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S & T REVIEW

HEAT STRESS EFFECT ON WHEAT: A REVIEW

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ABSTRACT

Heat stress is the main limiting factors for wheat production worldwide. Raising of temperature above 31°C during grain filling causes heat stress. Every 1°C rise in temperature reduced the wheat production by 6%. Under heat stress, the plant highly produced reactive element known as oxygen reactive species. ROS disturbs the function of the cell by their negative action on lipids, protein and DNA. Heat stress disrupt the plant water relation, cell turgidity, reduced seed germination and seedling growth, deactivation of photosynthetic enzymes, disturb translocation of photosynthate due to which it reduced grain number and grain filling. Management approaches like agronomic management and genetic management can be applied against heat stress. The main objective of this review is to study the responses of wheat towards heat stress and its management practices.

KEYWORDS

Wheat, Heat Stress, HSP (Heat Shock Protein), ROS (Reactive Oxygen Species), Protectants and Osmo-Protectant

1. INTRODUCTION

Wheat (*Triticum aestivum*), the most widely cultivated cereal crop belonging to Poaceae family. It is the largest contributor with nearly 30% of the world grain production and 50% of the world grain trade. According to FAO estimation, world would require additional 198 million tonnes of wheat by 2050 to fullfilled the future demands, for which wheat production need to be increased by (77-80)% in the developing countries (Sharma et al., 2015). Wheat is the third most important cereal crop in Nepal after rice and maize both in area and production. Wheat is grown in 7,03,992ha with total production of 20,05,665 metric ton and the productivity of 2.84 ton ha^{-1} in Nepal. Wheat shares about 7.14 % in National Agriculture Gross Domestic Product (MOALD, 2018/2019). It has contributed 6.98 % in AGDP and 2.30 % in GDP (MoF, 2014). Wheat is grown in all three domains (agro-climatic regions) of the country, ranging from sea level to 4000m, which faces various abiotic stress in various phenological stages. The threshold temperature of vegetative development was reported to be 20–30°C (J Kobza, 1987). Anthesis that of reproductive growth was 15°C (SI Chowdhury, 1978). Anthesis and grain filling have a threshold temperature of 12–22°C (H Tewolde, 2006). Wheat is highly susceptible to heat stress (Gupta et al., 2013). Around 100 million hectares of wheat are cultivated at low latitude zones are predominantly heat prone areas worldwide (Braun et al., 2010). The experiment in which 30 wheat crop models were tested in the growing season where mean temperature ranged from 15 to 32°C with artificial heating. The result showed that majority of grain yield of the wheat already decreased due to warming this growing loaction. The effect of stimulated median temperature on declining the wheat yield varied widely, and the decreased average yield ranging between 1 to 28 % for an increase in 2^0C on 30 sites for the period between 1981 and 2010, and for a temperature of 4^0C this value rises between 6 sand 55%. Also they estimated that global wheat production falls by 6% for each 1°C of further temperature increase. (Asseng et al., 2014). Wheat is a thermo sensitive crop mostly grown in temperate environment. However, it is predominantly consumed in tropical and subtropical regions of the world. In subtropical regions it is cultivated in winter season but it exposed to high temperature stress at the end of the season i.e at grain filling stage. Heat stress is one of the major limiting factors for growth and productivity in wheat crop particularly in warmer region. Exposure to higher than normal temperature or heat stress reduces yield and decreases quality (Dev Hingra, 2016).High temperature stress is a major environmental factor that limits yield in wheat. More than 40% of total wheat area in the world is affected by high temperature stress (Hede et al., 1999). High temperature stress induces several alterations in physiological, biochemical and molecular components of wheat crop production. The main aim of this review is to study the causes, response of plant and different management practices to overcome damage from heat stress.

2. OBJECTIVE

i. To study about the concept of heat stress on different genotypes of wheat.

ii. To study the responses of wheat on heat stress.

iii. To study the effects of heat stress on wheat in its yield and yield attributing characters.

iv. To study the various management practices that can be adopted to overcome from heat stress and increase the wheat production.

