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Effect of Heat Stress in Wheat: A Review

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This is a review on the effects of heat stress in wheat crop. Wheat is a large cereals crop used to meet the rising calorie needs of the world's population. Changes in the global climate are projected to have direct effect on crop production. The main stresses restricting crop production are abiotic stress such as heat and drought. Heat stress inhibits wheat growth by disrupting various physiological and biochemical processes, and the developmental stage of the plant is important in demonstrating the vulnerability of different species and cultivars to high temperature. The heat stress is found to obstruct germination of seed, which obviously cause decline in yield. Higher temperature stress was found to reduce meristematic growth, dehydration with excessive transpiration and leaf senescence, distorting photosynthetic activities and increasing the rate of respiration, in wheat. Wheat has a propensity to react to temperature stress and heat stock in a number of ways, including developing thermo-tolerance to improve grain quality and yield. We can formulate the appropriate strategies for heat stressed wheat yield improvement by the detailed overview of morpho-physiological responses of wheat to heat stress.

Introduction

Wheat (*Triticum aestivum*) is a very important cereal grass placed in family Poaceae. Wheat is ranked as one of the major cereal crop across the world. Wheat fits in everywhere in our diet, sometimes as bread, biscuit, muffins, crackers, pasta and many other baked items. The role of wheat is undoubtly very important in our life. Wheat is ranked at 3rd position in Nepal in terms of both area and productivity (MoAD, 2015). In Nepal and worldwide the cultivated area, yield and overall productivity of wheat is increasing. Similarly the demand and the consumption is also increasing but the consumption is quite increasing faster as compared to that of production in hilly and terai regions of Nepal (Gairhe, Karki, Upadhyay, & Sapkota, 2017). Crop yield of wheat is affected by many factors like soil properties, seed properties and variety, cultivation practices and natural factors like rain, temperature, moisture etc. These factors may alter the yield of the crop drastically and hence either of them is very much necessary to be considered prior and during cultivation. One of these factors is temperature which is very vital for the performance from seed germination to yield. The rise in temperature and the temporal anomalies drastically change the growth and development and in turn brings catastrophic reduction in production and productivity of wheat. For each degree increase the decrease in production is about 6% (Akter & Islam, 2017).

The production and other yield attributing characters of wheat are greatly affected by hyperthermal conditions(Gupta et al., 2013). Usually in areas with lower altitude where there are large areas of wheat cultivation, these crops are largely found to be prone to heat(Braun, Atlin, & Payne, 2010). Research with different model for mean temperature exhibited that there was significant decrease in the yield of wheat in higher temperature. As a result of elevated temperature there is change in germination, root emergence, stem development, tillering, root growth, dry matter production, seed characteristics, panicle exertion, fertilization and pollination (Iqbal et al., 2017).

Plant response to heat stress

Actual duration and extension of heat, growth stage which have to tackle with heat stress plays great role to determine plant response to it (Ruelland, Zachowski, & botany, 2010). Heat stress has high impact on physiological and morphological development which results in great loss of yield. Here are some usual effects on production as well as growth of wheat.

Morphological effect

In many crops together with wheat, heat stress primarily obstructs germination of seed and leads to vulnerable crop establishment. When temperature exceeds or equals to 45˚C, embryonic cells are affected and hence seed germination and emergence is delayed(Essemine, Ammar, & Bouzid, 2010). Meristem tissues of plant are mostly affected leading to leaf death, abscission and photosynthetic reduction(Kosová, Vítámvás, & Prášil, 2011). Also warmer the surrounding lesser is the biomass production if compared with optimum environmental condition. It is found to be more hazardous if their prevails heat stress in reproductive stage in wheat production (Nawaz, Bourrie, & Trolard, 2013). Severe loss in yield can be seen even from one degree rise in average temperature(Li et al., 2014). Heat stress degrades mitochondria, alters expression of protein and there occurs decline in ATP formation and less oxygen is taken by imbibing embryos of wheat. This results more loss of seed. As per Hasanuzzaman, Nahar, Alam, Roychowdhury, and Fujita (2013) for every 1 to 2˚C rise in temperature, decreases mass of seed by decreasing grain filling time period in wheat.

Physiological effect

- Water relations

The most erratic becomes water status in plant when the temperature keeps on changing. When temperatures uplifts plant tissues face dehydration, which retards development as well as growth of plants. 31˚C is considered as maximum limit that maintains water content of crop during flowering stage of crop. Almeselmani, Deshmukh, and Chinnusamy (2012) research showed that when temperature after tillering is high (about 35 to 25˚C), water potential in wheat reduces and more reduction occurs in genotypes that are more prone to heat stress. Dehydration tolerance is correlated with various antioxidants which are stimulated at the time of heat stress as a result of increment in transpiration in stressed leaf and decrement in osmotic potential. Also, heat stress is found to reduce water viscosity and increases hydraulic conductivity in cell membrane and in plant tissues(López-Pérez, del Carmen Martínez-Ballesta, Maurel, & Carvajal, 2009).

