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IMPACT OF GLOBAL CLIMATE CHANGE ON MAIZE (ZEA MAYS): PHYSIOLOGICAL RESPONSES AND MODERN BREEDING TECHNIQUES

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ABSTRACT

In the context of global climate variability, it is foreseeable that multiple agricultural regions worldwide will experience an upsurge in instances of drought and heat stress. Today, these abiotic stresses are the primary limiting factor affecting crop development and yield. It's prevalent in semiarid regions, but climate change is having a major impact on maize output. Climate change presents significant challenges for maize production, with rising heat stress emerging as a major problem. Lower yields, worse grain quality, and increased susceptibility to pests and diseases are some of the negative effects of heat stress on maize physiology. The optimum management choices for maize can be made with the help of predictions of future maize yield based on climate change projections and the projected developmental and physiological stomatal responses. The current results of this study summarize the physiological responses of maize to heat stress, which include adaptations in photosynthesis, respiration, water usage efficiency, and reproductive activity. Furthermore, many genetic engineering strategies, including breeding for heat tolerance and biotechnological treatments, including genetic engineering, to mitigating the adverse effects of heat stress on maize production and adaptation in Maize stomatal development. In maize's adjustment to climatic threats, molecular processes play a key role, particularly emphasizing the function of stomata. Some specific genes like AOX, Zm-AN13, and ZmSEC14p plays a crucial role in fortifying maize against severe temperature fluctuations. By amalgamating this data, the combination of conventional breeding, current techniques, and grasping the physiological reactions emerges as crucial in augmenting maize's capability to withstand upcoming climatic changes.

***Keywords*:** Heat stress, Maize physiology, Maize production, Stomatal responses, Breeding Strategies

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1. INTRODUCTION

Environmental issue of heat stress impacts the globe's ecosystems and agriculture systems. It transpires when temperatures exceed a vital limit, causing harm to numerous creatures, including crops. The issue is notably destructive within the climate change framework, as increasing worldwide temperatures become more frequent and severe due to greenhouse gas emissions. The planet faces a growing challenge from the escalating and worrying outcomes of heat strain. As stated by the Intergovernmental Panel on Climate Change (IPCC), heatwaves are on the rise, growing more frequent and intense, bringing substantial dangers to human well-being, food safety, and natural surroundings. These extraordinary episodes of high temperatures are causing disruptions in everyday existence and applying pressure on worldwide farming output. Climbing temperatures and the connected heat strain are vital factors that influence harvest production, encompassing essential crops such as maize (Masson-Delmotte, 2018). Maize (Zea mays), a crucial global staple crop, exhibits great sensitivity to heat strain. When temperatures surpass the ideal range for maize cultivation, it triggers a sequence of unfavorable consequences. Elevated temperatures can reduce photosynthesis, disrupt reproductive growth, and diminish kernel production, ultimately causing significant yield reductions. Moreover, heat strain during the flowering phase can yield unsatisfactory kernel formation and diminished grain quality (Lobell and Field, 2007).

Food security and agricultural sustainability are two major issues raised due to global climate change (Ali et al., 2017). Due to its location, socioeconomic standing, and reliance on agriculture, Pakistan is one of the country's most at risk from the consequences of climate change (Syed et al., 2022). Food security and economic growth in Pakistan owe a great deal to maize, a crucial staple crop (Rehman et al., 2015). Its output, however, is negatively impacted by heat stress brought on by global warming, altered precipitation patterns, and a rise in the frequency of

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extreme weather events (Chaudhry et al., 2019). The adverse effects of heat stress on maize growth, development, and production impact farmers of all sizes. As the climate changes, the negative impacts of heat stress on maize productivity will become more pronounced (Chen et al., 2018).

Deforestation and burning fossil fuels are two examples of human activities that raise the atmospheric concentrations of greenhouse gases (GHGs), which in turn contribute to the worldwide climate change phenomenon (Abbass et al., 2022). Global temperatures are caused by a rise in greenhouse gases (GHGs), mainly carbon dioxide, methane, and nitrous oxide (Cassia et al., 2018). Agriculture is one industry where the effects of climate change will be particularly severe. Latitude, crop type, and agricultural practices are a few of the numerous factors affecting how global climate change affects agriculture (Syed et al., 2022). Rising global temperatures, changing rainfall patterns, and extreme weather occurrences, including floods, droughts, and storms, have negatively influenced agricultural production in many parts of the world (Gornall et al., 2010). Furthermore, new pests and diseases are multiplying due to climate change, which can severely impact livestock and crops (Jamil et al., 2022). Climate change is delaying planting and harvesting of crop from their natural time period, which might result in reduced yields and increased food insecurity (Ali et al., 2017).

Fig. 1: Burning of crops remaining also source of Greenhouse gases:

Source: The Tribune India

Despite being crucial to the sustainability of farming systems, climate change threatens agricultural biodiversity (Ajani and van der Geest, 2021). Climate change may cause some species to go extinct while causing others to relocate. Loss of genetic diversity threatens the ability to breed crops better able to withstand shifting climates. Climate change is endangering the quality and availability of water resources essential to agricultural output (Syed et al., 2022). Climate change is increasing water scarcity and poor water quality, which could have a negative impact on agricultural output. Maize is grown worldwide and is used for food, animal feed, and as a raw material in numerous industries. Maize (*Zea mays*) is a multipurpose cereal grain, flour, and vegetable (Tariq and Iqbal, 2010). Because of its high caloric and protein content, this crop is vital for the survival of millions of people worldwide, especially in underdeveloped regions. After rice and wheat, maize will produce more than 1.1 billion metric tons in 2020, making it the third-most significant cereal crop. (Erenstein et al., 2022). It's a great way to get carbs, fiber, and nutrients like thiamin, niacin, and phosphorus (Rouf Shah et al., 2016). Due to its low glycemic index, maize is also beneficial for diabetics. Maize is vital not only as a food staple for humans but also as a source of nutrition for livestock. Animals like chickens, pigs, and cows rely heavily on it as a food source (Klopfenstein et al., 2013). Because of its high energy and protein levels, maize is a vitally important component of animal feed (Klopfenstein et al., 2013).

