Agriways **ISSN (Print)** 2321-8614 & **ISSN (Online)** 2454-2318
(A Multidisciplinary Peer –Reviewed Refereed Journal)
www.agriwaysjournal.com Vol 10 Issue 02 July-Dec 2022

Heat stress effects and tolerance mechanism in wheat: A Review

Magar Bimal Roka
Institute of Agriculture and Animal Sciences (IAAS), Paklihawa
Tribhuvan University, Nepal

KCBarsha, PandeyBiddhya, KayasthaPreeti, LamichhanePawan, BhandariJanak, Chand Himani, BaduwalPrakash
Institute of Agriculture and Animal Sciences (IAAS), Paklihawa
Tribhuvan University, Nepal

Poudel Mukti ram
Institute of Agriculture and Animal Sciences,
Department of Genetics and Plant Breeding,
Tribhuwan University, Nepal

Abstract:
Heat stress has become a dominantly crucial factor in limiting wheat yields threatening global food security.Therefore, understanding the effects of temperature on phenology and the physiological traits is very crucial for plant breeders to combat increasing temperature as wheat is a cool-season crop having 15°C at the reproductive stage. In this article, we briefly review only the effects of heat stress and tolerance mechanism on wheat regarding its different aspects. We reviewed that heat stress adversely affects photosynthesis, membrane stability, grain filling, dough properties and gluten proteins, pollen fertility, fruit and/ or seed yield, and photosynthetic characteristics in flag leaves.The photosynthetic efficiency is greatly reduced by unwanted production of reactive oxygen species, denaturation of heat shock proteins, and alternation in many enzymes.

Keywords: Heat stress, Tolerance mechanism, Heat shock proteins, ROS, antioxidants

Date of Submission: 17-11-2022 **Date of Acceptance: 10-12-2022**

Introduction:

Wheat is one of the most important staple crops which contributes to about 30% of the world grain production and 50% of world grain trade belonging to the Poaceae family(Padam Bahadur Poudel and Mukti Ram Poudel 2020). Wheat has fantastic nutritional background with 12.1% protein, 1.8% lipid, 1.8% ash, 2.0% reducing sugars, 6.75 pentosans, 9.2% starch, 70% total carbohydrates and supplies 314 Kcal/100g of food along with ample source of minerals and vitamins viz., Fe(4.1mg/100g),Ca(37 mg/100g, riboflavin (0.13mg/100g), thiamine(0.45mg/100g), and nicotinic acid (5.4 mg/100 mg) (Iqbal et al. 2017).It is also considered "The King of Cereals" as wheat provides 85% of basic calories and 82% of the protein in more than 40 countries(Padam Bahadur Poudel and Mukti Ram Poudel

2020). The main objective of the wheat breeder is to maintain its yield stability because every decade the average global temperature is increasing at a rate of 0.18°C and this global increase in temperature disturbs agricultural productivity beyond the threshold level to cause irremediable damage. Wheat alone contributed 30% of the world grain production and 50% of the world grain trade (Ni et al. 2018). According to FAO, by 2050, 198 million tonnesare additionally required for the world to meet wheat demands and in developing countries, there should be a 77% increment in wheat production. Especially in developing countries, it is forecasted that to fulfill the need of increasing world population for 2020 ranges between 840 and 1050 million tons so increasing the yield is a prime need to meet the feeding demand of the world in the 21st century to assure food security(Iqbal et al. 2017) because, by the end of 21st century, an increase of 1.8-5.8°C in day-night temperature is estimated by global climate change (Ihsan et al. 2019).

According to the FAO, the annual cereal supply will need to increase by about one million metric tons by 2050 to feed the anticipated population of 9.1 billion people. Increased agricultural output and productivity are needed to meet rising food demand in the twenty-first century (Padam Bahadur Poudel and Mukti Ram Poudel 2020). The 35 cultivars of wheat which were originated include Nepal, India, and Mexico. Four cultivars were developed in Nepal, whereas Mexico produced the most cultivars. Wheat farming will be impacted, as wheat is sensitive to high temperatures, drought, and heat stress. After rice and maize, wheat is the major cereal grain cultivated in Nepal, ranking third in terms of both acreage and yield. In many places of the world, including Nepal, drought and heat stress are serious issues in wheat production. In Nepal, wheat is generally sown after rice harvesting, which delays the optimal sowing time for wheat, resulting in higher temperature stress during grain filling and low wheat yields.(Poudel et al. 2020).

Terai's long-term meteorological parameters show that the winter days are getting a little later and shorter, while the hot summer days are getting longer. Wheat farming in the Indo Gangetic region, particularly the Nepal Terai, could be harmed by this type of temperature fluctuation (Puri, Gautam, and Joshi 2015). Nearly half of Nepal's wheat-growing area, which is entirely in the Terai (plain) region, is affected by terminal heat stress. Beginning in mid-March, this area is subjected to western hot winds and a dramatic temperature increase (min and max), resulting in grain shriveling up (Puri, Gautam, and Joshi 2015). From 1980 to 2015, the world experienced the warmest period in its 1400-year history, with global average temperatures rising to around 0.85°C (Poudel et al. 2020). So, wheat production has been a global constraint for all breeders and producers.

Materials and methods

The review completely uses secondary sources of information. Pieces of Literature were collected from different Journal articles, the Agricultural Institute, other sources like FAO, CIMMYT, and relevant reports were studied and the major findings were summarized. Also, a suggestion from related professors and officers were considered in the paper.

Result and Discussion

Heat stress

(Iqbal et al. 2017)suggested that the temperature level beyond the threshold level for some time which can summon and cause destructive damage tothe growth and development of a plant is considered heat stress while the ability of a plant can withstand and tolerate to give economic yield in presence of higher temperature is referred as heat tolerance. High temperature and drought are the significant elementsthat harm cereal yield (Raza et al. 2019) because the threshold temperature for wheat is 26°C and above this temperature, remarkable changes in growth habits occur (Wahid et al. 2007).

