ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0858 (Print)
ISSN: 2521-0866 (Online)
CODEN: SHJCAS

Science Heritage Journal (GWS)

DOI: http://doi.org/10.26480/gws.01.2023.27.31

CrossMark

REVIEW ARTICLE

RESPONSE OF WHEAT TO DIFFERENT ABIOTIC STRESS CONDITIONS: A REVIEW

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ARTICLE DETAILS

Article History:

Received 03 June 2023
Revised 02 August 2023
Accepted 05 September 2023
Available online 08 September 2023

ABSTRACT

Wheat serves as the number one crop for ensuring food and nutritional security in the world. The production and productivity of wheat have been greatly influenced by global warming and climate change which have created environments such as drought, heat stress, and saline conditions. To address the advances in the study of the response of wheat against such climatic implications, this review was done. Abiotic stress mainly affects the morphology, phenology, and physiology of wheat. Abiotic stress induces reactive oxygen species (ROS) in wheat causing a reduction in root, shoot, and reproductive growth. Impact on important yield-related traits such as spike length, grains per spike, grain weight, thousand-grain weight, and reduces the yield of wheat. The plant has earliness as a phenological, rolling of leaves as morphological, waxiness as physiological, and production of heat shock proteins and proline content as a biochemical defense. A proper study of these effects and responses at the genetic and molecular level is necessary to cope with the existing yield gap in a farmer's field as compared to normal conditions. The study of wheat against such circumstances would help plant breeders identify stress-tolerant genotypes that could significantly contribute to eradicating existing hunger and malnutrition in the world.

KEYWORDS

Wheat, Abiotic, Stress, Morphology, Physiology

1. INTRODUCTION

Climate change and global warming has been the major challenge in the global wheat production (Krupnik et al., 2021). The temperature rise had created a heat-stress environment in wheat and the evaporation of water from the soil surface had created drought field sites (Arora, 2019; Vuković et al., 2022). Wheat requires a temperature of 12-22 ^{0}C with a mean precipitation of 350-500 mm and a salt concentration of 6.0 ds/m in soil (Khan et al., 2020). Insufficient rainfall and an imbalanced hydrological cycle had accumulated sodium ions in the soil thus creating salinity. About 15.4% of the total cultivating area in the world is suffering from drought stress, 42% from heat stress, and 33% from salinity (Arora, 2019; Hafeez et al., 2021; Singh et al., 2020). Heat stress and drought have been major threats in South Asian regions whereas salinity is a threat under arid and semi-arid regions in the world (Seleiman and Kheir, 2018; Shalaby, 2018). Wheat is cultivated in different environments in the world. The majority of wheat is grown under irrigated conditions in the world. The production and the productivity of wheat declined up to 60%, 8-46%, 50%, and under drought, heat stress, and saline condition, respectively (Bennani et al., 2016; Fahad et al., 2017; Ram Poudel et al., 2020). Lower production and the productivity of wheat are creating a hunger gap among the increasing population in the world.

The agroecosystem in South Asian regions is vulnerable to climate change. Being the major food basket, the farmers from Indo-Gangetic plains like Pakistan, India, Bangladesh, and Nepal are facing challenges such as rising temperature, heat waves, drought, flood, and the effect have been observed in wheat (Aryal, Sapkota, Khurana, et al., 2020; Aryal, Sapkota, Rahut, et al., 2020; Hossain et al., 2019). An increase in temperature by 1.8% and 2.6% is predicted by 2030 and 2050 in South Asia thus, the area under heat stress is predicted to rise to 12% in 2030 and 21% in 2050 (Tesfaye et al., 2017). Wheat is the number one crop in the world providing 20% of total calories and 15% of daily dietary protein to the global population (Goriewa-Duba et al., 2018; Zhi et al., 2023), reduction in the production and productivity of wheat would have major concerns (Bhandari et al., 2021). Cultivation of wheat ranges from the eastern Gangetic plains of South Asia to Eastern Europe (Bhatt et al., 2021). The environment varies from tropical humid in South Asia to oceanic regions in Europe and the adverse climatic variation causes yield reduction on wheat.

Abiotic stress has several impacts on the morphology, phenology, and physiology of wheat (Seleiman et al., 2021). The review focuses on the impact of abiotic stresses on wheat morphology, phenology, and physiology to address advances in wheat crop designing and provides potential areas that plant breeders should focus on to get high-yielding abiotic stress-tolerant genotypes. A proper study about the effects of different wheat growing environments on morphophysiological parameters would help plant breeders to breed high-yielding stress-tolerant genotypes. Increment in the yield of wheat will help to address current hunger-related problems in wheat (Hefferon et al., 2021). Hence, the review summarizes the impact of abiotic stresses on the major parameters of wheat.

