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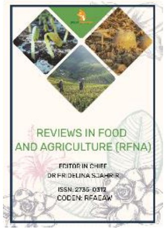

REVIEW ARTICLE

PHYSIOLOGICAL, MORPHOLOGICAL & BIOCHEMICAL RESPONSE OF WHEAT (*TRITICUM AESTIVUM*) AGAINST HEAT & DROUGHT STRESS AND THE TOLERANCE MECHANISM - A REVIEW

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ABSTRACT

Wheat is a mainstay of Nepalese cuisine, and it is the third most important cereal crop cultivated throughout the nation all through the winter months. The impact of abiotic stress on wheat, such as heat and drought, is discussed in this review article. Drought and heat stress influence biochemical, physiological, and morphological processes in plants, causing a significant reduction in yield and yield attributing characteristics. Drought at CRI reduces yield by 60%, while Heat stress causes about 16 yield loss depending on the severity of the environment. Understanding the physiological and biochemical responses of crops to any unfavorable circumstance is essential for developing mechanisms and techniques for plant tolerance. Drought tolerance is managed by drought escape, drought avoidance and drought traits. Heat stress is also endured by the plant's anti-oxidative defense mechanism and the synthesis of heat shock proteins (HSPs).

KEYWORDS

Drought stress, Heat Stress, Tolerance, ROS, Heat shock protein (HSPs)

1. INTRODUCTION

Wheat is the most favored staple food of the world which can be processed into various products. It is easy to store, transport and furthermore is highly nutritious. Wheat crops are highly nutritious to human health. It contains about 53-74% carbohydrate, and protein 11-20%, wheat also contains fats, fiber, vitamins like Vitamin B, calcium, iron and macro and micronutrients (Ahmed et al., 2017). Wheat anthesis and grain filling is best in temperature range 12 to 22C. When the temperature alleviates above 24C during the reproductive stage, the grain yield is reduced remarkably (Bhandari et al., 2021). Among all grains (including rice and maize), wheat has the biggest total harvested area (38.8%), but the lowest overall production. The majority of losses in wheat production are caused by a variety of elements, including biotic and abiotic stressors. Low or high temperatures, insufficient or excessive water supply, high salt, heavy metals, and ultraviolet radiation are all abiotic stresses that are harmful to wheat. They pose a serious threat to agriculture and the environment and significantly reduce crop yields (Dhakal et al., 2021).

Wheat is the 3rd most important cereal crop of Nepal, whereas 1st in the world (MOALD, 2020; Subedi et al., 2019). The Terai region, which accounts for 57.8 percent of total agricultural area, produces around 65.2 % of the wheat of Nepal. Being the most important and one of the prioritized cereal crops of Nepal. It suffers annually from a series of drought and terminal heat stress in most of the wheat growing sites of Nepal. Of the total area only 66.21 % of the area is irrigated, the rest being fully dependent upon irrigation (MOALD, 2017; Akter and Rafiqul, 2017). In 2020-21 the wheat production volume was more than 768.9 million metric tonnes in the world, whereas 2210 tonnes in 2020 in Nepal (Anjana et al., 2021; Dhakal et al., 2021). It is grown on 703992 hectares, with a national average yield of 2.84 t/ha (MOALD, 2020). Even Though improved varieties cover 95.8% of the entire wheat acreage in Nepal, Nepal is having poor wheat production (Bhandari et al., 2021). The major reason being rainfed & delayed transplanting of rice that shifts wheat to heat stress in March & April (Poudel et al., 2021). Along with other abiotic stresses, heat and drought stress affects the wheat production abundantly. It is believed that global wheat production is decreased by 6% with every 1°C increase in temperature (Poudel et al., 2021). Drought conditions affect all stages of the plant growth but drought during the critical stage of growth decreases the grain yield dramatically and during the reproductive stage by 70%-80% (Gaikwad et al., 2020; Asseng et al., 2015; Lobell et al., 2012). Climate change and rise in the temperature would definitely have a great impact on the global wheat production. The Grain Yield of wheat was predicted to aggravate in future due to high temperature ambient heat radiation.

Production of wheat is drastically influenced by abiotic stresses in arid and semi-arid regions (Chen et al., 2012; Hristov et al., 2010). Drought is a water shortage state that reduces crop yield by causing significant changes in the morphological, biochemical, physiological, and molecular aspects of plants (Bhandari et al., 2021). Wheat grain size decreases due to heat and drought stress, which also lowers output overall (Ahmed et al., 2017). Grain quality is decreased by heat stress due to a decrease in assimilate production and remobilization. Due to the negative impact of high temperature on the growing process, wheat productivity is significantly decreased. A considerable reduction in grain yield can occur when wheat is exposed to ambient temperatures above 35 C for a brief length of time (Poudel et al., 2021). Heat stress firstly damages the complex phenomena of photosystem II and secondly changes the photosynthetic behavior. Wheat under stress from heat and dryness, producing ROS (reactive oxygen species).

