IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

IJARSCT

Impact Factor: 6.252

Volume 2, Issue 9, June 2022

# Impact of Rising Atmospheric Temperature on Wheat

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**Abstract:** *Since the industrial revolution, temperatures have been steadily rising over the world at a pace of 0.15 to 0.17°Cevery decade. The productivity of agricultural crops is being impacted. To maintain crop output under increased temperatures, thermotolerance measures are therefore required. More than 80% of the world's population relies on wheat, a significant grain crop, as a source of essential protein and calories. Concerns about how rising temperatures could affect wheat output due to recent global climate change are spreading around the globe. Abiotic stressors such as heat and drought are what primarily limit wheat productivity. Under projected future climatic scenarios, extreme weather events (such as frost and heat shock), which presently pose a considerable burden to grain growers, are expected to get worse. The crucial physiological and biochemical processes of the plant are halted by heat stress. Stress brought on by high temperatures decreases the quantity of grains, photosynthetic activity, chlorophyll content, and endosperm starch synthesis. The high temperature has a negative impact on the phenology, growth, and development of the crop. The pollen viability, seed germination, and embryo development are all slowed down by the high temperature before anthesis. The accumulation of starch granules, stem reserve carbohydrates, and photosynthate translocation into grains are all reduced by the high postanthesis temperature. A temperature above 400°C prevents photosynthesis from happening by harming photosystem-I, photosystem-II, and the electron transport chain. The crop suffers significant oxidative damage when reactive oxygen species that have accumulated due to heat stress. In order to reduce the effects of heat stress, plants quickly synthesise heat shock proteins.*

**Keywords:** Atmospheric Temperature.

## I. INTRODUCTION

An increase in greenhouse gases including carbon dioxide ($CO_2$), nitrous oxide, and methane is what causes climate change ($CH_4$). The severity of extreme occurrences for crop development can be increased by these gases' ability to trap solar radiation (Xiao *et al*., 2018). Early in the 1960s, $CO_2$ levels climbed by 0.6±0.1 ppm/year, and within the past ten years, they increased by 2.3±0.6 ppm/year. In the meantime, the amount of $CH_4$ gas has doubled since the Industrial Revolution and has continued to rise at a rate of 12 parts per billion each year. But during the past three decades, it has been rising by 2 to 5 parts per billion year. The annual increase in nitrous oxide content was 0.8 parts per billion, or 18% greater than in the 1970s (Nicolai *et al*., 2019).

Extreme weather patterns, an increase in disease prevalence and insect pest survival, and eventually crop yield are all impacted by the rising levels of global warming. In comparison to $CO_2$, the global warming potential (GWP) of a compound is the amount of warmth it can cause over a century. It enables comparisons between the various gas contributions to global warming and the amount of energy that 1 tonne of gas absorbs compared to 1 tonne of $CO_2$ during a specific time frame. The greater the global warming potential, the more likely it is that the given gas will continue to exist and have the power to raise Earth's temperature throughout time. Over a 100-year period, the GWP of carbon dioxide is 1, $CH_4$ is 28–36, and nitrous oxide is 265-298. Although these gases have a greater capacity and persistence to absorb solar radiation than $CO_2$, $CO_2$ is a major factor in global warming (Skytt *et al*., 2020). Abiotic (heat, drought, and salinity) and biotic (diseases and insect pests) variables affect the productivity of agricultural crops. The increased temperature is one of the key abiotic factors affecting crop growth and development. According to the Intergovernmental Panel on Climate Change (IPCC), the average global temperature increased by 1.5°C starting in the 1970s and was expected to rise by 2.5 to 5.8°C until the year 2100. The National Oceanic and Atmospheric

Administration reports that the average annual global temperature has risen by 0.04-0.07°C and 0.15-0.17°C every decade during the 1880s and 1970s, respectively (NOAA, 2018). Therefore, the challenge of increasing crop yield potential exists due to global warming, which is characterised by an extreme temperature. Therefore, it is imperative to comprehend how wheat reacts to the high temperature and to develop a suitable plan of action to increase its productivity.