2. RESULT AND DISCUSSION

2.1 Drought Stress

2.1.1 Effect on Morphological Attributes

Drought causes oxidative damage to wheat by destroying the lipids in cell membranes and impairing the root and shoot growth (Vuković et al., 2022). Generally, root growth is suppressed due to lack of water but increments in root length, root angle, number of lateral roots and overall

Quick Response Code	Access this article online	
	Website: www.jscienceheritage.com	**DOI:** 10.26480/gws.01.2023.27.31

Cite The Article: Harikala Paudel, Radhakrishna Bhandari, Anjali Dhakal, Shivalal Nyaupane, Binod Panthi, Mukti Ram Poudel (2023). Response of Wheat to Different Abiotic Stress Conditions: A Review. *Science Heritage Journal, 7(1): 27-31.*

root architecture have been reported under drought in wheat (Kang et al., 2022). Plant under water stress condition adopts the defense mechanism by altering the growth pattern and stomatal conductance to reduce transpiration loss and rolling of the leaf, increasing root length, osmotic and hormonal regulation, and delayed senescence to combat the water stress (Seleiman et al., 2021).

2.1.2 Effect On Phenological And Agronomical Attributes

Drought stress reduces days to booting, heading, anthesis, and grain filling duration in wheat creating earliness in maturity (Chowdhury et al., 2021; Rao et al., 2022). Drought imposes reactive oxygen species (ROS) in the cell, production of ethylene and ABA-like substances induces a senescence-related metabolic reaction that promotes early booting, heading, and anthesis on wheat (Yao et al., 2021). The earlier maturity of wheat genotypes under drought stress has been reported as a defense mechanism that has been used to identify climate-resilient wheat genotypes under drought stress conditions (Lopes et al., 2012; Mondal et al., 2013). Drought affects all the yield traits such as Spike length, spike weight, grains per spike, seed weight, and seed volume (Rao et al., 2022).

2.1.3 Effect On Physiology And Biochemistry

Drought causes stomata closure in wheat which lowers the CO_2 assimilation resulting in lower photosynthate accumulation(Li et al., 2021). Drought causes the malfunctioning of photosystem II(PS-II) and C3 cycle (Huang et al., 2019). It changes the chemical kinetics of lipids causing lipid peroxidation and oxidation of cell membrane (Vuković et al., 2022). Oxidation of cell membranes and ions produces reactive oxygen species such as superoxides(O^{-2}), hydroxyl radicals(OH^-), and peroxides(H_2O_2) (Sies et al., 2022). It also altered the leaf-water relation by decreasing the leaf-water potential, osmotic potential, and turgor osmotic potential(Abid et al., n.d.). Carbohydrate metabolism and photosynthesis processes are affected by ROS due to the reduction in CO2 in wheat crops (Foyer, 2018; Hasanuzzaman et al., 2018; Xin et al., 2018). Wheat accumulates the proline under drought conditions which contributes to osmotic stress tolerance (Maghsoudi et al., 2018). In response to drought, the plant produces a wax-like substance as a defense mechanism.

2.2 Heat Stress

2.2.1 Effect on Morphological Attributes

An increase in global temperature has been leading wheat to suffer from heat stress in wheat. South Asian countries suffer from terminal heat stress due to delayed sowing of wheat. Terminal heat stress in wheat causes poor germination, reduced water and nutrient uptake, and increased evapotranspiration which affects the growth, development, and productivity of wheat (Gajghate et al., 2020). Heat stress on wheat affects the survivability of effective tiller which decreases the tiller number by 15.38% and grain yield by 53.57% (Poudel and Poudel, 2020). Heat stress inhibits seed germination, and reduces tiller formation, leaf development, leaf senescence, and overall plant growth duration (Akter and Rafiqul Islam, 2017). Wheat reduces the plant's fresh and dry biomass, root and shoot length, leaf area, and leaf number under heat stress (Iqbal et al., 2019). Rolling of leaves occurs when the wheat is exposed to heat stress(Hassan et al., 2021).

