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EFFECT OF HEAT STRESS ON WHEAT (*TRITICUM AESTIVUM*) AND STRATEGIES TO COPE WITH THIS STRESS

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ABSTRACT

Wheat (*Triticum aestivum* L.) is an important cash crop and is widely grown on approximately 220 million thousand hectares around the globe. Pakistan is included in the top ten wheat-producing countries in the world. However, due to climate change and biotic and biotic stresses, wheat yield and quality are continuously compromising. Heat stress is a negative constraint on wheat production (it is anticipated to decrease by 6% for each degree increase in temperature) and quality characteristics. Specifically terminal heat stress is a more devastating factor, while the plant responds in a variety of ways to withstand heat stress, for instance, scavenging of reactive oxygen species (ROS) and osmotic adjustment. To, address the global food security challenges, it is essential to develop genetically superior heat-tolerant cultivars that can withstand heat stress with high yield per hectare. Achieving thermotolerance in wheat involves a multifaceted approach, incorporating various procedures such as screening, breeding utilizing existing wheat germplasm, molecular breeding techniques, genetic engineering methods, and the incorporation of genes from wild germplasm.

***Keywords*:** Wheat, Climate Change, Biotic, Biotic Stress

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1. INTRODUCTION

Wheat is one of the significant crops after rice, belongs to the Poaceae family, and is most produced, consumed, and stored globally (Tyagi and Pandey 2022; Igrejas et al. 2020). Over 80% of the world's wheat producers include Australia, China, Canada, Europe, Pakistan, India, Turkey, Ukraine, Russia, and the USA. While the world's top producer of wheat is China, followed by Europe, the USA, and India (Carter 2002) whereas Pakistan is the eighth-largest producer of wheat (Ahmad et al. 2021).

Global climate models predict that average ambient temperatures will climb by 1.8 to 5.8°C by the end of the century (IPCC 2007). High fluctuation in the temperature and frequent hot days will affect future climate. Furthermore, temperatures between 12 and 22°C are ideal for wheat anthesis and grain filling, whereas exceeding temperatures have been shown to the reduction of yield (Yadav et al. 2022; Farooq et al. 2011)

Heat stress (HS) affects grain filling time and protein and starch accumulation during grain growth by inhibiting the activity of enzymes involved in grain biosynthesis. It also diminishes the efficacy of flag leaf assimilation and stem reserve mobilization (Ullah et al. 2022). This ultimately has an impact on wheat grain number, size, and maturity, which lowers crop productivity (Lal et al. 2021).

2. Effects of Terminal Heat Stress on Wheat

Several researchers examined the effects of HS on various phenological and physiological features of wheat throughout the reproductive stage (Fig. 1), and they found that HS causes metabolic changes associated with senescence in wheat. The inhibition of photosystem II (PSII) brought on by HS reduces photosynthesis. Plants are most vulnerable to HS during pollination and grain filling; this is known as terminal heat stress, and it disrupts the metabolic activities of plants (Mustafa et al. 2021; Zafar et al. 2022; Manan et al. 2022).

Wheat is particularly susceptible to the impacts of high temperatures during the anthesis stage. When wheat is exposed to temperatures above its optimal range, HS causes modifications in physiological and biochemical processes like photosynthesis, respiration, proteins, oxidative damage, water and nutrient relationships, and yield-forming characteristics (tiller count, biomass, grain size, and number) (Yadav et al. 2022).

During anthesis, HS induces floret abortion and also results in pollen sterility, tissue dryness, decreased CO_2 assimilation, and increased photorespiration during the reproductive period. However, temperatures above 30°C

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during the floret-forming process may cause absolute sterility. As a result, grain production decreases when temperatures are high between anthesis and grain maturity as there is less time for resource capture and translocation (Farooq et al. 2011).

