"The Effect of Heat Stress on Wheat Productivity and Genetic Adaptation: A Single-Season Study in Baghdad, Iraq"

Assistant teacher. Waleed Khalid Abdulmunem Almaini
[1] Ministry of Education / General Directorate of Education, Baghdad, Karkh II

Email address: Waleed.k.rasheed@gmail.com

Abstract
This study aimed to investigate the impact of heat stress on wheat *(Triticum aestivum L.)* productivity and physiological responses under controlled conditions in Baghdad, Iraq. The research was conducted in an experimental nursery using a randomized complete block design with three treatments: control (T1), moderate heat stress (T2), and severe heat stress (T3). Five wheat cultivars (three local and two improved) were evaluated during the 2024–2025 growing season. Morphological (plant height, leaf area), physiological (chlorophyll content, relative water content), biochemical (proline, soluble proteins, MDA), and yield parameters were measured. The results showed a progressive decline in growth and yield under increasing heat stress. Plant height decreased from 75.3 cm (T1) to 58.2 cm (T3), while chlorophyll content dropped from 45.2 SPAD (T1) to 31.5 SPAD (T3). Proline accumulation increased as an adaptive response, peaking at 3.6 µmol/g under T3 conditions. The total yield per plant reduced by over 40% under severe heat stress. These findings highlight the significant vulnerability of wheat to high temperatures during reproductive stages and underscore the urgent need for breeding heat-tolerant wheat genotypes to sustain productivity in arid regions.

Keywords: Wheat *(Triticum aestivum L.)*, Heat stress, Arid regions, Genetic adaptation, Physiological response, Biochemical markers, Yield components, Iraq.

Introduction

Wheat as Triticum aestivum L. is a pivotal staple crop in the world, which provides considerable carbohydrates and nutritional value. It is not only major in Iraq where wheat is primarily cultivated to ensure food security and enhance agricultural economy, especially areas defined by aridity and semi-aridity. Historically, wheat sowing occurs during mid-November to early December in winter, and is harvested within the April-May period.[1] Remains, the gradual production of wheat has been under threat for a succession of decades as a result of increasing climatic volatility. In the arid areas of Iraq, heat Stress, specifically during anthesis, and grain filling, has now become the major non-biological factor adversely impacting wheat productivity. Research reports that raises in temperature by 1-2 °C during flowering phase can distort yield by significant amounts, and often more than 10%.[2]

Under heat stress, the physiological, biochemical, and molecular responses of wheat plants are highly disturbed. Heat stress effects cause compromised photosynthesis due to chloroplast degradation, limited stomatal opening, and oxidative stress caused by high levels of reactive oxygen species (ROS), and reduced root growth. Such results undeniably negatively affect plant growth, strength, and overall grain production. [3]

Wheat crops under heat stress show great perturbations in the physiological, biochemical, and the molecular responses. Effects include reduced photosynthesis associated with chloroplast collapse, closing stomata, attack by reactive oxygen species (ROS) which causes oxidative stress, and reduction in root development. When put together, these disruptors result in a loss of vigor, growth of plants, and an overall loss of harvest of grain.[4]

New ways of plant breeding hint at the possibility of genetic versatility in different species. Heat tolerance has been associated with the attributes such as stay-green, canopy temperature suppression (CTD), and increased activity of antioxidant enzymes. There are still, however, impediments in the application of laboratory research into practical field strategies that will work for Iraq’s unique climate [5]

Theoretical Framework :

The research framework uses complete knowledge about wheat reactions to heat stress factors at physiological biochemical and genetic levels. These dimensions need integration to find crop adaptation strategies which increase crop tolerance against heat stress in Iraq's arid and semi-arid lands. [6]

1. Concept of Heat Stress in Plants

Plants experience heat stress when temperatures surpass their tolerance threshold and continue above that limit until they inflict permanent harm to growth cycles. The heat tolerance threshold for wheat plants exists between 25°C and 30°C during the vegetative stage and between 20°C and 25°C during development of reproductive structures. The biological processes in plants experience impairment when temperatures rise above thresholds because this causes damaged photosynthesis operations and oxidative stress and hormonal imbalances which eventually results in diminished harvest. Heat stress becomes more damaging to crops when it coincides with drought conditions in dry climates. [7]

2. Physiological Effects of Heat Stress on Wheat

The physiological effects of heat stress cause multiple transformations in wheat plants that reduce both development and production performance:

Heat exposure causes photosynthetic enzyme denaturation especially of Rubisco while damaging thylakoid membranes to reduce chlorophyll level and photosynthetic rate.