One of the most important cereal crops, wheat (*Triticum* spp.), contributes to around 30% of global grain output and 50% of global grain trade (Akter and Islam, 2017). More than 40 nations throughout the world regard wheat to be a staple crop, and 85% and 82% of the world's population, respectively, rely on it for their daily protein and calorie needs (Sharma *et al*., 2019). According to FAO estimates, there must be a nearly one billion increase in yearly cereal production to feed the expected 9.1 billion people by 2050. The 21$^{st}$ century calls for increased crop yield and production in order to meet the rising demand for food. Wheat is grown in tropical and subtropical climates, which are subject to a number of abiotic stressors. Crop output is severely reduced by adverse environmental conditions. Heat, drought, salinity, cold, chemical, and water surplus are some of the main abiotic stressors. However, the primary abiotic factors impacting wheat productivity globally are heat and drought. By the end of the twenty-first century, the mean ambient temperature is predicted to increase by 6°C according to the global climate model (De Costa WAJM, 2011). Under future climate scenarios, extreme weather events are expected to become even more problematic for grain growers (Zheng *et al*., 2012). With the exception of the United States, all of the main agricultural nations have experienced an increase in temperatures since 1980. (Lobell *et al*., 2011). According to Teixeira *et al*. (2013), global analysis of potential "hot-spots," the main cropping regions at risk of heat stress were continental lands in the high latitudes (between 40 and 60 N), particularly Central and Eastern Asia, Central North America, and the northern part of the Indian subcontinent. According to future climate forecasts, it has been shown by Gouache et al. (2012) that rising heat stress will significantly contribute to lower wheat yields in France.

## II. IMPACT OF HIGH TEMPERATURE ON WHEAT

In tropical, subtropical, dry, and semi-arid parts of the world, high temperatures have an impact on the production of the wheat crop. While the Mediterranean region's reproductive stage is very susceptible to temperature, the high temperature in the tropical region is an unavoidable restraint for wheat during the germination and early growth phases (Akter and Islam, 2017). With the current production techniques and varieties, a high temperature of 3–4°C above the optimal temperature at grain filling reduces the yield of wheat in Asia by 10–50%. (Hussain *et al*., 2018). Depending on the type of wheat used, high temperatures reduce grain output by 0.07 percent per °C. (Nuttall *et al*., 2018).Each degree of temperature increase during the grain filling period lowers wheat output by 6% globally and by 3–17% in South Asia, which includes India and Pakistan (Pask *et al*., 2014). It attributed, directly or indirectly, the alteration in many cellular, physiological, and metabolic pathways linked to the wheat grain yield (Figure 1).

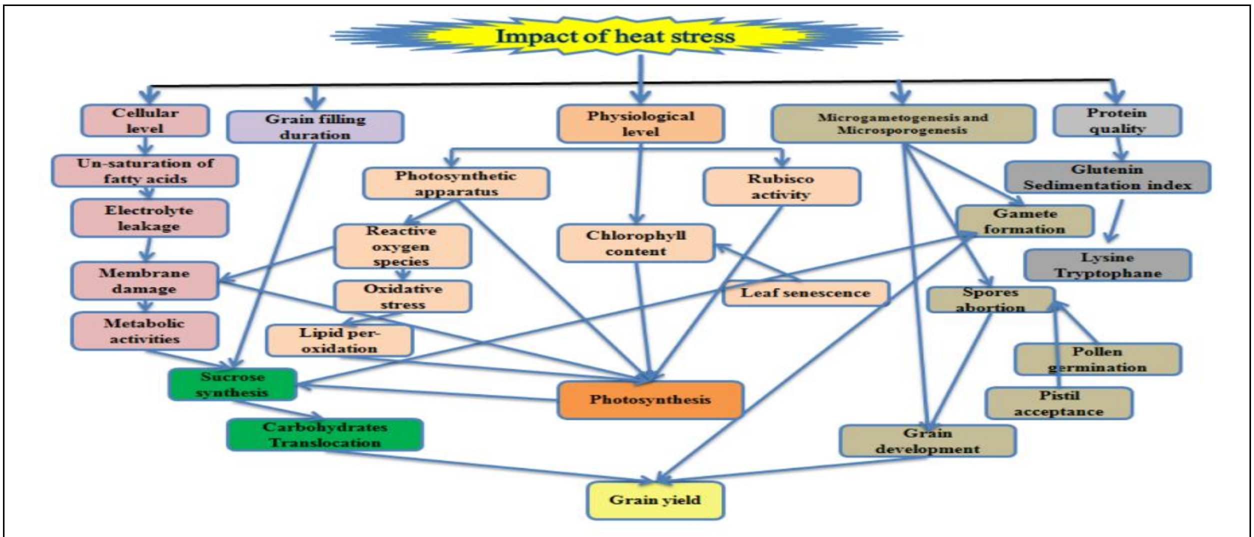


**Figure 1.** Schematic illustration of the high temperature impact on wheat associated with the grain yield.

IJARSCT
ISSN (Online) 2581-9429
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### 2.1 Cellular Metabolism