The production of ethanol, biofuels, and bioplastics is among the industrial uses of maize, which is also a significant crop for human and animal sustainability. In recent years, the need to lessen emissions of greenhouse gases and the consumption of fossil fuels has increased the demand for maize as a feedstock for biofuels and other industrial uses (Ambaye et al., 2021). Many nations, especially those still on the path to economic development, owe a great deal to the success of their maize-based economies (Erenstein et al., 2022). Millions of people are

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employed in the maize industry, from farming to processing to selling. Heat stress is a major abiotic stress factor affecting maize production globally, especially in countries with high temperatures like Pakistan. Extreme heat causes maize to undergo physiological and biochemical changes that reduce its productivity when temperatures are above the optimal range for growth and development (Shrestha et al., 2022).

Heat stress is especially harmful to maize plants at the time of silk and tassels emergence and also during the pollination or reproduction stage. also. Reduced pollen viability and reduced seed set due to high temperatures during this stage can reduce yields. Heat stress can disrupt photosynthesis, respiration, and the efficiency of maize using water. If temperatures are too high, photosynthesis will slow down, and the plant's biomass and yield will suffer. Increased respiration rates due to heat stress can also cause plants to lose their ability to store carbohydrates, leading to stunted development. Due to water stress, heat stress can also cause an increase in evaporative losses, which further inhibits plant development and output. Heat stress not only negatively affects maize plants, but it can also make them more susceptible to pests and diseases. Fusarium ear rot is just one example of a fungal disease that can spread quickly in warm conditions and cause serious crop losses. Directly affecting soil fertility and water availability, heat stress indirectly affects maize production. Soil moisture stress and decreased nutrient uptake by maize plants are both effects of high temperatures, which can increase the rate at which water evaporates from the soil (El-Sappah et al., 2022).

Annual crop failure is commonly attributed to weather extremes including drought and high heat (Fahad et al., 2017; Lipiec et al., 2013). Due to rising temperatures and altered rainfall patterns, climate change poses a danger to agricultural output and food security. According to climate models, changes in rainfall patterns reduce the occurrence of storms but increase their severity in many parts of the world (Gupta et al., 2020). The increased variability of precipitation raises the risk of drought caused by water drainage. In addition to potentially damaging crops directly, high temperatures have been linked to drought (Kharin et al., 2007) because of the quick evaporation of water from plant tissues and the soil's surface. The combined and individual effects of drought and heat extremes on the agricultural industry pose a significant danger to food security.

With a global output of over 1.1 billion tonnes in 2021, maize became the most extensively produced crop, surpassing all other grains. It is a member of the grass family *Poaceae*, which also includes wheat (*Triticum aestivum*), rice (*Oryza sativa*), and barley (*Hordeum vulgare*). The domestication of maize is credited to the people of Mexico's tropical Balsas River valley (Matsuoka et al., 2002). This crop is grown on more land than any other major crop despite its principal producers being the United States, China, and Brazil (Matsuoka et al., 2002). This plant can be used to make glue, industrial alcohol, and fuel ethanol, just to name a few of its many industrial applications. Humans only consume 13% of the world's maize harvest; the other 61% is utilized for animal feed. Masses of Africa rely on it as a primary source of nutrition. As the region's population rises, human consumption of this resource is projected to increase (Ranum et al., 2014).

The crop is susceptible to climate change (Pereira, 2016), despite its widespread availability due to maize's resilience to numerous agro-ecologies. By 2040, less precipitation is expected to hinder maize cultivation across southern Africa and Europe, according to an analysis of annual mean precipitation and specific growth seasons and regions (Rojas et al., 2019). This is because maize is typically grown in semi-arid areas that are prone to drought and high heat. More and more places throughout the world that grow maize will be concerned about precipitation and its unpredictability. Water availability in the early phases of plant development affects the final product (Zargar et al., 2017). Climate change impacts maize growth via altered rainfall patterns and rising temperatures (Halubok and Yang, 2020). Over 35ºC is Optimum for maize development at every stage from fertilization to grain filling (Adam, 2021). If Russia invaded Ukraine, maize output would drop by 54% in 2022/23 compared to the previous year. In 2050, the world's population is projected to reach 9.7 billion, up from the current population of 7.7 billion (Adam, 2021). Therefore, the effects of climate change on the cultivation of maize would be worsen. South Africa is particularly vulnerable to the effects of climate change because maize is a staple food there. ("OECD-FAO Agricultural Outlook 2021-2030," 2021). This country, along with others in Southern Africa, is particularly vulnerable due to their dismal economic position.

This article examines how maize productivity and stomatal development are affected by climatic change. Drought lowers transpiration and the rate of photosynthesis because it affects stomatal growth and function. Plants are less able to transpire, photosynthesize, and build biomass when both drought and heat stress are present at the same time (Hussain et al., 2019). It is possible that ZmSHR1 activity causes alterations in stomatal density that are further from the longitudinal veins of the leaves, which operate as a physiological buffer to protect plants from heat stress. This stomatal response to warmer temperatures is a red flag for the sustainability of maize agriculture in the future. Finding solutions to the effects of climate change on its production is necessary even though it may be negatively affected by warming temperatures and unpredictable precipitation. In fact, maize only benefits from increased CO2 levels during mild drought, when yields are threatened anyway (Rosenzweig et al., 2013). Plants may reduce their stomatal conductance by closing their pores (stomata) in response to drought (Webber et al., 2018).

