase of wheat growth can result in reduced cell division rates and impaired floret development, leading to shorter spikes and lower grain yields (Fahad *et al.*, 2017).

Table (2). Effect of heat waves and water stress on spike length and biological yield of some wheat cultivars.

Cultivars	Heat Waves	Spike length (cm)			Biological yield (g/m^2)		
		Water stress		Mean	Water stress		Mean
		Irrigated	Unirrigated		Irrigated	Unirrigated	
Misr 1	Control	7.1^{a-d}	7.7^{a}	7.4^{a}	1640^{ab}	1692^{a}	1666^{a}
	Flowering	7.3^{abc}	7.3^{abc}	7.3^{a}	820^{hi}	960^{f-i}	890^{e}
	Maturity	7.5^{ab}	7.0^{a-d}	7.2^{a}	1063^{d-i}	1375^{a-e}	1219^{bc}
	F & M*	6.9^{a-d}	7.0^{a-d}	7.0^{ab}	1322^{a-f}	1545^{abc}	1433^{ab}
	Mean	7.2^{a}	7.2^{a}	7.2^{A}	1211^{a}	1393^{a}	1302^{A}
Misr 2	Control	6.7^{a-e}	7.1^{a-d}	6.9^{ab}	1188^{c-h}	1263^{b-g}	1225^{bc}
	Flowering	7.3^{abc}	6.2^{b-f}	6.7^{ab}	1208^{c-h}	1258^{b-g}	1233^{bc}
	Maturity	6.8^{a-e}	6.7^{a-e}	6.7^{ab}	1210^{c-h}	1128^{d-i}	1169^{cd}
	F & M	6.4^{a-f}	6.6^{a-e}	6.5^{abc}	1258^{b-g}	1405^{a-d}	1332^{bc}
	Mean	6.8^{a}	6.6^{a}	6.7^{B}	1216^{a}	1264^{a}	1240^{B}
Giza 168	Control	6.0^{c-f}	6.0^{c-f}	6.0^{a}	926^{f-i}	965^{e-i}	946de
	Flowering	5.4^{ef}	6.0^{c-f}	5.7^{ab}	1027^{d-i}	868^{ghi}	948de
	Maturity	5.8^{def}	5.2^{f}	5.5^{b}	963^{e-i}	730^{i}	847^{e}
	F & M	5.0^{f}	5.4^{ef}	5.2^{c}	800^{hi}	1063^{d-i}	932de
	Mean	5.5^{b}	5.7^{b}	5.6^{C}	929^{b}	907^{b}	918^{C}
Heat waves Means	Control	6.4^{ab}	6.9^{a}	6.7^{A}	1251^{ab}	1307^{a}	1279^{A}
	Flowering	6.8^{ab}	6.1^{b}	6.5^{A}	1018^{c}	1029^{bc}	1024^{B}
	Maturity	6.7^{ab}	6.7^{ab}	6.7^{A}	1079^{bc}	1078^{bc}	1078^{B}
	F & M	6.1^{b}	6.3^{ab}	6.2^{B}	1127^{abc}	1338^{a}	1232^{A}
Water stress Mean		6.5^{A}	6.5^{A}		1119^{A}	1188^{A}	

* F & M = Flowering and Maturity stages

1.2. Weight of 100 grains and yield/ feddan:

Data presented in Table (3) showed that there was no significant difference between Misr1 and Giza 168 cultivars in terms of the weight of 100 grains whereas they showed significant differences when compared with Misr2 cultivar. The effect of wheat cultivars on yield indicated that there was no significant effect with the same highest yield recorded by both Misr1 and Misr2 compared to Giza 168. The impact of heat waves on both yield parameters showed that the control treatment recorded the highest significant values compared to heat waves exposed to treatments where the lowest recorded values were observed when the plants exposed to heat waves during F & M stages. In addition, grains' weight and yield of irrigated cultivars increased significantly compared with non-irrigated ones.

Regarding the interaction between cultivars and heat waves, the obtained data showed that control of Misr1 detected the highest values of grain weight and yield, while exposing Giza 168 plants to heat waves during both F & M stages caused the lowest values for both measured parameters. As for the interaction between cultivar and water stress treatments, the irrigated plants of Misr1 recorded the highest values of both characteristics, while the unirrigated plants of Misr2 and Giza 168 showed less values of grain weight and yield. As for the interaction between heat waves and water stress, the obtained results indicated that the plants of positive control significantly recorded the highest grain weight and yield, while the unirrigated plants that were exposed to heat waves during both F & M stages recorded the lowest values.

Table (3). Effect of heat waves and water stress on weight of 100 grains and yield/ feddan of some wheat cultivars.