The antioxidants defense, Heat shocks protein, Stay- green and leaf area

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index are the tolerance mechanisms of wheat against abiotic stresses like drought and heat stress. A plant under heat stress environment produces antioxidant defense mechanisms obtained through different enzymatic and non-enzymatic antioxidants by detoxification of excess ROS to tolerate these stresses (Bhardwaj et al., 2017). Heat tolerance is characterized as the ability of plants to endure, develop and produce economic yield under HS. Antioxidant defense, generation of Heat Shock Proteins (HSPs) and staying green are significant heat tolerance mechanisms in wheat (Poudel et al., 2021). HSPs60 for protein stability, HSPSs90 for HS-related signal transduction, and tiny HSPs that aid in refolding denatured proteins to stop heat aggregation (Anita et al., 2021). There is a great role of wheat in the nutritional security of Nepal but improper irrigation facilities along with delayed sowing of wheat bring a complex equation leading toward poor production of wheat (Bhandari et al., 2021).

2. Methodology

This review article draws on a variety of secondary sources, including research and review articles that have been approved by reputable journals. It focuses on a study and review that were carried out in Nepal.

3. Result and Discussion

3.1 Drought Stress and Heat Stress Effects

Drought and heat stress cause the development of reactive oxygen species (ROS), an increase in proline, a decrease in photochemical efficiency, hormonal changes, a decrease in starch deposition, and an increase in soluble protein content in wheat (Aroca et al., 2012). A group researchers reported that the combined effect of both heat stress and drought stress is hypo additive in nature (Dias et al., 2008). Wheat grain size is reduced as a result of heat and drought stress, and total productivity is reduced. Moreover, water scarcity and sub optimal temperature at any growth stage of wheat evoke negative effects on wheat growth and development. Such a detrimental effect on wheat depends on the magnitude of stress and its period and growth stage. Such effects are explained in terms of morphological, physiological, biochemical and molecular processes in wheat crops (Bahadur, 2020).

3.1.1 Effect of Drought in Wheat

3.1.1.1 Biochemical Effects

3.1.1.1.1 Starch Content

Starch is the reserved carbohydrate in plants and a mixture of two polysaccharide (Regmi et al., 2001). On a dry weight basis, wheat grain contains approximately 60 to 75 percent starch (Dipendra et al., 2013). Heat and drought stress affects the starch content in wheat grain (Poudel et al., 2021). The decreased level of non-structural carbohydrate (glucose, starch) changes the proportion of soluble sugars (Fahad et al., 2017). Due to heat stress in wheat, the level of fructose, hexose phosphate also declined (Hamal et al., 2020). Decreasing starch content is due to decreasing efficiency of enzymes that involves in starch biosynthesis (Poudel et al., 2017).

3.1.1.1.2 Production of ROS

ROS (reactive oxygen species) are produced due to heat and drought stress in wheat (Kaur, 2020). The reactive oxygen species bring change in membrane stability. It can cause damage to the cell components and cell death. Lipid peroxidation, oxidation of protein and nucleic acid damage can occur by ROS (Poudel et al., 2017; Poudel et al., 2021). In Drought Reactive oxygen species (ROS) eg, singlet oxygen ($^1O_2$), hydrogen peroxide (H_2O_2), superoxide radicals (O_2) & (-OH) radical forms that oxidizes the photosynthetic pigments, proteins, nucleic acids & membrane lipids by altering cellular redox potential of cell causing reduction in growth & productivity of Wheat (Bhandari et al., 2021).

3.1.1.1.3 Proline Content

Proline is the amino acid that plays a vital role in the mechanism of plants. It responds to various environmental stresses such as heat stress, drought stress (Li and Liu, 2016). It includes destruction of free radicals, stabilization of sub cellular structures, osmotic adjustments, redox potential buffering in the cell (Koirala, 2019). The stability of protein and membrane is enhanced by proline under heat or drought stress (Nazim et al., 2018). Drought and heat stress increase proline levels by 53 percent and 58.9%, respectively, according to (Sattar et al., 2020). Accumulation of certain amino acids like glutamine, ornithine, valine tryptophan and tyrosine, purslane plants in response to combined drought and heat stress (Sattar et al., 2020).

