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# Heat stress and tolerance in wheat: A review

**Prithviraj Patil, Shiv Prakash Shrivastav, Rushikesh Landge, Kulbhushan Patil and Harshraj Salunkhe**

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**Prithviraj Patil**
M.Sc. Student, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

**Shiv Prakash Shrivastav**
Assistant Professor, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

**Rushikesh Landge**
M.Sc. Student, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

**Kulbhushan Patil**
Ph.D. Student, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

**Harshraj Salunkhe**
M.Sc. Student, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

**Corresponding Author**
**Prithviraj Patil**
M.Sc. Student, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India

## Abstract

Wheat is a common grain crop that provides basic calories and protein to more than 80% of the world's population. Concerns about the impact of rising temperatures on wheat production have grown as a result of global climate change in recent decades. The main abiotic stresses limiting wheat yield are heat and drought. Heat stress disrupts the plant's vital physiological and biochemical processes. In the endosperm, high temperatures lower grain number, photosynthetic activity, chlorophyll content, and starch production. Heat stress accumulates reactive oxygen species, which cause significant oxidative damage to the crop. Heat shock proteins are produced quickly by plants to reduce the effects of heat stress. Heat tolerance is influenced by several features such as stay green, chlorophyll fluorescence, and canopy temperature. Knowledge of heat stress effect and tolerance at the physiological, biochemical, and morphological levels is critical for developing novel crop types that can cope with future climates.

**Keywords:** Heat stress, heat shock proteins, oxidative stress, wheat

## 1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the Gramineae family, accounting for around 30% of global grain output and 50% of global grain trade (Akter *et al.*, 2017) [1]. Wheat is a staple food in over 40 countries throughout the world, supplying basic calories and protein to 85 percent and 82 percent of the global population, respectively (Sharma D *et al.*, 2019) [69]. According to the FAO, annual cereal production must increase by over one billion tonnes by 2050 to feed the anticipated population of 9.1 billion people (Chaves MS *et al.*, 2017) [15]. Increased agricultural output and productivity are needed to meet rising food demand in the twenty-first century (Iqbal M *et al.*, 2017) [36]. Wheat is grown throughout the tropics and subtropics of the world, where it is subjected to a variety of abiotic stressors. Crop productivity is severely reduced by adverse environmental conditions (Rahaie M *et al.*, 2017) [72]. Heat, drought, salinity, cold, chemical, and water excess are all prominent abiotic stresses. Heat and drought, on the other hand, are the principal abiotic factors impacting wheat productivity over the world (Lesk C and Liu B 2016) [48]. According to a global climate model, the average ambient temperature will likely climb by 6 degrees Celsius by the end of the 21st century (De Costa WAJM, 2011) [11].

Wheat is extremely susceptible to heat stress. According to estimates, every 1°C increase in temperature reduces global wheat yield by 6%. (Asseng, 2011) [7]. Even a 1°C increase in temperature above the mean during the reproductive stage can result in a greater loss in grain production (Bennett D and Yu Q, 2014) [12]. Wheat undergoes physiological, biological, and biochemical changes as a result of high temperatures (Asseng S., 2015) [6]. Heat stress (HS) in wheat results in poor seed germination, shorter grain filling times, fewer grains, inactivation of the Rubisco enzyme, reduced photosynthetic capability, slower nutrient transport, premature leaf senescence, lower chlorophyll content, and lower yield (Hossain A. and Din R., 2013) [32]. Grain starch and protein composition are also affected by heat stress.