Cultivars	Heat waves	Weight of 100 grains (g)			Yield /feddan (Ardeb)*		
		Water stress		Mean	Water stress		Mean
		Irrigated	Unirrigated		Irrigated	Unirrigated	
Misr 1	Control	5.75^{a}	5.53^{ab}	5.64^{a}	17.2^{a}	15.9^{c}	16.5^{a}
	Flowering	4.06^{cd}	3.57^{e-h}	3.81^{b}	13.0^{def}	13.0^{ef}	13.0^{b}
	Maturity	3.94^{de}	3.08^{d-g}	3.51^{c}	12.3^{h}	11.3^{h}	11.3^{c}
	F & M**	2.92^{fgh}	2.74^{gh}	2.83^{d}	9.3^{j}	7.3^{j}	7.3^{d}
	Mean	4.17^{a}	3.73^{b}	3.95^{A}	13.0^{a}	11.9^{c}	12.5^{A}
Misr 2	Control	4.91^{ab}	5.11^{ab}	5.01^{a}	16.8^{c}	15.5^{b}	16.2^{a}
	Flowering	3.74^{def}	3.46^{d-h}	3.60^{c}	13.2^{def}	13.1^{def}	13.2^{b}
	Maturity	3.90^{de}	3.24^{d-g}	3.57^{b}	13.6^{d}	12.8^{f}	13.2^{b}
	F & M	2.72^{gh}	2.81^{gh}	2.77^{d}	7.6^{j}	7.4^{j}	7.5^{d}
	Mean	3.82^{ab}	3.66^{c}	3.74^{B}	12.8^{a}	12.2^{b}	12.5^{A}
Giza 168	Control	5.29^{ab}	5.21^{ab}	5.25^{a}	16.6^{b}	16.0^{c}	16.3^{a}
	Flowering	5.14^{ab}	4.83^{bc}	4.99^{b}	13.4^{de}	13.1^{def}	13.3^{b}
	Maturity	3.17^{d-h}	2.78^{gh}	2.98^{d}	11.8^{i}	10.6^{g}	11.2^{c}
	F & M	2.90^{fgh}	2.33^{h}	2.61^{c}	7.4^{j}	7.2^{j}	7.3^{d}
	Mean	4.13^{a}	3.79^{b}	3.96^{A}	12.2^{b}	11.8^{c}	12.0^{A}
Heat waves Means	Control	5.31^{a}	5.28^{a}	5.21^{A}	16.9^{a}	15.8^{b}	16.3^{A}
	Flowering	4.31^{b}	4.0^{b}	4.23^{B}	13.2^{c}	13.1^{c}	13.2^{B}
	Maturity	3.67^{c}	3.03^{c}	3.23^{C}	12.6^{d}	11.6^{e}	11.9^{C}
	F & M	2.85^{d}	2.63^{d}	2.86^{D}	8.1^{f}	7.3^{g}	7.4^{D}
Water Stress Mean		4.04^{A}	3.73^{B}		12.7^{A}	12.0^{B}	

* Ardeb = 150 Kg

** F & M = Flowering and Maturity stages

Concerning the interaction among wheat cultivars, heat waves and water stress, the obtained data indicated that the positive control plants of Misr1 detected the highest values of grain weight and yield/ feddan, while the unirrigated Giza 168 plants that exposed to heat waves during both F & M stages recorded the lowest values.

These obtained results could be attributed to the negative effects of heat waves and water stress on reducing photosynthesis and grain filling, like the mechanisms identified in other studies. Several studies have reported that wheat is highly sensitive to heat stress during the flowering and grain-filling stages, which are critical stages for determining grain yield (Hozayn *et al.*, 2012) and (Fahad *et al.*, 2017). Also, high temperature causes a high rate of transpiration, which causes drought that ultimately leads to low productivity (Elahi *et al.*, 2022). On the other hand, water stress can result in increased oxidative stress in plants, which further exacerbates the negative effects on wheat growth and yield (Farooq *et al.*, 2009).

Under temperature increases, production decreases and plants become susceptible to disease pressure. Temperatures above 32°C at the time of anthesis reduce grain size and grain filling duration in the spikes, ultimately affecting wheat yield, which decreases by 5–7% per degree of temperature increase (Elahi *et al.,* 2022). Several studies have reported similar results in Egypt, where wheat production is often limited by heat and water stress. For example, a study conducted by (Shalaby *et al.*, 2020) found that water stress during grain filling reduced wheat yield by 3.51% and 11.15 % in all different wheat cultivars studies.

2. Effect of heat waves and water stress on chemical contents of wheat grains and leaves:

2.1. Protein and total carbohydrates contents:

Understanding the physical and chemical properties of wheat and flour is essential for determining the quality and type of flour produced by the milling process (Keran *et al.*, 2009). The wheat cultivars tested showed insignificant differences in protein content as well as in Total Carbohydrates (T. C.) content (Table 4). The impact of heat waves indicated that the treatment exposed to heat during Flowering and Maturity (F & M) significantly increased protein content in grains compared to other treatments where the control recorded the lowest value. An opposite trend was observed with T. C. content as the control recorded the highest significant value compared to other treatments, while F & M treatment recorded the lowest T. C. content. As for water stress, the results showed that unirrigated plants (negative control) recorded the highest significant values of both measured characteristics compared to irrigated plants (positive control).

