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Effect of Drought and Heat Stress on Physiological and Biochemical Characteristics of Wheat

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Abstract

Wheat is the main crop containing basic calories and proteins. In tropics and subtropics, heat and drought are the major stresses related to environmental conditions that reduce the wheat production. In plants, heat as well as drought stress alters vital activities and generates reactive oxygen species that cause severe oxidative damage to plants. Plants have evolved various protective mechanisms including production of protective proteins to lessen the effect of heat stress. Heat and drought stress alter water relations, osmolyte contents, soluble proteins and sugars. Turgor pressure, ascorbate peroxidase (APX) and peroxidase (POD) are lowest in heat stress. Combined effect of drought and heat stress is more damaging than individual stress on wheat plant.

Keywords: wheat, heat stress, heat shock proteins, oxidative damage

Introduction

Wheat (*Triticum aestivum* L.) is a staple crop that accounts for 20% of the calories intake and proteins consumption in the human diet. Wheat is rich in carbohydrates, proteins, essential vitamins and minerals such as vitamin B & E, calcium and iron, and fiber **(Poudel *et al.*, 2020).** It is world's most cultured crop evolved from wild grasses. The center of origin of wheat is South Asia. Production of wheat at world level is about 757.6 million tonnes while annual intake of crop in various form is 734 million tonnes **(Peter, 2015).**

Heat stress, drought, high salt concentration, cold, chemical and water excess affect the wheat production worldwide however major stresses are high temperature and water scarcity. The mean environmental temperature is expected to rise by 6°C by the end of current century **(Ali, 2019).** Researchers predicted 5.5% reduction in global wheat production amount due to harsh environmental conditions. Drought and heat both stresses reduce photosynthetic efficiency, stomatal conductance, leaf area and water-use efficiency of wheat and other cereals **(Zhang *et al.*, 2010).**

Impact of Heat Stress on Wheat

Heat stress effects the wheat plant throughout all developmental age and growth conditions and results in severe reduction in average production to high

yield loss. Rise in temperature and adverse alteration in climate are drastically disturbing plant growth. For each degree increment in the earth's temperature, overall yield of wheat is projected to decline more than 5%. Heat stress mostly causes reduction in average leaf area, lowering germination percentage, early leaf falling and injury of photosynthetic apparatus of plant ultimately loss of photosynthesis in wheat. It also leads to change in morphology, physiology, and biochemistry of the wheat plant (**Habash, *et al.*, 2009).**

High temperature has bad impact on wheat embryonic cells this leads to poor germination of seed and emergence which leads to low germination percentage and poor crop stand. Grain rate decreases by heat stress is 53.7% while tiller rate is 15.38% thus effecting germination and root growth that causes lower production **(Brunel-Muguet *et al.*, 2015)**. Wheat grain yield decreased with every one degree Celsius raise in temperature during reproductive stage, while a suitable temperature for wheat flowering and grain filling is 12-22 degree Celsius. Early stage of gametogenesis is badly affected by increase in external environmental during Meiosis **(Islam, 2019)**.

Heat stress also effects the life cycle of wheat plant as well. Every raise in 1-2 degree raise in temperature lowers the seed weight due reason that there is shortening in length of life cycle of wheat and duration of grain maturation **(Narayanan *et al.*, 2016).** This can result in grain yield loss by 23% due to high temperature stress. Harvest index also affected by heat stress due to reduction in grain numbers. It is also associated with decrease in remobilization of nutrients and assimilates production that also results in loss of grain quality. An ambient temperature >35°C causes reduction in production of wheat **(Akhter, 2017).**

Effect on Heat Physiology

The most important physiological process of plants is photosynthesis that directly influenced by raise in temperature. Because Stromal and thylakoid lamella are very heat sensitive. Higher temperature up to ~ 40°C caused permanent alternation of RuBisco this activates photosystem II. Heat stress condition cause deactivation of RuBisco enzymes in less than 7 days. This also caused membrane deterioration that leads in the reduction of photosynthetic capacity. Heat stress affects photo system II by causing alteration in membrane fluidity of thylakoid and deactivation of photosystem II of light harvesting complex during photosynthic process **(Sattar *et al.*, 2020)**.

