Effect of temperature rise on crop growth and productivity

Abstract

The present study highlights the effect of temperature rise on crop growth and productivity. Improving crop resilience to temperature stress is a vital step towards ensuring global food and fuel demands are met. Temperature is a critical meteorological determinant of crop development and function. Essential physiological processes including carbon assimilation and leaf chlorophyll content are very sensitive to high temperature extremes. High-temperature stress occurs when morpho-physiological and biochemical attributes of plant development are altered. Flowering optimum temperature was 25-30 °C. higher temperature (both max. and min.) and low diurnal variation in temperature are more conducive for early flowering rice variety. Advances in molecular techniques now allow for swift identification of beneficial traits in wild varieties. It is crucial to adopt advanced agricultural practices worldwide to mitigate the impact of rising global temperatures. This includes implementing climate-smart strategies and employing high-throughput phenotyping methods to identify and utilize resilient traits, thereby safeguarding future food security.

Keywords: crop growth, climate-smart strategies, food security, biochemical attributes

Introduction

Due to rising atmospheric CO2 from anthropogenic emissions driving climate change, global land surface temperatures are rising. This presents a problem for supplying the need for food and fuel under more demanding crop-growing conditions. Global emissions are currently tracking the worst-case "business as usual" emissions scenario (RCP 8.5), which will very likely equate to unprecedented warming from pre-industrial (1850–1990) levels of 3–5 °C by 2100 (IPCC, 2014), despite a drop in emissions associated with the coronavirus pandemic of 2020 (COVID-19; Le quere et al., 2020).

According to a recent IPCC assessment, crop yields will suffer "severe and widespread impacts" if global warming surpasses 1.5 °C above pre-industrial levels, but these effects can be controlled below this warming threshold (IPCC, 2018). This prediction was made with a medium degree of confidence. A predicted increase in the frequency, severity, and length of intense heatwave events—which have the potential to severely impair crop yields—coexists with the rising mean global temperature (Battisti and Naylor, 2009; Perkins et al., 2012; Hatfield and Prueger, 2015; Hoegh-Guldberg et al., 2018). Furthermore, some cropping zones—such as temperate, high-latitude regions—will probably experience warming that is much more intense than that of tropical regions worldwide (Hoegh-Guldberg et al., 2018). As a result, mitigation strategies to keep global warming to 1.5 °C are desperately needed (IPCC, 2018). We also need to develop our main cropping systems to make them more resilient to hotter growing seasons and extreme temperature events, which seem inevitable in the next century.

Higher growing season temperatures have been linked to global yield losses in important crops including wheat and maize (Lobell et al.,2011; Lobell and Gourdji, 2012; Asseng et al.,2015). For the primary cropping systems of maize (7.4%), wheat (6.0%), rice (3.2%), and soybean (3.1%), significant yield declines per °C of warming have been predicted in the absence of crop improvement strategies, including genetic engineering and adaptation under carbon dioxide (CO2) fertilization (Zhao et al., 2017). However, based on the average yield in 2005, agricultural production will need to quadruple throughout this century to fulfill the increased caloric demand and keep up with feeding and fueling the world's expanding population (Long and Ort, 2010; Ray et al., 2013). In addition, the effects of rising temperatures make it unlikely that the CO2 fertilization effect will reach its full theoretical magnitude (Long et al., 2006; Ainsworth and Long, 2020). Ensuring that the world's food and fuel needs are satisfied thus requires increasing crop tolerance to temperature stress. The meteorological factor of temperature has a crucial role in determining crop growth and productivity. Temperature influences the way that enzymes work in leaves (Bernacchi et al., 2001; Walker et al., 2013; Florian et al., 2014; Kumarathunge et al., 2019; Timm et al., 2019). It also causes changes in the developmental growth stage, which are closely related to crop yield (Ruiz-Vera et al., 2018; Zhu et al., 2018). Moreover, the temperature-dependent rise in the saturation level of water vapor in the air raises the vapour pressure deficit (VPD) and increases the potential water loss from plants (Novick et al.,2016; Grossiord et al., 2020). Due to these widespread crop physiological reactions to temperature, changes in the long-term mean annual temperature and high temperature occurrences are projected to have a major effect on crop production across the world's major regions for the production of food and fuel.