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Table 1: Yield losses in some major crops caused by drought and heat stress

Crop species	Stress	Yield losses (%)	Reference
Maize	Drought	63-87	Kamara et al., 2003
	Heat	42	Badu-Apraku et al., 1983
Wheat	Drought	57	Balla et al., 2011
	Heat	31	Balla et al., 2011
Rice	Drought	53-92	Lafitte et al., 2007
	Heat	50	Tian et al., 2010
Chickpea	Drought	45-69	Nayyar et al. 2006
Soybean	Drought	46-71	Samarah et al. 2006
Sunflower	Drought	60	Mazahery-Laghab et al. 2003

1.1. Effects of Heat Stress on Maize Physiology and Production

The potential effects of heat stress seriously jeopardize the productivity of maize (*Zea mays*), which is a significant crop worldwide. Due to the consequences of global climate change, it is projected that heat stress will become more frequent and intense. The number and quality of maize crops may be considerably reduced. Maize plants may exhibit various physiological responses to heat stress, including alterations in photosynthesis, respiration, and water usage efficiency (Lobell and Gourdji, 2012). The heat stress affects maize's photosynthetic rate, stomatal conductance, and chlorophyll concentration. Modifying photosynthesis can minimize the energy allocated toward growth and reproductive functions within the plant. Heat stress could have a negative impact on the growth and development of maize. The elevated temperatures delay the growth rate of maize, leading to a delay in its blooming and an extended vegetative phase. Heat stress may impair maize ability to produce new roots and assimilate nutrients, reducing crop growth and lowering yields. Heat stress has the potential to drastically lower maize productivity and quality. The heat stress caused a 25% decrease in maize yields in the United States. The nutritional value of grains may be compromised, and their market value may decrease due to heat stress and it also induced reductions in grain quality. Maize exhibits varying degrees of susceptibility to heat stress across different regions. The regions characterized by low wind speed and high humidity are more prone to experiencing heat stress. High humidity and low wind speeds in Ireland made it harder for corn crops to deal with heat stress, which led to a drop in yield and quality.

Using adaptive management techniques could make it less likely that heat stress will decrease maize yield. Viable strategies include planting heat-tolerant cultivars, optimizing irrigation management, adjusting planting schedules, and implementing shading techniques. The empirical evidence suggests that certain maize varieties can endure elevated temperatures for extended durations. Drip irrigation and collecting rainwater are two efficient ways to handle irrigation that could help reduce water stress and high heat effects. Changing the timing of planting activities to avoid the hottest times of the year is one method for lessening the effects of heat stress. Last but not least, using shade strategies like mulch or including leguminous crops in intercropping systems can help to protect against high temperatures.

1.2. Thermal Effect on Maize Crops

Maize cultivation requires a range of temperatures during the day, night, and growing season for maximum growth. The optimal daytime temperature is between 25-33 °C and the ideal overnight temperature is between 17-23 °C (Obeng-Bio et al., 2019). Typically, 20 to 22 °C is the ideal temperature range for the growth season. Between 25-28 °C is the optimal temperature range for maize seedling germination. Throughout the whole reproductive period, maize is extremely sensitive to deviations from the optimal temperature range. High temperatures at this stage significantly slow down growth and reduce grain yield because they change the seed setting ratio and interfere with a few physiological processes (Hatfield and Dold 2018). Waxy maize produced smaller, lighter grains, which decreased grain yields by up to 31% in conditions of 35 °C throughout the day (Huan et al., 2020. In response to inputs that produce heat stress, plants often seek to escape or minimize the stress period through phenotypic plasticity, which reduces the amount of time grain fills. It's noteworthy to notice that in high temperatures, the maize plant speeds up the normal endosperm development process till it is finished (Settles et al., 2007) Further proof that the effects of heat stress vary greatly depending on the time of day and the intensity of the stress is provided by the fact that the maize plant only expedites endosperm growth under high daytime and nocturnal temperatures, not simply during the day. Shows how a system is affected by heat stress (Martinez-Feria et al., 2020).

1.3. Techniques for Managing the Effects of Heat Stress

Since maize is a staple crop grown in many countries, heat stress are serious threats to crop output. Change in climate increase the impacts of heat stress on maize productivity and quality. Numerous management techniques have been suggested to deal with this issue and lessen the detrimental effects of heat stress on maize yield. The development of maize varieties with heat tolerance can be enhanced through the utilization of breeding methods and

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biotechnology strategies. By pinpointing genes linked to heat resilience, both conventional and molecular breeding techniques have facilitated the creation of heat-tolerant maize cultivars.

The Table 2 highlights maize yield responses to different temperature intervals. At 20-25°C, maize shows typical growth without a drop in yield. Yet, when the temperature rises, heat stress negatively influences the yield. Between 25-30°C, there's a noticeable mild heat stress causing a 5-10% drop in yield. For temperatures of 30-35°C, the yield drops are sharper at 15-25% due to increased heat stress. Above 35°C, severe heat stress significantly affects maize, with yield drops ranging between 30-50%. It's key to understand that these data points might not be consistent everywhere, as factors like the length of heat exposure, soil's water content, and specific maize types play a role.

Various techniques have been proposed to address the impact of heat stress on maize crops in the context of changing climate conditions. One approach involves creating maize varieties with improved heat tolerance. This can be accomplished through breeding techniques and biotechnology strategies aimed at genes linked to heat resilience. Both traditional and molecular breeding methods have played a vital role in producing heat-tolerant maize strains (Prasanna 2014). Besides breeding approaches, diverse agronomic methods can help alleviate the influence of heat stress on maize yields. Implementing practices such as enhanced irrigation management, including the use of effective irrigation systems, can preserve soil moisture levels and reduce the detrimental effects of high temperatures on maize. Crop diversification and rotation with heat-resistant crops or varieties can also distribute the risk and offer some relief to maize crops during heatwaves.

Furthermore, integrating trees and shrubs into maize farming systems through agroforestry practices can supply shade and diminish heat stress on maize plants. The application of mulching and cover cropping can conserve soil moisture and control soil temperature, contributing to improved resilience against heat stress. It is essential to note that maize's reaction to various temperature ranges can differ, influenced by factors such as the duration of heat exposure, soil moisture content, and specific maize strains. For example, in the 20-25°C temperature range, maize usually displays normal growth without a significant yield decrease. Nevertheless, as temperatures increase, the adverse effects of heat stress intensify, resulting in yield reductions ranging from 5-50% in response to rising temperature ranges. These techniques, in conjunction with ongoing research and innovation, are crucial for alleviating the unfavorable consequences of heat stress on maize production and guaranteeing food security in a shifting climate.

