

## PHYSIOLOGICAL AND MORPHOLOGICAL CHANGES UNDER HEAT STRESS IN THE «ASTANA» WHEAT VARIETY: THE ROLE OF RELATIVE WATER CONTENT

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## ABSTRACT

Wheat (*Triticum aestivum* L.) is one of the most widely consumed cereal crops in the world. High temperature is one of the most important abiotic stresses affecting plant growth, and global warming is one of the major problems facing the world today. Physiological and biochemical changes occurring in cells under abiotic stress conditions slow down plant growth and development, ultimately leading to a decrease in wheat yield. The aim of this research was to study how heat stress affects wheat growth and to identify changes in the morphological and physiological functions of wheat plants under high-temperature conditions. In this study, the «Astana» wheat variety was used, and a comparison was made between control plants grown at 25°C and stressed plants grown at 40°C. As a result of the study, morphological and physiological changes were observed. We measured the average length of wheat roots and shoots and the relative water content (RWC) of the «Astana» wheat plants. In the stress group, the roots and shoots of wheat plants were reduced in size compared to the control plants, and the RWC of plants grown at the optimal temperature was higher than in plants grown under heat stress.

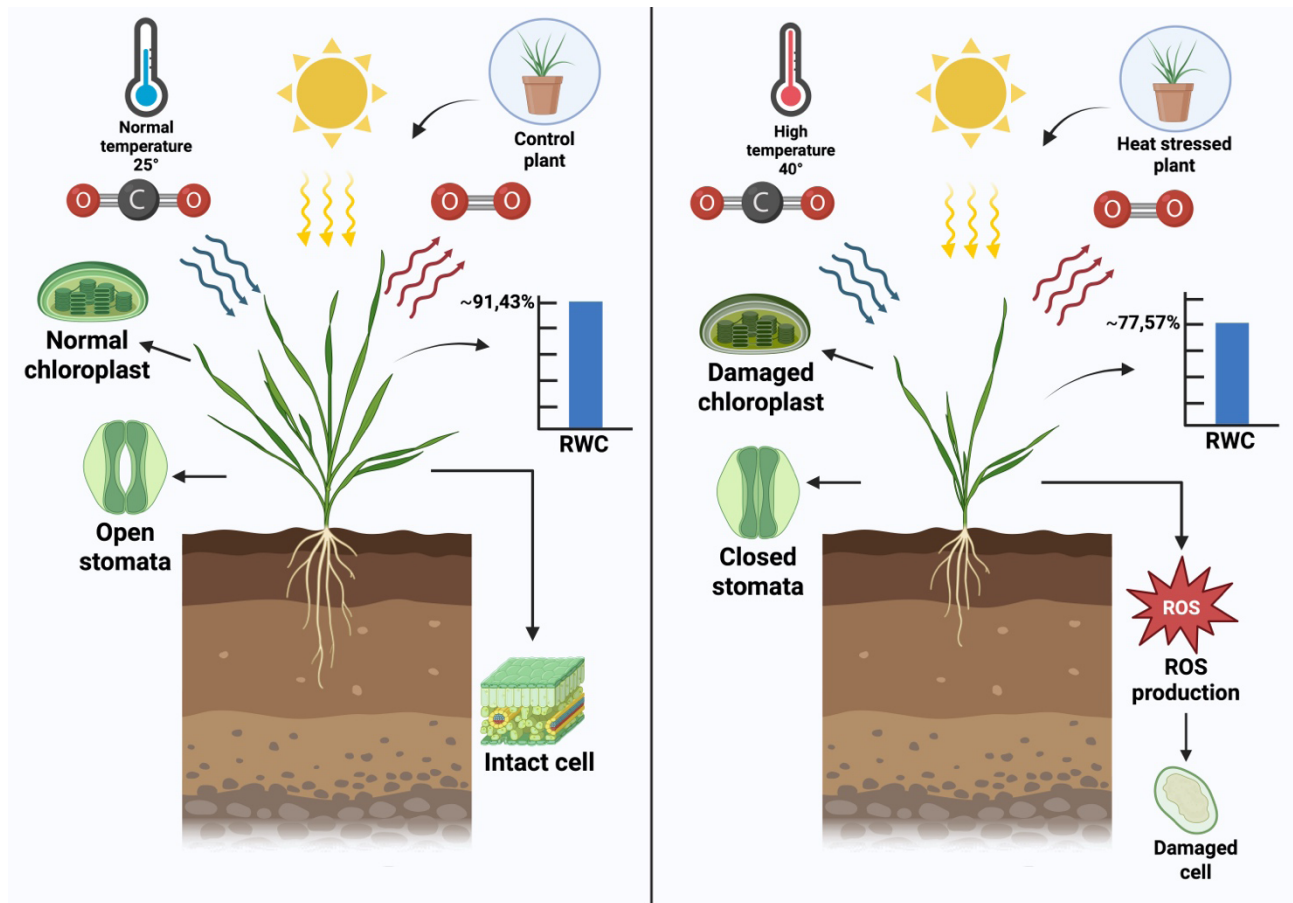
**Key words:** *Triticum aestivum* L., «Astana» variety, abiotic stress, high temperature, relative water content (RWC), heat tolerance