Importance of temperature in plant growth and development

- ✓ Temperature is one of the most important ecological factors.
- ✓ It regulates the many physiological processes of plants like photosynthesis, transpiration.
- ✓ The plant grows best at optimum temperature.
- ✓ Both low and high temperatures have adverse effects on plants.
- ✓ The metabolic processes are low at minimum temperature. It increases at a particular temperature called as optimum temperature.
- ✓ Metabolism again decreases at maximum temperature. the plants cannot survive above this temperature**.**

Cardinal temperature: Every plant community has its own minimum, optimum, maximum temperature range for their growth and development.

Table 1: Cardinal points of important crops.

Crops	Germination (°C)			Growth (°C)		
	minimum	optimum	maximum	minimum	optimum	maximum
Rice	10	28	40	13-14	32	36-38

Wheat	4-405	25	30-32	4.5	20	30-32
Maize	8-10	31-35	40-44	8-10	23-30	40-43
Sorghum	8-10	31-35	40-44	12-13	25	40

Effect of high temperature on plant Photosynthesis and growth

C3 plants are more susceptible to high-temperature stress than C_4 plants because C_3 plants convert CO2 into a 3-carbon compound (PGA) with Rubisco. On the other hand, C4 plants convert CO2 into a 4-carbon intermediate (OAA) by using PEPC. CA carbonic anhydrase, PGA phosphoglyceric acid, RuBP ribulose-1,5-bisphosphate, PEP phosphoenolpyruvate, Rubisco ribulose-1,5-bisphosphate carboxylase/oxygenase, PEPC phosphoenolpyruvate carboxylase, NAD(P)-ME NAD(P)-malic enzyme, PCK phosphoenolpyruvate carboxykinase, PPDK pyruvate phosphate dikinase, NAD(P)-MDH NAD(P)-malate dehydrogenase (OAA) with substrates of phosphoenolpyruvate (PEP) by phosphoenolpyruvate carboxylase (PEPC) located in the cytosol. PEP is produced from pyruvate and ATP, catalyzed by pyruvate phosphate dikinase (PPDK) located in the chloroplast. Among C4 plants, there are three subtypes, based on the C4 acid decarboxylation enzyme: NADP-malic enzyme (NADP-ME) type, NAD-malic enzyme (NAD-ME) type, and phosphoenol-pyruvate carboxykinase (PCK) type. Malate (or aspartate) is transported to the vascular bundle sheath cells and is finally decarboxylated, producing CO2 and pyruvate. CO2 is then fixed by Rubisco in the chloroplasts of the bundle sheath cells, which have a normal Calvin cycle, as in C3 plants (Yamori *et al.,*2014).