Table 2: Impact of Heat Stress on Maize Yield

Temperature Range (°C)	Percentage Decrease in Yield
20-25	0% (optimal range)
25-30	5-10%
30-35	15-25%
>35	30-50%

Nevertheless, the efficacy of these methodologies has raised concerns due to the genetic uniformity within existing maize varieties. Furthermore, the extended duration required for the development of novel breeds can curtail the potential influence of these strategies. Several agronomic approaches, including altering crops, applying protective coverings, and planting in close proximity, can mitigate the adverse effects of heat stress on maize yield. These methods contribute to the maintenance of adequate soil moisture, organic material levels, and balanced nutrient administration. Nevertheless, the considerable expenses associated with these practices and their limited adoption, especially in developing countries, could constrain their effectiveness. While irrigation and water management can substantially alleviate heat stress, they might also pose challenges to maize productivity. Implementing efficient irrigation systems and appropriate timing can ensure that maize plants receive sufficient water during periods of elevated temperatures. Nevertheless, refining the efficiency of irrigation and water management strategies may be necessary due to water scarcities and high expenses, particularly in arid and semi-arid regions (Fahad et al., 2017).

When maize plant is under heat stress it would be more susceptible to attacks from insects and diseases. An integrated approach to controlling pests and diseases can lessen these effects. This strategy employs cultural, physical, and biological management strategies to control the pressure of pests and illnesses in times of heat stress. However, the effectiveness of these tactics may be constrained by the need for more workable and affordable pest and disease management solutions.

1.4. Problems and Restrictions with using Heat Stress Prevention Techniques

Heat stress may drastically lower the productivity and quality of maize. Several barriers and constraints exist in implementing techniques to reduce heat stress in maize cultivation. The low genetic diversity of current maize varieties may make breeding and biotechnology efforts to create heat-tolerant varieties less successful. The requirement to separate heat-tolerant traits and combine them into high-yielding varieties may make it difficult to create maize varieties that can resist high temperatures. The development of maize varieties capable of withstanding

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high temperatures poses challenges for various reasons. Limited genetic variation within existing maize strains complicates endeavors involving breeding and biotechnology, which seek to create heat-resistant variations. Integrating heat-tolerant traits with traits that promote high yields proves to be a multifaceted undertaking. Additionally, in regions where maize plays a vital role as a subsistence crop, as observed in numerous developing nations, the substantial expenses linked to the adoption of irrigation and water management systems may discourage small-scale farmers. These expenditures encompass the construction of infrastructure for water storage and distribution, an essential component for implementing techniques to mitigate the impact of heat stress (Xiao et al., 2018). Furthermore, in developing countries where maize is a vital subsistence crop, the high cost of implementing irrigation and water management systems may discourage small-scale farmers from using them. Water storage and distribution systems are only two examples of expensive infrastructure that must be built to implement these techniques.

Although effective pest and disease management techniques can be challenging to implement during heat stress. Pest and disease pressures may be mitigated using integrated pest and disease management systems that use various methods, including chemical, biological, and cultural control. However, these efforts may fall short if efficient pest and disease management products and services are not widely accessible (Fahad et al., 2017). The need for more information and awareness of the usefulness of agronomic methods such as crop rotation, mulching, and intercropping in alleviating heat stress effects among small-scale farmers might be a barrier to their implementation.

Heat stress during the cultivation of maize creates a complex issue, with numerous impediments and limitations hindering the effective utilization of preventive methods. An essential problem revolves around the limited genetic diversity present in existing maize strains, potentially obstructing the development of heat-resistant variants through both breeding and biotechnology (Awasthi and colleagues in 2022). This confinement of genetic diversity stands as a considerable obstacle in the journey towards crafting maize types capable of enduring elevated temperatures. Blending heat-resistant characteristics with those that enhance yield showcases a complicated pursuit, further entangling the creation of temperature-resistant maize strains. In areas where maize acts as a vital subsistence crop, particularly within various emerging nations, the acceptance of strategies to counteract heat stress confronts substantial costs linked to the application of irrigation and water management systems (Xiao et al., 2018). Small-scale farmers, who rely heavily on maize, may feel disheartened by the lofty expenses associated with constructing crucial infrastructure for storing and distributing water. These fundamental elements prove indispensable for effectively lessening the impact of heat stress and ensuring crop productivity. The economic difficulties experienced by farmers when introducing these systems. Besides these complications, dealing with pests and diseases within maize crops during periods of heat stress can be troublesome. Multiple pests and diseases possess the capacity to inflict substantial harm on maize crops, a situation exacerbated by high temperatures. A few of the common pests and diseases that significantly harm maize encompass: Fall Armyworm (Spodoptera frugiperda), this notorious pest ravages maize crops by devouring leaves, tassels, and developing kernels. The incidence of fall armyworm infestations tends to rise during bouts of heat stress, rendering it even more destructive to maize production. Maize Streak Virus (MSV) represents a viral ailment transmitted by leafhoppers, responsible for stunted growth, leaf yellowing, and a decline in maize grain quality. Heat stress undermines the plant's defense mechanisms, heightening susceptibility to MSV infection. Fusarium ear rot, a fungal ailment, harms maize ears, causing a decrease in both yield and grain quality. Heat stress fosters favorable conditions for the development of Fusarium spores, exacerbating the issue. Northern Corn Leaf Blight (Exserohilum turcicum) foliar fungal ailment can strip maize plants of their leaves and reduce their photosynthetic capacity. Heat stress diminishes the plant's ability to fend off this pathogen, amplifying vulnerability to infection. Challenges in managing these pests and diseases during heat stress include the diminished efficacy of pesticides and the heightened susceptibility of stressed maize plants. Integrated pest and disease management systems that incorporate an array of control techniques, encompassing chemical, biological, and cultural approaches, become imperative. Nonetheless, access to effective products and services for pest and disease management can be restricted, particularly among small-scale farmers in emerging nations (Fahad et al., 2017).

Furthermore, there exists a necessity for augmenting awareness and knowledge diffusion among small-scale farmers regarding agronomic practices that can alleviate the consequences of heat stress. Strategies such as crop rotation, mulching, and intercropping hold the potential to mitigate the impact of heat stress. However, a lack of awareness and information among farmers proves a substantial hurdle to their adoption. This underscores the significance of education and extension services, empowering farmers with the knowledge and tools required to combat heat stress and its linked challenges in maize cultivation.