Heat tolerance causes the generation of reactive oxygen species (ROS), which cause membrane instability, lipid peroxidation, protein oxidation, and nucleic acid damage (Mishra S and Mittler R., 2011) [63]. On the other hand, wheat has evolved distinct tolerance mechanisms to prevent injury and damage caused by heat stress in order to preserve its survival and growth. Heat shock proteins (HSPs) generated by heat shock ensure proper protein folding, refolding, and synthesis while also degrading protein aggregates (Hasanuzzaman M and Tripp J., 2013) [29]. The antioxidative defence system detoxifies the accumulated ROS using a variety of enzymatic and non-enzymatic antioxidants (Sharma *et al.*, 2012) [83]. Heat tolerance in wheat is linked to features like stay green (SG), chlorophyll fluorescence, and canopy temperature

(Pandey G *et al*., 2019).

Wheat (*Triticum aestivum* L.) is extremely sensitive to high temperatures, and the major wheat-producing regions have already observed rising growing season temperatures (Alexander *et al*. 2006; Hennessy *et al*. 2008) [2]. Though heat stress affects the metabolic pathways of wheat at every stage of its life, ultimately resulting in yield reduction, the effect of high temperatures is particularly severe during grain filling, with losses of up to 40% possible under extreme conditions (Wollenweber *et al*. 2003, Hays *et al*. 2007) [91, 31]. Reduced grain weight, early senescence, shrivelled grains, reduced starch accumulation, altered starch-lipid composition in grains, lower seed germination, and loss of vigour are some of the other impacts of high temperatures (Balla *et al*. 2012) [11]. Heat stress at the end of the season, or 'terminal' heat stress, is also expected to rise in the near future for wheat (Mitra and Bhatia, 2008; Semenov and Halford, 2009) [62, 76]. In recent years, available water resources for successful crop cultivation have also decreased. Droughts are expected to become increasingly frequent as a result of severe climatic changes around the world. Drought stress can affect plant membrane integrity, root depth and extension, stomata opening and closing, cuticle thickness, photosynthesis inhibition, chlorophyll content reduction, transpiration reduction, growth inhibition, hormone composition, protein changes, osmotic adjustment, and antioxidant production (Szegletes *et al*. 2000; Lawlor and Cornic 2002; Yordanov *et al*. 2000; Praba *et al*. 2009) [84, 47, 93, 70] to stand with some osmotic changes in their organs. Drought can also result in pollen sterility, grain loss, abscisic acid accumulation in spikes of drought-susceptible wheat genotypes, and abscisic acid production genes in the anthers of drought-susceptible wheat genotypes (Ji *et al*. 2010). One of the main priorities for current cultivar improvement, which is higher yielding even in water-limited situations, is the Triticum species, which is one of the most important human food sources, accounting for more than half of total human consumption (Fleury *et al*. 2010; Habash *et al*. 2009) [25, 27].

### 1.1 Effect of heat tolerance on wheat

Wheat's numerous growth and development stages are affected by heat tolerance, resulting in a large yield loss. The effect of heat tolerance in plants, on the other hand, is dependent on the length of heat exposure and the stage of growth during the high temperature period (Balla K and Ruelland E. 2010) [74]. Wheat photosynthesis is reduced due to poor germination, lower leaf area, early leaf senescence, and impaired photosynthetic machinery caused by heat stress (Asseng S, Ashraf M and Mathur, 2013) [6]. Wheat morphology, physiology, and biochemistry all change as a result of heat tolerance.