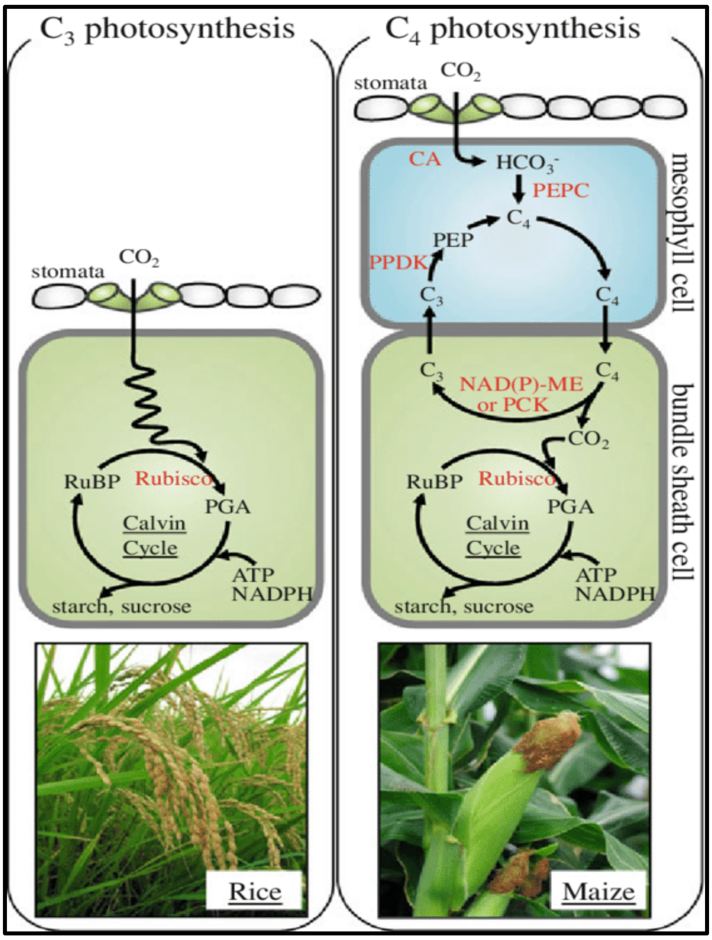

Fig. 1. Effect of high temperature on plant Photosynthesis and growth

Effect of high temperature on plant metabolism

Extremely high temperatures have a significant impact on vital physiological functions like leaf chlorophyll concentration and carbon uptake. Stress from high temperatures arises from modifications to the morpho-physiological and biochemical aspects of plant growth. Plants do less photosynthesis in air temperatures higher than 30 °C. According to Ekinci et al. (2017), cotton sympodial branch elongation is restricted by temperatures higher than 35 °C. In plants under temperature stress, signal transduction networks make up a significant amount of the intricate machinery that triggers a number of hormone-dependent and self-activated mechanisms (Awasthi et al., 2015; Pandey et al., 2016). Heat stress increases the generation of ROS, which has an impact on cell biochemistry. Heat stress changes how the mitochondria function, which allows lipid peroxidation to induce oxidative damage (Davidson and Schiestl 2001; Vacca et al., 2004). Enhanced lipid peroxidation under heat stress has been reported in numerous investigations (Wu et al.,2010). Extreme temperature causes the generation of ROS, such as OH−, H2O2, and O2−, which in turn results in oxidative stress (Yin et al., 2008). Due to its oxygenase activity, rubisco increases the rate at which H2O2 is produced during heat stress (Kim and Portis 2004). ROS cause lipids in cell membranes and pigments to undergo autocatalytic peroxidation, which alters the membrane's permeability and functionality (Xu et al.,2006).

According to Almeselmani et al. (2009), crop plants' ability to produce antioxidants is closely connected with their tolerance to oxidative damage." When temperatures are high, ROS scavenging enzymes produce proteins with elevated amounts (Rainwater et al., 1996; Rizhsky et al., 2002). According to Bergmuller et al. (2003), plants can also develop defense mechanisms against heat stress that help them avoid oxidative damage. Malondialdehyde (MDA), a consequence of lipid peroxidation that damages all cellular organelles, is produced in greater amounts during reproductive phases of cotton, according to Zhang et al. (2016). Stressed by elevated temperatures, the cotton plant was unable to scavenge ROS. Although cotton leaves have higher levels of the antioxidant enzymes SOD and CAT, these enzymes were not able to shield cells from oxidative damage (Snider et al., 2009). Singh et al. (2007) found that temperature stress decreased the number of sympodial branches and boll weight in cotton, which may have been caused by a blockage in the assimilate supply to growing bolls. In conclusion, increased strain on organelles under heat stress causes antioxidant enzymes in cotton to be upregulated yet unable to scavenge ROS (Snider et al., 2009). Recent research has shown that applying an H2O2 foliar spray can help to promote thermotolerance (Gao et al., 2010; Hossain et al., 2015). By preventing damage to DNA structures, exogenous H2O2 application enhanced plant development and decreased oxidative stress. According to Fahad et al. (2016), extract from moringa leaves (MLE) and AA are also thought to be necessary for boosting antioxidative activity. When exposed to extreme heat stress, H2O2 functions as a signaling molecule that raises the amount of chlorophyll. Zeatin, which shields cells from oxidative stress, is also abundant in moringa leaf extract. According to studies, cotton fiber length rose in response to these growth regulators—H2O2, ASA, and MLE. Li et al. (2007) reported that H2O2 was crucial for the cell division and expansion of cotton fibers. Based on Ali et al. (2011), there was a significant amount of cytokinins in moringa leaf extract that improved fiber quality components.

