Heat Stress: An Overview

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Abstract:

Heat stress is a major abiotic stress that slower down plant growth and development worldwide. Plant growth involves various metabolic reactions that are very sensitive to heat stress. Heat stress is now a major concern for world food production. Heat stress causes an array of physiological, morphological, biochemical and molecular changes in the plant which ultimately reduces the plant growth and ultimately grain yield. Plants exposed to high temperature adversely affects membrane component, water relation, respiration, photosynthesis and also affects the hormones level in plants. Heat stress enhances the expression of many heat stress associated proteins and production of reactive oxygen species.Plant Respond to such adverse effect through various ways which are interconnected which include the production of antioxidant enzymes, transcription factors, heat shock proteins etc. Though the biochemical and molecular level of information is quite known therefore further study should be focused onnutrient partitioning and morphological adaption.

Keywords: Heat stress; antioxidant enzymes; high temperature; heat shock proteins; transcription factor.

Introduction

Heat stress is defined as the increase in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant growth and development. In general, an increase in temperature, usually 10-15°C above normal is considered heat stress (Wahid *et al.*, 2007). In South East Asia heat stress is one of the major problems that is being faced by the most cereal crop grown in these regions. Heat stress causes the reduction in the economic value and yield of wheat as it damages the function of cell, tissue and whole plant".High-temperature stress causes modifications in the permeability of membrane, fluidity, stability, and loss of electrolyte subsequent from heat-induced cell membrane leakage, considered as a measure of stress-induced cellular damage (Wahid *et al.,* 2007). Burrell (2003), reported that some wheat varieties can lose 10-15% of yield with every 5ºC increase in temperature. In a study, Dupont *et al.*, (2006) found that heat stress reduces the period of grain development, they reported that heat stress shortened the period of grain filling stage, also reported that the kernel weight is reduced by 50%.Exposure to very high temperature, severe cellular injury or even cell death may take place in a very short span of time, which could be attributed to a catastrophic collapse of cellular organization (Schoffl *et al*., 1999). After long-term exposure to a

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moderately high-temperature injury or death may occur. The effect of direct exposure to high temperature is more fluidity of membrane lipid, denaturation of the protein. Protein degradation, inhibition of protein synthesis, chloroplastic enzyme inactivation, disruption of membrane integrity, these are the symptoms of indirect or slower heat injuries (Howarth *et al*., 2005).

The changes in temperature might induce cellular responses indicating that temperature is perceived and the temperature signal is transduced into the cell. While the signaling pathways triggered temperature changes, the way plants sense temperature is often considered as hard to pin down (Hemantaranjan *et al*., 2014). During pollination, a short period of heat stress has severe effects on pollen viability and fertilization process. It causes pseudo seed setting problem in wheat because of flower abortion; however, it varies with the species and cultivars (Young *et al*., 2004). Dysfunction of pollen and anther development because of heat stress is one of the critical factors responsible for the decrease in total yield. Plants are very temperature delicate and can sense variants of as little as one degree Celsius (Kumar *et al.,* 2012). A threshold temperature state to a value of everyday mean temperature at which a noticeable reduction in growth begins. For other plant species, the higher threshold temperature may be lower or higher than 35°C. Short-term exposure of plants to high temperatures during seed filling can quicken senescence, reduce seed set and seed weight and decrease yield (Siddique *et al.,* 1999).

The physio-chemical response of the plant to heat stress

Water is one of the significant constituents of life. The function of the metabolic processes and their rate in plants are mostly related to water content. Plant water status is one of the most crucial factors in altering ambient temperatures (Mazorra *et al*., 2002). Plants have a propensity to keep constant tissue water status irrespective of temperature when vapor is plenty; however, high temperatures harshly affects this propensity when water is limiting (Machado and Paulsen, 2001). Under field situations, high-temperature stress is often associated with reduced water accessibility (Simoes-Araujo *et al*., 2003). Under stress, wheat accumulates a variety of osmolytes such as sugars and sugar alcohol, proline etc. An increase in the lipid peroxidation, H_2O_2 production, and accumulation of proline was observed in response to differential heat shock treatment in wheat (Kumar *et al*., 2012). Proline synthesis may buffer cellular redox potential under heat and other environmental stresses (Wahid and Close, 2007). Under various abiotic stress production of H_2O_2 thought to be increased to enhance gene expression of active oxygen scavenging (AOS) enzymes. At high concentration, H_2O_2 is toxic to plant and may have an important role in signal transduction for abiotic stress tolerance. H_2O_2 was involved as an elicitor of several genes related to stress tolerance (Kumar *et al*., 2012). Increased accumulation of osmolytes might enhance the heat stress tolerance because osmolytes have the significant role in response to environmental stress. (Ashraf and Foolad, 2007)".