Heat stress causes a variety of issues, including poor germination, reduced photosynthesis, leaf senescence, decreased pollen viability, and small grain yield.Heat stress is more likely to influence the reproductive phase of wheat than the vegetative stage, according to (Farooq et al. 2011), especially the effect on grain number and dry weight as wheat experiences various degrees of heat at different phonological stages. The duration, intensity, and rate of fluctuation determine the magnitude of yield reduction for example temperature stress of 33-40°C causes a 23 percent decrease in maize yield at the early grain filling stage, according to (Ihsan et al. 2019).

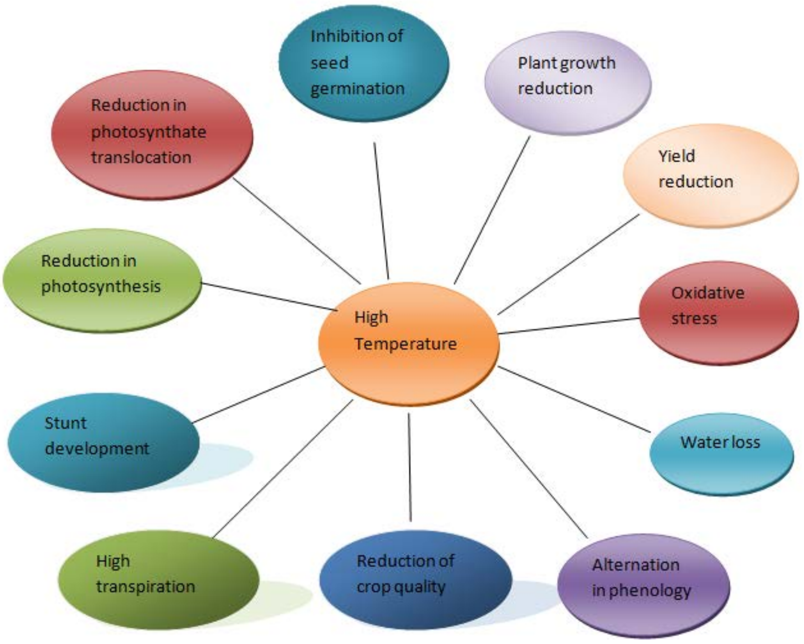

Fig: Major effects of high temperature on plants (Hasanuzzaman et al. 2013).

Table: 1. Effects of high-temperature stress on different crops

Crops	Heat treatment	Growth stage	Major effects	References
Wheat *(Triticum aestivum)*	30/25 day/night	From 60 DAS to maturity stage	Leaf size reduced, the shortened period for days to booting, heading, anthesis, and maturity, drastic reduction of the number of grains/spike and smaller grain	(Hasanuzzaman et al. 2013)

			size, and reduced yield.	
T. aestivum	28°C to 30°C		Reduced germination period, and days to anthesis booting.	(Hasanuzzaman et al. 2013)
Sorghum	40/30°C, day/night		Reduction in chlorophyll content	(Hasanuzzaman et al. 2013)
Cucumber	42°C		Chlorophyll levels are reduced by 60% due to the suppression of 5-aminolevulinate production.	(Fahad et al. 2017)

According to(Akter and Rafiqul Islam 2017a),climate change might have a significant impact on 21% of the world's food supply and 200 million hectares of cropland, and heat stress and drought were predicted to have cost 1.4 percent of cereal production, 0.5 percent of oilseed crops, 0.6 percent of pulses, 0.2 percent of fruits, and 0.09 percent of vegetable production between 1961 and 2014(Ihsan et al. 2019).These evidences are threatening global food security.

Heat stress effect on cell and tissue survival

Heat stress can affect various metabolic pathways relating to membrane thermostability, photosynthesis, and starch synthesis causing damage to cellular structure and organization within a minute by cellular damage or cell death at extreme HT (Hasanuzzaman et al. 2013). The temperature range between 30 °C and 40 °C is hazardous in wheat to reduce starch accumulation by over 30%(Ni et al. 2018).HS slows the flow of molecules through the cell membrane, causing chemical connections inside biological membrane molecules to loosen(Wahid et al. 2007). The tertiary and quaternary structure of membrane proteins is altered by HS, resulting in an increase in membrane permeability(Wahid et al. 2007).

High temperatures have a variety of effects on the photosynthetic process, including swelling, increased leakiness, physical separation of the chlorophyll light-harvesting complex II from the PSII core complex, and collapse of PSII-mediated electron transfer in the presence of high temperatures, all of which lead to chlorophyll loss because thylakoids contain chlorophyll(Ni et al. 2018). Heat stress changes hormonal homeostasis content, biosynthesis stability, and compartmentalization. Under high temperatures amount of ABA increases whereas ethylene production stops at 40°C (Wahid et al. 2007).

Heat stress effect on growth and development/morphology

Heat stress on wheat has the most significant influence on seed germination and crop establishment(Akter and Rafiqul Islam 2017b). Reduced germination percentage, plant emergence, aberrant seedlings, low seedling vigor, and reduced radical and plumule growth of germinated seedlings are some of the significant consequences documented in diverse cultivated plant species(Fahad et al. 2017; Hasanuzzaman et al. 2013). Impairing seed germination and its establishment severely reduces plant meristems promoting leaf senescence and abscission at a temperature around 45°C(Akter and Rafiqul Islam 2017a).High soil temperatures, according to (Driedonks, Rieu, and Vriezen 2016), impair germination and plant emergence and can cause root heat necrosis. According to(Akter and Rafiqul Islam 2017a) if the plant is grown above 42°C, there is a delay or reduction in emergence due to damage tothe embryonic cell.

