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Mini Review

The effects of heat stress on wheat and its vulnerability. A review

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Abstract

More than 80% of the world's population relies on wheat, a significant grain crop, as a source of essential protein and calories. Concerns about how rising temperatures could affect wheat output due to recent global climate change are spreading around the globe. Abiotic stressors such as heat and drought are what primarily restrict wheat productivity. Crop output is anticipated to directly be impacted by changes in the global climate. Abiotic stress, including drought and heat, is the principal factor limiting crop yield. The developmental stage of the plant is crucial in highlighting the susceptibility of distinct species and cultivars to high temperature. Heat stress limits wheat growth by interfering with several physiological and biochemical processes. In wheat, it was discovered that higher temperature stress reduced meristematic development, dehydrated by excessive transpiration, and leaf senescence, distorted photosynthetic activities, and increased the rate of respiration. Wheat is prone to responding to temperature stress and heat stock in a variety of ways, including by developing thermo-tolerance to enhance grain quality and production. With a thorough understanding of the morph physiological reactions of wheat to heat stress, we can develop the best tactics for increasing heat-stressed wheat production.

Keywords: Wheat, Oxidative stress, Heat stress, Heat shock protein

INTRODUCTION

Wheat (*Triticum spp.*) is major cereal crops belonging to the Poaceae family which is contributes about 30% of the total world grain production and 50% of the world grain trade also. (Akter & Rafiqul, 2017), This cereal fits in everywhere in our diet such as muffins, crackers, pasta, bread, biscuit, and many other baked items wheat play major role in our life.

In more than 40 countries of the world wheat is considered as staple food which provides basic calories and protein for 85% and 82% of the world population respectively (Sumesh et al., 2008).

Different physiological, biological and biochemical process in wheat is altered by high temperature. Because of heat stress in wheat causes poor seed germination, reduction in grain number, decrease in photosynthetic capacity, deactivation of Rubisco enzyme, decrease in grain filling duration, decrease chlorophyll content, reduction in rate of assimilate translocation, premature leaf senescence, and ultimately decrease in yield (Hossain et al., 2013; Din et al. 2010; El-Daim et al., 2014). ROS cause change in membrane stability along with protein oxidation, lipid peroxidation, and damage to nucleic acids (Mishra et al., 2011; Mittler et al., 2011; Kosova et al., 2011; Singh et al., 2011). Heat shock proteins (HSPs)that maintain correct protein folding, refolding, synthesis and degrade the protein aggregate(Sharma et al., 2019; Hasanuzzaman et al., 2013; Tripp et al., 2009; Raaijmakers et al., 2009; Shewry, 2009). According to FAO, the annual cereal production have to grow by almost one billion to feed the population of 9.1

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billion by 2050, increase in crop production and productivity is the demand of 21st century In order to meet the increase food requirement (Iqbal et al.,2017; Gairhe et al, 2017).

Wheat and the impact of heat stress

Due to HS, wheat experiences considerable yield loss at several growth and development stages. However, the effect of HS in plants relies on the length of heat exposure and growth stage during the high temperature (Ruelland et al. 2010). Wheat photosynthesis decreases due to heat stress-related poor germination, reduced leaf area, early leaf senescence, and impaired photosynthetic machinery. Wheat morphology, physiology, and biochemistry are altered by heat stress in specific ways.