Because photosystem product is necessary for the development of plant growth, higher temperature caused deceased in membrane stability that reduces the process of translocation of product from source to sink. The translocation of water-soluble carbohydrates from source to sink are necessary for grain growth and development **(Akhter and Islam 2017).**

Remobilization of various nutrients from stem to developing wheat grain before pre-anthesis heat stress is also essential. It helps to improve the effect on grain starch content in post-anthesis. Solubility of various atmospheric gases such Oxygen and Carbon dioxide also observed during heat stress condition causing increase rate of photorespiration in expanded leaf wheat (**Liu, *et al*., 2020).**

Plant Leaf Senescence

Aging process in plants is actually named as plant leaf senescence. This process occurs due to ovacular collapse,

membrane integrity loss and due to homeostatic disturbance in cells of plant leaves and these are specific characteristics of leaf senescence. Gradual senescence occurs when there is long period heat stress. But when the heat stress is applied for transient time period, it results in denaturation of protein and the process of aggregation starts which ultimately results plant's death. **Wahid *et al.*, 2007.**

Dehydration occurs due to increase in osmotic potential reduction which in turn develops by heat stress conditions. Canopy temperature affects the transpiration rate, conductance of stomata and relative content of water. Photosynthetic activity is measured by association of chlorophyll florescence which can use to determine normal growth of wheat plant. With the help of canopy temperature and the chlorophyll florescence we can find out the genotype of plant which can be heat tolerant. During the conditions of drought, canopy temperature helps in the growth of deeper roots **(Zwack, 2013).**

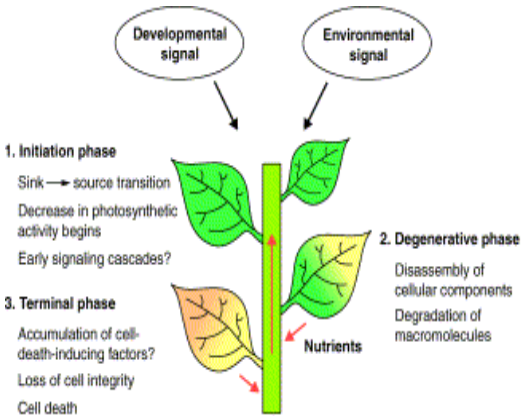

Fig 1: Interplay of Signals with Plant Developmental Phases

Effect on Biochemistry

Starch is one of the crucial nutrient of wheat endosperm which is composed of two specific forms namely; amylase and amylopectin. By amylase content and wheat grain we can estimate the quality of starch in wheat. By rise in the temperature, amylase content as well as amylopectin to amylase ratio can be altered in wheat grains **(Schmidt *et al.*, 2020)**. For starch synthesis in plants, two vital enzymes are required, one of them is ADP glucose phosphorylase and other is starch synthase. By the inactivation of these two enzymes due to high temperature, content of total endosperm starch declines to about 1/3rd. At temperature nearly about 40^{o} C, grain size is also low due to this high temperature and decline in production of starch and other proteins. On the other hand, wheat grain quality is dependent upon the composition and content of protein **(Zi et al., 2013).**

Heat Tolerance Mechanism in Plants

There are different ways used by plants to protect them from drastic environmental conditions like high temperature and water deficiency. Different mechanisms like tolerance, avoidance allow plants to grow and survive under these conditions (Fig. 2). At high temperature, enzyme such as starch synthase lower its activity that is responsible for the reduction in wheat grain size. Protein content and composition is major factors on which quality of wheat depends **(Baita, 2013).**

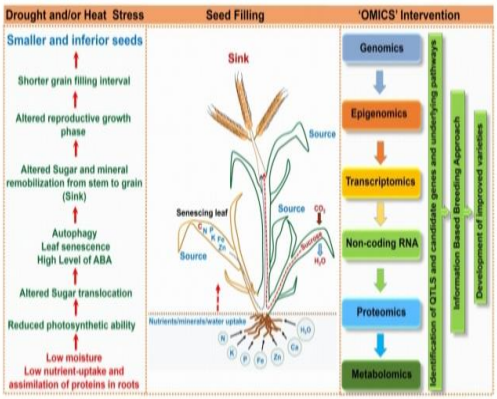

Fig 2: Effect of heat and drought stress on wheat plant and omics interventions

Heat Shock Protein

Protein function is dependent on three major factors like composition, its folding and synthesis. But protein function is disturbed by high temperature and this results in the production of stressing agents in plants. To counter all these effects plants synthesize a protein called heat shock protein that plays role in plants protection. Depending on different factors like composition, homology, function, encoding similarities etc. proteins are of different types **(Haq *et al*., 2021).**