Temperature increases cause faster growth and shorter crop duration, as well as a reduction in cumulative light perception and assimilation(Driedonks, Rieu, and Vriezen 2016). Due to high temperature, along with booting, anthesis, and grain filling, there is a negative effect on sexual reproduction especially in male reproductive organsi.ePollen fertility is low, pollination is poor, and no embryos are produced (Ihsan et al. 2019).

The best range for wheat growth and development is 12°C to 22°C but when the temperature rises above the normal range, especially in the reproductive stage, grain yield reduces. In the heat-stressed plant, less tiller is formed, and pollen and pollen viability are reduced, resulting in spikelet sterility (Abdelrahman et al. 2020). When there arefewer tillers, the plant produces less number of grains of poor quality and hasa remarkable reduction in grain yield(Akter and Rafiqul Islam 2017a). In the prolonged drought condition from flowering to grain filling stage, there is a 92% reduction in grain yield (Raza et al. 2019).Wheat productivity depends upon both day and night temperature but night temperature playsa vital role to determine grain yield (Devasirvatham, Tan, and Trethowan, n.d.).

HT also plays a negative impact on water and nutrient relations as it reduces the number, mass, and growth of the roots A important element in nutrient metabolism is the decrease of the enzyme nitrate reductase(Fahad et al. 2017).

Effect of heat stress onwheatphysiology

The reproductive stage of wheat is much more likely to be affected than other stages (Tricker et al. 2018) and to be more detrimental, especially after heading at heat stress(Barlow et al. 2015). Even a 1°C alter in temperature results in unprecedented yield loss in wheat(Raza et al. 2019).Temperatures of 30°C during the day and 25°C at night may have disastrous consequences for wheat leaf development and the formation of productive tillers(Akter and Rafiqul Islam 2017a).In rice, heat treatment of more than 33°C at the heading stage leads to a reduction of another dehiscence and pollen fertility rate which causes sterile seed (Hasanuzzaman et al. 2013). The leaves become senesced and may die as the soil water content is reduced to 18% due to decreased relative water content and leaf water potential when water is withheld under higher temperatures(Farooq et al. 2011).

The review article analyzed by (Iqbal et al. 2017)for thermo-tolerance in wheat shows differences in physiological characteristics like significant changes(increase) in average leaf area(LA), Specific leaf weight (SLW), leaf width, plant height, total dry weight, and days to flowering and maturity of wheat were found to be falling, although leaf area per shoot, leaf weight ratio (LWR), and leaf length were increasing.(Hasanuzzaman et al. 2013)reported that ethylene production due to heat stress causes inhibition of the major enzyme in sugar-starch metabolism causing weakening of sink strength and grain filling finally to produce sterile grain.(Hasanuzzaman et al. 2013)also identified that higher yield is reduced more specifically at pre-silking and silking stage at flowering period than grain filling of maize at heat stress.

Assimilates move from source to sink where steam, leaves, and spikes act as a source of assimilates and grain as a sink. A recent study shows that there arefewer chances of movement of assimilates from source to sink in heat stress plant which means sink limitation is the main responsible factor for poor yield (Abdelrahman et al. 2020).At low moderate heat stress, the activity of the source and sink both decreases naturallybut continuous heat stress may lead to a drastic reduction in growth, economic yield, and harvest index (Wahid et al. 2007).Because the reaction of source, sink, and transport pathway to HS is optimum at 20-30°C, while the significant fall is detected above 30°C, assimilate portioning is indirectly related to dysfunctional behavior of source and sink, as well as lowered photosynthetic rate(Fahad et al. 2017).

Photosynthesis is optimum between 20 to 30°C but it rapidly declines above 30°C so transportation from flag leaves to stem and stems are independent of the temperature range of 1-50°C (Wahid et al. 2007). Leaf tissue water content in sugarcane is found rapidly reduce when exposed to increased temperature along with the number, mass, and growth of the roots limiting the supply of water and nutrients to the shoot system (Fahad et al. 2017).

Heat stress effect on wheat during grain filling and wheat protein

Temperature can have an impact on the critical stage of wheat developmenti.e. grain filling stages.(Tricker et al. 2018) reported that drought and high temperatures in major growing regions reduced the size and weight of individual grains during grain filling by slowing the division rate of endosperm cells and shortening the duration of grain filling..However, because wheat is unable to supply assimilates during the grain filling period, this review does not go into detail about the enhanced delivery of assimilates during grain filling at high temperatures(Barlow et al. 2015). It is reviewed that the post-anthesis period of grain filling is more common to heat shock (Barlow et al. 2015). In a short time of high temperature at the pre-flowering and flowering stages, the capacity of pollen to germinate and the rate of pollen tube growth are fundamentally affected, which can reduce grain number per spike and yield(Ni et al. 2018). For instance,a wheat plant subjected to 30°C for3 days at anthesis shows structurally and functionally, abnormal anthers, in 80% of florets (Ni et al. 2018). According to (Wahid et al. 2007), heat stress elongate the period of grain filling period and reduce kernel weight which leads to a 7% loss in the yield of spring wheat. When temperatures are around 30°C, protein and starch deposition is reduced throughout grain filling phases, and the proportion of gliadin to glutenin increases in heat-stressed samples(Blumenthal, Barlow, and Wrigley 1993).(Devasirvatham, Tan, and Trethowan, n.d.)reported that in wheat, heat stress during the grain filling stage enhances the protein content because there is a reduction in the starch deposition so the protein: starch ratio of seed is high under heat stress conditions. The baking quality of wheat is determined by the starch granule, gluten to gliadin ratio and insoluble protein polymer in grain and starch granule size reduces when the temperature is above 30°C(Devasirvatham, Tan, and Trethowan, n.d.).During high temperatures, reductions in current leaf and ear photosynthesis by heat stress cause a serious problem in the grain filling stage of wheat which leads to drastic low yield by inducing pollen sterility, pollen incompatibility with stigma, and seed abortion. Seed weight, grain yield, and dough quality are all affected as a result of this(Feng et al. 2014; Ihsan et al. 2019).Heat shock causes premature senescence, decreased leaf chlorophyll, suppression of kernel growth due to reduced photosynthate translocation to the grain, and starch synthesis and deposition in the developing grain during grain filling(Barlow et al. 2015).