## INTRODUCTION

Abiotic stresses negatively affect plant growth, development, reproduction, and the productivity of agricultural crops [1]. Abiotic stresses such as salinity, high temperatures, and UV radiation reduce plant growth and yield, thus negatively impacting crop productivity [2,3]. Plants are regularly affected by environmental factors such as high or low temperatures, drought, saline soil, diseases, and natural aging. These conditions increase the production of reactive oxygen species (ROS), which leads to the formation of aldehydes [4,5]. Heat stress disrupts normal growth and cellular metabolism. It affects various physiological processes in plant cells, including cytoplasmic enzyme dysfunction, protein degradation, and damage to membrane stability. Additionally, heat stress disturbs plant water balance, decreases photosynthetic efficiency, and suppresses overall metabolic activity [6]. Environmental stresses such as drought, salinity, and extreme temperatures frequently occur simultaneously, thereby compounding their detrimental effects on plant growth and productivity. Plants can sense these stresses and adjust their growth to survive and produce new seeds [7]. The problem of stress factors has worsened because the world's climate is changing rapidly. Elevated temperatures cause thermal stress that results in leaf and shoot sunburn, chlorosis, and tissue damage, ultimately reducing yield and adversely affecting plant morphology [8]. Heat and drought are major problems that strongly reduce the growth and yield of crops [9,10]. In the near future, global warming will pose significant challenges for agricultural crops in maintaining their development, growth, reproduction, and productivity [11]. To minimize the effects of heat stress, plants have developed a range of mechanisms, including molecular responses and changes in their physiology and biochemistry, in an attempt to protect themselves from damage caused by

rising temperatures [12,13]. These changes have negatively affected agricultural production [14,15]. Wheat is one of the most widespread and important cereal crops in the world. It serves as a primary food source for billions of people and provides essential nutrients and energy [16].

It has been shown that winter wheat exposed to heat and light simultaneously demonstrated reduction in RWC, chlorophyll content and photosystem II activity [17]. Under direct solar radiation, plants including wheat respond to heat stress by leaf curling and reduction in leaf area. These morphological adjustments decrease exposed surface area and consequently limit transpirational water loss, as commonly observed in crop species [18]. Rising temperatures and subsequent climate changes negatively affect plant growth and development leading to a catastrophic loss of wheat productivity [19]. Heat stress at critical stages of development leads to a significant reduction in wheat yield, as it negatively affects plant reproduction [20]. Heat stress affects plant growth in different ways depending on how strong it is, how long it lasts, and at which growth stage it occurs. The propagation and grain-filling stages are especially sensitive to high temperatures. In many regions of the world, temperatures above 33 °C often lead a significant decrease in crop yield [21]. High temperatures influence nearly all stages of wheat growth and development, including seed germination, the emergence of roots and leaves, stem elongation, as well as seed yield and quality [22]. It was shown that high temperature for three consecutive days can dramatically reduce grain capture, quantity, and weight, which can ultimately lead to grain deformation [23,24]. High temperatures impair protein function and alter membrane lipid fluidity, which negatively impacts the activity of enzymes in chloroplasts and mitochondria, also compromises the stability of cellular membranes. Both intense



Note: The image was created by BioRender program.

**Figure 1** - Comparative effects of optimal and heat stress conditions on wheat physiology, chloroplast integrity, and relative water content (RWC).

heat stress and extended exposure to moderately high temperatures can cause damage to cells and ultimately lead to cell death [25]. Also in wheat heat stress harms cell membranes, thylakoid parts and cell organs which makes photosynthesis slower (Figure 1) [26].

Under drought and heat stress conditions, plants exhibit accelerated phenological development accompanied by a marked decline in leaf greenness and chlorophyll concentration, ultimately leading to premature senescence [27,28]. These physiological and biochemical alterations are increasingly observed on a global scale as climate variability intensifies. In Kazakhstan, where agriculture represents a major sector of the national economy and wheat is a principal staple crop, such stress-induced responses pose a significant threat to crop productivity and food security [29]. The «Astana» variety was selected for this research because its response to heat stress hasn't been previously investigated. To address this knowledge gap, we evaluated key morphological parameters and RWC in wheat plants of the «Astana» variety under elevated temperature conditions. This approach enabled us to assess its physiological and growth responses to heat stress and to provide new insights into its potential adaptive capacity.

## MATERIALS AND METHODS

### Plant growth conditions and treatment duration

Seeds of the «Astana» variety were used in this research. Before planting, the seeds were sterilized with  $H_2O_2$  for 10 minutes, rinsed three times with distilled water, and dried.