#### 1.1.1 Effect on wheat morphology

Heat tolerance has a negative impact on seed germination and plant establishment in a variety of crops, including wheat (Hossain A. *et al*., 2013) [32]. High temperatures (45°C) harm embryonic cells, resulting in incorrect germination and emergence, resulting in poor crop stand (Essemine J. *et al*., 2010) [22]. High temperatures reduce the productive tiller's ability to survive, resulting in a reduction in yield. Heat tolerance in wheat resulted in a 53.57 percent fall in grain output and a 15.38 percent decrease in tiller number (Din R, *et al*., 2010) [19]. Heat tolerance causes a reduction in root growth, which has an impact on crop yield (Huang B, *et al*., 2012) [34]. During the reproductive phase, heat tolerance has a substantial impact (Nawaz A, *et al*., 2013) [66]. A 1°C increase in average temperature during the reproductive stage could result in a larger loss of grain production (Bennett D and Yu Q., 2012) [12]. The ideal temperature for blooming and grain filling is between 12 and 22 degrees Celsius (Sharma D, *et al*., 2019) [69]. When heat tolerance develops during meiosis, it affects the early stages of gametogenesis (Ji X. and Shiran B. 2010) [41]. Heat tolerance during floral initiation has a deleterious impact on microspore and pollen cell development (Kaur V. *et al*., 2010) [43]. The grain development phenomena is influenced by the pace and length of grain filling, which is particularly sensitive to heat tolerance (Gourdji SM and Lobell DB, 2012) [16]. Wheat's life cycle is shortened in heat stress compared to normal temperatures (Alam M. *et al*., 2014) [29]. 1°C-2°C As the temperature rises, the time of grain filling decreases, lowering seed weight (Nahar K. *et al*., 2010) [65]. Short-term heat stress during grain filling can result in a 23 percent reduction in grain production (Mason RE. *et al*., 2010) [57]. Heat tolerance has a negative impact on grain quantity and quality. Grain number is reduced in HS conditions, resulting in a lower harvest index (Lukac M. *et al*., 2012) [56]. Grain quality is lowered as a result of heat stress-related decreases in assimilate production and remobilization (Lizana XC. *et al*., 2013) [53]. Wheat productivity is significantly diminished as a result of the negative effects of high temperatures throughout the growth period (Janjua P. *et al*., 2010) [39]. Wheat grain yields can be significantly reduced when exposed to ambient temperature (>35°C) for a short length of time (Sharma P. *et al*., 2017) [81].

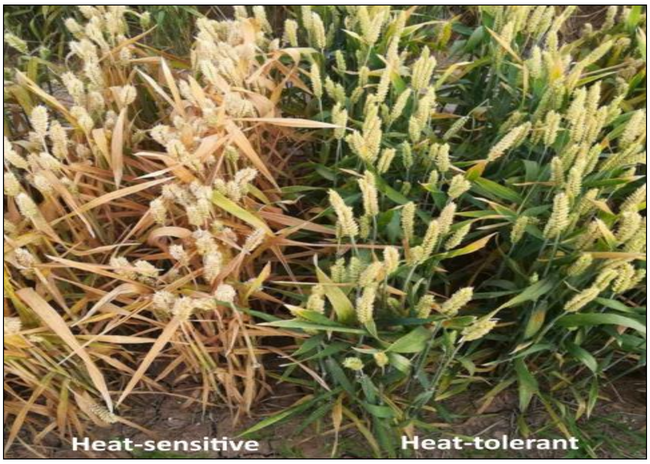

**Fig 1:** Examples of heat-sensitive and heat-tolerant genotypes after heat stress under field conditions at Linfen in Shanxi province in 2017.

#### 1.1.2 Effect on wheat physiology

The most significant physiological activity in plants is photosynthesis, which is greatly influenced by high temperatures. Wheat stroma and thylakoid lamellae are the most vulnerable to heat stress (Mathur *et al*., 2014) [59]. The constant alternation of Rubisco, Rubisco activase, and Photosystem II occurs at high temperatures (40°C) (Mathur S. *et al*., 2011) [58]. The Rubisco enzyme was discovered to be deactivated in less than 7 days when wheat was exposed to heat tolerance conditions (Kumar RR. *et al*., 2016). Under heat stress, rubisco activase breaks down, resulting in a reduction in photosynthetic ability (Raines CA. *et al*., 2011) [73]. Heat stress changes the flexibility of the thylakoid membrane, causing the light harvesting complex II to separate from the photosystem II (Iwai M. *et al*., 2010) [38]. For growth and development, the photosynthetic product must be transported to various plant sections. Under high temperature stress, the rate of assimilate translocation from source to sink is slowed due to a decrease in membrane integrity (Farooq M. *et al*., 2011) [24]. Grain growth and development are aided by the mobilisation of water soluble carbohydrate to the reproductive sink (Talukder ASMHM *et al*., 2014) [85]. Seed set and seed filling are reduced when the source and sink are limited (Lipiec J. *et al*., 2013) [50]. Plants must discover another means to translocate the photosynthetic product into the grain if the supply is limited due to heat tolerance (Akter N. *et al*., 2017) [1]. During pre-anthesis heat tolerance, there is a rise in carbohydrate remobilization from the stem to the developing grain, which helps to recoup the effect on grain starch content in post-anthesis heat tolerance (Wang X. *et al*., 2012) [89]. Photorespiration is aided by the availability of high $O_2$ concentrations. Under heat tolerance conditions, a shift in the solubility of $O_2$ and $CO_2$ gases was detected, resulting in increased photorespiration in wheat flag leaf (Almeselmani M. *et al*., 2012) [4].