The mutual interaction effects between the wheat cultivars and heat waves showed that the plants of Misr2 which treated during both F & M stages recorded the highest protein content, while the lowest value was observed in untreated Misr1 plants. Also, the untreated plants of Misr2 detected the highest T.C. content, while the treated plants during both F & M stages recorded the lowest content. The mutual interaction effects between the wheat cultivars and water stress showed that unirrigated plants of Misr2 recorded the highest value of protein accumulation, while the lowest value was for Giza168 irrigated plants. Misr1 and Giza 168 non-irrigated plants recorded significantly higher T. C. content compared to irrigated ones. Also, unirrigated plants detected the highest values of T. C. in all studied cultivars compared to irrigated plants. The mutual interaction effects between the heat waves and water stress showed that the highest protein value was recorded for unirrigated plants treated by heat waves during both F & M stages, while the lowest value was detected for the irrigated control plants. Meanwhile, the highest significant T.C. accumulation was recorded for unirrigated control plants, while the lowest value was detected for the irrigated plants treated by heat waves during both F & M stages.

Concerning the mutual interaction among cultivars, heat waves and water stress on protein and Total Carbohydrates (T.C.) concentrations, the obtained results indicated that the unirrigated plant of Misr2 gave the highest value for protein accumulation under heat waves treatment during F & M stages, while Giza168 plants recorded the lowest protein concentration for the irrigated control. Meanwhile, the T.C. concentration was the highest for Misr1 unirrigated control when compared with Misr2 which recorded the lowest value for the irrigated plants which were exposed to heat waves during F& M stages. These results agree with those obtained by Mahdavi *et al.* (2022) which claimed that the protein content and quality of the grain of wheat plant under the heat-stress are impacted. Also, Fernie *et al.,* (2022) suggest that heat stress can have significant effects on wheat grains chemical and physical characteristics and ultimately on the quality of wheat-based products in various regions, including Egypt. Several studies have reported that water stress can significantly reduce wheat grain yield, as well as alter the quality of wheat grains. In terms of carbohydrate composition, water stress has been reported to reduce starch content in wheat grains, while increasing the concentration of simple sugars and other minor components such as fructose. For instance, a study by *Hütsch et al.* (2019) reported that water stress reduced the biomass of wheat and its content of carbohydrates. These changes in carbohydrate composition can have a significant impact on the processing and nutritional value of wheat-based products. Regarding protein, in a study conducted by Abdellaoui *et al.* (2022), it was found that exposure to water stress during grain filling resulted in a decrease in wheat various parameters studied, except for the protein content which was higher in arid conditions compared to the favorable ones.

Table (4). Effect of heat waves and water stress on protein, and total carbohydrates contents of wheat grain.

Cultivars	Heat waves	Protein (%)			Total Carbohydrates (T.C.) (%)		
		Water stress		Mean	Water stress		Mean
		Irrigated	Unirrigated		Irrigated	Unirrigated	
Misr1	Control	13.5^{ij}	14.0^{f-j}	13.7^{d}	66.1^{c-f}	68.2^{a}	67.2^{ab}
	Flowering	15.5^{bcd}	16.2^{b}	15.8^{ab}	64.6^{fg}	66.2^{b-f}	65.4^{bc}
	Maturity	14.9^{c-g}	15.1^{cde}	15.0^{bcd}	65.1^{c-f}	66.1^{def}	65.6^{bc}
	F & M*	14.8^{c-g}	16.3^{b}	15.5^{abc}	63.4^{g}	66.7^{a-d}	65.1^{c}
	Mean	14.7^{bc}	15.4^{a}	15.1^{A}	64.8^{b}	66.8^{a}	65.8^{AB}
Misr2	Control	13.9^{g-j}	14.3^{e-i}	14.1^{cd}	67.9^{ab}	68.1^{a}	68.0^{a}
	Flowering	13.7^{hij}	14.6^{d-h}	14.2^{cd}	67.9^{ab}	66.7^{a-d}	67.3^{ab}
	Maturity	15.7^{bc}	15.1^{cde}	15.4^{abc}	65.8^{c-f}	64.9^{efg}	65.4^{bc}
	F & M	14.9^{c-f}	18.0^{a}	16.5^{a}	47.3^{h}	66.2^{b-f}	56.7^{d}
	Mean	14.6^{bc}	15.5^{a}	15.1^{A}	62.2^{c}	66.5^{a}	64.4^{A}
Giza168	Control	13.3^{j}	14.3^{e-j}	13.8^{d}	65.9^{c-f}	67.2^{abc}	66.5^{abc}
	Flowering	14.5^{d-h}	15.2^{cde}	14.8^{bcd}	65.7^{c-f}	67.4^{abc}	66.5^{abc}
	Maturity	15.5^{bcd}	15.4^{bcd}	15.4^{abc}	66.0^{c-f}	66.3^{e-f}	66.2^{abc}
	F & M	14.9^{c-g}	14.2^{e-j}	14.6^{bcd}	66.1^{c-f}	66.4^{b-e}	66.2^{abc}
	Mean	14.5^{c}	14.8^{bc}	14.7^{A}	65.9^{b}	66.8^{a}	66.4^{A}
Heat waves means	Control	13.7^{d}	14.2^{cd}	14.0^{C}	66.6^{b}	67.8^{a}	67.2^{A}
	Flowering	14.7^{c}	15.3^{b}	15.0^{B}	66.1^{c}	66.8^{b}	66.5^{AB}
	Maturity	15.4^{b}	15.2^{b}	15.3^{AB}	65.6^{d}	65.7^{d}	65.7^{B}
	F & M	14.9^{c}	16.2^{a}	15.6^{A}	58.9^{e}	66.4^{b}	62.7^{C}
Water stress Mean		14.6^{B}	15.2^{A}		64.3^{B}	66.7^{A}	