(Blumenthal, Barlow, and Wrigley 1993)a suggested mechanism that by identifying many heat shock elements in gliadin genes, grain filling might produce altered quality characteristics, and these gliadin genes allow synthesis of gliadin during high-temperature while synthesis of glutenin decreased. When the flowering period of wheat and stress condition occurs simultaneously, the nutritional and milling quality of wheat reduces(Devasirvatham, Tan, and Trethowan, n.d.).

Heat stress effect on photosynthesis

Photosynthesis is one of the most heat-sensitive physiological processes in plants. Heat stress causes significant changes in chloroplasts, such as modified structural organization of thylakoids, damage to grana stacking, and change in the structure of grana (Hasanuzzaman et al. 2013).Photosynthesis system both the components existing in a dark and light-dependent reaction is more liable to be affected by heat stress which causesa prominent change in the electron transport chain decreasing the rate of chlorophyll content affecting photosynthesis (Ihsan et al. 2019).The activity of 5-aminolevulinate dehydratase, an important enzyme in the pyrrole biosynthesis pathway, decreased significantly in wheat under heat stress as a result of the deactivation of various enzymes, including 5-aminolevulinate dehydratase, an essential enzyme in the pyrrole biosynthesis pathway(Fahad et al. 2017). Likewise, there is a reduction in the action of key enzymes such as sucrose phosphate synthetase, adenosine diphosphate-glucose pyrophosphorylase, and inventors, and, all of which affect starch and sucrose synthesis.

Heat stress affects the structure and function of the chloroplast where photosynthesis takes place, resulting in a decrease in chlorophyll content(Farooq et al. 2011).Degeneration of mitochondria along with reduction of ATP accumulation and oxygen uptake in imbibing wheat embryos with an increase in high temperature(Akter and Rafiqul Islam 2017a).Heat creates changes in photosynthetic pigment and components. Due to high temperature, plants lose the balance between the production of relative oxygen species(ROS) and also acts as an antioxidant defense but its high secretion interrupts water and ion homeostasis leading to inhibition of plant growth and development(Mohammadi 2018; Ihsan et al. 2019)and free radicals at cellular levels disturbs the normal function by altering its organelles shapes, protein assembly and denaturation of enzymes (Ihsan et al. 2019).When there is less water in the cell, the plant closesits stomata which decreases carbondioxide influx. Carbon dioxide reduction inhibits carboxylation directly, but it also carries more electrons, resulting in the formation of reactive oxygen species (ROS)(Mohammadi 2018). The activities of ribulose 1,5-bisulphate carboxylase/oxygenase NADP-malic enzyme (NADP-ME), fructose-1,6-bisulphate (FBPase), and pyruvate orthophosphate dikinase (PPDK) are lowered in severe drought conditions, which is directly linked to a reduction in the photosynthetic process(Mohammadi 2018).The disruption of the central enzyme of photosynthesis i.e. Rubisco enzyme takes place when the temperature climbs up from 35° leading to the termination of photosynthesis (Raza et al. 2019). The Rubisco enzyme is more sensitive than other enzymes participating in carboxylation so the catalytic activity of Rubisco has a low affinity for carbondioxide and its ability to behave as oxygenase confined the probability of increasing net photosynthesis with high temperature (Farooq et al. 2011).The heat-tolerance adjustment of the PSII is affected by temperature increases in leaf and photon flux density, according to (Fahad et al. 2017).

Table: (Fahad et al. 2017)Activity of the photosynthetic enzyme

crops	stress	enzyme	activity
Wheat	heat	Rubisco	Reduced
Cotton	heat	Rubisco	Reduced
Sugarcane	drought	PEP carboxylase	Reduced
maize	heat	Rubisco-activase	Reduced

Effect of heat stress on biochemistry

The quality of starch is determined by the major constituents, amylase, and amylopectin present in wheat. High-temperature cause a reduction in starch content by 1/3rd of total endosperm starch due to a decrease in efficiency of AGPase and starch synthase enzyme involved in starch biosynthesis (Akter and Rafiqul Islam 2017a). At a high temperature of around 40°C, there is a drastic decrease in starch deposition and lower grain size but the reduction of soluble starch synthase activity upto 30°C doesn't affect starch deposition but affects starch composition (Akter and Rafiqul Islam 2017a).

Heat stress affects membrane composition and stability

Heat shock impairs cellular function by increasing cell membrane permeability, resulting in protein denaturation and an increase in unsaturated fatty acids, which obstructs the flow of water, ions, and organic solutes across membranes(Ni et al. 2018). The high temperature causes thylakoid membranes to swell, increasing leakiness and the physical apartment of chlorophyll light-harvesting complex II from the PSII core complex, resulting in cell death(Cossani and Reynolds 2012)

The chemical composition, metabolism, morphology, quantity, and quality of pollen at 30°C during a 3-d period lead impaired phase of gametogenesis fertility which results in reduced pollen viability under HS. In female reproductive organs, the development of an abnormal ovary along with accelerated stigma causes reduced pollen tube growth and seed formation during meiosis when coinciding with HS (Cossani and Reynolds 2012).

Tolerance mechanism of wheat against heat stress

Plants have a different defensive mechanisms for dealing with HS. The key three strategies that allow plants to live and thrive in high-temperature environments are avoidance, escape, and tolerance.