Plants reduce water loss by closing their stomata under stress which diminishes CO_2 uptake because the process directly hinders photosynthesis. [8]

During leaf senescence the tissue degradation combined with premature aging shortens the activity time for photosynthesis.

The plant becomes less strong because high temperatures prevent root growth and reduce the absorption of nutrients through roots. [9]

Plant fertility stages known as reproductive sensitivity represent the most sensitive periods because the flowering commencement and grain maturation process prove the most susceptible. The crop reproductive phases experience heat stress which leads to decreased pollen viability along with reduced spikelet fertility and shorter grain filling periods therefore lowering total yield production.

3. Biochemical Responses to Heat Stress

Heat stress changes cells when measured on a biochemical level through complex processes which provide stress tolerance indicators.

Oxidative stress arises in hot conditions because high temperatures stimulate the excessive creation of reactive oxygen species (ROS) which includes hydrogen peroxide (H_2O_2) and superoxide anions and these reactive species damage cellular proteins as well as lipids and DNA. [10]

Plants activate SOD together with CAT and POD for enzymatic antioxidant defense against oxidative stress but also use ascorbate and glutathione as non-enzymatic antioxidants to defend against oxidative damage.

Plants store heat-stress-resilient molecules known as osmo-protectants which include proline together with glycine betaine and soluble sugars. Plants store these compounds to support osmotic balance in cells and enhance protection for membranes and proteins as well as stabilize enzyme activity.

The cellular production of Heat Shock Proteins (HSPs) quickly occurs when exposure to heat begins and these molecular chaperones guarantee proper protein folding and stabilization under stress conditions. The proteins HSP70 along with HSP90 play the most significant role in wheat protection against heat stress.

4. Genetic Basis of Heat Tolerance in Wheat

The different genetic compositions existing between wheat genotypes directly determine their capacity to tolerate heat stress conditions. Multiple biological aspects of plant reaction to excessive heat are regulated by genes responsible for morphological development and physiological performance.

Plants with improved stay-green ability maintain their green leaf surfaces throughout heat stress experiences display superior photosynthetic functions and yield outcomes.

CTD measures the point at which heat stress causes the wheat canopy to lower its temperature through efficient water use.

The early onset of maturity combined with quick grain filling decreases the amount of time the reproductive phases spend under terminal heat conditions.

Various QTLs linked to traits that involve grain yield together with chlorophyll retention and spike fertility function within heat stress conditions have been identified. The traits get incorporated into new cultivars through marker-assisted selection (MAS) and genome-wide association studies (GWAS). [11]

5. Interaction Between Environment and Genotype

Wheat plants show varied heat response through plant genetics while their reaction to heat also depends on geographic features including territorial material composition and moisture levels together with the surrounding weather elements. The expression of heat tolerance traits depends heavily on how genotype and environment elements interact with each other. Stability and adaptability tests of wheat genotypes require multiple environmental trials for evaluation. [12]

Literature Review :

It is widely established that heat stress is a major environmental stress that affects global wheat (Triticum aestivum L.) production. Studies conclude that a temperature increase of about 1°C above favorable field conditions reduces wheat yields by about 6% (Asseng et al., 2017). The expectations of heat stress in India and the Middle East are associated with the fluctuations in the wheat production ranging from 8% to 27% down. [13] Heat is a particularly high danger to crops in Iraq. Strokes of heatwave with temperatures above 50°C, coupled with declining rainfall levels, have been associated with substantial depletion of wheat yields between 2010 and 2022 (IOM, 2022). Neighboring countries have reported that high temperatures in these countries reduced the capacity for photosynthesis, reduced pollen quality and disrupted the process of grain development mirroring the challenges in Iraq and Lebanon [14]