Reactive Oxygen Species and Scavenging Defense Mechanism

Reactive Oxygen species are produced by only due to heat stress. In normal situation the rate of production of scavenging enzymes and ROS is balanced and equal but when production rate is high it may cause life threatening condition for plants and this stress is called Oxidative stress. A variety of enzymatic and non-enzymatic scavenger are involved in plant defense including catalases, peroxidases, glutathione peroxidase and tocopherols (Table 1). These scavenging agents protect cell by preventing lipid peroxidation of lipid membranes**. Luo *et al*., 2008.**

Table 1: List of Enzymatic and Non-Enzymatic Scavengers in Plant Defense

Antioxidants	Functions
Enzymatic oxidants	
CAT	Convert H2O into water and oxygen without using any reducing power.
SOD	Catalyze dis-mutation of O2 to H2O2 and O2
GPX	Catalyze the removal of H2O2.
APX	Scavenging H2O2 by oxidizing ascorbate.
Non-enzymatic antioxidants	
Tocopherol	Scavenging H2O2: up regulation of APX and GR
Ascorbic acid	Donate electron in various enzymatic and non-enzymatic reaction
Carotenoids	Inhibit singlet oxygen formation
glutathione	Scavengers of singlet oxygen, hydrogen peroxide and hydroxyl radical

Stay Green (SG)

The genotype that is related to stay green has high rate of photosynthesis and heat stress tolerance through the late expression of drought related genes. It is crucial adaptation related to high temperature tolerance in wheat as it protects plant photosynthetic area and enhances rate of nitrogen translocation to the grains of wheat that are going to fully mature before crop harvest (**Abdelrahman *et al*., 2017).**

During growing phases of female reproductive organs in plants, amount of starch in the ovary declines abruptly but under high temperature shock, the sugar level is depleted in the leaves due to less photosynthetic activity which may cause seed early death. Increased photosynthetic rate as a result of SG, helps to maintain regular sugars and other solutes supply in

maturing anther and pollen thus helps to retain viability of male reproductive organs **(Kamal *et al.*, 2019).**

Previously few studies was conducted to relate canopy temperature depression (CTD) with SG traits. It was noted that relative elevated value of CTD in SG genotypes under condition of high temperature and concluded that SG is highly associated with CTD. Therefore, under high temperature condition, SG genotype can be taken as selection criteria for best wheat genotypes **(Pinto *et al.*, 2016).**

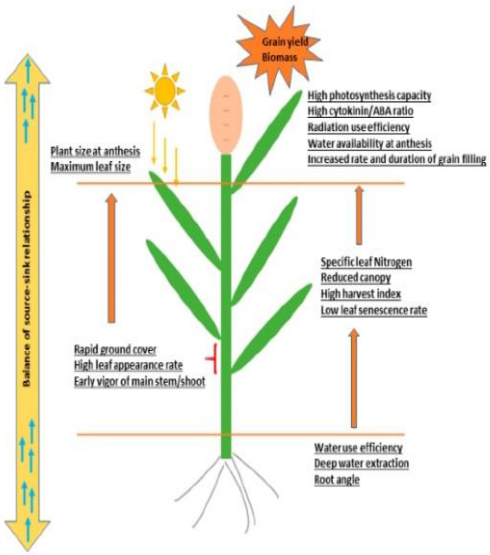

Fig 3: Balance of Source and Sink Tissues in Plants

Conclusion

Wheat has wide range of capability to survive for keep growing and developing under high temperature, drought and other stress conditions. Both high temperature as well as high temperature effects drastically the growth and yield of wheat plant. Heat stress mostly affects the activities of scavengers like peroxidases and ascorbate peroxidases. Frequency of heat stress is increasing worldwide, regarded as global warming. Grain yield, duration, quality, grain setting, time of these are affected specifically by HS. This affect is because of genotype and also it depends on intensity, duration and timing of HS and drought. That's why tolerant varieties are developed which helps in reducing the consequences of HS.

Different metabolites like antioxidants from different plants are produced under stressful environmental conditions. Those metabolites plays an awful crucial role so different mechanisms can be known underlying stress tolerance. So under various stress conditions we are able to measure the range of wheat seed. Grain yield can also be improved by detecting genetic differences. Additionally, morphology of wheat may also be verified under different stress conditions.

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