Release of heat-shock protein

Hsp100, Hsp90, Hsp70, Hsp60(Chaperonins), small Hsps, and ubiquitin are the different classes under the family of heat shock protein(Science and 2009 2009; Grigorova et al. 2011).

The specific proteins formed after the changes in protein synthesis accompanied by high-temperature stress are called heat-shock proteins (HSPs). It is a cosmopolitan response shown by all organisms ranging from bacteria and human beings and its large diversification shows it is an adaptation mechanism to temperature stress i.e. HSPs act as thermo-tolerance reactions (Iqbal et al. 2017). The stages like grain filling and other stages which are subjected to heat stress and released heat shock proteins may affect grain quality and grain yield. The induction of HSPs depends on temperature i.e. temperature above normal growing from 4°C to 14°C indicated heat shock proteins are produced in wheat leaves, shoots, embryos, endosperm, bracts, and glumes (Blumenthal, Barlow, and Wrigley 1993). When a plant faces heat shock(30-38°C) for 3 days at the end of a tillering phase, the photosynthetic rate devaluates. It is found that there is a devaluation in the photosynthetic rate by 40-70% (Devasirvatham, Tan, and Trethowan, n.d.). The different families of HSPs include HSP900 family, HSP100, HSP60, and HSP70 which are associated with different functions under HS conditions (Table 1). Heat Stress Transcription Factors (Hsfs) are dormant proteins found in the cytoplasm that act as transcriptional regulators for HSP genes, and these Hsfs serve as transcriptional activators in the presence of HS(Padam Bahadur Poudel and Mukti Ram Poudel 2020).

Table 1: Heat shock proteins function under heat stress.

Heat shock proteins	Functions	References
HSP100	Protect protein denaturation or aggregation of the protein.	(Padam Bahadur Poudel and Mukti Ram Poudel 2020; Science and 2009 2009)
HSP70	Binds to denatured proteins facilitating protein refolding/assembly accompanied by hydrolysis of ATP.	(Vierling 1991)
HSP60	Correct assembly of protein synthesized in mitochondria using nucleus-encoded folding.	(Grigorova et al. 2011)
HSP90	Manage protein folding, protein degradation, and protein trafficking.	(Science and 2009 2009)

Reactive oxygen species(ROs) and antioxidative defense mechanism

The mitochondrial site is where oxygen metabolism occurs, where the cell consumes approximately 85 percent of the oxygen(Slimen et al. 2014). The balance between the production and scavenging of ROS takes place in normal cell conditions(Padam Bahadur Poudel and Mukti Ram Poudel 2020). The plant produces unfavorable reactive oxygen species (ROS) such as superoxide (O2), singlet oxygen (O2),(Slimen et al. 2014), and hydroxyl radical(OH) under heat stress (Padam Bahadur Poudel and Mukti Ram Poudel 2020).

The ROS defense mechanism consists of two components: non-enzymatic and enzymatic antioxidants that aid in the reduction of oxidative stress caused by heat stress.(Das and Roychoudhury 2014).

Table 2: Role of different antioxidants in scavenging ROS.

Antioxidants	functions	References
Enzymatic antioxidants		
Superoxide dismutase(SOD)	Catalyzes the dismutation of O2•– to H2O2and O_2	(Padam Bahadur Poudel and Mukti Ram Poudel 2020)
Catalase(CAT)	Dismutation by catalyzing H_2O_2 into H_2O and O_2.	(Das and Roychoudhury 2014)
Guaiacol peroxidase(GPX)	Removal of H_2O_2	(Padam Bahadur Poudel and Mukti Ram Poudel 2020)
APX	Scavenges H_2O_2 into H_2O and DHA	(Das and Roychoudhury 2014)
Non-enzymatic antioxidants		
Ascorbic Acid(AA)	Detoxifies H_2O_2 through the action of APX	(Das and Roychoudhury 2014)
Reduced Glutathione(GSH)	Scavenges hydrogen peroxide, singlet oxygen, hydroxyl, etc.	(Padam Bahadur Poudel and Mukti Ram Poudel 2020)
Flavonoids	Scavenging of H_2O_2 and singlet oxygen and hydroxyl.	(Agati et al. 2012)

Conclusion

The above review article encompasses the overall effects of heat stress on wheat. But most significantly, we reviewed that during high temperatures, reductions in current leaf and ear photosynthesis by heat stress cause a serious problem in the grain filling stage of wheat which leads to drastic low yield by inducing pollen sterility, pollen incompatibility with stigma, and seed abortion. This decreases seed weight, grain yield, and dough quality. These problems seek the attention of researchers and plant breeders to take various strategies and breeding programs through various understanding to cope with heat stress. The basis for high genetic differences is possible by evaluating wheat germplasm genetic variation which helps in discovering various parental combinations and producing segregating progeny.Improving the genetic variability of wheat varieties could increase output.

Acknowledgment

We are sincerely thankful to Assistant Prof. Dr. Mukti Ram Poudel, Department of Plant breeding, Paklihawa Campus, Institute of Agriculture and Animal Science for his constructive guidance and valuable advice for the completion of the manuscript.

Conflict of interest

The authors state that the publication of this work does not include any conflicts of interest.

References:

Abdelrahman, Mostafa, David J. Burritt, Aarti Gupta, Hisashi Tsujimoto, Lam Son Phan Tran, and Christine Foyer. 2020. "Heat Stress Effects on Source-Sink Relationships and Metabolome Dynamics in Wheat." *Journal of Experimental Botany* 71 (2): 543–54. https://doi.org/10.1093/jxb/erz296.

Agati, Giovanni, Elisa Azzarello, Susanna Pollastri, and Massimiliano Tattini. 2012. "Flavonoids as Antioxidants in Plants: Location and Functional Significance." *Plant Science* 196: 67–76. https://doi.org/10.1016/j.plantsci.2012.07.014.