Prior to sowing, 12 special plastic pots were prepared. Each pot was filled with 150 g of soil and supplied with 30 ml of water. Twenty seeds were sown in each pot. The 12 pots were divided into two groups: six control and six stress-treated plants. Both groups were grown at room temperature (25°C) for three days. Afterward, the heat-stressed plants were placed in a Biobase BJPX-A400E climate chamber and grown under a 16/8 h light/dark regime, with daytime conditions of 40°C, 20% humidity, and 5200 Lux light intensity, and nighttime conditions of 22°C, 65% humidity, and 0 Lux light intensity. The control group was grown in a chamber under conditions of 25°C temperature, 65% humidity, and 5200 Lux light intensity. Plants in both groups were grown for three days after germination. The study was conducted using three independent biological replicates. For each replicate, 12 pots were used, and nine measurements were collected per pot. Measurements were taken from three different sides of each pot to minimize spatial bias and improve data reliability.

### Measurement of morphological parameters of wheat plants

The morphological parameters of wheat plant, including root and shoot length were evaluated. First, the plants were carefully removed from the soil, gently cleaned, washed with distilled water and dried. Subsequently, the lengths of roots and shoots were measured and the data for each plant were recorded and analyzed for comparison between groups.

### Determination of root and shoot biomass in wheat plants

Wheat seedlings were carefully removed from the soil to avoid damaging the roots. The roots and shoots were separated, and the roots were thoroughly washed with water to remove all soil residues. The fresh weight of the roots and shoots was measured using an analytical balance. Subsequently, the biomass of the control group was compared with that of the heat-stressed plants.

#### Determination of relative water content (RWC) in wheat plants

In this study, fully expanded young leaves were immersed in water and maintained under dark conditions at 15 °C. After 24 hours, the turgid weight was measured. The leaves were then dried at 60 °C for 72 hours, and the dry weight was recorded. RWC was calculated using the standard formula as previously described [30]. The formula for determining RWC is:

$$RWC = (FW-DW)/(TW-DW)*100$$

Where:

FW – Fresh weight

TW – Turgid weight

DW – Dry weight

#### Statistical Analysis

The experiments were conducted with three biological replicates. The data were expressed as the mean ± standard error (SE). Statistical differences between the control and heat-stressed groups were analyzed using one-way ANOVA followed by Tukey's HSD test. A value of  $p < 0.05$  was considered statistically significant.

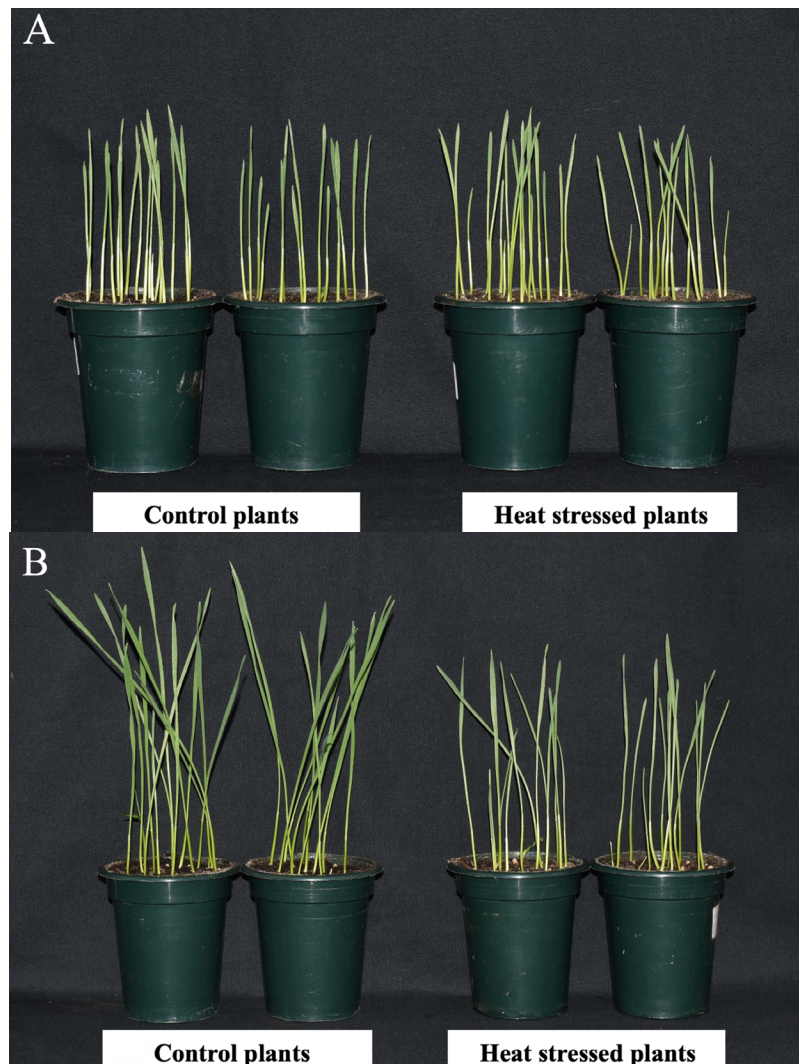
## RESULTS

#### Phenotypic changes in wheat plants under high temperature

Clear phenotypic differences were observed between the control and heat-stressed groups of wheat plants. The heat-stressed plants were compared with the control plants. The stressed plants exhibited slower growth, with significantly shorter shoots and roots (Figure 2).