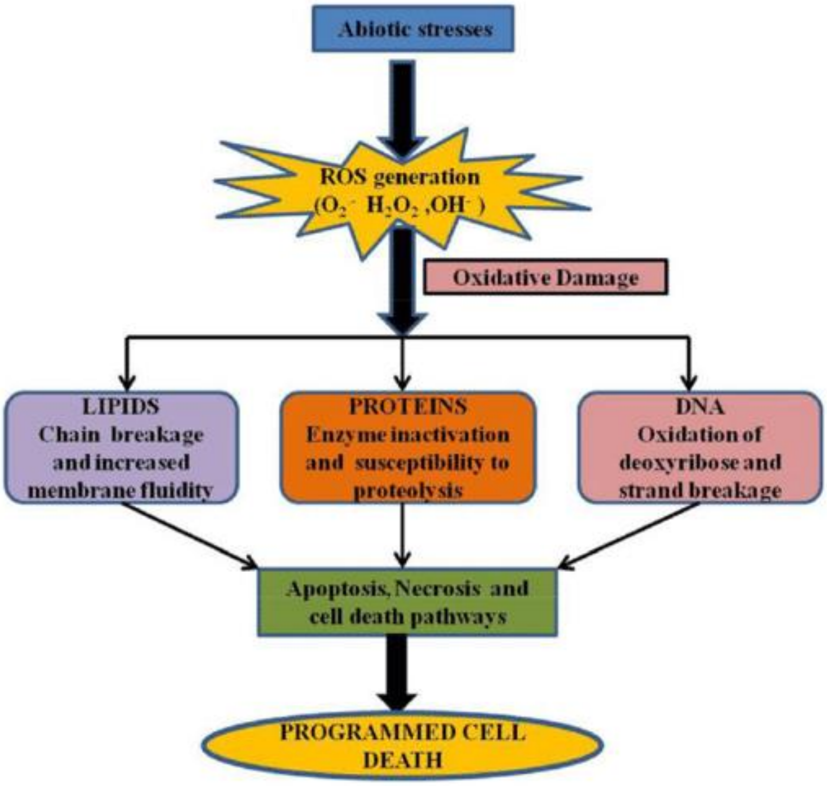

Fig. 2. Effect of high temperature on plant metabolism

Effect of temperature on plant growth and development in rice crop

There is main three stage

1.Vegetative Stage

2. Reproductive Stage

3. Ripening Stage

(1) Vegetative stage effect of temperature on germination, seedling growth (shoot and root elongation), leaf emergence, plant height and last one is tillering.

In germination the optimum temperature is 20-30 °C. low temperature depresses the rate of germination and prolongs it beyond the desirable span of 6 days. High temperature 35 °C or more halted the germination because of high respiration rate. Seedling growth rate increase linearly between 22-31 °C, suggesting that chemical reaction dominate growth and above 40 °C the plant may die. Shoot and root elongation critical minimum temperature is 7-16 and 12-16 °C respectively. Elongation is a combination of two components; cell division and cell enlargement and for which extreme temperature are 15 °C and 40 °C. Leaf emergence; before panicle initiation, leaf emerges about every 4-5 days, afterwards about 7-8 days. Temperature affects the rate of leaf emergence. Example rice plant is grown at 20 °C leaves emergence every 5 days, when grown in 25°C leaves emergence is every 4 days before panicle initiation. Plant height increased with the rise of temperature within the range of 30-35 °C. the plant elongate vigorously until 30 DAT, then slowly ceases to elongate at the heading stage. Tillering, optimum temperature for 25-31°C, tillering rate is inhibited by low temperature but the period of tillering is prolonged.