- Photosystems, photosynthesis and leaf senescence

To talk about photosynthetic tissues, the most sensitive to heat stress is photosystem-II and photosystem-I is more stable. At first, complex phenomenon of photosystem-II is damaged and secondly photosynthetic behaviour is changed by heat stress. Rubisco activase is inactivated and carbon assimilation is suppressed. As a process protein synthesis is reduced and photosystem-II is unable to compensate its damage(Murata, Takahashi, Nishiyama, & Allakhverdiev, 2007).

The most sensitive physiological event that is the cause for pathetic growth performance in wheat is photosynthesis. This is the result of decreased expansion of leaf area, defected mechanism of photosynthesis, premature leaf death and ultimate wheat production reduction(O'Neill et al., 2014). Stroma, thylakoid lamellae of chloroplast are major sites for heat stress injury as there occurs carbon metabolism. It checks enzyme associated activities and disrupt electron carriers leading to less rate of photosynthesis(Prasad, Pisipati, Ristic, Bukovnik, & Fritz, 2008). Either in dark or light when wheat leaf is exposed to temperature more than 40˚C, there occurs change in Rubisco and Rubisco activase which is irreversible in dark condition(Feller, Crafts-Brandner, & Salvucci, 1998).

Leaf senescence was another the unavoidable outcome of heat stress whose symptoms are structural alteration in the chloroplast, collapse of vacuole, loss of integrated plasma membrane and interference in homeostasis of cells. Flag leaf senescence in wheat was seen more when there occurs large variation in diurnal temperature (Khanna-Chopra, 2012).

- Oxidative damage

Reactive Oxygen Species (ROS) are generated when plants are exposed to heat stress which includes oxygen (O_2), superoxide radical (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (OH^-). The stress gradually increases the peroxidation of membrane and decreases thermo stability of wheat plant(Savicka & Škute, 2010). Antioxidants like superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (CAT), glutathione reductase (GR), peroxidase (POX) have ameliorating effects of heat stress in wheat (Caverzan, Casassola, & Brammer, 2016).

- Respiration

The rate of respiration in flag leaf of wheat is observed higher in heat susceptible varieties as compared when they are in heat stress than in tolerant varieties (Almeselmani et al., 2012). Respiration alteration caused by heat stress leads to mitochondrial changes. With increase in temperature, rate of respiration too increases but after certain threshold level respiration rate begin to decrease due to malfunction or destruction of respiratory apparatus(Prasad & Djanaguiraman, 2014). This is another cause for the rise of ROS. Solubility of CO_2 and O_2 is also affected due to the heat stress (Cossani & Reynolds, 2012).

Effect on grain growth and development

Wheat anthesis and grain filling is best at temperature range 12 to 22˚C (Shewry, 2009). When the temperature alleviates above 24^0 C during reproductive stage, the grain yield is reduced remarkably (Prasad & Djanaguiraman, 2014) .

- Grain number, grain filling and grain quality

The rate of grain filling in wheat cultivars were reduces at day/night temperature of 32/22°C as compared to that of 25/15°C (Hu et al., 2015). Because of limitation of assimilates and less remobilization of nutrients, heat stress affects grain quality of many cereals and legumes. A strong correlation was observed between leaf nitrogen content and grain protein (Iqbal et al., 2017).

To escape from high temperature at grain filling stage, the wheat variety should be short duration for late planting (Menshawyet.al, 2015). Heat stress influence both size of grains as well as their numbers as per growth stages. In between spike initiation and anthesis stage if temperature is above 20˚C growth of spike is seen more but the number of spikelet will be reduced(Semenov & Halford, 2009)

- Starch synthesis

60-75% dry weight of wheat contains starch but heat stress decreases the starch synthesis in wheat and increases total soluble sugar and protein content(Sumesh, Sharma-Natu, & Ghildiyal, 2008). Lu et al. (2019) state that more than 97% wheat products was lost due to decrease in soluble starch synthase at temperature 40˚C which caused less starch accumulation in wheat.

- Translocation of photosynthetic products

Sucrose and glutamine are the main photosynthetic products translocated to respective sink for the purpose of seed development. The source and sink limitation is seen under heat stress condition which may restrict seed set and grain filling (Lipiec, Doussan, Nosalewicz, & Kondracka, 2013). Heat stress when decreases photosynthetic rate, stem reserves are used as carbon source necessary for grain filling (Mohammadi & Richon, 2009). At high temperature both symplastic as well as apoplastic pathways are reduced through which translocation mainly occurs. Wang et al. (2012) showed that the carbohydrate translocation from stem to grain increased when high temperature was induced in pre-anthesis period which resulted less decline in starch content in wheat grains when they face heat stress at the post anthesis period.