*F & M = Flowering and Maturity stages

2.2. Fiber and fat contents:

The results presented in Table (5) showed that there was no significant difference detected between studied cultivars. As for heat waves treatments, the obtained results showed that exposed plants to heat waves during both flowering and maturity stages recorded the highest fiber content, while the untreated plants detected the lowest value. As for water stress treatments, the findings indicated that there was no significant difference in fiber contents between irrigated and non-irrigated plants.

The mutual interaction effects between the wheat cultivars and heat waves showed that the plants of Misr1 cultivar which were treated during the maturity stage recorded the highest value for fiber accumulation, while the lowest value was observed for the control as well as Misr2 cultivar plants when treated at flowering stage. The mutual interaction effects between the wheat cultivars and water stress showed that the unirrigated plants of Misr1 cultivar recorded the highest value for fiber accumulation, while the lowest value was for the irrigated plants of Giza168. Meanwhile, the unirrigated plants exposed to heat waves during maturity stage recorded the highest fiber content, while the irrigated plants (positive control) detected the lowest fiber accumulation. The mutual interaction effects among the cultivars, heat waves and water stress on fiber concentrations indicated that the unirrigated plants of Misr1 cultivar recorded the highest value for fiber accumulation under heat waves treatment during the maturity stage, while the non-irrigated plants of Misr2 cultivars recorded the lowest fiber concentration which was treated by heat waves during the flowering stage.

Table (5). Effect of heat waves and water stress on fiber and fat contents in wheat grains.

Cultivars	Heat waves	Fiber (%)			Fat (%)		
		Water stress		Mean	Water stress		Mean
		Irrigated	Unirrigated		Irrigated	Unirrigated	
Misr1	Control	4.44^{fg}	4.69^{efg}	4.57^{c}	0.77^{g}	0.80^{fg}	0.78^{d}
	Flowering	5.62^{a-e}	4.92^{d-g}	5.27^{abc}	1.04^{b-g}	1.10^{b-e}	1.07^{bc}
	Maturity	5.37^{b-f}	6.58^{a}	5.98^{a}	1.08^{b-f}	1.16^{bcd}	1.12^{bc}
	F & M*	5.09^{b-g}	6.08^{abc}	5.59^{ab}	0.96^{d-g}	0.85^{efg}	0.90^{cd}
	Mean	5.13^{ab}	5.57^{a}	5.35^{A}	0.96^{c}	0.98^{bc}	0.97^{B}
Misr2	Control	4.68^{efg}	4.80^{efg}	4.74^{c}	0.98^{d-g}	1.04^{b-g}	1.01^{cd}
	Flowering	5.06^{c-g}	4.09^{g}	4.57^{c}	1.04^{b-g}	1.04^{b-g}	1.04^{c}
	Maturity	5.13^{b-g}	5.99^{a-d}	5.56^{ab}	1.05^{b-g}	1.13^{b-e}	1.09^{bc}
	F & M	6.23^{ab}	5.18^{b-g}	5.71^{ab}	2.00^{a}	1.10^{b-e}	1.55^{a}
	Mean	5.27^{ab}	5.01^{b}	5.14^{A}	1.27^{a}	1.08^{bc}	1.17^{A}
Giza168	Control	4.90^{d-g}	5.09^{b-g}	5.00^{bc}	0.98^{d-f}	1.01^{c-g}	1.00^{cd}
	Flowering	4.87^{d-g}	5.46^{b-f}	5.16^{bc}	1.04^{b-g}	1.07^{b-f}	1.06^{c}
	Maturity	4.50^{efg}	4.75^{efg}	4.63^{c}	1.30^{fg}	1.28^{bc}	1.29^{b}
	F & M	5.11^{b-g}	5.35^{b-f}	5.23^{abc}	1.04^{b-e}	1.06^{b-g}	1.05^{c}
	Mean	4.85^{b}	5.16^{ab}	5.00^{A}	1.09^{bc}	1.10^{b}	1.10^{A}
Heat waves means	Control	4.67^{c}	4.86^{c}	4.77^{C}	0.91^{d}	0.95^{d}	0.93^{B}
	Flowering	5.18^{abc}	4.82^{c}	5.00^{BC}	1.04^{bcd}	1.07^{bcd}	1.06^{AB}
	Maturity	5.00^{bc}	5.77^{a}	5.39^{AB}	1.14^{bc}	1.19^{b}	1.17^{A}
	F & M	5.48^{ab}	5.54^{ab}	5.51^{A}	1.33^{a}	1.00^{cd}	1.17^{A}
Water stress Mean		5.08^{A}	5.25^{A}		1.11^{A}	1.05^{A}	

*F & M= Flowering and Maturity stages

Concerning the fat accumulation in wheat grains, the data illustrated in Table (5) indicated that Misr2 cultivar recorded the highest fat content followed by Giza 168 and Misr1. Also, the exposed plants to heat waves during both F & M stages detected the highest value, while the lowest value was observed with untreated plants. As for water stress treatments, there was no significant difference between irrigated and unirrigated plants.