3.1.1.1.4 Catalytic Activity

Found that the production of catalase, hydrogen peroxide (H_2O_2), superoxide dismutase, and ascorbate peroxidase increase in response to drought or heat stress alone or in combination with both (Sehgal et al., 2018). According to Ashir and Bhatia, such stress causes an increase in total soluble protein in wheat. Due to heat and drought stress, total soluble protein content increased by 62% and 61%, respectively (Sattar et al., 2020).

3.1.2 Morphological Effects

3.1.2.1 Germination & Growth

Both chilling stress and drought stress results in disturbance of osmotic balance, impaired metabolic activity at cellular level and it also leads to alterations in DNA, RNA and protein structure membranes that cause reduced respiration and less ATP production ultimately causing loss in seed germination and vigor (Suman, 2021; Hussain et al., 2018). Simultaneous heat and drought stress initiate various processes like a decreased rate of photosynthates coupled with abnormal respiration. Closed stomata and high leaf temperature which leads to reduced plant and decrease the yield residue (Van der Weijde et al., 2017). Drought and chilling temperature impair mitosis, cell elongation and result in poor growth of the plants (Hussain et al., 2018). Plant height, leaf size and yield production are significantly reduced under the water limiting conditions and at chilling temperature. Overall root water uptake under drought condition depends on soil, soil root air gaps and limits overall root water uptake in the initial phases of drought and chilling period and soil conductivity and lack of contact between soil are limiting to water movement when drought becomes pronounced as a result proper growth is not developed.

3.1.2.2 Leaf Area Index

It helps in the leaching of the grain yield in drought conditions on the basis of a reflected water retention mechanism. Leaf rolling or decreased in exposed leaf surface area which helps in the leaf water retention (Bhandari et al., 2021). The management of Osmo protectants i.e. proline, glycine, betaine which help in drought tolerance conditions by providing energy (Rashid et al., 2021). The drought conditions are managed by drought escape that means change their life cycle and drought avoidance that means by increasing the number of the water saver or water spenders on the basis of minimization of water loss. It helps to adjust in water scarce environment and drought tolerance varieties or traits which is helped by increasing water use efficiency. Early maturing landraces are especially good for drought stress because they may avoid severe drought throughout their reproductive phases (Ghimire et al., 2017).

3.1.2.3 Yield and Yield Related Attributes

The impact of future drought episodes on wheat is expected to increase due to effects of drought and heat stress. It is estimated that the 1 degree increase in temperature that has occurred during the last 29 years resulted in a 6% reduction of wheat yield compared with the expected yield without global warming effects (Ojha and Ojha 2020). The wheat production in Nepal has a positive response to the precipitation however an increase in temperature and drought conditions controls the production level. Moreover, agriculture contributes about 27% of National gross domestic product GDP being a very crucial sector in the overall economy of Nepal. Agriculture in Nepal is suffering from lots of natural hazards including drought, flood, soil erosion and landslides which ultimately reduce the yield of wheat (Poudel et al., 2021).

3.1.3 Physiological Effects

3.1.3.1 Decrease the Photosynthesis Process

It is reported that the combined heat and drought stress reduce chlorophyll content in the leaf by 49% while the drought stress alone reduce by 9%. The loss of chlorophyll content can be considered as a major factor responsible in wheat and is determined by the intensity, duration and rate of the stress. The main physiological effect of the drought is that it limits the photosynthesis through the closing of stomata which decreases the uptake of carbon dioxide by leaves and prevent the transpiration loss of carbon dioxide in the leaf turgor and water potential.

3.1.3.2 Change in the Cell Wall Structure and Composition

Longer exposure to heat and drought stress challenges the plant to modify their cell wall to sustain growth under conditions with reduced water potential. Although the cell wall is clearly affected by drought stress surprisingly little is known about drought induced changes in cell wall composition. One of the consequences of drought is a loss of cell turgor.

3.2 Effect of Heat stress in Wheat

Wheat, when sown in late condition, suffers from extreme heat & hot wind of spring in March-April, that causes significant reduction in yield & yield attributing traits of wheat genotypes. The Effects of heat stress in wheat are discussed in following headings.

3.2.1 Biochemical Effects

Amylose and amylopectin make up the majority of the ingredients in wheat, which is starch. Because the enzymes involved in starch manufacture are less effective at high temperatures, the amount of starch in grains can drop by up to one-third of the total amount of endosperm starch. Up to 30°C, Soluble Starch Synthase activity is reduced but does not influence starch deposition; however, it does change the nature of the starch. Protein composition and content significantly influence wheat grain quality (Poudel et al., 2021).