Akter, Nurunnaher, and M. Rafiqul Islam. 2017a. "Heat Stress Effects and Management in Wheat. A Review." *Agronomy for Sustainable Development* 37 (5): 1–6. https://doi.org/10.1007/s13593-017-0443-9.

———. 2017b. "Heat Stress Effects and Management in Wheat. A Review." *Agronomy for Sustainable Development* 37 (5). https://doi.org/10.1007/S13593-017-0443-9.

Barlow, K. M., B. P. Christy, G. J. O'Leary, P. A. Riffkin, and J. G. Nuttall. 2015. "Simulating the Impact of Extreme Heat and Frost Events on Wheat Crop Production: A Review." *Field Crops Research* 171: 109–19. https://doi.org/10.1016/j.fcr.2014.11.010.

Blumenthal, C. S., E. W.R. Barlow, and C. W. Wrigley. 1993. "Growth Environment and Wheat Quality: The Effect of Heat Stress on Dough Properties and Gluten Proteins." *Journal of Cereal Science*. https://doi.org/10.1006/jcrs.1993.1030.

Cossani, C. Mariano, and Matthew P. Reynolds. 2012. "Physiological Traits for Improving Heat Tolerance in Wheat." *Plant Physiology* 160 (4): 1710–18. https://doi.org/10.1104/pp.112.207753.

Das, Kaushik, and Aryadeep Roychoudhury. 2014. "Reactive Oxygen Species (ROS) and Response of Antioxidants as ROS-Scavengers during Environmental Stress in Plants." *Frontiers in Environmental Science* 2 (DEC): 1–13. https://doi.org/10.3389/fenvs.2014.00053.

Devasirvatham, Viola, Daniel K Y Tan, and Richard M Trethowan. n.d. "Breeding Strategies for Enhanced Plant Tolerance to Heat Stress." https://doi.org/10.1007/978-3-319-22518-0.

Driedonks, Nicky, Ivo Rieu, and Wim H. Vriezen. 2016. "Breeding for Plant Heat Tolerance at Vegetative and Reproductive Stages." *Plant Reproduction* 29 (1–2): 67–79. https://doi.org/10.1007/s00497-016-0275-9.

Fahad, Shah, Ali A. Bajwa, Usman Nazir, Shakeel A. Anjum, Ayesha Farooq, Ali Zohaib, Sehrish Sadia, et al. 2017. "Crop Production under Drought and Heat Stress: Plant Responses and Management Options." *Frontiers in Plant Science* 8 (June): 1–16. https://doi.org/10.3389/fpls.2017.01147.

Farooq, Muhammad, Helen Bramley, Jairo A. Palta, and Kadambot H.M. Siddique. 2011. "Heat Stress in Wheat during Reproductive and Grain-Filling Phases." *Critical Reviews in Plant Sciences* 30 (6): 491–507. https://doi.org/10.1080/07352689.2011.615687.

Feng, B., P. Liu, G. Li, S. T. Dong, F. H. Wang, L. A. Kong, and J. W. Zhang. 2014. "Effect of Heat Stress on the Photosynthetic Characteristics in Flag Leaves at the Grain-Filling Stage of Different Heat-Resistant Winter Wheat Varieties." *Journal of Agronomy and Crop Science* 200 (2): 143–55. https://doi.org/10.1111/jac.12045.

Grigorova, B, I Vaseva, K Demirevska, and U Feller. 2011. "The Roles of Heat Shock Proteins in Plants." *Annualreviews.Org* 55 (1): 105–11. https://www.annualreviews.org/-doi/pdf/10.1146/annurev.pp.42.060191.003051.

Hasanuzzaman, Mirza, Kamrun Nahar, Md Mahabub Alam, Rajib Roychowdhury, and Masayuki Fujita. 2013. "Physiological, Biochemical, and Molecular Mechanisms of Heat Stress Tolerance in Plants." *International Journal of Molecular Sciences* 14 (5): 9643–84. https://doi.org/10.3390/ijms14059643.

Ihsan, Muhammad Zahid, Ihsanullah Daur, Fahad Alghabari, Saleh Alzamanan, Shahid Rizwan, Maqshoof Ahmad, Muhammad Waqas, and Waqas Shafqat. 2019. "Heat Stress and Plant Development: Role of Sulphur Metabolites and Management Strategies." *Acta Agriculturae Scandinavica Section B: Soil and Plant Science* 69 (4): 332–42. https://doi.org/10.1080/09064710.2019.1569715.

Iqbal, Muhammad, Naveed Iqbal Raja, Farhat Yasmeen, Mubashir Hussain, Muhammad Ejaz, and Muhammad Ali Shah. 2017. "Impacts of Heat Stress on Wheat: A Critical Review." *Advances in Crop Science and Technology* 5 (1): 1–9. https://doi.org/10.4172/2329-8863.1000251.

Mohammadi, Reza. 2018. "Breeding for Increased Drought Tolerance in Wheat: A Review." *Crop and Pasture Science* 69 (3): 223–41. https://doi.org/10.1071/CP17387.

Ni, Zhongfu, Hongjian Li, Yue Zhao, Huiru Peng, Zhaorong Hu, Mingming Xin, and Qixin Sun. 2018. "Genetic Improvement of Heat Tolerance in Wheat: Recent Progress in Understanding the Underlying Molecular Mechanisms." *Crop Journal* 6 (1): 32–41. https://doi.org/10.1016/j.cj.2017.09.005.

Padam Bahadur Poudel, and Mukti Ram Poudel. 2020. "Heat Stress Effects and Tolerance in Wheat: A Review." *Journal of Biology and Today's World* 9 (3): 1–6. https://www.iomcworld.org/articles/heat-stress-effects-and-tolerance-in-wheat-a-review-53182.html.