The interaction between cultivars and heat waves showed that the exposed Misr2 plants to heat waves during both F & M stages gave the highest significant fat content, while the positive control of Misr1 recorded the lowest fat accumulation. As for interaction between cultivars and water stress, it was noted that the irrigated Misr2 and Misr1 plants recorded the highest and lowest fat contents, respectively. The mutual interaction impacts between heat waves and water stress showed that irrigated plants exposed to heat waves during both F & M stages detected the highest significant fat content, while the lowest value was observed with positive control plants. Regarding the interaction among cultivars, heat waves and water stress, it was noted that irrigated Misr2 plants exposed to heat waves during both F & M stages recorded the highest fat accumulation, while the positive control of Misr1 plants recorded the lowest fat content.

2.3. Gluten and proline percentages:

Concerning gluten, the data illustrated in Table (6) showed the effects of heat waves and water stress on gluten percentage of some wheat cultivars where no significant differences were observed in gluten accumulation among cultivars studied. As for the heat waves treatments, the results revealed that exposing plants to heat waves had significant effect on their gluten content compared to the control. Also, there was no significant difference in gluten accumulation noted between irrigated and unirrigated plants.

The mutual interaction effects between the wheat cultivars and heat waves showed that Misr2 plants which were treated during both F & M stages recorded the highest value of gluten, while the lowest value was for the positive control plants of Misr1. Also, the interaction between cultivars and water stress revealed that there was a weak significant difference in gluten concentration. In addition, the interaction effects between the heat waves and water stress indicated that the highest gluten value was recorded for irrigated plants treated by heat waves during both F & M stages, while the lowest value was observed with positive control plants. The mutual interaction effects among the cultivars, heat waves and water stress on gluten concentration indicated that the irrigated Misr2 plants recorded the highest value for gluten accumulation under heat waves treatment during both F & M stages, while the positive control plants of Misr2 detected the lowest gluten concentration.

These obtained results could be attributed to wheat plants under stress conditions produce a range of stress-responsive proteins, which can replace or modify the composition of the normal storage proteins (glutenin's and gliadins) (Shewry, 2019). Keran *et al.* (2009) suggested that the reduction in gluten quality could negatively impact the baking properties of wheat flour produced from these cultivars.

Regarding the proline percentage in wheat leaves, the results presented in Table (6) indicated that Giza 168 plants recorded the highest proline content followed by Misr1 and Misr2. Also, plants exposed to heat waves during both F & M stages recorded the highest proline value, while the untreated plants detected the lowest proline percentage. As for the water stress treatments, unirrigated plants gave the highest significant proline value compared to irrigated plants.

The mutual interaction between studied cultivars and heat waves revealed that exposed Giza 168 plants to heat waves during both F & M stages recorded the highest significant proline percentage, while untreated Misr2 plants detected the lowest value. Unirrigated Misr1 plants significantly recorded higher value for proline concentration, while irrigated Misr2 plants showed the lowest proline accumulation. In addition, the interaction between heat waves and water stress treatments showed that the unirrigated plants exposed to heat waves during both F & M stages recorded the highest significant proline percentage, while the lowest percentage was observed with positive control plants. The interaction among cultivars, heat waves and water stress revealed that unirrigated Misr1 plants exposed to heat waves during both F & M stages recorded the highest proline content, while the lowest content was observed with irrigated Giza 168 plants exposed to heat waves during flowering stage.

These findings could be attributed to stress impacts on wheat crops where the proline is known as a potential indicator for heat and water stress tolerance in wheat, due to its accumulation in plants leaves in response to these stresses. These findings are consistent with previous studies conducted in Egypt, (Abou Gabal, 2014) reported that proline content increased significantly in Giza168 wheat cultivars in response to heat stress as an indicator of its tolerance to heat stress. Meanwhile, Hayat *et al.* (2012) also found that the cultivars with higher proline content had better growth and yield under water stress conditions. Similarly, Farooq *et al.*(2012) indicated that water stress significantly increased proline content in wheat.

Table (6). Effect of heat waves and water stress on contents of gluten in grains and proline in leaves of wheat.