The mean temp. exceeded 26 °C the tiller production stopped abruptly by 5 weeks after transplanting and whenever it falls below 26°C the duration of tillering increased to 7-8 week after transplanting. Temperature above 28 °C during vegetative phase reduce the day to heading and shorter the life cycle.

(2) Reproductive stage the temperature effect on panical initiation, booting & heading, flowering and emergence of flag leaf. After the tillering stage high temperature decrease the number of panicles, panicle weight at maturity Booting and heading stage when the rice plant subjected to low temperature for 3 days it is more sensitive at the booting stage than heading stage as indicated by higher percentage of spikelet sterility. Flowering optimum temperature was 25-30 °C. higher temperature (both max. and min.) and low diurnal variation in temperature are more conducive for early flowering rice variety.

(3) Ripening stage the temperature effect on grain filling grain quality and yield. Optimum temperature for ripening is 20-25 °C. low temperature reduced the grain dry matter increasing rate, extends the grain filling delay grain maturation although moderate cool temperature sometimes benefits grain yield. Higher temperature decreased the grain yield significantly due to the reduction of percentage of ripened grain.

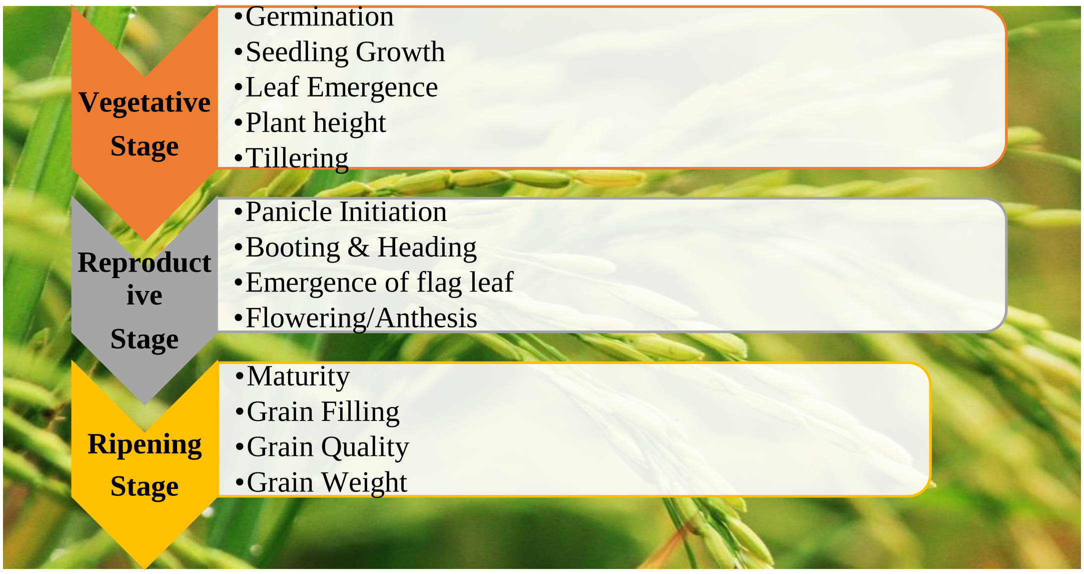

Fig. 3. Effect of temperature on plant growth and development in rice crop

Adaptive mechanisms of plants under high temperature

▪ Avoidance Mechanism

Plants have developed a variety of survival strategies to withstand high temperatures. These strategies include long-term evolutionary phenological and morphological adaptations as well as short-term avoidance or acclimation strategies like modifying leaf orientation, transpirational cooling, or lipid composition changes in membranes. Common heat-induced characteristics in plants include stomatal closure and decreased water loss, higher stomatal and trachomatous densities, and bigger xylem vessels (Srivastava et al.,2012). Early maturation in many crop plants is associated with lower yield losses under heat stress (HT); this could be because an escape mechanism is activated (Rodriguez et al.,2005; Adams et al., 2001). Heat-stressed plants minimize their absorption of solar radiation in order to evade heat stress. This ability is reinforced by the presence of cuticles, a waxy protective covering, and tiny hairs (tomentose) that form a thick coat on the leaf's surface. Leaf blades in these plants frequently face away from light and align themselves parallel to the sun's rays, a phenomenon known as parheliotropism. Moreover, moving leaf blades might lessen solar exposure. Because their smaller leaves allow for quicker heat evacuation to the ambient, plants with smaller leaves are also more likely to withstand heat stress than those with larger leaves. When there is a water shortage, plants use the same physiological and anatomical adaptation mechanisms to reduce transpiration. Strong transpiration shields well-hydrated plants' leaves from heat stress, allowing their temperature to drop by as much as 6 °C or even 10-15 °C below the surrounding air. Many animals have adapted their life cycles so they can stay away from the warmest part of the year. In desert annuals, this can be accomplished by completing the whole reproductive cycle during the colder months, or by abscising leaves and leaving heat-resistant buds (Fitter and Hay 2012). Although C3 plants are also widespread in desert floras, such morphological and phenological adaptations are typically linked to biochemical adaptations promoting net photosynthesis at HT (namely, C4 and CAM photosynthetic pathways) (Fitter and Hay 2012). Many plants' degree of leaf rolling can be impacted by high temperatures. The physiological function of leaf rolling in wheat flag leaves under high temperature (HT) was to