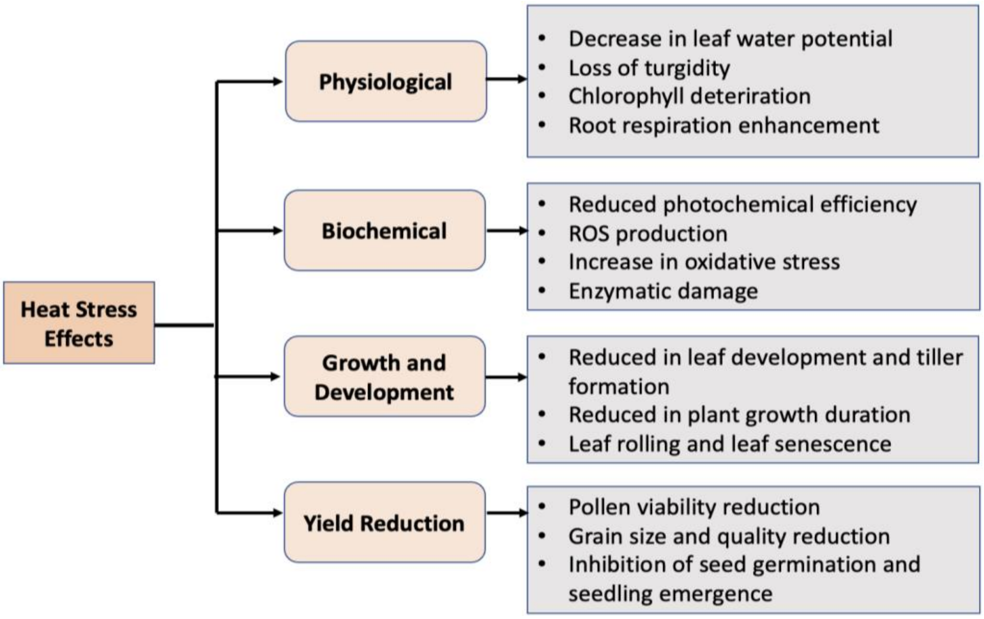

Fig. 1: Physiological, biochemical, growth and development and yield loss effects of heat stress.

HS inhibits the development of pollen tubes, which reduces the germination of pollen grains on the stigma and affects embryo development. Reduced grain setting can result from pollen mother cell division under high-temperature stress. Wheat's total biomass can be reduced by up to 44% during the reproductive phase when temperatures are high (30-38°C) (Yadav et al. 2022).

The onset of floral development, pollination, fertilizing, seed production, and seed quality are only a few of the stages of wheat growth and development that are affected by high temperatures (Lal et al. 2021). Furthermore, HS shortens the vegetative development and flowering period, hence reducing the efficiency with which grains can capture available stem reserves (carbohydrates) (Elbasyoni 2018; Ahmad et al. 2021). As the temperature rises (1-2°C), the time it takes for grain to fill reduces, resulting in a decrease in seed weight. During grain filling, short-term HS can cause a 23 percent decrease in grain yield. Between 12 and 22°C is the best range for grain filling and blooming (Patil et al. 2022).

Studies investigating the impact of high-temperature stress on wheat at different stages have revealed that 45°C heat treatment at the seed germination stage causes embryo death and decreases seedling growth rate, as well as decreases in root/shoot length, and dry mass, chlorophyll content, and membrane stability index. It was discovered that the post-anthesis stage has a temperature threshold of 26 degrees Celsius, indicating that terminal heat stress is extremely damaging to reproductive development. Improving wheat output under terminal stress during the grain-filling phases should be the key objective of the future (Lal et al. 2021).

In Pakistan, 20% of the wheat is planted on schedule, but 80% of it is planted after the rice has reached physiological maturity and the cotton has been picked (Ahmad et al. 2021). In a finding of 21 experiments, the decreased kernel weight owing to HS was drawn, and in Australia and the USA, increases in temperature above the optimum in the anthesis and grain filling stage of wheat results in a 10-15% reduction in grain production (Shahzad et al. 2021). Therefore, terminal or late sowing HS in wheat is considered to be one of the primary environmental factors significantly limiting wheat yield in the majority of the wheat-producing areas (Khan et al. 2007; Menshawy 2007; Barutcular et al. 2017).