Cultivars	Heat waves	Gluten (%)			Proline (%)		
		Water stress		Mean	Water stress		Mean
		Irrigated	Unirrigated		Irrigated	Unirrigated	
Misr1	Control	30.63^{hi}	31.43^{f-i}	31.03^{d}	13.1^{fg}	12.48^{fg}	12.79^{d}
	Flowering	36.47^{b}	34.80^{bcd}	35.63^{ab}	15.54^{efg}	24.14^{de}	19.83^{c}
	Maturity	33.95^{cde}	33.43^{c-f}	33.69^{cd}	14.57^{fg}	61.95^{b}	38.26^{b}
	F & M*	33.29^{c-f}	36.56^{b}	34.92^{bc}	18.06^{ef}	95.69^{a}	56.88^{a}
	Mean	33.58^{ab}	34.05^{ab}	33.82^{A}	15.32^{d}	48.57^{a}	31.94^{B}
Misr2	Control	30.14^{i}	32.15^{e-i}	31.15^{d}	10.16^{fgh}	13.46^{fg}	11.81^{d}
	Flowering	30.88^{ghi}	32.89^{d-g}	31.88^{cd}	13.69^{fg}	21.8^{ef}	17.75^{c}
	Maturity	35.33^{bc}	33.97^{cde}	34.65^{bc}	12.68^{fg}	23.32^{ef}	18.00^{c}
	F & M	40.60^{a}	33.62^{c-f}	37.11^{a}	17.98^{ef}	24.48^{de}	21.23^{c}
	Mean	34.24^{a}	33.16^{b}	33.70^{A}	13.63^{d}	20.77^{c}	17.20^{C}
Giza168	Control	31.60^{f-i}	32.14^{e-i}	31.87^{cd}	10.75^{fgh}	13.68	12.22^{d}
	Flowering	32.55^{d-h}	34.14^{cde}	33.35^{cd}	9.57^{gh}	19.82^{ef}	19.70^{c}
	Maturity	34.76^{bcd}	34.53^{bcd}	34.64^{bc}	25.9^{d}	53.79^{b}	39.85^{b}
	F & M	33.56^{c-f}	31.92^{e-i}	32.74^{cd}	32.67^{d}	87.94^{a}	60.31^{a}
	Mean	33.12^{b}	33.18^{b}	33.15^{A}	19.72^{c}	43.81^{b}	33.02^{A}
Heat waves means	Control	30.79^{d}	31.91^{d}	31.35^{B}	11.34^{f}	13.21^{e}	12.27^{D}
	Flowering	33.30^{c}	33.94^{bc}	33.62^{A}	12.93^{ef}	21.92^{c}	19.09^{C}
	Maturity	34.68^{b}	33.98^{bc}	34.33^{A}	17.72^{d}	46.35^{b}	32.04^{B}
	F & M	35.82^{a}	34.04^{bc}	34.93^{A}	22.90^{c}	69.37^{a}	46.14^{A}
Water stress Mean		33.65^{A}	33.46^{A}		16.22^{B}	37.72^{A}	

*F & M= Flowering and Maturity stages

Conclusion

Wheat is one of the most important crops globally, providing a significant source of food for billions of people. However, its production is greatly influenced by environmental stress factors, such as heat and water stress which are projected to increase gradually due to climate change with wide agreements among scholars and high confidence according to the Intergovernmental Panel on Climate Change (IPCC, 2021). These stress factors affect wheat growth, development, and yield, resulting in significant losses in productivity. Therefore, understanding the impact of heat waves and water stress on wheat is essential for developing strategies to improve wheat production and ensure food security, especially in Egypt as it is considered one of the highest wheat consumers in the world. The results showed that heat waves and water stress had significant negative effects on wheat yield for all wheat cultivars studied. The research findings reveal that the adverse impact of high temperature and water stress on wheat production is expected to worsen in the coming years due to climate change. In Egypt, the situation is further exacerbated by the country's dependence on the Nile River, which is threatened by upstream development projects and climate change. Therefore, adopting measures such as breeding tolerant cultivars and drought-resistant varieties, improving irrigation techniques, and promoting sustainable water management practices are necessary to ensure the long-term sustainability of wheat production nationally and internationally.

REFERENCES

Abdalla, A. A., Stellmacher, T., M. Becker (2023). Trends and prospects of change in wheat self-sufficiency in Egypt. 13 (1). https://doi.org/10.3390/agriculture13010007

Abdelaal, H. S. A., Thilmany, D. (2019). Grains production prospects and long run food security in Egypt. 11 (16). https://doi.org/10.3390/SU11164457 \

Abdellaoui, M. A., Taghouti, M., Diria, G., Hassane, M. M., EL Yacoubi, H., Bennani, S. (2022). Impact of water stress on the productivity and quality parameters of wheat and their potential use in the breeding program. Envi. Sciences Proceedings, 16 (1):13. https://doi.org/10.3390/environsciproc2022016013

Abou Gabal, A., Tabl, K. M. (2014). Heat tolerance in some Egyptian wheat cultivars as measured by membrane thermal stability and proline content. Middle East Journal of Agriculture Research, 3(2):186-193.

Akter, N., Rafiqul, M. I. (2017). Heat stress effects and management in wheat. A review. Agron. Sustain. Dev. 37, 37. https://doi.org/10.1007/s13593-017-0443-9

Ashgan, A. G. A., Tabl, K. M. (2014). Heat tolerance in some Egyptian wheat cultivars as measured by membrane thermal stability and proline content. Middle East Journal of Agriculture Research, 3 (2): 186-193.