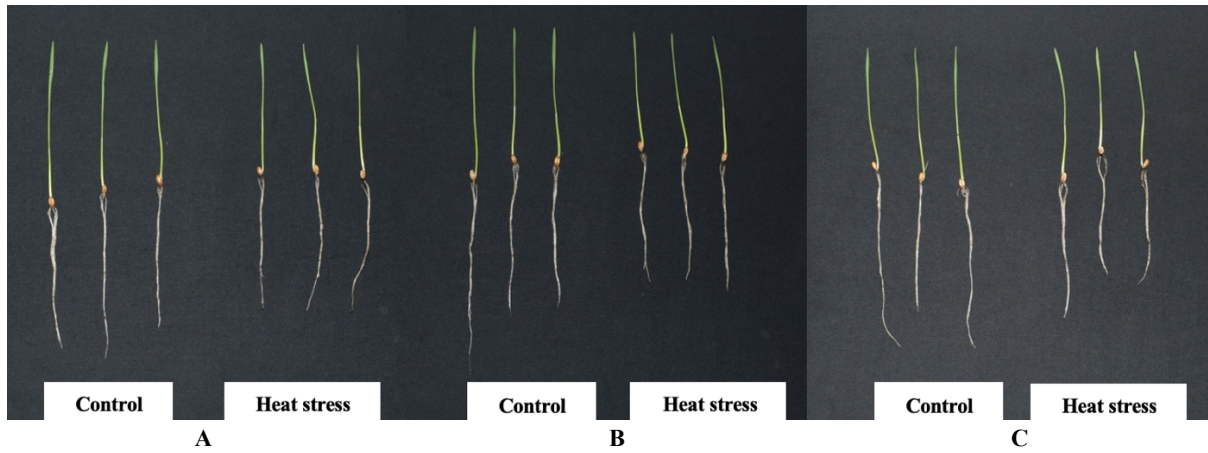
#### Changes in root and shoot length of wheat plants

In this study, the lengths of wheat shoots and roots were measured over a three-day period, and the growth characteristics on day 1 and day 3 were determined. From each pot, both central and edge seedlings were selected for measurement (Figures 3–4).



**Figure 2** - Comparison of wheat plants grown under optimal temperature and heat stress for three days

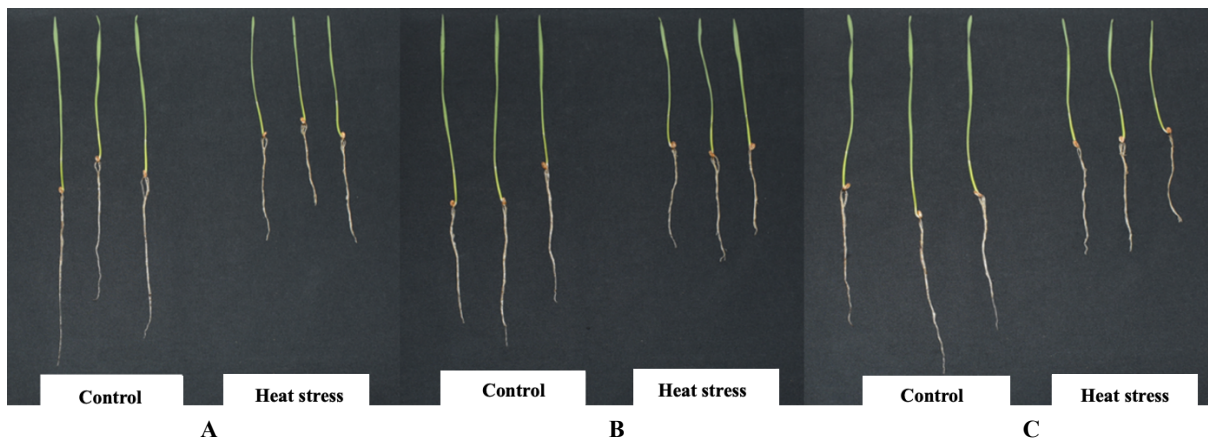
Figure 2A – day 1; Figure 2B – day 3



**Figure 3** - Root and shoot length of wheat plants under control and heat stress conditions on day 1

Figure 3A - the right edge of the plant; Figure 3B- the center of the plant; Figure 3C – the left edge of the plant

cm, whereas in the stressed plants it reached 13.1 cm. Sim-



**Figure 4** - Root and shoot length of wheat plants under control and heat stress conditions on day 3

Figure 4A - the right edge of the plant; Figure 4B – the center of the plant; Figure 4C – the left edge of the plant

**Table 1.** Morphological parameters of wheat plants in control and heat stress groups on the day 1. Values represent measurements from nine biological samples across three independent experiments.