3.2.2 Morphological Effects

Heat stress negatively influences the seed germination and plant establishment. High temperature 45 C has a negative impact on embryonic cells, followed by improper germination and emergence which leads to poor crop stand. The increase in average temperature by 1C during the reproductive stage may lead to high loss in grain yield. Heat stress associated with decrease in assimilate production and remobilization result in reduced grain quality. Wheat productivity is reduced remarkably due to the harmful effect of high temperature in the growth process. When wheat is subjected to ambient temperature greater than 35 C for a short period of time it can result in significant loss in grain yield (Poudel et al., 2021).

3.2.3 Grain Growth and Development

The rate of grain filling in wheat cultivars was reduced at day/night temperature of 32/33C as compared to that of 25/15C. Because of limitation of assimilates and less mobilization of nutrients heat stress affects grain quality of many cereals and legumes. Heat stress influences the size of grains as well as their numbers as per growth stages (Bhandari et al., 2021). In between spike initiation and anthesis stage if temperature is above 20C growth of spike is seen more but the number of spikelets will be reduced. More than 97% wheat products were lost due to decrease in soluble starch synthase at temperature 40C which caused less starch accumulation in wheat. At high temperature both symplastic as well as apoplastic pathways are reduced through which translocation mainly occurs. Wang et al 2019 showed that the carbohydrate translocations from stem to grain increased when high temperature was induced in the parenthesis period which resulted in less decline in starch content in wheat grains when they face heat stress at the post anthesis period.

3.2.4 Physiological Effect

High temperature seems to cause dehydration in plant tissue and subsequently restricts growth and development of plants. During flowering, a temperature 31C is generally considered as the upper limit if maintaining water status of crops. Heat stress also increases hydraulic conductivity of all membranes as well as plant tissue primarily for increased aquaporin activity and to a greater extent for reduced water viscosity. A major effect of heat stress in reduction in photosynthesis resulting from decreased leaf area expansion impaired photosynthetic machinery, premature leaf senescence and associated reduction in wheat production (Bhandari et al., 2021). Heat stress firstly damages the complex phenomena of photosystem II and secondly changes the photosynthetic behavior. The stress causes suppression of carbon assimilation due to inactivation of rubisco activate in wheat. The reduction of carbon assimilation reduces RDS generation which in turn reduces protein synthesis and inhibits repairing of damaged photosystem II. At high temperature the key regulatory enzyme of Rubisco i.e Rubisco activate is reported to be dissociated causing a reduction in the photosynthetic capacity of leaf in wheat (Poudel et al., 2021). Wheat plants exposed to heat stress during maturity enhanced leaf senescence, accentuated the loss of chloroplast integrity and accelerated the turndown of photosystem II, mediated electron transport.

4. Stress Tolerance Mechanism in Wheat

4.1 Drought Stress Tolerance Mechanism

Drought is due to the deficit of water which is a major problem in agricultural crops that are grown in tropical and subtropical areas. In wheat, there is more loss which effect by altering the physiological, biochemical, morphological, molecular responses traits of Wheat genotypes. 27.5% decrease in the mean yield under drought conditions whereas 34.4% reduction in the Wheat biomass at the tillering stage (Bhandari et al., 2021). The changes in morphological, biochemical, physiological, and molecular properties of the plant during changes in different stages due to shortage of water in drought stress conditions (Dhakal et al., 2021). During physiological changes: - Yield loss, Diminished growth rate, Changes in cell wall integrity, Leaf water potential reduction, Reduction in the rate of photosynthesis, Reduced chlorophyll content. Biochemical changes: - Antioxidant properties, Proline content. Morphological changes: - Small plant size, Reduced leaf area, Leaf Senescence, Change in root system.

The important part in the drought tolerance is antioxidant defense system and lipid peroxidation (Rashid et al., 2021). It's a biochemical change where reactive oxygen species (ROS) increase and proline also increases. Epicuticular wax coating on leaves, leaf rolling and inducing water rolling mechanism helps in the adaptation of the plant under drought stress conditions (Bhandari et al., 2021). In wheat, the drought tolerance traits are water use, water use efficiency, biomass yield and flag leaf water content (Water Use Efficiency = Biomass production /Water use). The elite line NL1420 is the most accessible line followed by BL4407 according to which-won-where model but line NL1412 is most suitable according to AMMI model in drought stress conditions. The drought tolerance traits produced by Genomic DNA Extraction, SSR marker (including 8 drought tolerance), PCR, Electrophoresis and scoring (Poudel et al., 2017).

4.2 Heat Stress Tolerance Mechanism

Plants have a diverse variation system to adjust under HS. Avoidance, escape and tolerance are fundamental three systems that permit plants to endure and fill in high temperature climates. Heat tolerance is characterized as the ability of plants to endure, develop and produce economic yield under HS. Antioxidant defense, generation of Heat Shock Proteins (HSPs) and staying green are significant heat tolerance mechanisms in wheat (Poudel et al., 2021).