Asseng, S., Ewert, F., Martre, P., Rotter, R.P., Lobell, D.B., ……. (2015). Rising temperatures reduce global wheat production. Nat. Clim. Change, 5 (2):143-147.

Barnabas, B., Jäger, K., Fehér, A. (2008). The effect of drought and heat stress on reproductive processes in cereals. Plant, cell and environment, 31 (1): 11-38.

De Boeck, H.J., Dreesen, F. E., Janssens, I. A., Nijs, I. (2011). Whole-system responses of experimental plant communities to climate extremes imposed in different seasons. New Phytol. Feb;189(3): 806-817. doi: 10.1111/j.1469-8137.2010.03515.x.

Elahi, I., Saeed, U., Wadood, A., Abbas, A., Nawaz, H., Jabbar, S. (2022). Effect of climate change on wheat productivity. Intech Open. Doi: 10.5772/intechopen.103780

Elsayed, M., Khalil, A.A., Hassanein, M.K., Fahim, M.A., Abdel-Wahab, M.M. (2021). Impact of weather extremes on wheat production in Egypt. Middle East Journal of Agriculture Research, 10 (4): 1273-1283.

Encyclopedia (2022). encyclopedia. Retrieved from https://www.encyclopedia.com /environment/energy-government-and-defense-magazines/heat-waves

Erenstein, O., Jaleta, M., Mottaleb, K. A., Sonder, K., Donovan, J., Braun, H. J. (2022). Global trends in wheat production, consumption, and trade. In: Reynolds, M.P., Braun, HJ. (eds) Wheat Improvement. Springer, Cham. https://doi.org/10.1007/978-3-030-90673-3_4

Fahad, S., ,A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Ihsan, M.Z., Alharby, H., Wu, C., Wang, D., Huang, J. (2017). Crop production under drought and heat stress: Plant Responses and Management Options. Front Plant Sci.29; 8:1147. doi: 10.3389/fpls.2017.01147.

FAO (2022). GIEWS - Global Information and Early Warning System. Retrieved from www.fao.org: https://www.fao.org/giews/countrybrief/country.jsp?code=EGY&lang=ar

Farooq, A., Farooq, N., Akbar, H., Hassan, Z.U., Gheewala, S. H. (2023). A Critical Review of Climate Change Impact at a Global Scale on Cereal Crop Production. *Agronomy*.13 (1):162. https://doi.org/10.3390/agronomy13010162

Farooq, M., Wahid, A., Kobayashi, N. (2009). Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev., (29): 185–212.

Farooq, M., Mubshar, H., Kadambot, H.M.S. (2014) Drought stress in wheat during flowering and grain-filling periods. Critical Reviews in Plant Sciences, 33 (4): 331-349.

Farooq, M., Hussain, M., Wahid, A., Siddique, K.H.M. (2012). Drought Stress in Plants: An Overview. In: Aroca, R. (eds) Plant Responses to Drought Stress. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-32653-0_1

Fernie, E., Tan, D.K.Y., Liu, S.Y., Ullah, N., Khoddami, A. (2022). Post-anthesis heat influences grain yield, physical and nutritional quality in wheat: A Review. Agriculture. 12 (6):886. https://doi.org/10.3390/agriculture12060886

Frich, P., Alexander, L.V., Della, P.M., Gleason, B., Haylock, M., Tank, A.M.G.K., Peterson, T. (2002). Observed coherent changes in climatic extremes during the second half of the twentieth century. Climate Research, 19 (3): 193–212.

Hasanuzzaman, M., Nahar, K., Alam, M.M., Roychowdhury, R., Fujita, M. (2013). Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants. International Journal of Molecular Sciences, (14): 9643 - 9684.

Hatfield, J. L., Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, (10): 4-10.

Hayat, S., Hayat, Q., Alyemeni, M. N., Wani, A. S., Pichtel, J. T., Ahmad, A. (2012). Role of proline under changing environments. Plant Signaling and Behavior, (7): 1456 - 1466.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., Zhou, G. (2018). Impacts of 1.5 ºC Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty]Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I.Gomis, E. Lonnoy, T.Maycock, M.Tignor, and T. Waterfield (eds.)]. In Press.

Hozayn, M., Abd El-Monem, A.A., Abd El-Hameed, E.M., Tawfik, M.M. (2012). Mitigating global warming impact on wheat productivity in Egypt. Australian Journal of Basic and Applied Sciences, 6 (10): 525-531.

Hütsch, B.W., Jahn, D., Schubert, S. (2019). Grain yield of wheat (*Triticum aestivum L.*) under long-term heat stress is sink-limited with stronger inhibition of kernel setting than grain filling. J Agro Crop Sci., (205): 22–32.

IPCC (2007). Fourth Assessment Report: Climate Change, Working Group II: Impacts, Adaptation and Vulnerability. Cambridge: Cambridge University Press.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Keran, H., Salkic, M., Odobasic, A., Jasic, M., Ahmetovic, N., Sestan, I. (2009). The Importance of Determination of some Physical – Chemical Properties of Wheat and Flour. Agriculturae Conspectus Scientificus, 74 (3): 197-200.