3. METHODOLOGY

This review article is based on various secondary source of data such as: literature reviews, articles published in different journals, books, newspapers etc.

4. RESULT AND DISSUCTION

4.1 Heat stress

The rise in temperature beyond a certain threshold level for a period sufficient to induce irreversible damage to plant growth and development is referred to as heat stress, where as heat tolerance is the ability of the plants to grow and produce economic yield under high temperatures (Najam W. Zaidi, 2014). Different research indicate that the most of the wheat growing region of world are experiencing episode of above optimum temperature leading significant decrease in grain yield. Wheat is sensitive to high temperature during reproductive stage compare to vegetative stages.

5. Causes of Heat Stress

5.1 Climatic Variation

Average global temperatures are predicted to rise by about 2^{0}C over the next 50 years, making many cereals growing regions even less suitable, based on predicted temperature ranges (Wringle C., 2006).The mean ambient temperature is predicted to increase by 1–6°C by the end of twenty-first century (De Costa Wajm, 2011). Such increase of global temperature may have a significant influence on agricultural productivity in accordance with the severity of the high temperature, drought, salinity, waterlogging, and mineral toxicity stresses. High temperature-induced heat stress is expressed as the rise in air temperature beyond a threshold level for a period sufficient to cause injury or irremediable damage of crop plants in general (Edmark l. Texeira, 2013). The heat stress situation is aggravated when soil temperature increases as a result of increase in air temperature associated with decline in soil moisture. Thus, heat stress has appeared as a great menace to successful crop production in the world (S Kumar et al., 2012), (David B Lobell et al., 2012)

5.2 Late sowing

Different studies demonstrate that delayed sowing increases the probability to occurring terminal heat stress during grain filling stage which significantly reduces grain yield. The timely sowing in the period between 15and 25 November may be advocated to avoid terminal heat stress in wheat in the IGP region (Dubey et al., 2020). Each day delay in sowing of wheat after 30th November on ward decreases grain yield at the rate of 36 kg/ha/day (Hussain et al., 1998). In general, late sowing wheat varieties faces severe temperature stress, shortens the heading and maturity duration, ultimately affecting final yield and grain quality (Hossain et al., 2012), (Hakim et al., 2012).

6. Response of Wheat Towards Heat Stress

6.1 Physiological response

Heat stress affects various plant processes leading to morpho-physiological alterations in wheat plants, hindering the development processes and eventually resulting into great yield loss (McClung et al., 2010). Plant responses to heat stress differ significantly with the extent and duration of temperature, and the growth stages encountering the stress. Photosynthetic processes depending upon crop species exhibit more tolerance to heat stress with considerable level of stability in the temperature range of 30°C to 35°C, however as the temperature reaches to (>40°C), the process of photosynthesis is affected adversely. High temperature result in the decreased solubility of O2 and CO2 however, increased photorespiration and lower photosynthesis is the result of increased level of CO2 than O2. (Sadras et al., 2007). RUBISCO activities breakdown under heat stress condition. (Kumar RR et al., 2016) under heat stress causes decrease in photosynthetic capacity (Raines CA et al., 2011). Amongst the photosynthetic apparatus photosystem II being more tolerant to drought stress than heat relatively plays a key role in leaf photosynthesis (Crafts et al., 2000). Moreover, mitochondrial respiration is also considered important in determining the growth and survival of plants (M Havaux., 1993). Mitochondria show greater stability to heat stress and their activity increases over most of the temperature range in which plants are grown. However, heat stress is more detrimental to mitochondrial activity than chloroplast activity in some crop species and injured plants because of disrupting growth and maintenance of respiration (Gifford et al., 2003). Under heat stress conditions the respiratory losses by seeds (grains or kernels) offset the increased influx of assimilates which ultimately account for greater yield losses. (Byrla et al., 2001). With a increase in leaf temperature, wheat plants exposed to heat stress substantially decrease the water potential land the relative water content in leaves, and eventually reduce photosynthetic productivity (Farooq et al., 2009). Heat stress during grain filling decreases sink source transportation. (Lipiec et al., 2013)