### 1.1.3 Effect on wheat biochemistry

Wheat contains a lot of starch, which is made up of amylose and amylopectin. The amount of amylose in a starch is an important criterion for determining its quality. Variations in amylose content have an impact on starch properties. High temperatures are linked to an increase in amylose content and the ratio of amylose to amylopectin (Sharma *et al*., 2015) [82]. AGPase (ADP-Glucose Pyrophosphorylase) and starch synthase are important enzymes in starch production. The two types of starch synthase are soluble starch synthase and granule bound starch synthase (Sharma D. *et al*., 2019) [69]. Because the efficiency of enzymes involved in starch manufacture decreases at high temperatures, grain starch concentration drops by up to one-third of total endosperm starch (Liu P. *et al*., 2011) [52]. Reduced activity of soluble starch synthase at high temperatures about 40°C results in smaller grains and less starch deposition (Chauhan H. *et al*., 2011) [14]. However, Sharma *et al*. found that lowering Soluble Starch Synthase activity to 30°C does not influence starch deposition, but it does affect starch composition. He also stated that heat stress in wheat has no discernible effect on the activity of granule bound starch synthase (Sharma D. *et al*., 2018) [80]. Under heat stress, Asthir and Bhatia found a significant decrease in starch production in wheat grain, but an increase in total soluble sugar and protein (Asthir B.*et al*., 2014) [8]. Protein level and composition have a big impact on wheat grain quality. Under heat stress, Lizana and Calderini found no significant influence on protein content (Lizana XC. *et al*., 2013) [53]. On the other hand, Iqbal *et al*., found that in the heat stress condition, grain protein concentration increases along with important amino acid fractions, leaf nitrogen content, and sedimentation index (Iqbal M. *et al*., 2017) [36].