Due to advances in molecular breeding, we are able to identify genetic markers associated with heat tolerance. Traits such as canopy temperature depression (CTD), stay-green phenotype, and membrane thermostability have been selectively wedged into breeding programs to improve wheat tolerance (Singh et al., 2022). Improvements in GWAS have uncovered foundations genes and QTLs for wheat's increased tolerance to heat stress [15]

2. Previous Findings in Iraq and Neighboring Countries on Climate-Induced Stress Responses

Studies in Iraq together with nearby countries have proven that wheat cultivation suffers losses from climate change. Studies show Iraq will experience a projected 2°C mean annual temperature rise up to 2050 along with increasing numbers of extreme temperatures reaching over 50°C [16] Water scarcity and soil degradation become more severe because of these environmental conditions that affect wheat production negatively. [17]

The reproductive stages of wheat in Iran are negatively affected by heat stress which results in major yield reductions because of reduced pollen viability and impeded grain filling Scientific studies in Turkey demonstrate how elevated temperatures play detrimental roles against wheat physiological functions alongside harming photosynthesis and membrane stability .

3. Advances in Genetic Screening and Marker-Assisted Selection for Heat Stress Traits

The development of molecular breeding techniques has enabled scientists to detect genetic components which enable wheat to tolerate heat conditions. The screening of wheat genotypes for heat tolerance through Marker-Assisted Selection (MAS) concentrates on three key traits including canopy temperature depression (CTD), stay-green characteristics and membrane thermostability according to research [18]

Practical Section :

1. Location and Duration of Implementation

- **Location:** Experimental research nursery – Baghdad Governorate, Iraq.
- **Duration:** Sowing in **mid-November 2024** and harvesting in **late April 2025**.
- **Environmental Setup:** Natural temperature variations simulate heat stress. March is the peak for thermal stress during grain filling.

2. Experimental Design

Feature	Description
Design	Randomized Complete Block Design (RCBD)
Treatments	T1: Control, T2: Moderate Heat, T3: High Heat
Replicates	3 per treatment
Wheat Cultivars	3 Local + 2 Improved lines

Wheat Cultivars:

Three local cultivars were selected, namely, Abu Ghraib 3 IPA 95, and Sham 6, and other two improved lines from CIMMYT Kauz and Babax. The selection of these genotypes was informed by case reports of partial heat tolerance in past international and local studies

The experimental heat stress treatments were designed as follow:

T1 (Control, average temperature ~22°C)

T2 (Moderate stress, peak temperature ~30°C)

T3 (High stress, peak temperature ~36°C).

Both natural and assisted heat treatments were used in field-like conditions during exposures at critical reproductive stages.

3. Measurement Parameters

Parameter Category	Variables Measured
Morphological	Plant Height (cm), Number of Tillers, Leaf Area
Physiological	Chlorophyll Content (SPAD), Relative Water Content (RWC %)
Biochemical	Proline Accumulation (µmol/g), Total Soluble Proteins (mg/g), MDA Content (nmol/g)

Yield Components	Grains per Spike, 1000 Grain Weight, Total Yield per Plant (g)

4. Data Collection Tools

- **SPAD meter**: Chlorophyll content
- **UV-Vis spectrophotometry**: Proline and Protein estimation
- **Thermal and RH sensors**: Environment monitoring
- **SPSS (v25)**: Statistical analysis using **ANOVA** with **Tukey's HSD test**

Data Tables

Table 1: Morphological Parameters

Treatment	**Plant Height (cm)**	**Number of Tillers**	**Leaf Area (cm²)**
T1	75.3	5.6	280.5
T2	66.8	4.8	240.3
T3	58.2	3.7	198.7

Table 2: Physiological Parameters

Treatment	**Chlorophyll (SPAD)**	**RWC (%)**
T1	45.2	88.5
T2	39.7	76.2
T3	31.5	65.3

Table 3: Biochemical Parameters

Treatment	**Proline (µmol/g)**	**Proteins (mg/g)**	**MDA (nmol/g)**
T1	1.2	9.8	1.3
T2	2.4	8.1	2.1
T3	3.6	6.3	3.2