6.2 Morphological responses

Heat stress has negatively influence in wheat morphology and seed germination (Hussain et al. S. M., 2013). Decreased number of roots, root length and root diameter are the manifestations of heat stress. Heat stress during reproductive development also retards root growth mainly because of decreased carbon partitioning to the roots (Porter et al., 1999). As compared to other growth processes root growth has a very narrow range of optimum temperature (Prasad et al., 2006). Leaf appearance rate is the most affected feature of temperature which commonly implies to the concept of thermal time. Moreover, it is reported that high temperatures are generally involved in regulation of leaf appearance rates and leaf elongation rates along with decreasing leaf-elongation duration. Heat stress also resulted in significant increase in number of leaves, particularly during the arrested reproductive development stage and without any decrease in leaf photosynthetic rate (Roberts et al., 1987). Morphological and growth responses. The primary effect of heat stress is the impediment of seed germination and poor stand establishment in many crops including wheat (Jokhan et al., 2011); (Hussain et al. S. M., 2013). Ambient temperature around 45°C severely affects embryonic cell in wheat which reduces crop stands through impairing seed germination and emergence (Essemine et al., 2010). Heat stress mostly affects the plant meristems and reduces plant growth by promoting leaf senescence and abscission, and by reducing photosynthesis (Kosova et al., 2011). Heat stress ranging from 28 to 30°C may alter the plant growth duration by reducing seed germination and maturity periods (Yamamoto et al., 2008). Warm environment produces lower biomass compared to plants grown under optimum or low temperature. Day and night temperature around 30 and 25°C, respectively, may have severe effects on leaf development and productive tiller formation in wheat (Rahman et al., 2009). However, the prevalence of reproductive stage heat stress has been found to be more detrimental in wheat production (Nawaz et al., 2013). One degree rise in average temperature during reproductive phase can cause severe yield loss in wheat (Bennet et al., 2012). High temperature stress degenerates mitochondria, changes the protein expression profiles, reduces ATP accumulation, and oxygen uptake in imbibing wheat embryos, resulting in increased occurrence of loss of seed quality relating to seed mass, vigour, and germination (Balla k et al., 2007) . Increase in temperature of 1–2°C reduces seed mass by accelerating seed growth rate and by shortening the grain-filling periods in wheat (Nahar et al., 2010).

6.3 Grain growth and development

Heat stress reduces the number of grains leading to lower harvest index in wheat ((Lukac et al., 2011). However, the influence of heat stress on both the number and size of grains varies with the growth stages encountering heat stress. For instance, temperatures above 20°C between spike initiation and anthesis speed up the development of the spike but reduce the number of spikelet and grains per spike (MA, 2009). Heat stress adversely affects pollen cell and microspore resulting into male sterility (Anjum et al., 2008). Even high temperature of above 30°C during floret development may cause complete sterility in wheat depending on genotypes (Kaur et al ., 2010). In wheat, the anther produced under 3 days heat stress during anthesis was found to be structurally abnormal and nonfunctional florets (Hedhly et al., 2011). Day night high temperature of 31/20°C may also cause shrinking of grains resulting from changing structures of the aleurone layer and cell endosperm (Dias et al., 2008) Grain filling stage in wheat is very sensitive to high temperature (Farooq et al. B. H., 2011). Heat stress generally accelerates the rate of grain filling and shortens the grain filling duration (Dias et al. L. F., 2009a). However, the grain growth rate and duration decreased in plants having different grain weight stability (Vijayalakshmi et al., 2010)In wheat, grain filling duration may be decreased by 12 days with the increase of 5°C temperature above 20°C (Yin et al., 2009). The increase in night temperature is more responsive, shortens the grain filling period, and reduces the grain yield than that of day temperature. Night temperatures of 20 and 23°C reduced the grain filling period by 3 to 7 days (Prasad et al. P. S., 2008). Recently, (Song WF, 2015)observed a significant reduction in the rate of grain filling in wheat cultivars at day/night temperature of 32/22°C when compared with that of 25/15°C..Heat stress affects grain quality of many cereals and legumes, essentially because of limitation of assimilates and less remobilization of nutrients. Heat stress hardly affects the protein concentration of grain in wheat (Lizana XC, 2013), but a strong correlation was observed between leaf nitrogen content and grain protein (Iqbal et al., 2017)