1.5. Impact of Extreme Weather Conditions on Maize Yields

In addition to many other factors, drought and heat have a major impact on maize production. Multiple studies have demonstrated the effect that these factors have on maize output in different parts of the world (Ciais et al.,

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2005). Overall yield and yield rate were shown to have increased between 1961 and 2010, before declining afterward, in tandem with a period of reduced precipitation. Since 2010, as temperatures have increased, both total yield and yield rate have decreased. An increase of one degree Celsius in temperature resulted in a 1% decrease in ultimate yield under ideal rainfed circumstances and a decrease of 1.7% under drought conditions, according to data collected from more than 20,000 past maize experiments in Africa between 1999 and 2007. This shows that maize's ability to grow in hotter climes depends critically on access to water. To maintain an ideal internal temperature, plants rely on a process called transpiration (Curtis, 1936). In addition to Europe and Africa, an analysis of maize yield in Khyber Pakhtunkhwa (Pakistan) between 1996 and 2015 indicated that precipitation increases maize productivity while high temperatures decrease it. Increased evaporative demand and the resulting depletion of water supplies caused lower maize yields in the United States from 1959 to 2004 (Lobell et al., 2013). Based on our results, it appears that dryness brought on by either a lack of precipitation or elevated temperatures reduces maize output (Ali et al., 2017).

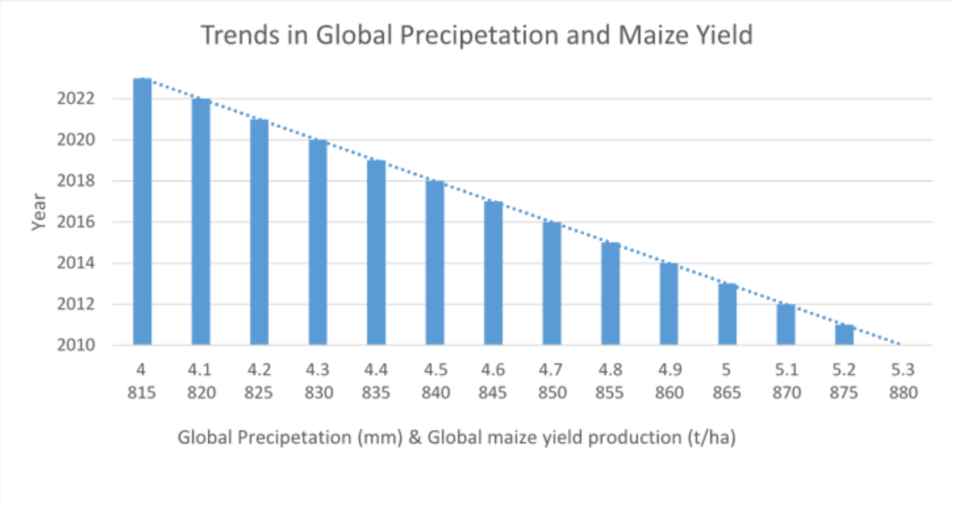

Fig. 2: The impact of extreme weather conditions on maize yields

Extreme weather in the middle and late 21st century, as expected, has also reduced worldwide maize production. Climate warming will reduce Europe's corn harvest by 20 percent by the year 2050. Furthermore, even in low-yielding years, drought is the primary driver of losses for maize production. Higher concentrations of carbon dioxide will help in minimizing these losses if the drought is not too severe (Schauberger et al., 2017). The amount of maize grown in Turkey is predicted to decrease by 10.1% by the middle of the century due to drought and heat stress. The years 2056–2065 and 2081–2090 were predicted for the maize harvest in Sub-Saharan Africa (Yu et al., 2021). These estimates shifted by a range of +6.3% to 33.33%. Researchers showed that weather fluctuations could have a major impact on the maize crop. For instance, a decrease in rainy season precipitation would have a greater impact on maize productivity than an increase in temperature in the southern parts of Mozambique and eastern Africa. However, the authors conceded that it was possible for the model to exaggerate the impact of rising temperatures (Waha et al., 2013). Maize production in the United States is expected to decrease by 39-68% by 2050 compared to 2013-2017 levels due to changes in weather and precipitation. Science's ability to adapt crops to excessive heat and drought is called into doubt when the expected effects of climate-neutral technology developments are factored into the model and the net change in yield ranges from -13% to 62%. Recent climate and crop model suites project a +5 to 6% (SSP126) and +1% to 24% (SSP585) shift in global maize production by the century's end. However, possible changes in agricultural practices or adaptations, such as the creation of more tolerant crop kinds, are not taken into account by these projections (Yu et al., 2021). However, this effect is not taken into consideration by all models. As a result, many regions will see their maize output continue to decline. The effect varies depending on the genotypes, the growing season, and the geographic location of the crops. To quantify the influence of climate change on maize crop output and to create methods for its mitigation, it is vital to incorporate changes in agricultural practices, adaptations such producing more resilient varieties of crops, and economic incentives into the models (Gonzalez and Barrett, 2010). Adapting cultivars to a wide range of situations is more important than making them more drought and heat-resistant since severe climatic events will alternate with routine ones over the next 50 years.

1.6. Effect of Drought and Heat on Maize Stomata

Adaptations at the developmental, physiological, and molecular levels have developed in plants to help them survive under extreme conditions (Killi et al., 2016). Changing the number and function of stomata may aid plants

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in withstanding drought and heat stress and avoiding harm. When plants need carbon dioxide (CO2) for photosynthesis, their stomata open, and when they don't, they shut to prevent water evaporation. It is generally known that plants close their stomata in response to drought stress in order to save water. Maize farming is hampered by a lack of water and excessive temperatures in many places (Kulkarni et al., 2017). It has been known for a century that transpiration causes leaves to cool. Stomata closure, which reduces transpiration, also increases leaf temperature. But how can maize thrive in dry and hot conditions without its leaves wilting and losing water?