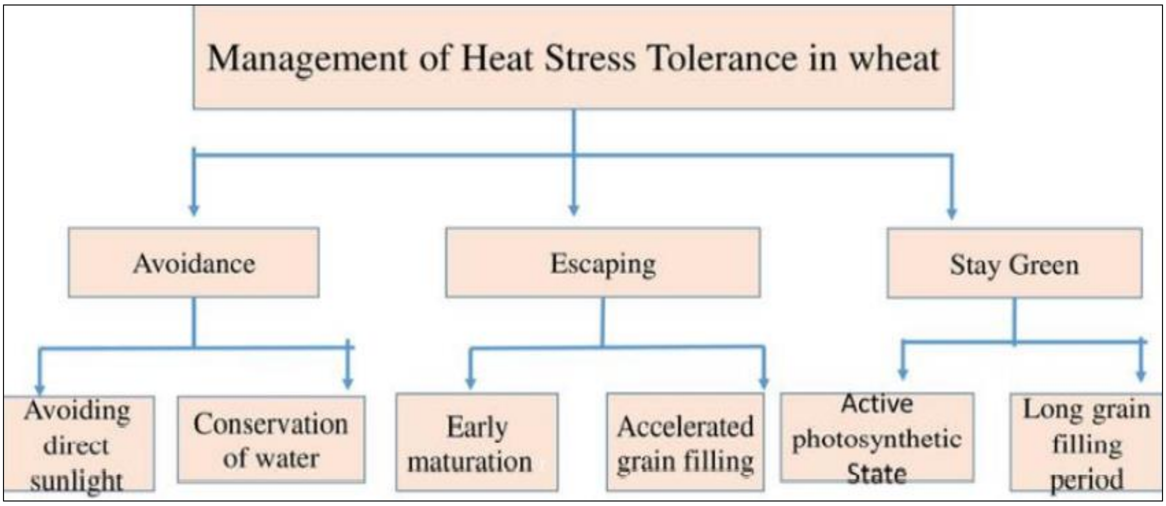

**Fig 2:** Tolerance mechanism of wheat against heat stress

## 2. Causes of heat stress

### 2.1 Climatic Variation

Based on projected temperature ranges, average worldwide temperatures are expected to rise by around 20 degrees Celsius over the next 50 years, making many cereal-growing locations even less suited (Wringle C., 2006) [92]. The average by the end of the year, the ambient temperature is expected to rise by 1–6°C. Century twenty-first (De Costa Wajm, 2011) [11]. Such a rise in global temperature has the potential to have a substantial impact on agricultural productivity based on the intensity of high temperatures, drought, and salinity Stresses from waterlogging and mineral toxicity Induced by high temperatures heat stress is defined as a rise in air temperature above a certain point level for a long enough duration to produce severe or irreversible damage to plants for agriculture in general (Edmark l. Texeira, 2013) [21]. When soil temperature rises as a result of rising air temperature combined with a decrease in soil moisture, heat stress is exacerbated. As a result, heat stress has emerged as a significant threat to crop success (S Kumar *et al*., 2012), (David B Lobell *et al*., 2012) [16].

### 2.2 Late sowing

Several studies show that delaying planting increases the risk of terminal heat stress at the grain filling stage, which reduces grain yield significantly. Sowing at the right time in the right place at the right time to avoid the worst of the heat, go between the 15th and the 25th of November. Wheat stress in the IGP region (Dubey *et al*., 2020) [20]. Every day that passes brings a new set of problems. Sowing wheat after the 30th of November reduces crop production a daily rate of 36 kg/ha (Hussain *et al*., 1998) [35]. Late seeding is, in general, a bad idea. Wheat types are subjected to high temperatures, which reduces the length of the heading & maturation time, all of which have an impact on final yield and grain quality (Hossain *et al*., 2012) [33], (Hakim *et al*., 2012) [28].

## 3. Factors affecting wheat growth

Wheat is classified as a member of the Poaceae family, tribe Triticeae, and genus Triticum. It's a self-pollinated, annual plant with a lengthy day. Wheat is the most significant food crop on the planet. On a worldwide scale, it covers more farmed area than any other crop (Muhammady S 2007) [64]. Wheat quality qualities that are significant for its usage flour protein percentage, milling yield, and rheological properties qualities, as well as properties that aid in the production of bread. Typically, genetics and genotype-environment interactions impact these features. Interactions between genotype and environment can result in size or overall performance of genotypes has shifted in rank. Understanding genotype (crop bio-system) system interactions that are impermeable. It is the soil, the atmosphere, and the habitat in which plants exist that are important. Cultivar selection, for example, is critical in planning major frame decisions agricultural management that is sustainable, as well as economic planning.