7. Management of Heat Stress in Wheat

7.1 Agronomic Management

Wheat can be grown successfully in a warmer environment through manipulating some agronomic management practices (Ortiz R, 2008). Adoption of various agronomic practices like

(i) water conserve techniques

(ii) the appropriate amount and methods of fertilization

(iii) maintaining proper time and methods of sowing, and

(iv) the application of exogenous protectants can effectively alleviate the adverse impact of heat stress in wheat (Singh et al., 2011b)

7.1.1 Water Conservation techniques

A continuous supply of water is necessary for sustaining the grain filling rate and duration, and grain size in wheat. This could not be possible in rain-fed wheat growing area, but here, mulching can be the best option for maintaining optimum moisture and thermal regimes in the soil system. Straw mulch conserves soil moisture by reducing soil evaporation (Chen et al., 2007). However, mulching is advocated to avoid yield reduction in wheat when reduced tillage is practiced (Glab et al., 2008)

7.1.2 Appropriate amount and method of fertilization

Adequate and balanced supply of mineral nutrients is essential in plants exposed to temperature stress

(Waraich et al., 2012). The exogenous application of calcium promotes heat tolerance in plants. Adequate supply of magnesium (Mg) was identified as an effective nutritional strategy to minimize heat stress-related losses in wheat production. (Mengutay et al., 2013). Potassium orthophosphate causes a delay in the heat stress-induced leaf senescence and enhances grain yield (Dias AS, 2010). The advantages of NO3 through delaying abscisic acid synthesis and promoting cytokinin activity, and similarly K+ induced increasing photosynthetic activities and assimilates accumulation are well recognized for increasing grain yield under heat stress environment (Singh et al. S. D., 2011a)

7.2 Use of exo protection

In recent times, exogenously applied several growth promoting protectants such as osmoprotectants, phytohormones, signaling molecules and trace elements have resulted in the potential to protect the plants by neutralizing the harmful and adverse effects of heat stress (Sharma et al. J. A., 2012). Exogenously applications of these substances improve thermotolerance in wheat under heat stress by managing the ROS (Farooq et al. B. H., 2011) and up regulating the antioxidant capacity (Hemantaranjan et al., 2014).

7.3 Genetic management

Breeding is an adaptation response of crops under changing environment. Therefore, it requires the evaluation of genetic diversity for adaptation to future climate change conditions, and thereby the selection and induction of stress inducible genes of genetic resources for developing new varieties in the production systems (Chapman et al., 2012). Breeding for heat tolerance is still in the preliminary stage and therefore much attention is given to the genetic improvement of wheat to heat stress. In recent years, several studies have been done to find out wheat genotypes tolerant to heat stress (Kumar et al., 2010) , (Nagar et al., 2015).

8. Conclusions

Heat stress was found to lead to enormous loss of wheat productivity worldwide. Wheat shows various physiological and morphological response towards it. For fighting towards heat stress plant lost its yield at very huge quantity. Plant produces different metabolites such as antioxidants and HSPs under heat stress condition. Molecular studies of such metabolites play crucial role to know the mechanism underlying stress tolerance. Hence, it is very essential for management of wheat towards heat stress through various agronomic practices and heat stress tolerance variety.

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