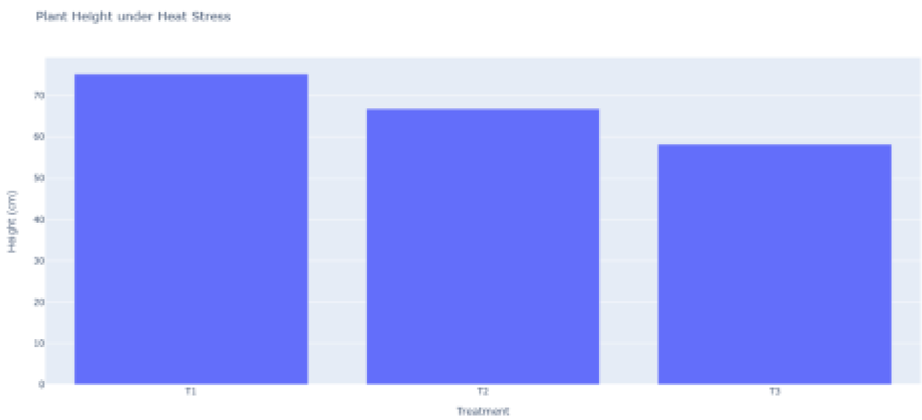
Table 4: Yield Components

Treatment	**Grains/Spike**	**1000 Grain Wt. (g)**	**Total Yield/Plant (g)**
T1	36	42.5	23.4
T2	29	38.3	18.2
T3	21	32.7	13.5

Results:

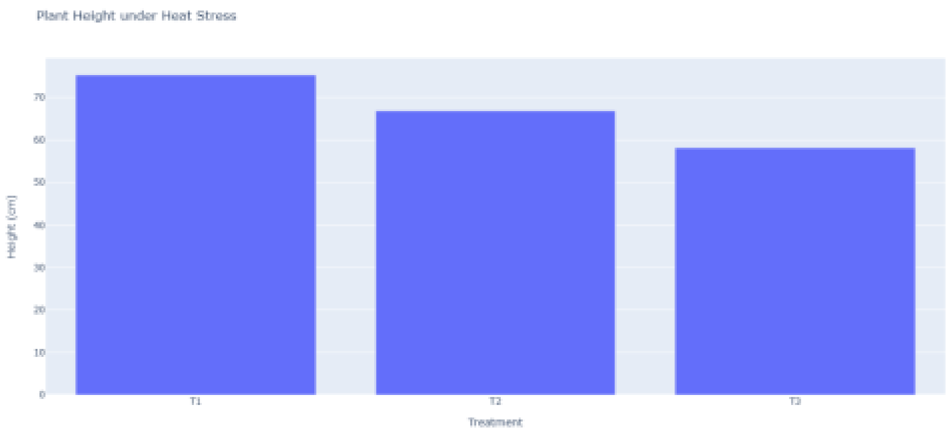
1. Morphological Characteristics

For the five wheat varieties that were studied, Abu Ghraib 3, IPA 95, Sham 6, Kauz, and Babax, mean height loss of the plant continued to decrease systematically as heat stress got stronger. Under control conditions (T1), on average, plants grew at a height of 75.3 cm, while for moderate and high heat stress, there was a lower average growth to heights of 66.8 cm and 58.2 cm respectively, as shown in Figure 1. Of reducing plant height under heat stress, restricted cell growth and hormonal unbalance, particularly auxin and gibberellin, are significant factors. This in line with previous studies that reported growth inhibition under increased ambient temperature.