Sample	Shoot length of control plants (cm)	Shoot length of heat stressed plants (cm)	Root length of control plants (cm)	Root length of heat stressed plants (cm)
1	11,7	9,5	9,8	9,5
2	11,0	9,4	11,4	10,0
3	10,3	9,7	10,1	10,3
4	10,9	8,5	13,3	9,3
5	9,5	9,0	10,5	8,7
6	9,8	8,9	9,5	9,1
7	9,5	10,4	13,3	10,0
8	10,1	8,3	10,0	9,2
9	10,8	9,2	12,0	9,1
SE	10,04±0,007	9,2±0,006	11,1±0,15	9,5±0,05

On the day 1 of the study, the average shoot length of the control plants was 10.4 cm, whereas the average shoot length of the wheat plants exposed to heat stress was 9.2 cm. Regarding the roots, the control plants had an average length of 11.1 cm, while the roots of the heat-stressed wheat plants measured 9.4 cm on average (Table 1). On day 3 of the study, the average shoot length of the control plants increased to 18.9

ilarly, the average root length of the control plants was 14.9 cm, compared to 10.3 cm in the heat-stressed plants (Table 2; Figure 5).

Table 2. Morphological parameters of wheat plants in control and heat stress groups on the day 3. Values represent measurements from nine biological samples across three independent experiments.

Sample	Shoot length of control plants (cm)	Shoot length of heat stressed plants (cm)	Root length of control plants (cm)	Root length of heat stressed plants (cm)
1	18,0	12,8	16,0	10,5
2	19,5	11,5	14,8	9,8
3	19,6	12,3	16,5	10,4
4	20,0	13,5	15,3	10,1
5	19,6	14,1	13,8	11,0
6	19,3	13,3	13,7	9,5
7	18,3	14,2	15,5	11,2
8	19,0	13,6	13,8	11,2
9	17,6	12,7	14,7	9,6
SE	18,9±0,08	13,1±0,08	14,9±0,1	10,4±0,06

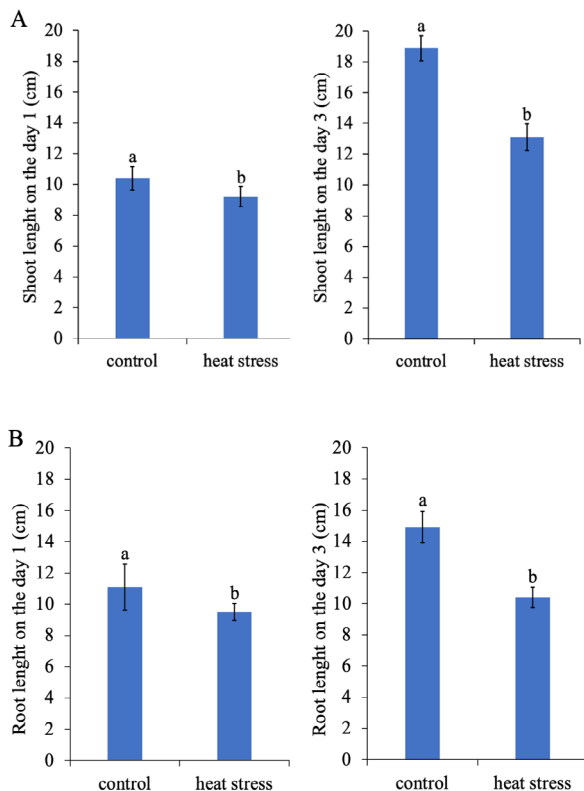


Figure 5 - Comparison of shoot and root length of wheat plants in control and heat-stressed groups over three days.

Figure 5A – Shoot length; Figure 5B – Root length

Values are mean  $\pm$  SE (n=9). Different letters indicate statistically significant differences according to Tukey's HSD test ( $p < 0.05$ ). Different letters indicate significant difference between control and heat stress plants.

#### Changes in shoot and root weight of wheat plants

As a result of high temperature, significant differences were observed between the control group and the heat-stressed plants. Wheat plants exposed to heat stress showed a reduction in biomass over time compared to the control plants. On day 1, the average shoot weight of the control group was 0.25 g, whereas in the stressed group it was 0.18 g (Table 3). The average root weight in the control plants was 0.44 g, while in the stressed group it was 0.029 g. On day 3 of the study, the