However, HS during the early stages of grain filling increases the concentration of total soluble sugars while decreasing starch synthesis in the wheat grain. HS increases protein content, but the functionality of proteins is greatly reduced, which hurts their ultimate usage. Due to a sharp decline in grain yield, even with a high proportion of grain protein, overall protein yield decreases under HS. However, it has been noted that a higher protein content lowers the sedimentation index, which influences the usefulness of wheat flour for producing bread. Additionally, the heat-induced accumulation of gliadins under HS impairs the quality of wheat flour (Yadav et al. 2022). During heat stress, the starch content is reduced which is considered the primary reason for yield reduction. A range of extremely heat-labile enzymes, including sucrose transporter, sucrose synthase, ADP-glucopyrophosphorylase, soluble starch synthase, etc., are involved in the buildup of starch. Under HS, the starch synthesis is slowed down because of the aggregation and denaturation of the starch synthase enzyme and resulting in a low level of starch in the endosperm tissue (Kumar et al. 2017).

2.1. Heat Stress Influence on Yield Attributes of Wheat

The most important yield-contributing features in wheat are stem weight, spike length, spike weight, awn length, number of fertile tillers m-2, number of spikes m-2, number of grains spike-1, and 1000-grain weight (Forgone & Informatics Department of Plant Biology, 2009). HS has a significant impact on the grain production of several wheat genotypes (Hossain et al. 2012).

The duration and pace of seed filing are the final stages of development affecting the seed weight. Terminal HS reduces the time the plant is required to fill the grain and therefore reduces the time required to mature and apoptosis by damaging the assimilation capacity of the flag leaf (Ullah et al. 2022).

2.2. Response of Wheat to Heat Stress

Crop plants are more susceptible to drought stress due to increased evapotranspiration caused by HS; consequently, water relations in plants are adversely impacted by drought stress. Plants to respond to individual or combination stresses use different strategies, for instance, in response to high HS and limited moisture availability, photosynthesis is inhibited, and stomata are closed. Under HS, biological processes also change. Reduced yield is caused by changes in physiological and gas exchange features (Sattar et al. 2020).

HS produces reactive oxygen species (ROS) that harm chloroplasts, especially without a detoxifying system. ROS are produced by HS-induced chlorophyll overexcitation. During leaf senescence, ROS production is observable (Sattar et al. 2020). Oxidative damage has a negative impact on stomatal conductance and photosynthetic processes. Plants have an inherent defense mechanism that appears as superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), etc. under stressful circumstances (Mustafa et al. 2021).

Regardless of the temperature, plants keep their water status constant when there is an unlimited supply of water. In contrast, when there is a limited quantity of water, HT reduces the ability of plants to keep their water status constant in their tissues. In field situations where there is typically insufficient water availability, HT further lowers the plant's ability to maintain tissue water status (Hassan et al. 2021). The length and intensity of structure, as well as the fluidity of membranes in reaction to changes in temperature, all play a role in determining how severe the effects of stress are on the various phases of plant development (Lal et al. 2021).

2.2.1. Biochemical and Molecular Alteration of Plants in Heat Stress

As HS causes plants to experience oxidative stress, related to the generation of ROS (Zafar et al. 2021). To neutralize this ROS, plants have a variety of enzymatic and non-enzymatic antioxidant mechanisms. Antioxidant activity significantly increases under HS, shielding plants from HS's harmful effects. For example, increased production of superoxide dismutase (SOD) in the presence of HS decreases hydrogen peroxide (H_2O_2) and affects several metabolic processes, including those involved in cell wall lignin formation, auxin metabolism, plant response to injury and insect attack, and many respiratory processes (Zafar et al. 2022). Additionally, APX (Ascorbate peroxidase) expression is linked to several physiological harms brought on by HS. The decrease in antioxidant activity under HS aids in reducing plant damage (Hassan et al. 2021).