Lipids and proteins make up the highly ordered structure known as the plasma membrane. It controls ion transport and enzymatic activity. Microtubule organisation, expansion, elongation, and cell differentiation are all affected by high temperature. It results in membrane fluidity, decreases nearby fatty acid hydrogen bonds, and raises their kinetic energy. The electrolyte leakage is brought on by this fluidity, unsaturation of fatty acids, and disruption of several proteins. According to ElBasyoni *et al*. (2017), high temperature results in electrolyte leakage of 25–55% at 45 °C for 1 h and 21–40% at 40 °C for 30 min (Khan *et al*., 2013). As a result, the cell suffers damage to its internal structure and physiological functions that are necessary for the synthesis and transfer of carbohydrates into the grains, such as photosynthesis, respiration, and transpiration.

### 2.2 Grain Filling Duration

High temperatures compel plants to finish their growth cycle days earlier, which leads to a shorter lifespan, reduced accumulation of biosynthetic products, and eventually inferior grain development. The photoperiodic (PPD-A1, PPD-D1) sensitive gene and the vernalization (VRN1, VRN2) gene govern the developmental phases at volatile temperature events and cause earliness in wheat by restricting different growth periods (Dubcovsky et al., 2006). The proper grain development related with the grain yield is determined by the longer grain filling period (Whittal *et al*., 2018). High temperatures, however, shorten the time needed for the intake of available nutrients and the movement of photosynthates.

### 2.3 Grain Formation and Development

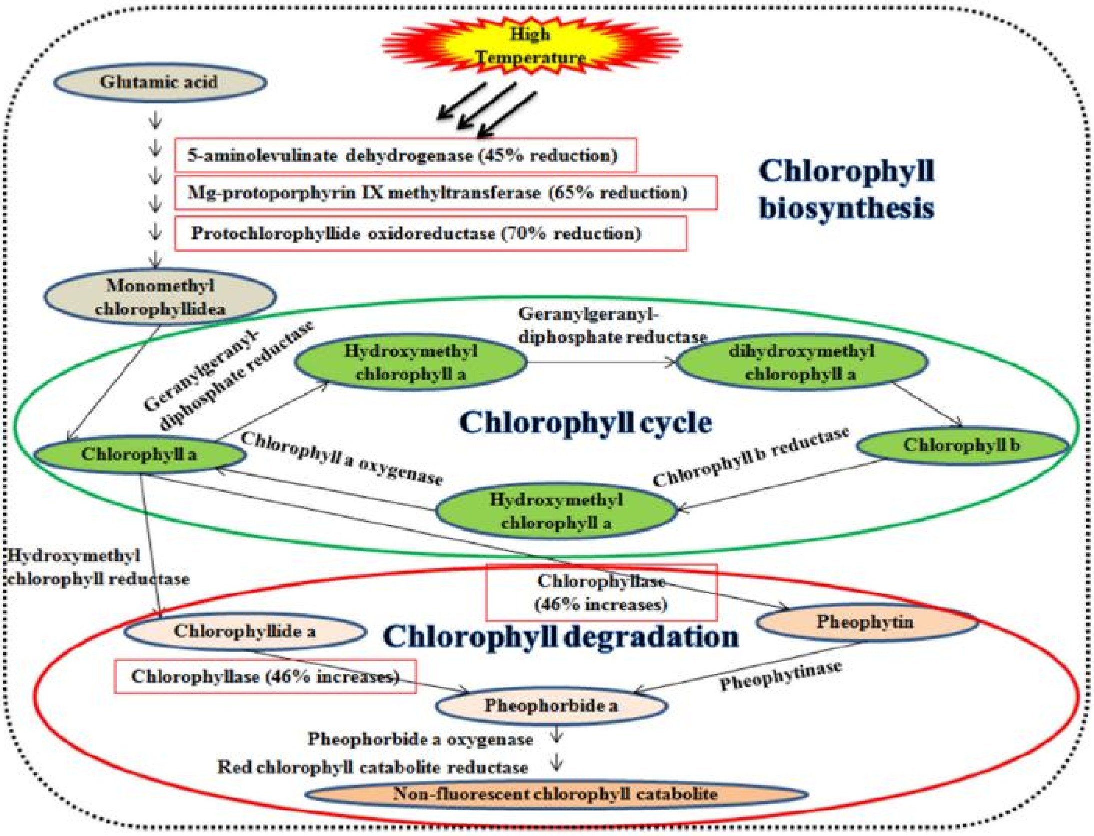


**Figure 2.** Impact on the high temperature of leaf senescence. Enzymes associated with chlorophyll synthesis viz., 5-aminolevulinate dehydrogenase, mg-protoporphyrin IX methyltransferase, and protochlorophyllide oxidoreductase, whereas chlorophyllase is responsible for chlorophyll degradation