maintain the capacity for adaptation by boosting the effectiveness of water metabolism (Sarieva et al.,2010). All plants are extremely susceptible to temperature stress when they are actively growing. Some terrestrial plant species only get more heat resistant in the summer, whereas other species show the greatest heat tolerance during their winter hibernation. When dormant plants enter a developmental stage brought on by variables other than high ambient temperature, they become resistant to stress. Not much of a difference in heat tolerance is seen in many land plant species. The impacts of each stressor on field-grown plants can be difficult to discern because of the strong relationship between drought and HT. Consequently, adaptations to dry conditions are only beneficial if they help plants avoid or tolerate both pressures on their flora (Fitter and Hay 2012).

Crop management techniques, such as choosing the right cultivars, irrigation techniques, sowing dates, and so on, can also help prevent high temperature stress. For example, high soil temperatures in subtropical zones might cause cool-season annuals like lettuce that are sown in the late summer to show inadequate germination and emergence (Hall, 2011). Sowing lettuce seed into dry beds during the day and then irrigating the beds with sprinklers in the late afternoon is one way to solve the partial emergence problem. This issue can also be resolved by seed priming, which is soaking the seeds in an osmotic solution for a few days at a moderate temperature before drying them. However, because of their extremely hot soil surface, numerous warm-season annual crops may not be as productive in tropical regions due to poor plant emergence and establishment. In some situations, deep placement can solve the issue. By altering the sowing date, one might raise the likelihood that annual crop species in temperate or subtropical climate zones—which experience seasonal temperature fluctuations—will be able to evade very stressful hybrid crops during later, vulnerable developmental stages. Fruit can occasionally become damaged by high temperatures and strong direct sunlight. If fruit is sheltered by leaves, this can be prevented (Hall, 2011).

Tolerance Mechanisms

The ability of a plant to develop and yield a profit under high temperatures is the common definition of heat tolerance. Due to the extreme specificity of this characteristic, even closely related species—or even distinct organs and tissues within the same plant—

may differ greatly in it. Different strategies have been developed by plants to survive in environments with higher average temperatures. These consist of long-term evolutionary adaptations or short-term avoidance/acclimation mechanisms. To counteract the effects of stress, some important tolerance mechanisms are essential, such as ion transporters, late embryogenesis abundant (LEA) proteins, osmoprotectants, antioxidant defense, and factors involved in signaling cascades and transcriptional control (Rodriguez et al.,2005; Wang et al., 2004). The ability to respond quickly to acute heat stress is crucial for life. This includes modifications to membrane lipid composition, transpirational cooling, and leaf orientation (Rodriguez et al.,2005; Radin et al., 1994). Adams et al. (2001) suggest that heat stress tolerance may involve an escape mechanism, as evidenced by less yield losses resulting from early summer maturation. In terms of developmental complexity, exposure, and reactions to applied or prevailing stress types, different plant tissues exhibit differences (Queitsch et al., 2000). The initial stress signal, which can take the form of changes in membrane fluidity or ionic and osmotic effects, establishes the stress response system. According to Vinocur and Altman (2005), this aids in the restoration of homeostasis as well as the defense and restoration of damaged proteins and membranes.