Heat-tolerant plant development framework is set to understand the mechanisms through which many crops, such as wheat can withstand heat. An increase in proline accumulation is the most frequent response of plants under HS. Free proline is engaged in osmotic adjustment during high-temperature conditions to protect pollens and plant enzymes from heat damage (Ahmed et al. 2023). In wheat, cotton, and arabidopsis, proline accumulation has been demonstrated to occur under HS, and variations in genotypes for proline accumulation have been described for these species. There is evidence that under HS circumstances, the quantity of other soluble and insoluble proteins may alter. Additionally, certain heat shock genes are activated, which induces the production of heat shock proteins in HS conditions (Khan et al. 2015).

Heat shock proteins, a plant defense mechanism against the effects of heat stress, may have been upregulated under terminal heat stress, which would explain the higher protein concentration. Under HS treatment at 34 and 40°C, 6560 probe sets for heat shock proteins in wheat showed expression upregulation (Elbasyoni 2018).

The quantitative nature of heat tolerance is controlled by a number of genes and QTLs, some of which may interact with one another (QTL× QTL interaction) or with the environment (QTL×E and QTL×QTL×E interactions).

The wheat QTLs for heat tolerance have been reported using a variety of parameters, including GFD (Grain Filling Duration) and senescence-related traits. Additionally, efforts have been made in the identification of QTLs using other significant parameters, for instance, CTD (Canopy Temperature Depression) and TGW (Thousand Grain Weight). Therefore, the parameters heat susceptibility index for thousand-grain weight, grain filling length, and canopy temperature are crucial for locating the QTLs for heat tolerance (Kumar et al. 2013).

2.3. Genetic Variability of Traits Associated with Heat Stress

In order to increase yield and yield-related parameters, such as grain yield, plant height, and heading date, in the face of water scarcity and high-temperature stress, numerous studies have been undertaken on the genetic diversity of wild wheat germplasms (Abou-Elwafa and Shehzad 2021).

To boost wheat's ability to adapt to warmer climates, genetic diversity for heat tolerance is required. Although more variability may be found by carefully screening materials from a large germplasm collection of wheat and its relatives, the genetic diversity in several heat tolerance traits has already been established (Hede et al. 1999).

3. Strategies to Develop Heat Tolerance in Wheat

Wheat breeding has traditionally focused on improving the yield and sustainability of crops in such challenging conditions, and this objective is becoming more critical as the world population rises (Abdelrahman et al. 2020). To form an effective strategy for a breeding program, the overall response of the wheat to HS must be understood at the morphological, anatomical, and physiological levels (Suryavanshi and Buttar 2016; Sharma et al. 2019).

Nonetheless, heat-tolerant wheat cultivars can be produced by breeding and utilizing the best agronomic practices to cope with HS at the final growth stage. The application of exogenous plant-based (such as allelopathic water extracts) and other Osmo protectants is one practical method for managing HS in wheat at the final stage of development (Sattar et al. 2020). Other methods to increase wheat's thermotolerance comprise molecular breeding, screening or breeding of available wheat germplasm, and the use of genetic transformation techniques for heat tolerance (Sarkar et al. 2021; Patil et al. 2022; Ullah et al. 2022). Under the influence of HS, plants adjust themselves on morphological, physiological, biochemical, and molecular levels (Fig. 2).