Affects the morphology of wheat

The seed germination and plant establishment of many crops, including wheat, are significantly impacted by HS (Hossain et al. 2013). High temperatures (over 45°C) have a detrimental effect on embryonic cells, which is followed by faulty germination and emergence and poor crop stand (Essemine et al., 2010). The ability of the productive tiller to survive in high temperatures is impacted, which lowers productivity. According to Din et al. (2010), HS in wheat causes a drop in tiller number (15.38%) and grain yield (53.57%). According to Huang et al. (2012), HS reduces root growth, which has an impact on agricultural yield. During the reproductive phase, the impact of HS is extremely important (Nawaz, 2013). Higher loss in grain yield may result from an increase in average temperature of 1°C during the reproductive stage (Lu et al., 2014). Between 12°C and 22°C is the ideal temperature range for flowering and grain filling. When HS happen during meiosis, it damages the early stages of gametogenesis (Ji et al., 2010). At the period of floral initiation, HS negatively affects the development of microspore and pollen cells (Kaur et al. 2010). The rate and duration of grain filling, which are extremely sensitive to HS, determine how grains develop. Wheat's life cycle is shortened in HS compared to conditions of normal temperature. A temperature increase of 1°C to 2°C reduces seed weight by shortening the time grain fills up. Grain yield loss from short-term heat stress during grain filling may reach 23%. HS have an adverse effect on grain quantity and quality (Nain et al., 2010). Grain number decreases under HS conditions, which lowers the harvest index. Grain quality is decreased as a result of heat stress-related decreases in assimilates synthesis and remobilization. Due to the detrimental effects of high temperature on the growing process, wheat productivity is significantly decreased. A significant decrease in grain yield can occur when wheat is exposed to ambient temperature (>35°C) for a brief period of time.

Physiological impact on wheat

High temperatures have a significant impact on photosynthesis, the most crucial physiological function in plants. The wheat cell's stroma and thylakoid lamellae are the most vulnerable to heat stress. RuBisCO, Rubisco Activase, and Photosystem II alternate permanently at high temperatures (> 40°C) as a result, according to Matthew et al. (2011). Wheat exposed to HS conditions showed that the RuBisCO enzyme was inactivated in less than 7 days (Nain et al. 2010).

(i) Leaf ageing, photosynthesis, and photosystems

In terms of photosynthetic tissues, photosystem-I is more stable than photosystem-II, which is more sensitive to heat stress. Heat stress initially damages complicated photosystem-II phenomena and then alters photosynthetic behaviour. The inactivation of Rubisco activase and the suppression of carbon absorption. Protein synthesis is decreased as a result, and photosystem-II is unable to repair the damage (Murata et al., 2007). Photosynthesis is the most delicate physiological process that accounts for wheat's poor growth performance. According to O'Neill et al. (2014), this is due to reduced leaf expansion, a defective photosynthetic mechanism, premature leaf death, and ultimately decreased wheat yield. As carbon metabolism takes place there, stroma and thylakoid lamellae of chloroplasts are important locations for heat stress damage. It monitors enzyme-related activities and interferes with electron transporters, which reduces the rate of photosynthesis (Prasad et al, 2008). When wheat leaf is subjected to temperatures higher than 40 C, changes in Rubisco and Rubisco activase occur both in the dark and the light, and the changes in the dark are irreversible (Feller et al., 1998). Another inevitable result of heat stress is leaf senescence, which has symptoms like altered chloroplast structure, vacuole collapse, loss of integrated plasma membrane, and disruption of cell homeostasis. Wheat's flag leaf senescence is more noticeable when the daily temperature fluctuates widely (Khanna-Chopra, 2012).

(ii) Oxidative harm

Reactive oxygen species (ROS), which comprise oxygen (O_2), superoxide radicals (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH), are produced when plants are subjected to heat stress. The peroxidation of the membrane is gradually accelerated by the stress, which also causes the wheat plant to become less thermostable (Savicka & Kute, 2010). Wheat plants that are exposed to heat stress benefit from the antioxidants superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), and peroxidase (POX) (Caverzan et al., 2016).

Respiration

In contrast to heat-tolerant cultivars, heat-susceptible varieties of wheat have a higher rate of respiration when under heat stress (Almeselmani et al., 2012). Heat stress modifies mitochondria, which affects respiration. As the

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temperature rises, so does the rate of breathing, but after a certain point, the rate of breathing starts to slow down because the respiratory system has either failed or been destroyed (Prasad & Djanaguiraman, 2014; Li et al., 2014). Another reason for the increase in ROS is due to this. Heat stress also has an impact on the solubility of CO_2 and O_2 (Cossani & Reynolds, 2012).

Grain quantity, grain quality, and grain filling

When temperatures were 32/22°C during the day and 25/15°C at night, grain filling rates in wheat cultivars were lower (Hu et al., 2015). Heat stress lowers the grain quality of several cereals and legumes due to a restriction of assimilate and decreased remobilization of nutrients. Leaf nitrogen and grain protein levels were shown to be highly correlated (Iqbal et al., 2017). The wheat variety should be short-lived for late planting in order to avoid excessive temperatures during the grain filling stage (Menshawy et al., 2015). Both grain size and number as a function of growth stage are impacted by heat stress. When the temperature is above 20 C during the spike initiation and anthesis stages, the spike grows faster but produces fewer spikelets (Semenov & Halford, 2004).