Kim, K.H., Kim, J.Y. (2021). Understanding wheat starch metabolism in properties, environmental stress condition, and molecular approaches for value-added utilization. Plants. 10 (11): 2282. https://doi.org/10.3390/plants10112282

Lipiec, J., Doussan, C., Nosalewicz, A., Kondracka, K. (2013). Effect of drought and heat stresses on plant growth and yield: a review. Int. Agrophys., 27 (4): 463-477.

Lu, H., Hu, Y., Wang, C., Liu, W., Ma, G., Han, Q., Ma, D. (2019). Effects of high temperature and drought stress on the expression of gene encoding enzymes and the activity of key enzymes involved in starch biosynthesis in wheat grains. Front. Plant Sci. (10): 1414. Doi: 10.3389/fpls.2019.01414.

Mahdavi, S., Arzani, A., Mirmohammady, S.A.M.M., Kadivar, M. (2022). Grain and flour quality of wheat genotypes grown under heat stress. Saudi Journal of Biological Sciences, (29): 103417, Doi: 10.1016/j.sjbs.2022.103417.

McGill, J., Prikhodko, D., Sterk, B., Talks, P. (2015). Egypt: Wheat sector review. FAO and EBRD. 112p. Rome: FAO. Retrieved from https://www.ebrd.com/ documents/ comms-and-bis/egypt-wheat-sector-review.pdf

Nazir, M., Bano, A., Ullah, F., Khan, S., Khan, N. (2021). Physiological evaluation of wheat (*Triticum aestivum L.*) genotypes at pre-anthesis stage under heat stress conditions. American Journal of Plant Sciences, (12): 1780- 1790.

Ouda, S., Zohry, A.E.H. (2016). Significance of reduction of applied irrigation water to wheat crop. In: Major Crops and Water Scarcity in Egypt. Springer Briefs in Water Science and Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-21771-0_3

Ozturk, A., Erdem, E., Aydin, M. (2022). The effects of drought after anthesis on the grain quality of bread wheat depend on drought severity and drought resistance of the variety. Cereal Research Communications, (50):105–116.

Poudel, P.B., Poudel, M.R. (2020). Heat stress effects and tolerance in wheat: A review. Journal of Biology and Today's World, 9 (3): 217.

Shahin, A., Ashmawy, M., El-Orabey, W., Esmail, S. (2020). Yield losses in wheat caused by stripe rust (*Puccinia striiformis*) in Egypt. American Journal of Life Sciences, 8 (5): 127-134.

Shalaby, E., Galall, E., Ali, M., Amro, A., El Ramly, A. (2020). Growth and yield responses of ten wheat *(Triticum aestivum* L.) genotypes to drought. SVU-International Journal of Agricultural Sciences, 2 (2): 1-17.

Shenoda, J.E., Sanad, M.N., Rizkalla, A.A., El-Assal, S., Ali, R T., Hussein, M. H. (2021). Effect of long-term heat stress on grain yield, pollen grain viability and germinability in bread wheat (*Triticum aestivum L.*) under field conditions. Heliyon, 7 (6): https://doi.org/10.1016/j.heliyon.2021.e07096

Shewry, P. (2019). What Is Gluten—Why Is It Special? Front. Nutr. 6:101. Doi: 10.3389/fnut.2019.00101

Steel, R. G. D., J. H. Torrie and D. A. Dicky (1997). Principles and Procedures of Statistics, A Biometrical Approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York, 352-358.

Ullah, A., Nadeem, F., Nawaz, A., Siddique, K.H., Farooq, M. (2022). Heat stress effects on the reproductive physiology and yield of wheat. J. of Agronomy and Crop Science, (208): 1–17.

Waha, K., Van Bussel, L.G. J., Muller, C., Bondeau, A. (2012). Climate-driven simulation of global crop sowing dates: simulation of global sowing dates Glob. Ecol. Biogeogr., (21): 247-259.

Yadav, M. R., Choudhary, M., Singh, J., Lal, M.K., Jha, P.K., Udawat, P., Gupta, N.K., Rajput, V.D., Garg, N. K., Maheshwari, C. (2022). Impacts, tolerance, adaptation, and mitigation of Heat Stress on wheat under changing climates. International Journal of Molecular Sciences, 23 (5):2838. https://doi.org/10.3390/ijms23052838

Zadoks, J. C., Chang, T. T., Konzak, C. F. (1974). A decimal code for the growth stages of cereals. Weed Research, 14 (6): 415-421.

Zhang, J., Zhang, S., Cheng, M., Jiang, H., Zhang, X., Peng, C., Lu, X., Zhang, M., Jin, J. (2018). Effect of drought on agronomic traits of rice and wheat: A Meta Analysis. Int. J. Environ. Res. PublicHealth2018,15,839; http://dx.doi.org/10.3390/ijerph15050839

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D.B., Huang, Y., Huang, M., … (2017). Temperature increase reduces global yields of major crops in four independent estimates. Proc. Natl. Acad. Sci., 114 (35): 9326-9331.