Poudel, Mukti Ram, Suryakant Ghimire, Madhav Prasad P, ey, Krishnahari Dhakal, Dhruba Bahadur Thapa, and Hema Kumari Poudel. 2020. "Yield Stability Analysis of Wheat Genotypes at Irrigated, Heat Stress and Drought Condition." *Journal of Biology and Today's World* 9 (4): 1–10. https://www.iomcworld.org/abstract/yield-stability-analysis-of-wheat-genotypes-at-irrigated-heat-stress-and-drought-condition-53403.html.

Puri, Ramesh Raj, Nutan Raj Gautam, and Arun Kumar Joshi. 2015. "Exploring Stress Tolerance Indices to Identify Terminal Heat Tolerance in Spring Wheat in Nepal" 7 (1): 13–17.

Raza, Ali, Ali Razzaq, Sundas Saher Mehmood, Xiling Zou, Xuekun Zhang, Yan Lv, and Jinsong Xu. 2019. “Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review.” *Plants* 8 (2). https://doi.org/10.3390/plants8020034.

Science, B Efeoğlu - Gazi University Journal of, and undefined 2009. 2009. “Heat Shock Proteins and Heat Shock Response in Plants.” *Dergipark.Org.Tr* 22 (2): 67–75. https://dergipark.org.tr/en/pub/gujs/issue/7389/96762.

Slimen, Imen Belhadj, Taha Najar, Abdeljelil Ghram, Hajer Dabbebi, Moncef Ben Mrad, and Manef Abdrabbah. 2014. “Reactive Oxygen Species, Heat Stress and Oxidative-Induced Mitochondrial Damage. A Review.” *International Journal of Hyperthermia* 30 (7): 513–23. https://doi.org/10.3109/02656736.2014.971446.

Tricker, Penny J., Abdeljalil Elhabti, Jessica Schmidt, and Delphine Fleury. 2018. “The Physiological and Genetic Basis of Combined Drought and Heat Tolerance in Wheat.” *Journal of Experimental Botany* 69 (13): 3195–3210. https://doi.org/10.1093/jxb/ery081.

Vierling, Elizabeth. 1991. “The Roles of Heat Shock Proteins in Plants.” *Annual Review of Plant Physiology and Plant Molecular Biology* 42 (1): 579–620. https://doi.org/10.1146/ANNUREV.PP.42.060191.003051.

Wahid, A., S. Gelani, M. Ashraf, and M. R. Foolad. 2007. “Heat Tolerance in Plants: An Overview.” *Environmental and Experimental Botany* 61 (3): 199–223. https://doi.org/10.1016/j.envexpbot.2007.05.011.

Abdelrahman, Mostafa, David J. Burritt, Aarti Gupta, Hisashi Tsujimoto, Lam Son Phan Tran, and Christine Foyer. 2020. “Heat Stress Effects on Source-Sink Relationships and Metabolome Dynamics in Wheat.” *Journal of Experimental Botany* 71 (2): 543–54. https://doi.org/10.1093/jxb/erz296.

Agati, Giovanni, Elisa Azzarello, Susanna Pollastri, and Massimiliano Tattini. 2012. “Flavonoids as Antioxidants in Plants: Location and Functional Significance.” *Plant Science* 196: 67–76. https://doi.org/10.1016/j.plantsci.2012.07.014.

Akter, Nurunnaher, and M. Rafiqul Islam. 2017a. “Heat Stress Effects and Management in Wheat. A Review.” *Agronomy for Sustainable Development* 37 (5): 1–6. https://doi.org/10.1007/s13593-017-0443-9.

———. 2017b. “Heat Stress Effects and Management in Wheat. A Review.” *Agronomy for Sustainable Development* 37 (5). https://doi.org/10.1007/S13593-017-0443-9.

Barlow, K. M., B. P. Christy, G. J. O’Leary, P. A. Riffkin, and J. G. Nuttall. 2015. “Simulating the Impact of Extreme Heat and Frost Events on Wheat Crop Production: A Review.” *Field Crops Research* 171: 109–19. https://doi.org/10.1016/j.fcr.2014.11.010.

Blumenthal, C. S., E. W.R. Barlow, and C. W. Wrigley. 1993. “Growth Environment and Wheat Quality: The Effect of Heat Stress on Dough Properties and Gluten Proteins.” *Journal of Cereal Science*. https://doi.org/10.1006/jcrs.1993.1030.

Cossani, C. Mariano, and Matthew P. Reynolds. 2012. “Physiological Traits for Improving Heat Tolerance in Wheat.” *Plant Physiology* 160 (4): 1710–18. https://doi.org/10.1104/pp.112.207753.

Das, Kaushik, and Aryadeep Roychoudhury. 2014. “Reactive Oxygen Species (ROS) and Response of Antioxidants as ROS-Scavengers during Environmental Stress in Plants.” *Frontiers in Environmental Science* 2 (DEC): 1–13. https://doi.org/10.3389/fenvs.2014.00053.

Devasirvatham, Viola, Daniel K Y Tan, and Richard M Trethowan. n.d. “Breeding Strategies for Enhanced Plant Tolerance to Heat Stress.” https://doi.org/10.1007/978-3-319-22518-0.

Driedonks, Nicky, Ivo Rieu, and Wim H. Vriezen. 2016. “Breeding for Plant Heat Tolerance at Vegetative and Reproductive Stages.” *Plant Reproduction* 29 (1–2): 67–79. https://doi.org/10.1007/s00497-016-0275-9.

Fahad, Shah, Ali A. Bajwa, Usman Nazir, Shakeel A. Anjum, Ayesha Farooq, Ali Zohaib, Sehrish Sadia, et al. 2017. “Crop Production under Drought and Heat Stress: Plant Responses and Management Options.” *Frontiers in Plant Science* 8 (June): 1–16. https://doi.org/10.3389/fpls.2017.01147.