The reproductive stage's crucial processes, including pistil receptivity, flowering initiation, pollen germination, and embryo development, govern the fertility of the florets. High temperatures can affect embryo formation and the embryo sac. High temperatures can impair gamete development and result in spore abortion during the processes of microgametogenesis and microsporogenesis, respectively. Under high temperatures, the 60–70% starch content of wheat grain steadily decreases (Balla *et al*., 2019). Due to the inactivity of the enzymes granule bound starch, soluble starch, and sucrose synthase during the grain filling phase, high temperature prevents starch from accumulating inside grains (Zi *et al*., 2018). Additionally, it reduces the synthesis of starch, moves carbohydrates from stem reserves, changes the structure of the aleurone layer, and affects the endosperm of seeds, which eventually affects grain development.

**2.4 Leaf Senescence**

As a result of a slowdown in the production of carotenoids and chlorophyll, green leaf area decreases during the reproductive phase. Carotenoid and chlorophyll concentration are essential for capturing sunlight for photosynthesis. Wheat leaves senescence, chloroplast integrity, and eventually photosynthesis are all affected by high temperatures (Haque *et al*., 2014). The amount of chlorophyll in the leaves declines due to senescence during the grain filling period. Initially, the chlorophyll cycle transforms chlorophyll-b into chlorophyll-a. Chlorophyll-a is converted by the chlorophyllase enzyme into chlorophyllide-a or pheophytin, which is then converted into pheophorbide-a. In order to create fluorescent and non-fluorescent chlorophyll catabolites, pheophorbide-a monooxygenase converts pheophorbide-a to red chlorophyll catabolites. In wheat, a temperature of 42°Cdecreases the activity of the enzymes 5-aminolevulinate dehydrogenase (45%) and increases chlorophyllase (46%), mg-protoporphyrin IX methyltransferase (65%) and protochlorophyllide oxidoreductase (70%) (Yang *et al*., 2018).

**2.5 Protein Quality**

The backing quality of bread items is determined by the protein content, protein quality, and glutenin/gliadin. High temperatures increase the total protein content but lower the quality of protein that may be used, which is more or less influenced by the amount of protein in the grains (Xue *et al*., 2019). Albumin, globulin, gliadin, and glutenin are four protein fractions that are crucial to the end-use quality of wheat grain. In wheat, high temperature during grain filling reduces the amount of albumin and globulin while increasing the amount of gliadin at the expense of glutenin (Branlard *et al*., 2015).The formation of glutenin, the sedimentation index, and the important amino acids lysine, methionine, and tryptophan, which govern the viscoelastic properties of wheat leaf, are all decreased by high temperature, in addition to increasing the protein content.

## III. PHYSIOLOGICAL PROCESS

Heat stress inhibits the photosynthesis, damaging photosynthetic apparatus, and synthesis of ROS (reactive oxygen species) as discussed below.

**3.1 Photosynthesis Response to High Temperature**

In wheat, a high temperature of 35/25°C (day/night) during the period of grain filling reduces leaf photosynthesis by up to 50%. The net photosynthesis during the wheat crop cycle is crucial for managing the biomass of the crop and grain output in hot climates. The ideal temperature for net photosynthesis is 20°C to 30°C, although wheat's photosynthetic activity rapidly drops above 32°C. Wheat leaves' photosynthesis is more delicate than leaves whose photosynthesis is linked to the mobilisation of stem stores into growing grains during grain filling. The activity of the photosynthetic system, the Rubisco (Ribulose Bisphosphate Carboxylase/Oxygenase) enzyme, and numerous green plant organs, such as the amount of chlorophyll and carotenoids, are all related to photosynthesis (Xu *et al*., 2003).