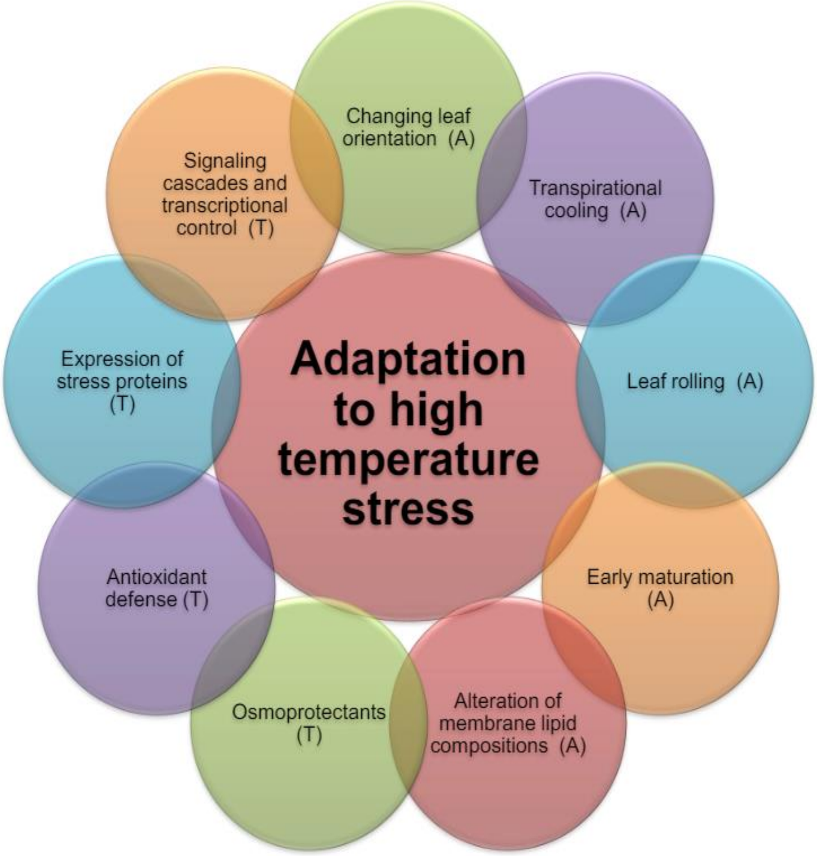

Fig. 4. Adaptive mechanisms of plants under high temperature

Table 2: Physiological disorder due to high temperature

Crop	Malady
Rice	Severe chlorosis of leaves
	Irregular flowering and chaffiness, multiple deficiency Of nutrients
	Tip drying and marginal scorching and browning
Maize	Chlorosis
	Yellowing in the bud leaves only (white bud)
	Tip drying and pinkish colouration of lower leaves
	Marginal scorching and yellowing
	Irregular drying of tips and margins
Sorghum	Chlorosis of younger leaves

Conclusion

High temperatures are a critical environmental factor that impacts crop growth and yield by influencing various mechanisms. This issue is alarming because it directly affects yield at a time when there is a pressing need to increase agricultural output to alleviate global hunger and ensure food security. Developing resilience to high temperatures is crucial not only for current conditions but also for the future, given predictions of increasing temperatures that will significantly impact yield. Therefore, it is essential to explore new strategies to bolster or enhance tolerance to high temperatures. Although numerous studies have examined the effects of high temperatures on crops, many wild types remain unexplored. Exploring these untouched wild types could uncover valuable insights into managing high temperatures through novel genes that confer tolerance. Advances in molecular techniques now allow for swift identification of beneficial traits in wild varieties. It is crucial to adopt advanced agricultural practices worldwide to mitigate the impact of rising global temperatures. This includes implementing climate-smart strategies and employing high-throughput phenotyping methods to identify and utilize resilient traits, thereby safeguarding future food security.

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