Crop output is influenced by a number of uncontrolled factors, the most significant of which is climate. Cloud cover, diurnal temperature range, precipitation, temperature, and humidity are the five meteorological variables provided. Vapour pressure Wheat is not farmed all year in any country. Within Pakistan, we must account for seasonal and regional variations. Climate variables are changing. (Janjua *et al*). looked into the effect, Climate change has a negative impact on wheat output, according to a new study. As a result, temperature had a detrimental impact on wheat growth. As a result, productivity is significantly affected. When the floral initiation stage and spikelet development were exposed to high temperatures, the quantity of grains decreased significantly. Having a negative influence on the highest yield potential. Strength of the sink and two crucial aspects in grain modification are source capacity and source capacity. Wheat genotypes subjected to prolonged heat yield and quality, as well as a thermal shock.

## 4. Morphological effect of heat stress

Heat stress inhibits seed germination and results in fragile crop establishment in several crops, including wheat. When the temperature surpasses or equals 45 degrees Celsius, embryonic cells are impacted, causing seed germination and emergence to be delayed (Essemine, Ammar, & Bouzid, 2010) [22]. The majority of the plant's meristem tissues are compromised, resulting in leaf loss, abscission, and other symptoms (Kosová, Vtámvás, & Práil, 2011). Photosynthetic decrease the environment is also less warm when it is warmer. When compared to ideal environmental conditions, biomass output increases. It has been discovered that it is more if heat stress is present in the reproductive stage of wheat production, it can be dangerous (Nawaz, Bourrie, and Trolard, 2013) [66]. Even a one-degree increase in average temperature can result in a significant decrease in yield (Li *et al*., 2014). Heat stress destroys mitochondria, changes protein expression, decreases ATP production, and causes wheat embryos to take up less oxygen. As a result, there is a greater loss of seed. According to (Hasanuzzaman, Nahar, Alam, Roychowdhury, and Fujita, 2013) [29], for every 1 to 2 degrees Celsius increase in temperature, in wheat, a rise in temperature reduces the bulk of the seed by shortening the time it takes for the grain to fill.

## 5. Conclusion

Wheat responses to high temperatures have been incorporated into the Sirius wheat model during sensitive phases of wheat growth, such as around anthesis and during grain filling. The Hot Serial Cereal experiment (Wall *et al*., 2011; White *et al*., 2011; Ottman *et al*., 2012) [88, 90, 68] and published data on a heat sensitive cultivar were used to calibrate the model parameters (Qin *et al*., 2008; Vara Prasad and Djanaguiraman, 2014) [71]. We were able to estimate yield losses for heat tolerance cultivars as a result of heat stress in future climate scenarios using this method.

Wheat ideotypes were optimised for the HadGEM2-ES (RCP8.5) climatic scenario. Based on criteria determined from the highly sensitive wheat cultivar 'Chinese Spring,' two types of ideotypes were investigated: totally tolerant to heat stress and heat-sensitive ideotypes (Qin *et al*., 2008) [71]. This allowed us to measure the uncertainty in predicting wheat yield potential in the face of future harsh weather. It's impossible to achieve complete tolerance to high temperatures. However, it has been discovered that wheat cultivars' vulnerability to high temperatures during anthesis and grain filling differs (Alghabari *et al*., 2014; Vara Prasad and Djanaguiraman, 2014) [3, 87]. As a result, between these two extremes, heat stress could have an impact on future yields. Our findings showed that in the future, a heat-tolerance trait will be crucial for southern and central Europe to achieve high yield potential. Higher and more consistent wheat yields could be developed by adjusting crop phenology to future weather patterns and prolonging the time of grain filling if heat stress tolerance is sufficient. Maintaining leaf green area until the conclusion of grain filling was also beneficial to wheat. Drought tolerance, which delayed leaf senescence, was also a desirable feature in water-scarce regions, particularly in southern Europe. To reduce the impact of heat stress during flowering and grain filling, the best anthesis date for heat stress ideotypes was pushed to the beginning of March, a month earlier than for heat tolerance ideotypes. As a result, grain yields for heat tolerance and heat tolerance ideotypes differed significantly, with heat tolerance ideotypes yielding 15.9 t ha–1 and heat stress ideotypes yielding only half that (7.3 t ha–1).

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