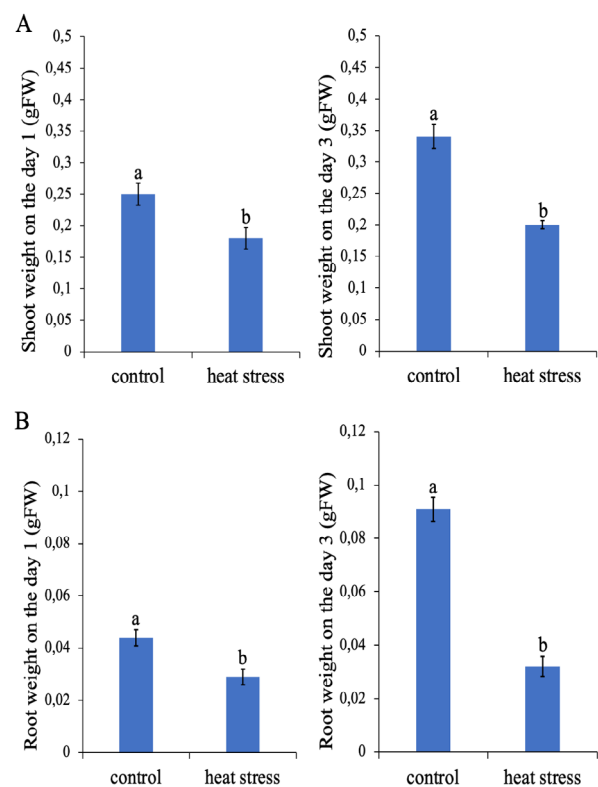


Figure 6 - Comparison of shoot and root length of wheat plants in control and heat-stressed groups over three days.

Figure 6A – Shoot weight ; Figure 6B – Root weight

Values are mean  $\pm$  SE (n=9). Different letters indicate statistically significant differences according to Tukey's HSD test ( $p < 0.05$ ). Different letters indicate significant difference between control and heat stress plants.

average shoot weight in the control group was 0.34 g, whereas in the heat-stressed plants it was 0.20 g. In plants grown under optimal temperature, the average root weight was 0.091 g, compared to 0.032 g in the stressed group (Table 4; Figure 6).

#### Changes in relative water content (RWC) under heat stress

The experiment was conducted over three days, and differences between the control and stress groups were observed.

Table 3. Morphological parameters of wheat plants in control and heat stress groups on the day 1. Values represent measurements from nine biological samples across three independent experiments.

Sample	Shoot weight of control plants (g)	Shoot weight of heat stressed plants (g)	Root weight of control plants (g)	Root weight of heat stressed plants (g)
1	0.271	0.201	0.044	0.029
2	0.266	0.198	0.048	0.031
3	0.276	0.204	0.044	0.031
4	0.244	0.170	0.049	0.035
5	0.253	0.183	0.041	0.028
6	0.231	0.166	0.045	0.031
7	0.229	0.170	0.044	0.029
8	0.234	0.159	0.040	0.024
9	0.245	0.168	0.041	0.029
SE	0,25±0,001	0,18±0,001	0,044±0,0002	0,029±0,0002

Table 4. Morphological parameters of wheat plants in control and heat stress groups on the day 3. Values represent measurements from nine biological samples across three independent experiments.

Sample	Shoot weight of control plants (g)	Shoot weight of heat stressed plants (g)	Root weight of control plants (g)	Root weight of heat stressed plants (g)
1	0.356	0.209	0.095	0.031
2	0.319	0.195	0.087	0.029
3	0.331	0.200	0.091	0.035
4	0.334	0.199	0.089	0.033
5	0.341	0.207	0.092	0.038
6	0.339	0.201	0.086	0.037
7	0.351	0.201	0.091	0.029
8	0.386	0.193	0.091	0.035
9	0.349	0.189	0.093	0.028
SE	0,34±0,002	0,2±0,0005	0,091±0,0004	0,032±0,0004

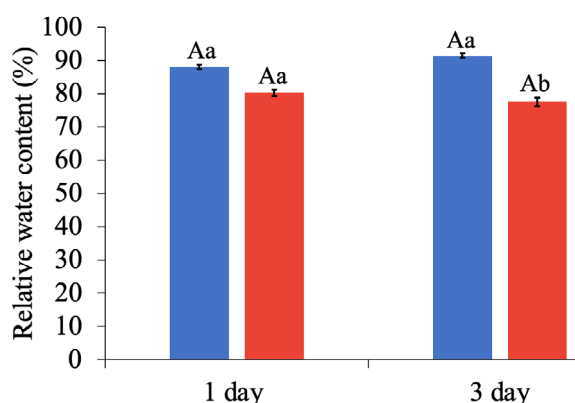


Figure 7 - Comparison of changes in RWC in control and heat stressed groups of wheat plants over three days.

Values are mean  $\pm$  SE (n=3). Different letters indicate statistically significant differences according to Tukey's HSD test ( $p < 0.05$ ).

Capital letters (A) denote comparison between control and heat stress plants on the day 1 and day 3. Lowercase letters (a) indicate comparisons between control and heat stress plants on the day 1. Lowercase letters (a, b) indicate comparisons between control and heat stress plants on the day 3.

The average RWC in the control plants was 88.03% on day 1 and 91.43% on day 3. In the stress group, it was 80.28% on day 1 and 77.57% on day 3. The results showed that plants exposed to high temperatures were unable to maintain water content as effectively as plants grown under optimal conditions. This indicates a deterioration of the physiological state of the plants under heat stress conditions (Figure 7).

The study identified changes in RWC under heat stress conditions. There was no significant difference between the control and stress groups on day 1, as the duration of heat exposure was insufficient to cause a substantial reduction in RWC. However, by day 3, a significant difference was observed between the control and heat-stressed plants. Reduced RWC is often associated with increased transpiration rates and disturbances in stomatal regulation. Such changes ultimately affect leaf turgor, photosynthesis, and overall plant growth.