Managing heat stress

Heat stress adversely affects the growth and development of wheat plants. These effects can be managed through appropriate plant genotypes together with various agronomic practices. Various efforts have been made to produce heat-tolerant genotypes using the knowledge gained until now on the responses of wheat plant to heat stress.

Genetic management

Breeding is an adaptation response of crops under changing environment (Akter & Islam, 2017). Several studies have been performed in recent years to classify wheat genotypes that are immune to heat stress (Nagar, Singh, Arora, Dhakar, & Ramakrishnan, 2015).

- Screening and breeding for heat tolerance

In several developing countries, various physiological approaches to breeding programmes have been found to be successful. Screening genetic bases for heat resistance in crops may be one of the approaches. Following physiological crossing of novel trait combinations, a desired plant form can be established to combat potential climates that involve high temperature events (Reynolds & Langridge, 2016).

Researcher has suggested some indirect selection criteria for developing heat tolerance in wheat. To breed heat stress tolerant plants, Asthir (2015) stressed the importance of understanding molecular pathways and protective mechanisms. Heat tolerance is clearly a polygenic trait, and the methods mentioned above will help research to investigate on the genetic basis of plant thermo tolerance. Wang et al. (2012) suggested that certain transcription factor could be used to help crops cope with various stresses.

- Biotechnical approach for improving heat tolerance

Many transcription factors have recently been implicated in various abiotic stress tolerance in crops(Wani, 2020) . Many plant genomes sequences have recently been produced, resulting in a significant increase in stress tolerance.

Agronomic management

Manipulating some agronomic practices can be great method to grow wheat in a warmer environment(Ortiz et al., 2008). Using water conservation methods, maintaining appropriate method and time of sowing, use of correct dose of fertilizer and applying them with correct way, mulching and use of external protectants can distinctly decrease the effect of high temperature on wheat(Singh, Dutt, & Tyagi, 2011).

- Use of exogenous protectants

Exogenously added growth promoting protectants such as Osmoprotectants, phytohormones, signalling molecules and trace elements have recently demonstrated the ability to protect plants from the harmful and adverse effects of heat stress (Upreti and Sharma, 2016). The commonly used plant bio-regulators in horticultural crops can potentially be used in field crops, including wheat and their prospects are now being whipped out as an emerging heat stress alleviating technology (Ratna Kumar et al., 2016).

- Bacterial seed treatment

Biological control agents like bacteria fungi are fast and cheap method to escape from heat stress when compared with varietal improvement and breeding programs(Raaijmakers, Paulitz, Steinberg, Alabouvette, & Moënne-Loccoz, 2009). Rhizobacteria which are great plant growth promoter are also found to work against high temperature effects in wheat(Nain et al., 2010).(Yang, Kloepper, & Ryu, 2009) said foliar application of various organic and inorganic agents and seed treatment with rhizobacteria enhanced heat tolerance in wheat. *Bacillus amyloliquefaciens* UCMB5113 and *Azospirillum brasilense* NO40 strains are good for seed treatment which increases heat tolerance of wheat seedlings by reducing ROS generation (Abd El-Daim, Bejai, & Meijer, 2014).

CONCLUSION

As a result of global warming, the level of heat stress in wheat is predicted to rise globally. Grain environment, length, intensity,quality and yield are all affected by heat stress. Heat stress has genotype specific effect that is also influenced by severity, timing, and length of heat stress. As a result, the production of heat tolerant varieties aids in reducing the effects of heat stress. Low grain production is primarily due to late wheat sowing. Wheat is often sown in Nepal after paddy harvesting which delays the required sowing period for wheat resulting in higher temperature stress during grain filling. As a result, wheat yield is extremely low. Even though the physiological mechanisms of heat tolerance in wheat are reasonably well understood, future research into assimilate partitioning and phenotypic flexibility is needed. It is well recognized that using conventional and modern molecular genetics methods in combination with agronomic management practices can help to resolve the heat syndrome's complexity. To investigate the actual effects of heat stress on final crop yield, various biochemical and molecular approaches, as well as agronomic options, are needed. Furthermore, exogenous application of protectants has shown beneficial effects on wheat heat tolerance improvement. Applying microorganism to wheat plants appears to be a useful tool in agriculture for reducing the negative effects of heat stress, but further research is required to define and optimize the parameters involve in efficient microbial efficiency.

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