In the plant, photosynthesis is very sensitive physiological processes in response to heat stress (Crafts-Brandner and Salvucci, 2002). Photosynthetic efficiency of plants are affected by high temperature and has a greater

influence on especially of C3 plants than C4 plants. In chloroplast, carbon metabolism of the stroma and photochemical reactions in thylakoid lamellae are considered as the primary sites of injury at heat stress (Marchand *et al*., 2005). Thylakoid membrane is highly susceptible to heat stress. Heat stress causes changes in the structural organization of thylakoids, loss of grana stacking and swelling of grana under heat stress (Ashraf and Hafeez, 2004; Rodriguez *et al*., 2005). The photosystem II (PSII) is very sensitive to temperature fluctuation and are affected by a slight change in temperature (Bukhov *et al*., 1999). Water status of leaf, the conductance of stomata, CO_2 concentration are markedly affected by the heat stress. (Greer and Weedon, 2012). Stomatal closure under heat stress is another reason for impaired photosynthesis that affects the intercellular CO_2 (Ashraf and Hafeez, 2004).

High temperature leads to the synthesis of reactive oxygen species which degrades the photosynthetic apparatus and ultimately reduces the photosynthates produced (Guo *et al*., 2006). Other reasons believed to hamper photosynthesis under heat stress are the reduction of small-subunits of Rubisco, large-subunits of Rubisco, soluble proteins, Rubisco binding proteins, and in darkness, and increases of those in light (Sharma-Natu *et al*., 2007). In general, heat stress leads to decrease in photorespiration and decrease in the biochemical reaction, the activity of starch synthase, starch branching enzyme as well as phosphorylating enzymes changes which lead to change in the source to sink ratio and improper grain-filling (Chaitanya *et al*., 2001). Heat imposes negative impacts on the leaf of plants like reduced leaf water potential, reduced leaf area, and premature leaf senescence which have negative impacts on total photosynthesis performance of plant (Greer and Weedon, 2012; Young *et al*., 2004). Depletion of reserve food material and starvation of plant has also been reported under prolonged heat stress (Djanaguiraman *et al*., 2009). High temperature changes the structure of membrane protein which increases the permeability of membrane leads to the loss of electrolyte, as the integrity of membrane protein is very much delicate to high-temperature stress. Thylakoid membranes normally show swelling, increased leakiness, the physical parting of the chlorophyll light-harvesting complex II from the PSII core complex, and disruption of PSII-mediated electron transfer (Ristic *et al.,* 2008). Most of the heat sensing occurred through protein unfolding. Since, protein conformation changes with temperature, both temperature downshift and temperature upshift can lead to protein unfolding (Pastore *et al*., 2007). Yamada *et al.,* (2007) showed that heat-induced protein denaturation could participate in the activation of some heat stress transcription factors (HSFs).

In wheat, both grain weight and grain number appeared to be sensitive to heat stress, as the number of grains per ear at maturity declined with increasing temperature (Ferris *et al.,* 1998). Reduced number of tillers with promoted shoot elongation was observed in the wheat plant under heat stress. In wheat, green leaf area and productive tillers/plant were drastically reduced under heat stress (Djanaguiraman *et al*., 2009). Observation of changes in plant phenology in response to heat stress can reveal a better understanding of interactions between stress atmosphere and the plant. Different phonological stages differ in their sensitivity to high temperature; however, this depends on

species and genotype as there are great inter and intraspecific variations (2003; Howarth, 2005). At extreme heat stress plants can show programmed cell death in specific cells or tissues may occur within minutes or even seconds due to denaturation or aggregation of proteins, on the other hand moderately heat stress for extended period cause gradual death; both types of injuries or death can lead to the shedding of leaves, abortion of flower and fruit, or even death of the entire plant (Rodriguez *et al*., 2005).

The presence of heat-responsive proteins and the pattern of their expression have been reported to vary in different plant species. Genetic diversity for stress associated proteins under heat stress has been identified in cotton (*Gossypium hirsutum*), and reduced pollen viability under heat stress has been linked to carbohydrate metabolism in other cereals like sorghum (Jain *et al*., 2007). Studies in our laboratory revealed a many-fold increase in expression of low as well as high molecular weight HSP and genes of antioxidant enzymes in thermotolerant wheat cultivars at pollination stage under heat stress as compared to the thermosusceptible cultivars (Kumar *et al*., 2012). Membrane integrity, chlorophyll content, photochemical effectiveness and cellular oxidizing capability were inhibited by the increase in temperature, with greater impacts on the heat-sensitive genotypes.Heat stress has been found to induce the expression of a number of new genes and many stress associated proteins (SAPs) which play an important role during heat stress. These proteins provide the tolerance to the plant defense system by scavenging the free oxygen radicals produced due to oxidative burst or by protecting the important key metabolic enzymes from denaturation under elevated temperature. The abrupt variations in genotypic expression because of an increase in the expression of heat shock transcription factors, heat-shock proteins (HSPs) and alteration in cell signaling (Gupta *et al*., 2010; Kumar *et al.,* 2013).

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