## DISCUSSION

Global warming and climate change of 1.1 °C causes serious damage worldwide. Rising global temperatures put food security and quality at risk. Extreme heat events and heatwaves have widespread negative effects, notably reducing crop yields worldwide [31]. A recent study found that over the last century temperature has risen by 0.6°C, with a further increase of 2-4°C expected by the end of the 21st cen-

ture, along with more frequent and intense heat waves [32]. According to one study, the reproductive stage is especially sensitive to elevated temperatures [33]. For instance, even a 1 °C increase in temperature is predicted to reduce wheat yields by 4–6% [34].

A plant's survival under high temperatures depends on its ability to perceive heat stress, activate signaling pathways, and initiate appropriate physiological and biochemical adjustments. Elevated temperatures also induce the expression of specific heat-responsive genes and the accumulation of protective metabolites that enhance stress tolerance. Ongoing research continues to elucidate these adaptive mechanisms, and advanced molecular techniques are being employed to improve heat tolerance in plants [35]. Learning the molecular mechanisms behind their heat response and tolerance, particularly in crops, is important for managing global food security under climate change [36]. The impact of heat depends on its duration and the developmental stage of the plant at the time of exposure. In other research under the influence of high temperature stressed plants showed reduced development of both shoots and roots [37]. When temperature rises plants change in shape and their seeds, roots and growth don't develop well and morphological changes occur. These changes are important indicators of damage, especially in economically important crops [38]. Previous studies have demonstrated that exposure of four wheat varieties to elevated temperature conditions (35/25 °C day/night) for three consecutive days resulted in a marked reduction in photosynthetic activity. A significant decline was detected in all varieties after only one day of heat treatment compared with plants maintained under control conditions (23/15 °C day/night) [39]. In another study, exposure of different wheat varieties to heat stress resulted in significant reductions in yield and grain weight. However, the extent of reduction differed between the two cultivars, suggesting variability in their tolerance to elevated temperature conditions [40]. In a recent was demonstrated that exposure of wheat plants to elevated temperatures significantly reduced growth compared with control conditions. Moreover, substantial genotypic variation in heat tolerance was observed between the studied varieties, indicating differential adaptive responses to heat stress [41]. So, our research also showed morphological differences between control and stressed plants. That is on the day 3 of this study under heat stress a decrease in the growth of morphological parameters of the «Astana» wheat variety was observed.

In general, the genotypic differences in RWC can be linked to variations in the plants' ability to take up more water from the soil and to regulate water loss through the stomata. A higher RWC has been reported to contribute to stress tolerance in wheat in recent research [42]. Measuring the RWC of a leaf is a simple and reliable method for assessing its water status and does not require specialized equipment. Similar to leaf water potential, RWC reflects how plants respond to changes in their environmental conditions [43].

At high temperatures, RWC was lower than in plants grown under optimal conditions. As leaf temperature increases, the rate of evaporation rises sharply. When plants are exposed to heat stress, transpiration increases, and they lose water more rapidly than they can absorb it from the soil. To minimize water loss, plants close their stomata. However, sto-

matal closure limits CO<sub>2</sub> uptake, reduces photosynthetic efficiency, and further disrupts water balance. One study reported that the combined effects of drought and heat stress resulted in a significant decrease in RWC on the third and sixth days in different crop species [44]. In the study evaluating high heat stress on wheat RWC was reduced to 83,76% at 30–35°C compared to the control value of 90,6% [45]. In this research where «Astana» variety was studied under heat stress, there were changes in RWC. There were significant differences under the influence of high temperature on the day 3 compared to the day 1 where values represent 77,57 % and 80,28 % respectively demonstrating significant effect of heat stress. As previously reported, heat stress at 37 °C significantly reduced leaf RWC in wheat seedlings. Control plants exhibited RWC values ranging from 86–96%, whereas heat-stressed plants showed a decline to 47–83%. Notably, sensitive genotypes demonstrated reductions of up to 45–48%, while tolerant genotypes exhibited comparatively smaller decreases (4–11%). These findings indicate that heat stress disrupts plant water balance and that the maintenance of higher RWC represents a critical physiological indicator of heat tolerance, consistent with previous research [46]. In comparison with the aforementioned studies, the results obtained in the present investigation suggest a relatively higher level of heat tolerance in the «Astana» variety. Under heat stress conditions, the «Astana» genotype maintained a comparatively higher RWC, indicating enhanced water retention capacity and improved adaptive response to elevated temperature stress.

## CONCLUSION

Global warming is one of the major challenges of the modern world. High temperatures have a negative impact on various plant species, including agricultural crops such as wheat. Heat stress negatively affects the growth, photosynthesis, and overall development of wheat plants. Here, we demonstrate that high temperature significantly affects stem and root growth as well as the RWC of wheat plants.