Farooq, Muhammad, Helen Bramley, Jairo A. Palta, and Kadambot H.M. Siddique. 2011. “Heat Stress in Wheat during Reproductive and Grain-Filling Phases.” *Critical Reviews in Plant Sciences* 30 (6): 491–507. https://doi.org/10.1080/07352689.2011.615687.

Feng, B., P. Liu, G. Li, S. T. Dong, F. H. Wang, L. A. Kong, and J. W. Zhang. 2014. “Effect of Heat Stress on the Photosynthetic Characteristics in Flag Leaves at the Grain-Filling Stage of Different Heat-Resistant Winter Wheat Varieties.” *Journal of Agronomy and Crop Science* 200 (2): 143–55. https://doi.org/10.1111/jac.12045.

Grigorova, B, I Vaseva, K Demirevska, and U Feller. 2011. “The Roles of Heat Shock Proteins in Plants.” *Annualreviews.Org* 55 (1): 105–11. https://www.annualreviews.org/doi/pdf/10.1146/annurev.pp.42.060191.003051.

Hasanuzzaman, Mirza, Kamrun Nahar, Md Mahabub Alam, Rajib Roychowdhury, and Masayuki Fujita. 2013. “Physiological, Biochemical, and Molecular Mechanisms of Heat Stress Tolerance in Plants.” *International Journal of Molecular Sciences* 14 (5): 9643–84. https://doi.org/10.3390/ijms14059643.

Ihsan, Muhammad Zahid, Ihsanullah Daur, Fahad Alghabari, Saleh Alzamanan, Shahid Rizwan, Maqshoof Ahmad, Muhammad Waqas, and Waqas Shafqat. 2019. “Heat Stress and Plant Development: Role of Sulphur Metabolites and Management Strategies.” *Acta Agriculturae Scandinavica Section B: Soil and Plant Science* 69 (4): 332–42. https://doi.org/10.1080/09064710.2019.1569715.

Iqbal, Muhammad, Naveed Iqbal Raja, Farhat Yasmeen, Mubashir Hussain, Muhammad Ejaz, and Muhammad Ali Shah. 2017. “Impacts of Heat Stress on Wheat: A Critical Review.” *Advances in Crop Science and Technology* 5 (1): 1–9. https://doi.org/10.4172/2329-8863.1000251.

Mohammadi, Reza. 2018. “Breeding for Increased Drought Tolerance in Wheat: A Review.” *Crop and Pasture Science* 69 (3): 223–41. https://doi.org/10.1071/CP17387.

Ni, Zhongfu, Hongjian Li, Yue Zhao, Huiru Peng, Zhaorong Hu, Mingming Xin, and Qixin Sun. 2018. “Genetic Improvement of Heat Tolerance in Wheat: Recent Progress in Understanding the Underlying Molecular Mechanisms.” *Crop Journal* 6 (1): 32–41. https://doi.org/10.1016/j.cj.2017.09.005.

Padam Bahadur Poudel, and Mukti Ram Poudel. 2020. “Heat Stress Effects and Tolerance in Wheat: A Review.” *Journal of Biology and Today’s World* 9 (3): 1–6. https://www.iomcworld.org/articles/heat-stress-effects-and-tolerance-in-wheat-a-review-53182.html.

Poudel, Mukti Ram, Suryakant Ghimire, Madhav Prasad P, ey, Krishnahari Dhakal, Dhruba Bahadur Thapa, and Hema Kumari Poudel. 2020. “Yield Stability Analysis of Wheat Genotypes at Irrigated, Heat Stress and Drought Condition.” *Journal of Biology and Today’s World* 9 (4): 1–10. https://www.iomcworld.org/abstract/yield-stability-analysis-of-wheat-genotypes-at-irrigated-heat-stress-and-drought-condition-53403.html.

Puri, Ramesh Raj, Nutan Raj Gautam, and Arun Kumar Joshi. 2015. “Exploring Stress Tolerance Indices to Identify Terminal Heat Tolerance in Spring Wheat in Nepal” 7 (1): 13–17.

Raza, Ali, Ali Razzaq, Sundas Saher Mehmood, Xiling Zou, Xuekun Zhang, Yan Lv, and Jinsong Xu. 2019. “Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review.” *Plants* 8 (2). https://doi.org/10.3390/plants8020034.

Science, B Efeoğlu - Gazi University Journal of, and undefined 2009. 2009. “Heat Shock Proteins and Heat Shock Response in Plants.” *Dergipark.Org.Tr* 22 (2): 67–75. https://dergipark.org.tr/en/pub/gujs/issue/7389/96762.

Slimen, Imen Belhadj, Taha Najar, Abdeljelil Ghram, Hajer Dabbebi, Moncef Ben Mrad, and Manef Abdrabbah. 2014. “Reactive Oxygen Species, Heat Stress and Oxidative-Induced Mitochondrial Damage. A Review.” *International Journal of Hyperthermia* 30 (7): 513–23. https://doi.org/10.3109/02656736.2014.971446.

Tricker, Penny J., Abdeljalil Elhabti, Jessica Schmidt, and Delphine Fleury. 2018. “The Physiological and Genetic Basis of Combined Drought and Heat Tolerance in Wheat.” *Journal of Experimental Botany* 69 (13): 3195–3210. https://doi.org/10.1093/jxb/ery081.

Vierling, Elizabeth. 1991. “The Roles of Heat Shock Proteins in Plants.” *Annual Review of Plant Physiology and Plant Molecular Biology* 42 (1): 579–620. https://doi.org/10.1146/ANNUREV.PP.42.060191.003051.

Wahid, A., S. Gelani, M. Ashraf, and M. R. Foolad. 2007. “Heat Tolerance in Plants: An Overview.” *Environmental and Experimental Botany* 61 (3): 199–223. https://doi.org/10.1016/j.envexpbot.2007.05.011.