**3.2 Rubisco Activity**

The Calvin cycle is controlled by the light-activated enzyme rubisco, which also has binding sites for $CO_2$ and rubisco activase. However, in high temperatures (25-40°C) in wheat, rubisco's effectiveness rapidly decreases (Sage and Kubien, 2007). Inhibitors of the Rubisco activity for photosynthesis, such as XuBP (D-xylulose-1, 5-bisphosphate), RuBP (Ribulose-1, 5-bisphosphate), CA1P (2-carboxy-D-arabinitol 1-phosphate), and CTBP (2-carboxytetritol-1, 4-bisphosphate), are sugar phosphates (Yin *et al*., 2014). These inhibitors are removed from the active site by Rubisco activase, which also speeds up the carboxylation reaction that the Rubisco enzyme controls. Although it is heat labile, it also prevents the nascent proteins from aggregating. As a result, a high temperature of >32°C changes the composition to make carbamylation more accessible. Due to decreased evapotranspiration and the weak specificity of the Rubisco enzyme activity, which cannot distinguish between $O_2$ and $CO_2$, high temperatures decrease the solubility of $CO_2$ and increase the level of $O_2$ from the compensation point. These elements cause photorespiration, which stimulates the consumption of ATPs, the release of fixed $CO_2$ and the production of the photorespiratory metabolite (glyoxylate), which consumes NADH2 and ultimately lowers wheat yield by up to 20%.

### 3.3 Reactive Oxygen Species

Wheat cell membrane damage and lipid peroxidation are caused by reactive oxygen species (ROS) that are created when PS-II and the Calvin cycle of photosynthesis are not functioning properly. High temperatures are frequently used to produce ROS like super oxides ($O^{-2}$), hydroxyl radicals (OH-), and hydrogen peroxide ($H_2O_2$). In contrast to the auto-oxidation of ubisemiquinone complex-I and complex-III, which results in super oxides radicals and causes oxidative stress in the cell as well as DNA damage, protein modification, and membrane instability, manganese superoxide dismutase (Mn-SOD) catalysis in mitochondria produces hydrogen peroxides (Pospil, 2016).

One electron is used to create super oxides, while two additional electrons are used to create peroxide, which is then neutralised by two hydrogen atom protons to create $H_2O_2$ (Figure 3). The incomplete oxidation of water molecules results in hydrogen peroxide, which is then reduced by manganese to produce the hydroxyl radical (Foyer, 2018). At a high temperature, the hydrogen peroxide concentration gradually rises from the vegetative to the milky dough stage and has a detrimental effect on photosynthesis.

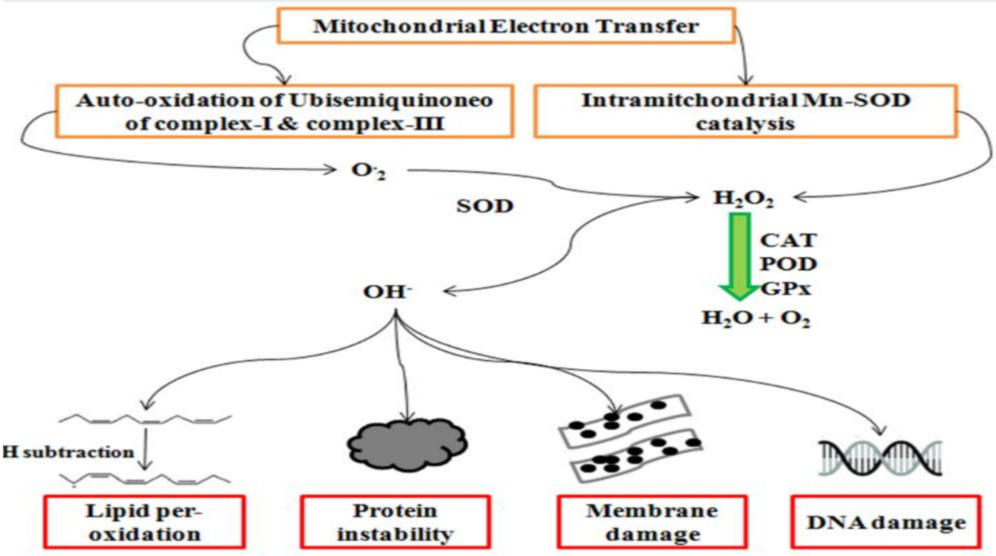


**Figure 3.** Synthesis of the reactive oxygen species and their consequences.

## IV. EFFECT OF HEAT STRESS ON WHEAT

Heat stress (HS) affects the different growth and development stages of wheat which leads to high yield loss. However, effect of HS in plant depends upon the length of heat exposure and growth stage during the high temperature.