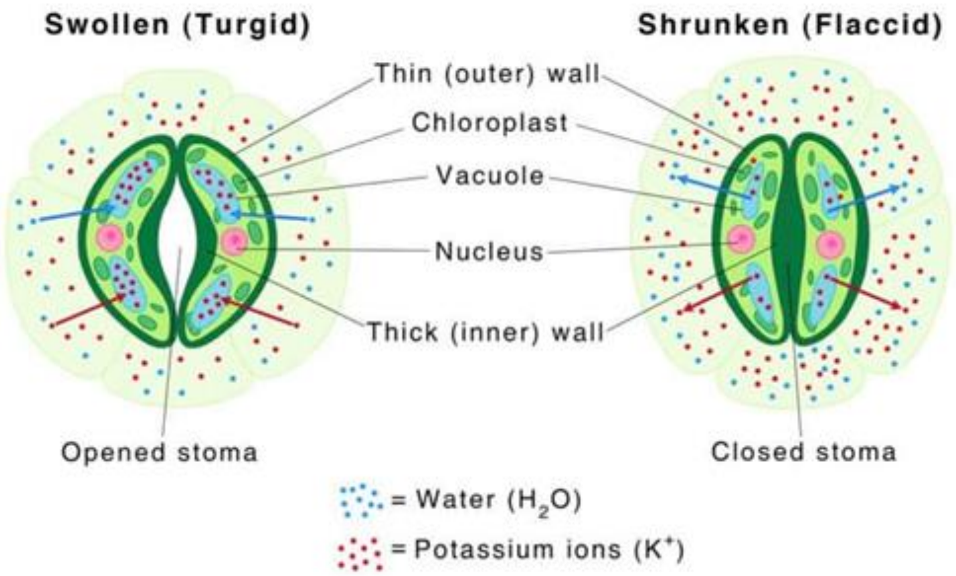

Fig. 3: Opening & closing of Stomata

Plants, such as maize, have developed diverse adjustments at the developmental, physiological, and molecular levels to address the challenges brought by drought and heat stress. One important adjustment relates to the control of stomata, the small openings on the surface of leaves and stems. Stomata have a significant role in the exchange of gases and water vapor between plants and the atmosphere. When dealing with environmental stressors like drought and heat, maize displays specific modifications aimed at boosting its resilience. Under drought conditions, maize plants often shut their stomata to save water and reduce transpiration, which is the release of water vapor through stomata. This closure minimizes water loss, assisting the plant in surviving under water-scarce circumstances (Xiong et al., in 2001). Although this conservation of water is beneficial, it can raise leaf temperatures due to reduced transpiration. Elevated leaf temperatures can intensify heat stress and impede photosynthesis. To tackle this problem, maize has developed an advanced process known as crassulacean acid metabolism (CAM) photosynthesis, which involves separating carbon dioxide uptake and photosynthesis over time. In CAM photosynthesis, maize opens its stomata during the night when temperatures are lower and humidity is higher. This enables the plant to acquire carbon dioxide without excessive water loss and store it for use during the day when stomata remain shut (Brilhaus et al. 2016). This adjustment supports efficient photosynthesis and enables maize to sustain its growth even in hot and dry conditions.

When grasses experience a severe drought (40-50% field capacity), the two dumbbell-shaped guard cells that make up their stomata shrink and close. It has been suggested that the latter is related to a biological need for evaporative cooling (Chaves et al., 2008). This drought response has unfavorable effects on stomatal conductance, photosynthetic rate, and transpiration. A major benefit of reducing stomatal size is that it enhances the speed of stomatal movement, reducing water loss via transpiration. However, this predicts a decline in photosynthetic CO2 uptake and crop productivity (Rizhsky, 2004).

The negative correlation between stomatal density and transpiration rate in maize is stronger than the one between stomatal density and photosynthetic rate, indicating a general tendency towards increased efficiency in the utilization of leaf water. When temperatures rise, plants speed up their transpiration and stomatal conductance to prevent leaf damage caused by overheating. Increased transpiration and decreased photosynthetic rate (although the changes were not statistically significant) were seen in response to heat stress (38°C for 15 days) (Hussain et al., 2019). This decrease in photosynthetic rate is certainly attributable to factors other than stomatal closure, such as alterations in electron mobility and activity. Above 35 degrees Celsius, maize chlorophyll degrades, and proteins are inactivated, significantly reducing carbon uptake (Boyer, 1982). However, when heat and drought coexist, they have a higher negative effect on the stomatal conductivity, evaporation rate, rate of photosynthetic buildup of biomass, and output than either stress alone. Heat increases leaf temperature by increasing the density of stomata

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and decreasing the pore area of stomata, which in turn intensifies the stomatal response to dryness. Reducing CO2 assimilation and yield may occur either directly (Ainsworth and Rogers, 2007) or indirectly (increased leaf temperature, lowering protein activity; Utsumi et al., 2019) as a result of high-water usage efficiency. As a result of these stomatal responses, maize yield loss is predicted to increase because of the frequent severe events caused by changes in the climate, such as extreme temperatures (Vogel et al., 2019).