(i) Synthesis of starch

Wheat contains between 60 and 75 percent starch by dry weight, however heat stress reduces starch production in the grain and increases the amount of total soluble sugar and protein instead (Sumesh et al., 2008; Ortiz et al., 2008). According to Lu et al. (2019), less starch accumulated in wheat as a result of the decrease in soluble starch synthase at a temperature of 40 C, which resulted in the loss of more than 97% of wheat products.

(ii) Product movement in the photosynthesis

For the purpose of seed development, the primary photosynthetic products translocated to each sink are sucrose and glutamine. Under heat stress, the source and sink limitations can prevent seeds from setting and grains from filling (Lipiec et al., 2013). Stem reserves are utilised as the carbon source required for grain filling when heat stress reduces photosynthetic rate (Mohammadi & Richon, 2009; Yang et al., 2009). Both symplastic and apoplastic pathways, through which translocation primarily occurs, are diminished at high temperatures. Wang et al. (2012) demonstrated that when high temperatures were produced in the pre-anthesis period, the translocation of carbohydrates from stem to grain increased, which led to less starch content drop in wheat grains when they were exposed to heat stress in the post-anthesis period.

Controlling heat stress Wheat plants have negative effects from heat stress on their growth and development. By using the right plant genotypes and a variety of agronomic techniques, these effects can be controlled. Utilizing what is known about how the wheat plant responds to heat stress, several efforts have been made to generate genotypes that are heat tolerant.

Genetic regulation

Breeding is a crop's adaptation to a changing environment (Akter & Islam, 2017). To categorise wheat genotypes resistant to heat stress, several investigations have been carried out recently (Nagar et al., 2015).

(i) Heat tolerance testing and breeding

Different physiological methods to breeding programs have been discovered to be effective in a number of developing nations. One strategy might be to test the genetic underpinnings of crops for heat resistance. A desirable plant shape can be generated by the physiological crossing of unique trait combinations to battle probable climates with high-temperature events (Reynolds & Langridge, 2016).

For wheat to improve heat tolerance, researchers have proposed certain indirect selection factors. Asthir (2015) emphasized the value of comprehending molecular pathways and defence mechanisms in breeding heat stress tolerance plants. The techniques described above will aid study on the genetic basis of plant thermo tolerance because heat tolerance is undoubtedly a polygenic characteristic. A specific transcription factor may be employed to assist crops in overcoming a variety of stressors, according to Wang et al. (2012).

(ii) Biotechnological strategy for enhancing heat tolerance

Recently, a number of transcription factors have been linked to diverse abiotic stress tolerance in plants (Wani, 2020). Stress tolerance has significantly increased as a result of the recent production of numerous plant genome sequences.

CONCLUSION

Global warming is expected to increase the amount of heat stress that wheat experiences. Heat stress affects the grain environment, length, intensity, quality, and yield. The degree, timing, and duration of heat stress all affect the genotype-specific effects of heat stress. Therefore, the development of heat-tolerant cultivars helps to mitigate the consequences of heat stress. Late wheat planting is the main cause of low grain production.

It's common to practice sowing wheat after paddy harvesting, delaying the necessary sowing window for wheat and increasing the temperature stress on the grain during filling. The outcome is a very poor yield of wheat. Future study is required on assimilate partitioning and phenotypic flexibility even though the physiological underpinnings of wheat heat tolerance are pretty well understood. It is generally known that integrating traditional and contemporary molecular genetics.

techniques along with agronomic management techniques can aid in resolving the complexity of the heat syndrome. There are a number of biochemical and molecular techniques that must be used, together with agronomic choices, to study the true impacts of heat stress on final crop output. Exogenous use of protectants has also demonstrated positive benefits on wheat heat tolerance development. Although further study is needed to define and enhance the parameters involved in effective microbial efficiency, applying microorganism to wheat plants looks to be a valuable tool in agriculture for decreasing the adverse impacts of heat stress.

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