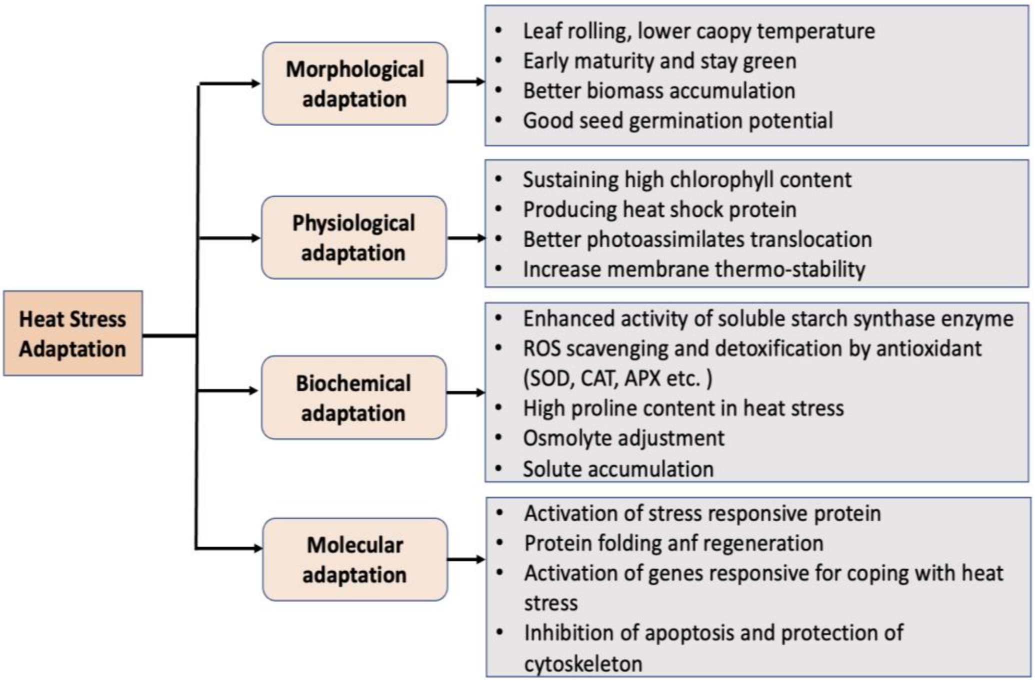

Fig. 2: Morphological, physiological, biochemical and molecular adaptation of plant in heat stress. SOD=Superoxide dismutase, CAT=Catalase, APX=Ascorbate peroxidase.

3.1. Morphological, Physiological Adaptation Strategy

Nevertheless, wheat plants have evolved several physiological defenses against terminal HS, including as early maturity, a stay-green trait, a lower canopy temperature, the storage of a higher stem water-soluble carbohydrate content, and a high biomass buildup that boosts output (Kumar et al. 2013).

Early maturation is a physiological response with lower yield loss over the summer indicating a potential role with HS tolerance. Therefore, wheat genotypes that mature earlier and offer the least amount of yield loss in comparison to the control condition can be regarded as truly compatible to cope with heat stress damage (Rehman et al. 2021; Sarkar et al. 2021). One of the effective strategies of the breeder was to screen the wheat genotypes against heat stress (Khan et al. 2007; Kumar et al. 2017).

Under HS, a trait such as stay-green keeps a high concentration of leaf chlorophyll that is linked to yield and its constituent parts. Loss of green space is expected to have an effect on grain size, although, under heat and drought stress, this can be compensated by boosting the remobilization of water-soluble carbohydrates from the leaf sheath and stem to growing grains (Rehman et al. 2021). In wheat, the stay-green character is connected to an increase in leaf area, grain filling rate and duration, and photosynthetic capability. The length of time that flag leaves remained green, and the harvest index correlated well with the effectiveness of water utilization during wheat grain development (Kumar et al. 2013).

Studies demonstrating a direct connection between grain yield and water-soluble carbohydrates under HS or drought stress are scarce. Additionally, wheat genotypes having cooler canopy temperatures during the terminal stage of growth can access subsoil moisture, which supports photosynthesis and evaporation under warm irrigation circumstances. Positive associations between grain yield and plants with cooler canopies have also been found. Consequently, the best combination of physiological traits because of a shared genetic base helps in the genetic improvement of wheat under drought and HS (Rehman et al. 2021).

4. Conclusion

Wheat is a significant edible crop that is consumed in most parts of the world population, however, due to climate change worsens the already present biotic and abiotic stresses specifically the heat stress that leads to drought or water deficit conditions in crops. Terminal heat stress is a more devastating factor that is seen in the reduction of crop yield, this situation is further augmented by the late sowing of wheat. Nevertheless, plants respond in a different way to cope with these stresses, whereas a variety of techniques are used by breeders in order to develop thermotolerant wheat genotypes. There is a need to screen the heat resistance genotypes in a diverse germplasm or introgression of the resistance gene from wild germplasm, furthermore, molecular breeding and genetic transformation are an effective strategy in this concern.

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