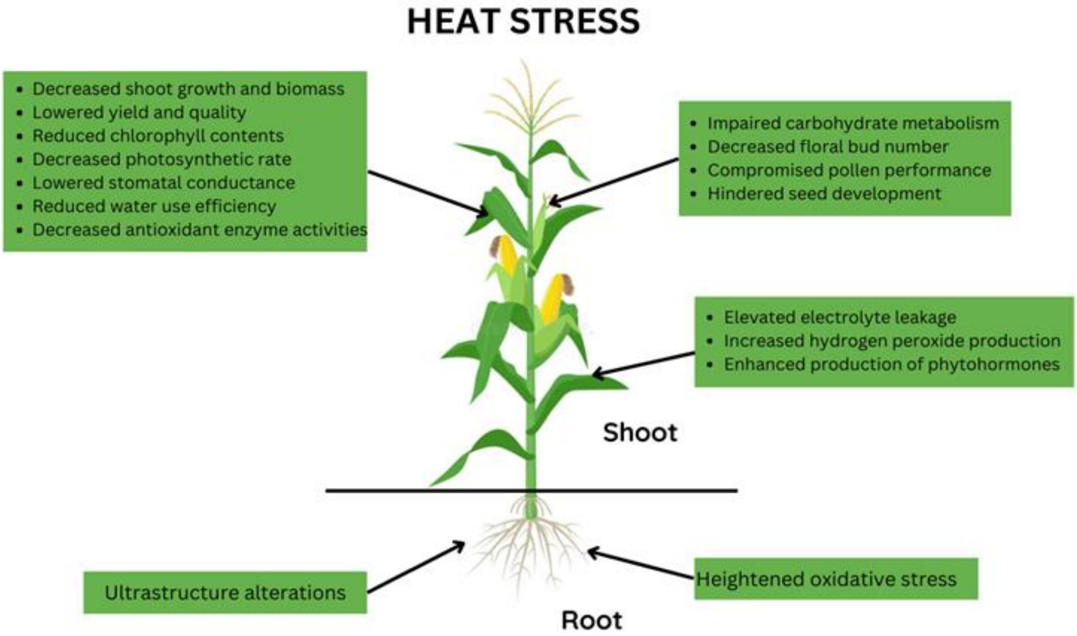

Fig. 3: Possible effects of heat stress on different parts of plants

1.7. Adaptation in Maize Stomatal Development

The density of a plant's stomata has a direct effect on its drought resistance since it determines how efficiently the plant can use water. Along the outer edges of the leaf's underlying longitudinal veins is where stomata develop in grass (Kwak, 2003). The transmission of an inhibitory signal from the vein to the epidermal cells above, and an inductive signal to the epidermal cells positioned at a particular distance from the vein, may explain why stomatal files are located where they are (Nelson and Dengler, 1997). Superfluous stomatal files appear between veins in transgenic rice lines expressing ZmSHR1 over a wider area than its orthologous OsSHR2 gene, showing that this gene is responsible for the inductive signal.

SPEECHLESS (AtSPCH), INDUCER OF CBF EXPRESSION1 (AtICE1), and SCREAM2 (AtSCRM2) are all basic helix-loop-helix (bHLH) proteins that regulate the initiation of the stomatal lineage in Arabidopsis. Ectopic stomatal development in new cell files is stimulated by overexpression of BdSPCH2, while a lack of functionality of both BdSPCH1/2 (bdspch1 and bdspch2) results in a phenotype in which no stomata are present. The SPCH gene has been duplicated in Brachy podium, resulting in BdSPCH1 and BdSPCH2. Cutler et al. (2010) state that BdICE1, and not BdSCRM2, regulates the initiation of the stomatal lineage. This data suggests that stomatal lineage is determined by heterodimers of BdSPCHs and BdICE1.

1.8. Methods and Techniques

1.8.1. Breeding Resistant Cultivars

It is the most cost-effective and long-lasting approach to reducing the negative effects of temperature stress. Climate-tolerant cultivars can boost African maize production by 5-25%. Due to their wide ranges in temperature and stress tolerance, several maize genotypes should be used. Under stressful conditions, selecting germplasm based on higher yield performance may be challenging (Paterniani 1990). In contrast, breeding followed by selection on the basis of ancillary variables that have a strong correlation to yield, and its contributing characteristics is more successful and lasts longer. However, the most cost-effective technology ought to serve as the foundation for this choice. Additionally, plant breeding efforts may be accelerated by sensors (Ali and Yan, 2012).

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Drought Stress		
Morphological Responses	**Physiological Responses**	**Biochemical Responses**
Decreased leaf longevity	Stomatal closure	Accumulation of ABA
Increased anthesis-silking interval	Reduced transpiration	Accumulation of stress metabolites
Increased root to shoot ratio	Decreased photosynthesis	Increase in antioxidative enzymes
Reduced leaf size	Elevated oxidative stress	Decrease in photochemical efficiency
Increased leaf thickness	Improved water use efficiency	Altered osmolyte accumulation
↓		
Yield and yield components		
Reduced grain filling, grain weight and size, even death of maize, etc		

Fig. 4: Maize's physiological and cellular metabolic responses to water-deficit situations result in stunted growth and decreased yield.

1.8.2. Phonemics, or High-throughput Phenotyping

It is now a cutting-edge breeding method with a lot of potential for effective selection. In any case, in view of its moderately significant expense, its reception by reproducers keeps on being troublesome, particularly in emerging countries. Thus, worldwide examination associations like the Food and Farming Association (FAO) and the Global Maize and Wheat Improvement Center (CIMMYT) ought to resolve this issue. Conventional breeding can take anywhere from a few years to a decade to create a new variety (Dar et al., 2021). New cultivars can be grown all the more rapidly with the utilization of more limited rearing cycles. One more technique for decreasing how much time expected to create an assortment is transport reproducing, which was created by the CIMMYT. This strategy can assist with propelling society by age every year (Gachoki et al., 2022).

Any breeding strategy must choose parent plants carefully that meet the study's goals. Among the maize genotypes that have demonstrated significant heat tolerance, inbred lines and hybrids can be utilized as breeding stock to impart heat tolerance to superior cultivars. Understanding important selection indicators is necessary when selecting wild species or tolerant cultivars. In maize under heat pressure, it has been found that dust shedding span, seed setting rate, chlorophyll content, and grain yield have positive connections while leaf terminating, tuft impact, decoration sterility, anthesis-silking stretch (ASI), and senescence have negative relationships (Antonucci et al., 2021). Plant molecular biology has facilitated rapid advancements in agriculture over the past few decades. Various strategies, for example, marker-helped choice, map-based quality cloning, genome altering, and grouped routinely interspaced short palindromic rehash (CRISPR)/CRISPR-related 9, Cas9, have been utilized for the determination and improvement of plant characteristics in different harvests (Gillani et al., 2021).