### 4.1 Effect on wheat morphology

HS has a detrimental effect on seed germination and plant establishment in several crops, including wheat. Poor crop stand is caused by faulty germination and emergence due to high temperatures. A productive tiller's ability to survive in high temperatures is impacted, which lowers production. Grain yield and tiller number in wheat both decreased as a result of HS (15.38%). (Din *et al*., 2010). HS inhibits root growth, which ultimately has an impact on agricultural output. HS has a very big impact during the reproductive phase. A larger loss in grain yield may result from an increase in average temperature of 1°C during the reproductive period. The ideal temperature for blooming and grain filling is between 12 and 22°C (Sharma et al., 2011).When HS happen during meiosis, it damages the early stages of gametogenesis. The growth of microspore and pollen cells is negatively impacted by HS at the beginning of the floral cycle (Kaur and Behl, 2010) When wheat is exposed to ambient temperature (>35°C) for a brief length of time, the grain production can be significantly reduced (Sharma et al., 2017). We conclude from the literature that seedling death, sterility, and the abortion of formed grains, as shown in Table 1, have the biggest effects on production.

**Table 1:** The key physiological damage to wheat in response to a frost event

| Growth stage | Damage observed | Wheat susceptibility | Potential yield impact | Potential for compensatory growth | Critical plant temperatures for damage to be initiated |
|---|---|---|---|---|---|
| Vegetative | Seedling death | Low–moderate | 0–100% | No | After 2 h exposure a threshold temperature of −4 ◦C was observed. In spring wheat 100% loss around −7 ◦C, in acclimated winter wheat 100% loss around −13 ◦C (Fuller *et al*., 2007) |
| Anthesis | Sterility | High | 10–100% | Low | After 2 h exposure a threshold temperature of −4 ◦C to −6 ◦C was observed. A 1 ◦C drop below threshold can result in 100% yield loss (Marcellos and Single, 1984). −5 ◦C for 2 h, with ice nucleation beginning after 15 min (Al-Issawi *et al*., 2012) |
| Grain filling | Death of formed grains (small, shrivelled grains) | Moderate–high | 0–80% | Low | Field frost (duration not defined) where a minimum temperature of −2 ◦Ca (early milk) resulted in a 13–33% yield loss (Cromey *et al*., 1998) |

### 4.2 Effect on Wheat Physiology

The most crucial physiological activity in plants, photosynthesis, is greatly influenced by high temperatures. Wheat is particularly vulnerable to heat stress in the stroma and thylakoid lamellae. The persistent alternation of RuBisCO, Rubisco Activase, and Photosystem II occurs at high temperatures (over 40°C) (Mathur *et al*., 2011). Wheat exposed to HS conditions showed a deactivation of the RuBisCO enzyme in less than 7 days (Kumar et al., 2016). Under heat stress, rubisco activase breakdown lowers photosynthetic capacity. The fluidity of the thylakoid membrane is altered by HS, and the light harvesting complex II separates from the photosystem II. For a plant to grow and develop, the photosynthetic product needs to be transported to various plant parts. Under high temperature stress, the rate of assimilate translocation from source to sink is slowed down due to a decrease in membrane integrity. Water soluble carbohydrate mobilisation to the reproductive sink promotes grain growth and development (Talukder *et al*., 2014). Lower temperatures during the growing season lengthened the crop while higher temperatures accelerated anthesis and crop maturity. Low anthesis temperatures increased pollen sterility, which reduced pollen germination in both aestivum and durum wheat. Wheat types that underwent anthesis in December and January encountered extremely low temperatures, which increased the number of sterile pollen. Wheat crop output decreased as a result of decreased pollen germination. This demonstrates the significant impact cold temperatures have on wheat crops. Wheat crops that were sown early would be most impacted by low temperatures during the anthesis stage. Better adaption strategies must be developed to lessen the negative effects of cold stress on wheat (Chakrabarti *et al*., 2011).

## V. CONCLUSION

The gradual rise in temperature has an impact on crop productivity. Although the effects of high temperatures on wheat crops have been thoroughly studied, it is still difficult to comprehend the mechanisms underlying thermotolerance. High temperature reduces grain filling time, grain formation, and starch accumulation into grains. It also disturbs the stability of the membrane. Stress brought on by the high temperature has been seen to inhibit physiological processes.

Crop management, however, uses mulches, additional irrigation, inorganic fertilizers, early sowing, exogenous micronutrient application, osmoprotectants, and bioregulators to stabilise the physiological process and metabolic pathways. Integrating crop management practises with molecular genetics tools can ameliorate the adverse effects of high temperature, but need to further explore the strategies associated with high yield under heat stress.