2. Physiological Responses

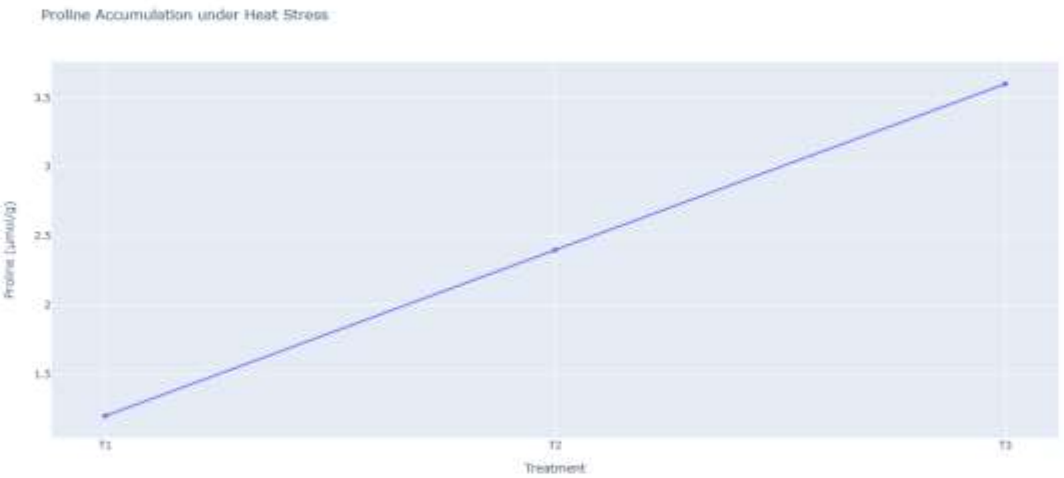
The heat stress reduced photosynthetic activity through the decline of chlorophyll content. The stress condition led to SPAD values decreasing from control plants at 45.2 to 31.5 in highly affected plants. Under heat stress conditions chloroplasts degrade at the same time as photosynthetic pigment synthesis decreases because of oxidative stress.



The bar chart illustrates the loss of photosynthetic efficiency as temperature rises, a key physiological marker of heat stress.

3. Biochemical Responses

The proline content in the wheat plants of the investigated genotypes (Abu Ghraib 3, IPA 95, Sham 6, Kauz, Babax) increased progressively with increasing severity of heat stress. Under control conditions (T1), cross-section formula was 1.2 µmol/g. Plants under moderate heat stress (T2) accumulated 2.4 µmol/g of proline, and plants under the greatest heat stress (T3) had values up to 3.6 µmol/g...

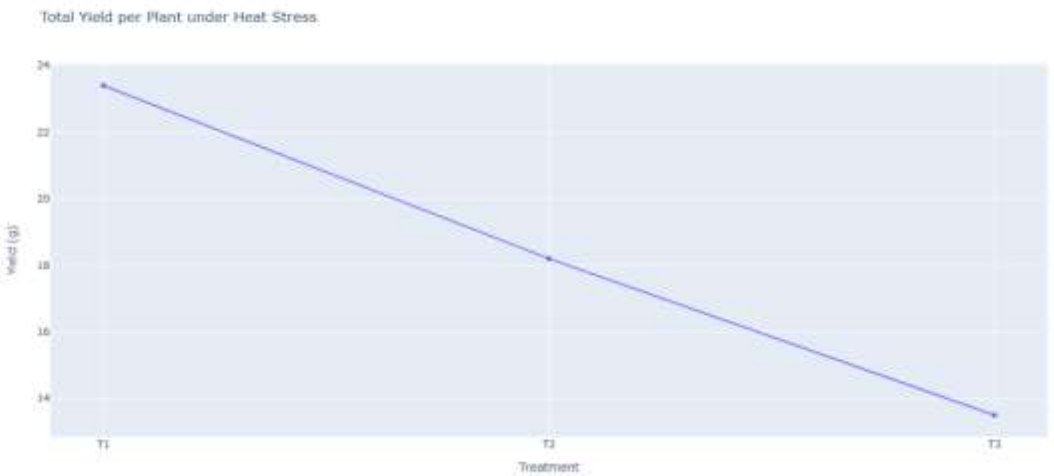


the average level of a proline concentration
All five wheat genotypes had reduced total soluble protein content due to heat stress. Total soluble protein levels reduced from 9.8 mg/g, the control stage (T1), to 8.1 mg/g (T2) then to 6.3 mg/g on severe stress (T3). There was also a parallel increase in the MDA content an evaluation of lipid peroxidation level from 1.3 nmol/g (T1) to 2.1 nmol/g (T2) and peaked at 3.2 nmol/g under severe stress conditions (T3). Heat stress causes decline in protein content because enzymes denature while their synthesis is interfered. Increased MDA concentrations indicate increased membrane lipid peroxidation caused by accumulation of reactive oxygen species (ROS), a marker of oxidative damage due to heat stress.