In this study, plants were exposed to high temperatures and compared with plants grown at optimal temperature. Morphological parameters and RWC were measured. The results showed that the duration of heat exposure and the phenological stage of plant development play a significant role in the degree of damage. These findings showed that the «Astana» wheat variety, which had not been previously studied, experienced changes in morphological parameters and in changes in RWC under heat stress. The observed decline in growth parameters and RWC highlights the sensitivity of this wheat variety to elevated temperature, suggesting that morphological traits and RWC are reliable indicators for assessing plant responses to heat stress. Understanding the physiological and morphological responses of wheat to heat stress is essential for developing strategies to enhance plant tolerance and sustain growth under elevated temperature conditions. The findings of the present study on the «Astana» wheat variety provide a valuable foundation for future comparative analyses with other wheat genotypes. Such comparative evaluations may facilitate the identification and selection of heat-resilient varieties suitable for cultivation in hot environments.

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## «АСТАНА» БИДАЙ СОРТЫ ӨСІМДІГІНДЕ ЖЫЛУ СТРЕССИ КЕЗІНДЕ БОЛАТЫН ФИЗИОЛОГИЯЛЫҚ ЖӘНЕ МОРФОЛОГИЯЛЫҚ ӨЗГЕРІСТЕР: САЛЫСТЫРМАЛЫ СУ МӨЛШЕРІНІҢ РӨЛІ

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### АНДАТПА

Бидай (*Triticum aestivum L.*) - әлемдегі ең көп тұтынылатын дәнді дақылдардың бірі. Жоғары температура өсімдіктердің өсуіне әсер ететін маңызды абиотикалық стресс факторларының бірі болып табылады, себебі жаһандық жылыну қазіргі уақытта әлемдегі негізгі мәселелердің бірі болып табылады. Абиотикалық стресс жағдайында жасушаларда жүретін физиологиялық және биохимиялық өзгерістер өсімдіктердің өсуі мен дамуын баяулатып, сонымен қатар бидай өнімділігінің төмендеуіне әкеледі. Бұл зерттеудің негізгі мақсаты жылу стрессінің бидайдың өсуіне әсерін зерттеу және жоғары температура кезіндегі бидай өсімдіктерінің морфологиялық және физиологиялық өзгерістерін анықтау. Бұл зерттеуде «Астана» сорты қолданылды және 25°C температурада өсірілген бақылау өсімдіктері мен жоғары температуралық стресс (40°C) жағдайында өсірілген өсімдіктер салыстырылды. Зерттеу барысында бидай сорттарының морфологиялық және физиологиялық өзгерістері анықталды. «Астана» сортының тамыры мен сабақтарының орташа ұзындығы, және де өсімдіктердегі судың салыстырмалы мөлшері де анықталды. Температуралық стресспен зақымдалған бидайдың тамырлары мен өркендері бақылау өсімдіктерімен салыстырғанда өлшеміннің кішірейгені байқалды, ал қалыпты температурада өсірілген өсімдіктердің салыстырмалы су мөлшері жылу стрессі жағдайында өсірілген өсімдіктермен салыстырғанда жоғары болды.

**Кілт сөздер:** *Triticum aestivum L.*, «Астана» сорты, абиотикалық стресс, жоғары температура, салыстырмалы су мөлшері, жылу төзімділігі.

### ФИЗИОЛОГИЧЕСКИЕ И МОРФОЛОГИЧЕСКИЕ ИЗМЕНЕНИЯ ПРИ ТЕПЛОВОМ СТРЕССЕ У РАСТЕНИЙ ПШЕНИЦЫ СОРТА «АСТАНА»: РОЛЬ ОТНОСИТЕЛЬНОГО СОДЕРЖАНИЯ ВОДЫ

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### АБСТРАКТ

Пшеница (*Triticum aestivum L.*) одна из наиболее широко потребляемых зерновых культур в мире. Высокая температура является одним из важных абиотических стрессовых факторов, влияющих на рост растений, поскольку глобальное потепление в настоящее время представляет собой одну из основных мировых проблем. Физиологические и биохимические изменения, происходящие в клетках в условиях абиотического стресса замедляют рост и развитие растений, что в конечном итоге приводит к снижению урожайности пшеницы. Целью исследования было изучение влияния теплового стресса на рост пшеницы, а также выявление изменений морфологических и физиологических функций пшеничных растений при высоких температурах. В данной работе использовалась пшеница сорта «Астана» и было проведено сравнение между контрольными растениями, выращенными при температуре 25 °C и стрессовыми растениями, выращенными при температуре 40 °C. В результате исследования были выявлены морфологические и физиологические изменения. Изучалась средняя длина корней и побегов пшеницы сорта «Астана», а также относительное содержание воды в растениях. В стрессовой группе корни и побеги пшеницы были уменьшены в размерах по сравнению с контрольными растениями, а относительное содержание воды в растениях, выращенных при оптимальной температуре, было выше по сравнению с растениями, выращенными в условиях теплового стресса.

**Ключевые слова:** *Triticum aestivum L.*, сорт «Астана», абиотический стресс, высокая температура, относительное содержание воды, тепловая устойчивость.