## REFERENCES


**[1].** Akter N, Islam M. (2017). Heat stress effects and management in wheat: Areview. Agron Sustain Dev. 37:37.

**[2].** Al-Issawi, M., Rihan, H., El-Sarkassy, N., Fuller, M.(2012). Frost hardiness expression and characterisation in wheat at ear emergence. J. Agron. Crop Sci. 199, 66–74.

**[3].** Balla, K.; Karsai, I.; Bónis, P.; Kiss, T.; Berki, Z.; Horváth, Á.; Mayer, M.; Bencze, S.; Veisz, O. (2019). Heat stress responses in a large set of winter wheat cultivars (*Triticum aestivum* L.) depend on the timing and duration of stress. PLoS ONE, 14, e0222639.

**[4].** Branlard, G.; Lesage, V.S.; Bancel, E.; Martre, P.; Méleard, B.; Rhazi, L. (2015). Advances in Wheat Genetics: From Genome to Field; Springer: Tokyo, Japan, pp. 255–264.

**[5].** Chakrabarti, B., Singh, S.D., Nagarajan, S. and Aggarwal, P.K. (2011). Impact of temperature on phenology and pollen sterility of wheat varieties. Indian Journal of Plant Physiology 5(8):1039-1043.

**[6].** Cromey, M., Wright, D., Boddington, H.(1998). Effects of frost during grain filling on wheat yield and grain structure. N. Z. J. Crop Hort. Sci. 26, 279–290.

**[7].** Din R, Subhani GM, Ahmad N, Hussain M, Rehman AU. (2010). Effect of temperature on development and grain formation in spring wheat. Pak J Bot. 42(2):899-906.

**[8].** Dubcovsky, J.; Loukoianov, A.; Fu, D.; Valarik, M.; Sanchez, A.; Yan, L. (2006). Effect of photoperiod on the regulation of wheat vernalization genes VRN1 and VRN2. Plant Mol. Biol., 60, 469–480.

**[9].** ElBasyoni, I.; Saadalla, M.; Baenziger, S.; Bockelman, H.; Morsy, S. (2017). Cell membrane stability and association mapping for drought and heat tolerance in a worldwide wheat collection. Sustainability, 9, 1606.

**[10].** Foyer, C.H. (2018).Reactive oxygen species, oxidative signaling and the regulation of photosynthesis. Environ. Exp. Bot. 154, 134–142.

**[11].** Fuller, M.P., Fuller, A.M., Kaniouras, S., Christophers, J., Fredericks, T.(2007). The freezing characteristics of wheat at ear emergence. Eur. J. Agron. 26, 435–441.

**[12].** Gouache, D., Le Bris, X., Bogard, M., Deudon, O., Pagé, C., Gate, P.(2012). Evaluatingagronomic adaptation options to increasing heat stress under climate change during wheat grain filling in France. Eur. J. Agron. 39, 62–70.

**[13].** Hussain, J.; Khaliq, T.; Ahmad, A.; Akhter, J.; Asseng, S. (2018). Wheat responses to climate change and its adaptations: A focus on arid and semi-arid environment. Int. J. Environ. Res. 12, 117–126.

**[14].** Iwai M, Yokono M, Inada N, Minagawa J. (2010). Live-cell imaging of photo system II antenna dissociation during state transitions. Proc Natl Acad Sci USA. 107(5): 2337-2342.

**[15].** Kaur V, Behl R. (2010). Grain yield in wheat as affected by short periods of high temperature, drought and their interaction during pre- and post anthesis stages. Cereal Res Commun. 38(4):514 520.

**[16].** Khan, S.U.; Gurmani, A.R.; Qayyum, A.; Khan, H. (2013).Heat tolerance evaluation of wheat (*Triticum aestivum* L.) genotypes based on some potential heat tolerance indicators. J. Chem. Soc. Pak. 35, 647–653.

**[17].** Kumar RR, Goswami S, Singh K, Dubey K, Singh S, Sharma R *et al*. (2016).Identification of putative RuBisCo activase (TaRca1)–The catalytic chaperone regulating carbon assimilatory pathway in wheat (*Triticum aestivum*) under the heat stress. Front Plant Sci. 7:986.

**[18].** Lobell, D.B., Schlenker, W., Costa-Roberts, J.(2011). Climate trends and global crop production since 1980. Science 333, 616–620.

**[19].** Marcellos, H., Single, W. (1984). Frost injury in wheat ears after ear emergence. Funct. Plant Biol. 11, 7–15.

**[20].** Mathur S, Jajoo A, Mehta P, Bharti S. (2011). Analysis of elevated temperatureinduced inhibition of photosystem II using chlorophyll a fluorescence induction kinetics in wheat leaves (*Triticum aestivum*). Plant Biol. 13(1):1-6.