2.2.2 Effect on Phenological and Agronomical Attributes

The impact of heat stress on the phenological stages of wheat such as days to 100% germination and days to seedling emergence has been reported(Abd El-Daim et al., 2014; Akter & Rafiqul Islam, 2017). Wheat growing under heat stress conditions, the phenological stages are achieved earlier. The duration of tillering, booting, floral initiation, pollination, and fertilization is reduced under heat stress. The extent of reduction of the phenological attributes depends upon the magnitude and length of exposure, genotype, and soil moisture status (Kumar et al., 2022). When the flowering and grain-filling stages of wheat coincide with high temperatures (>30◦C), the majority of the yield-attributing parameters are affected. Heat stress causes a deleterious effect on wheat at any developmental stage however, the reproductive stage is a sensitive stage that has a greater impact on grain quality, and grain yield (Fan et al., 2018; Tricker et al., 2018). Overall, heat stress has an impact on all the yield-attributing parameters of wheat. Heat stress reduces the number of grains per spike and seed weight due to accelerated growth of spike and grain shrinkage (Bheemanahalli et al., 2019). Earlier booting and heading causes shorter spike which accounts for lower grains per spike and the subsequent grain shrinkage causes lower seed weight and volume (Girousse et al., 2018; Khan et al., 2020). The effect of heat stress on yield attributing parameters is cumulated to the grain yield of wheat with up to 8-46% yield reduction (Poudel et al., 2020)

2.2.3 Effect on Physiology and Biochemistry

Heat stress alters the physiological and biochemical processes of wheat (Pandey et al., 2019). Chlorophyll content and photosynthetic activity are the major being affected by heat stress (Poudel and Poudel, 2020). Wheat when exposed to heat stress, generates reactive oxygen species(ROS) leading to various alternations on physiological processes such as acceleration of leaf senescence and photorespiration, reduction of Rubisco activity, inhibition of the enzymatic activity for starch synthesis, rattling of PSII efficiency and diminishing of the other cellular function (Tian et al., 2018). Heat stress causes a significant reduction in CO_2 assimilation and protein content in grain as well which reduces the grain quality (Aiqing et al., 2018). Proline content in wheat increases by 53.9% in wheat due to heat stress (Butt et al., 2020). High temperature causes a reduction in photochemical efficiency, an increase in antioxidant enzymes, loss of cell turgor pressure, and a reduction of cell water potential (Hassan et al., 2021).

2.3 Salinity Stress

2.3.1 Effect on Morphological Attributes

Saline soil mainly affects wheat by altering the cell water potential. Salinity reduces the germination percentage of wheat and morphological characteristics such as leaf number, leaf area, stem length, stem weight, and shoot dry matter. The seedling vigor is greatly affected by salinity. The growth of root and shoot is also retarded due to unbalanced cell water potential (Borlu et al., 2018; Din et al., 2019; EL Sabagh et al., 2021). The salt-affected wheat plant shows stunted growth and dark coloration in leaves (Rani et al., 2019). The plant shows chlorotic and early necrotic patterns due to reduced water content in the cell.

2.3.2 Effect on Phenological and Agronomical Attributes

Salinity stress reduces the agronomical traits such as plant height, spike length, number of spikes per meter square, number of grains per spike, grain weight, and grain yield (Mansour et al., 2020). Salinity reduces biomass accumulation and source-sink activity, which in turn favors the reproductive organ to senescence and affects grain yield (Khataar et al., 2018).

2.3.3 Effect on Physiology and Biochemistry

The physiological process and growth of the wheat were altered by salt stress which included reduced water absorption, inhibition of nutrient uptake, reduced photosynthesis rate, and ultimately reduced yield (Abdelaziz and Abdeldaym, 2019; Mahmoud et al., 2019). Salinity causes the increase in toxicity of Na+ and decrease the uptake of essential nutrients such as Ca+ and K+ and affects plant growth due to high cell membrane injury and senescence in developing embryo (Alamri et al., 2020; Salim and Raza, 2020). The root and shoot length of the wheat seedling decreases due to an increase in Na^+ and decreases in K^+ content in both the shoot and root (Zeeshan et al., 2020; Saddiq et al., 2021). The net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, transpiration rate, and chlorophyll content of the wheat decreases (Elkelish et al., 2019; Zeeshan et al., 2020). Salinity stress causes the stomata to close and reduces the CO_2 accumulation in plant resulting in the generation of cytotoxic reactive oxygen species (ROS) which can react with lipid, protein, and nucleic acid and disturbs the metabolic pathway (Hasanuzzaman et al., 2020).

3. Conclusion

Climate change has been one of the major challenges in the food and nutritional security of the world. The addition of abiotic stresses such as heat stress, drought, and salinity further aggravated the food and nutritional security status. Abiotic stresses have a major effect on the morphological, phenological, physiological, and yield-attributing parameters of wheat. Wheat has a defensive mechanism to avoid these stresses. Identification of the natural defense mechanism of wheat against such stresses would help plant breeders in the breeding of climate-resilient wheat genotypes.

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