4.2.1 Antioxidant Defense

Heat stress instigate the generation of reactive oxygen species (ROS) like superoxide radicals, hydrogen peroxide, hydroxyl radical, etc. which in extreme production causes state of oxidative stress leading to a decrease in membrane flexibility, stability and permeability and the inhibition of protein membrane polymerization (Bhardwaj et al., 2017). So, to relieve the toxic effects of ROS caused by stresses, plants developed antioxidant defense mechanisms obtained through different enzymatic and non-enzymatic antioxidants by detoxification of excess (Wu et al., 2020). So, this antioxidants defense mechanism contains ROS-scavenging compounds, like catalase (CAT), superoxide dismutase (SOD), peroxidase (POD), glutathione reductase (GR) and ascorbate peroxidase (APX), and non-enzymatic antioxidants, like carotenoids, glutathione (GSH) and ascorbate (AsA) (Buttar et al., 2020). These enzymes have different roles likewise, the production of definite enzymes depends upon the environment stress so, during HS it is reported that the activity of SOD, CAT, POX increases (Poudel et al., 2021). Observing the roles in wheat during HS, SOD catalyzes the dismutation of O2 to H2O2. GPX for scavenging of H2O2 to control stress response, CAT to convert H2O2 into water and oxygen without using any reducing power. ROS are well perceived for assuming a double part both as beneficial well as deleterious, depending on their concentration. The role of ROS as signaling molecules involved in growth, cell cycle, development, senescence, stomatal conductance, hormonal signaling, and regulation of gene expression has been broadly investigated. Accordingly, ROS ought not be dispensed completely and ought to be kept up within a level to keep away from oxidative injury (Caverzan et al., 2016).

4.2.2 Heat Shock Proteins (HSPS)

HSPSs are crucial for development and responses to diverse stresses and are also known as molecular chaperones. Heat shock proteins assume a significant part in protein homeostasis and cell survival against a variety of environmental and metabolic stresses. They can be found in all major cell compartments and these proteins direct changes in the protein course of action through films during transport. They direct adaptation - plan of proteins at the slight harm (Ni et al., 2018). Based on their atomic weight, amino acid sequence homologies and functions, HSPs have been grouped into a few significant families: Hsps100, Hsp90, Hsp70, Hsp40, Hsp60 and the little HSPs (Guo et al., 2021). So here the functions of each HSPs are different under heat stresses; HSPs100 –for protein accumulation and misfolding, HSPs70 prevents aggregation of proteins and helping again in folding of proteins, HSPSs90 helps in intervention HS related sign transduction, HSPs60 for protein stability and small HSPs- it prevents thermal aggregation by helping in refolding of denatured proteins. The relationship between these HSP variations and these characteristics may give new knowledge to HSPs likely commitment to thermo-tolerance which can be utilized for development of thermal resistance in wheat through marker helped determination (Sharma et al., 2015).

4.2.3 Stay- green (sg)

Under HS in wheat, delay in the expression of leaf senescence is shown which leads genes to permit stay-green (SG) genotypes to maintain photosynthesis and SG is recognized as an adaptive physiological trait under stress conditions (Cossani and Reynolds, 2012). The role of staying green has been introduced in promoting tolerance to heat and drought stresses. The usefulness of SG trait in the genotypes of heat tolerant wheat varieties is to maintain the green coloration even under high temperature (>30 degree Celsius) and significantly enhance the radiation use efficiency. It provides economically additional yield (up to 20%) to the crops.

5. Conclusion

The primary Abiotic stressors impacting crop yields are heat and drought, which degrade the biochemical and physiological processes of wheat. Wheat being the number crop of the world and the 3rd most importance cereal crop of Nepal, small reduction in yield percentage will have greater impact on society and nutrient supplement to the people all around the world. Heat stress and drought both are major Abiotic stresses causing a significant yield reduction in tropical and sub-tropical climate of poorly irrigated environment. Plants generate Heat shock protein and have anti-oxidative defense mechanisms to counteract these dire effects. Stressed wheat caused by high temperatures is expected to become more common around the world. Heat stress has a serious influence on grain setting, duration, and rate, as well as grain yield. Regardless, the impact of heat stress on grain yield is determined by the timing, duration, and intensity of the stress. Heat stress can be mitigated through the development of tolerant genotypes and agronomic strategies. Despite the fact that the physiological mechanisms of heat tolerance in wheat are relatively well understood, future research into assimilate partitioning and phenotypic flexibility is required.

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