[21]. Nuttall, J.G.; Barlow, K.M.; Delahunty, A.J.; Christy, B.P.; O'Leary, G.J. (2018).Acute high temperature response in wheat. Agron. J. 110, 1296–1308.

[22]. Pask, A.; Joshi, A.; Manes, Y.; Sharma, I.; Chatrath, R.; Singh, G.; Sohu, V.; Mavi, G.; Sakuru, V.; Kalappanavar, I. A.(2014). Wheat phenotyping network to incorporate physiological traits for climate change in South Asia. Field Crops Res., 168, 156–167.

[23]. Portner, H.O.; Roberts, D.C.; Masson-Delmotte, V.; Zhai, P.; Tignor, M.; Poloczanska, E.; Mintenbeck, K.; Alegría, A.; Nicolai, M.;Okem, A.; et al. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2019.

[24]. Pospíšil, P. (2016). Production of reactive oxygen species by photosystem II as a response to light and temperature stress. Front. Plant Sci. 7, e01950.

[25]. Sage, R.F.; Kubien, D.S. (2007).The temperature response of C3 and C4 photosynthesis. Plant Cell Environ. 30, 1086–1106.

[26]. Sharma D, Singh R, Tiwari R, Kumar R, Gupta V. (2019). Wheat Responses and Tolerance to Terminal Heat Stress: A Review. In: M Hasanuzzaman, K Nahar, M A Hossain (eds), Wheat Production in Changing Environments: Responses, Adaptation and Tolerance. 149-173.

[27]. Sharma P, Sareen S, Saini M, Shefali. (2017). Assessing genetic variation for heat stress tolerance in Indian bread wheat genotypes using morpho physiological traits and molecular markers. Plant Genet Resour. 15(6):539-547.

[28]. Skytt, T.; Nielsen, S.N.; Jonsson, B.G. (2020). Global warming potential and absolute global temperature change potential from carbon dioxide and methane fluxes as indicators of regional sustainability-A case study of Jamtland, Sweden. Ecol. Ind. 110, 105831.

[29]. Talukder ASMHM, McDonald GK, Gill GS. (2014). Effect of short-term heat stress prior to flowering and early grain set on the grain yield of wheat. Field Crops Res. 160:54-63.

[30]. Teixeira, E.I., Fischer, G., van Velthuizen, H., Walter, C., Ewert, F., 2013. Global hot-spots of heat stress on agricultural crops due to climate change. Agric. For.Meteorol. 170, 206–215.

[31]. Whittal, A.; Kaviani, M.; Graf, R.; Humphreys, G.; Navabi, A. (2018). Allelic variation of vernalization and photoperiod response genes in a diverse set of North American high latitude winter wheat genotypes. PLoS ONE, 13, e0203068.

[32]. Xiao, D.; Bai, H.; Liu, D.L. (2018).Impact of future climate change on wheat production: A simulated case for China's wheat system. Sustainability 10, 1277.

[33]. Xu, X.L.; Zhang, Y.H.;Wang, Z.M. (2003). Effect of heat stress during grain filling on phosphoenolpyruvate carboxylase and ribulose- 1,5-bisphosphate carboxylase/oxygenase activities of various green organs in winter wheat. Photosynthetica 42, 317–320.

[34]. Xue, C.; Matros, A.; Mock, H.P.; Mühling, K.H. (2019). Protein composition and baking quality of wheat flour as affected by split nitrogenapplication. Front. Plant Sci. 10, 642–650.

[35]. Yin, Z.; Zhang, Z.; Deng, D.; Chao, M.; Gao, Q.; Wang, Y.; Yang, Z.; Bian, Y.; Hao, D.; Xu, C. (2014). Characterization of RuBisCo activase genes in maize: An _-isoform gene functions alongside a _-isoform gene. Plant Physiol. 164, 2096–2106.

[36]. Zheng, B., Chenu, K., Fernanda Dreccer, M., Chapman, S.C.(2012). Breeding for the future: what are the potential impacts of future frost and heat events on sowing and flowering time requirements for Australian bread wheat (Triticum aes-tivium) varieties? Glob. Change Biol. 18, 2899–2914.

[37]. Zi, Y.; Ding, J.; Song, J.; Humphreys, G.; Peng, Y.; Li, C.; Zhu, X.; Guo, W.(2018).Grain yield, starch content and activities of key enzymes of waxy and non-waxy wheat (Triticum aestivum L.). Sci. Rep. 8, 1–12.