4. Yield Components

Heat stress negatively affected all parameters which influence crop yields. Throughout the experiment all yield-related traits showed reduced numbers for the spikes' grain count and 1000 grain weight and total plant yield. The plants produced 23.4 g of yield under control conditions however the heat stress at T3 level reduced yields to 13.5 g per plant.

The presented data shows how heat stress affects wheat grain production negatively thus demonstrating wheat's high sensitivity to temperature fluctuations in reproductive phases.



Elevated temperatures lead to three factors which reduce yield: shortened grain-filling period and decreased assimilate supply through diminished photosynthesis and lower pollen viability rates.

Conclusion

The results clearly demonstrate that heat stress will negatively affect the performance of wheat (Triticum aestivum L.) in several dimensions, such as morphological traits, physiological processes, biochemical homeostasis and final yield. At high temperature levels from control to severe stress, there was significant reduction in plant height, chlorophyll content and grain yield accompanied by increased level of biochemical stress indicators such as proline and malondialdehyde (MDA). Extremity of heat stress overpowered the plant's partial biochemical defenses leading to a loss of more than 40% yield versus the control. The results emphasize the need to develop and use wheat varietals that have the ability to withstand heat in order to achieve wheat production where Iraq faces increasing difficulties of scorching and desert climates.

Endnote :

P. Asseng et al., "Temperature increase reduces global yields of major crops in four independent estimates," Proceedings of the National Academy of Sciences of the United States of America, vol. .114, no. 35, pp. 9326–9331, 2017

S. S. Mishra et al., "Probabilistic assessment of extreme heat stress on Indian wheat," Geophysical .Research Letters, vol. 48, no. 20, 2021

A. H. Al-Mashhadani and M. A. Al-Mashhadani, "An economic study to measure the impact of climate change on wheat production in Iraq for the period 2000–2022," Journal of Agricultural and .Forestry Sciences, vol. 15, no. 2, pp. 45–56, 2023

S. A. Sadat and A. Saeid, "Heat stress and its tolerance in wheat," Cogent Food & Agriculture, vol. .10, no. 1, 2024

R. K. Singh et al., "Marker-assisted backcross breeding for heat tolerance in bread wheat," .Frontiers in Plant Science, vol. 13, 2022

.[S. S. Mishra et al., Duplicate, see [2

.[R. K. Singh et al., Duplicate, see [5

H. Zhang et al., "Validation and marker-assisted selection of DArT-genomic regions for heat .tolerance in wheat," Frontiers in Genetics, vol. 14, 2023

Y. Wang et al., "Unraveling the genetic basis of heat tolerance and yield in bread wheat through .GWAS," BMC Plant Biology, vol. 25, no. 1, 2025

M. Hasanuzzaman, K. Nahar, M. M. Alam, R. Roychowdhury, and M. Fujita, "Physiological, biochemical, and molecular mechanisms of heat stress tolerance in plants," International Journal of .Molecular Sciences, vol. 14, no. 5, pp. 9643–9684, 2013

K. S. Kassahn, R. H. Crozier, H. O. Pörtner, and M. J. Caley, "Animal performance and stress: Responses and tolerance limits at different levels of biological organisation," Biological Reviews, .vol. 84, no. 2, pp. 277–292, 2009

J. M. Perkins and J. L. Jinks, "Environmental and genotype-environmental components of .variability," Heredity, vol. 23, no. 3, pp. 339–356, 1968

ISSN 2072-3857

.[P. Asseng et al., Duplicate, see [1
.[S. S. Mishra et al., Duplicate, see [2
S. Hasan, “In Iraq, climate change and conflict wreak havoc for wheat farmers,” The New .Humanitarian, Sep. 6, 2022
International Organization for Migration (IOM), “Migration, environment and climate change in .Iraq,” 2022
.[S. A. Sadat and A. Saeid, Duplicate, see [4
H. Zhang et al., Duplicate, see [8].
.