1.9. Standard Breeding Procedure

Due to inherited affiliation, the standard raising procedure of pyramiding various positive characteristics presents a huge issue for plant raisers. However, the introduction of marker-assisted selection (MAS) has fundamentally altered this aspect by reducing the amount of time required to select intricate traits like drought, salt, cold, and heat tolerance and increasing efficiency (Weiß et al., 2022). Different characteristics influence the heat resilience of maize crops. Because of the disclosure of various sub-atomic markers that are connected to maize's resilience to both cold and intensity, it is presently conceivable to screen lenient germplasm at an early developing stage, saving time, work, and space (Ribaut and Ragot, 2007).

SNPs are frequently used as sub-atomic markers because they are ubiquitous in the genome, simple to identify and study, and co-prevailing. The identification of a few SNPs associated with intensity and cold resistance properties enables their use in MAS to accelerate the decision making process and general rearing projects (Moreau et al., 2004).

Putative genes involved in the resistance to heat and cold stress were successfully identified through the use of QTL mapping, genome-wide association studies (GWAS), and candidate gene analysis (Li et al., 2020). Preceding being used in raising undertakings, these contender characteristics ought to be endorsed using various procedures, for instance, over-verbalization or steady explanation assessments. Target quality inspection occasionally makes use of the guide-based cloning method developed in subatomic physics (Zhao et al., 2018). Researchers have found various characteristics associated with power and cold obstruction in maize by using arranging peoples or recombinant natural lines, followed by cloning and complementation (Xiao et al., 2017). For instance, the functional characterization of genes like AOX, Zm-AN13, ZmCCT, ZmCCA1, ZmLEA3, and ZmSEC14p revealed that they regulate the germination of seeds in maize at low temperatures and provide stress resistance. In quality introgression programs pointed toward expanding the intensity and cold obstruction of maize cultivars, these qualities might be used (Waqas et al., 2021).

1.10. Future Outlook on Climate Change and Maize Cultivation

There's a growing concern about the rising global temperatures. Particularly, the Intergovernmental Panel on Climate Change (IPCC) in their Special Report on Global Warming foresees temperatures rising around 1.5°C

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above pre-industrial measurements by 2040. Such predictions hint at more regular and severe heatwaves, alongside changes in patterns of precipitation. Temperature elevations present undeniable impacts on farming, notably maize growth. Research, including the work by Lobell et al. (2011), identified a decrease in maize production by about 7.4% with each 1°C temperature ascent. This downward trend is worrisome, given maize's central role in many world diets, posing threats to consistent food availability. In the plant world, they possess sophisticated ways to counteract these shifts. To illustrate, stomata, tiny openings on their exterior, are pivotal for CO2 absorption and water emission. Rising temperatures may compel these plants to close their stomata, preserving moisture. However, such water-saving tactics also reduce carbon dioxide uptake, impinging on photosynthesis. Insights from Ainsworth and Rogers (2007) indicate that increased CO2 concentrations can alleviate some adverse impacts on photosynthesis, but may not wholly recover the losses arising from thermal stress.

Addressing these hurdles, the scientific community is embarking on advanced breeding methodologies. A cornerstone of this exploration is spotlighting genetic indicators tied to thermal endurance. Research by Cairns et al. (2013) accentuates the potential of these indicators in crafting maize breeds more adept at withstanding elevated temperatures. Beyond mere genetic solutions, redefining farming techniques is vital. Adopting practices like rotating crops, soil conservation methods, and efficient water use can safeguard water resources, uphold soil quality, and stabilize crop yields under fluctuating weather conditions. Administrative entities play a pivotal role in steering the agricultural sector. Policies advocating for eco-friendly farming, incentives for climate-adaptive crops, and elaborate strategies for water retention can sculpt a conducive farming scenario.

Recognizing the universal scale of these impediments, global teamwork is essential. Entities such as the Consultative Group on International Agricultural Research (CGIAR) spearhead collective efforts, pushing for adaptable farming practices and promoting collective wisdom. Educational endeavors hold great potential in this context. Harnessing the knowledge pool of academic institutions, NGOs, and local organizations can amplify understanding about climatic impacts on farming, enabling communities to act judiciously. The primary objective is clear, develop an agricultural environment characterized by endurance and sustainability. Addressing current obstacles is vital while simultaneously laying groundwork for future generations, ensuring they receive agricultural systems capable of handling climatic uncertainties.

1.11. Discussion and Perspective

The impact of heat stress on maize can result in a reduction in both crop yield and quality. According to Ahmad et al. (2021), certain studies have indicated a reduction in protein levels and an elevation in mycotoxin pollution. A decline in quality could jeopardize food security and public health, particularly in regions where maize is a staple food. Adaptive management options such as breeding and biotechnology methods, agronomic techniques, irrigation and water management, and integrated pest and disease management can mitigate heat stress's impact on maize productivity. Different approaches have been implemented to mitigate the effects of heat stress on maize yields, with varying degrees of effectiveness. Studies have demonstrated that agronomic techniques, such as modifying planting schedules and utilizing crop residues as mulch, can mitigate the adverse effects of heat stress on maize production. Additionally, advancements in breeding and biotechnology have exhibited the potential to create heat-resistant maize cultivars. The application of irrigation and water management practices has the potential to raise maize output and improve water consumption efficiency, particularly in heat stress. Implementing integrated pest and disease control measures might be a workable strategy to lessen the negative effects of heat stress on maize yield.

Heat waves, for example, occur more often due to climate change. Maize is feeling the effects of heat and drought even more acutely because of the reduction in gas exchange caused by the formation of smaller stomata and the resulting reduction in their opening. This reaction may help reduce hydraulic demand since photosynthesis is limited by current CO2 levels in C4 species (Miller et al., 2010). Reduced transpiration, however, will raise leaf temperatures, harming plants in certain regions of the world. Farmers must use plant breeding and agronomic management strategies to mitigate production declines in this climatic setting. Genetic engineering that increases stomatal size and density may reduce leaf temperatures and protect plants from heat stress if sufficient water availability (Dakora et al., 2015). However, in the face of water shortages, it is possible to protect plants against heat-related tissue damage by timely watering and keeping a constant eye on their temperatures. Rainfed maize might adapt to climate change in certain locations with greater water demand in warmer seasons by being sown earlier in the year. When drought stress dominates during the pre-tasseling stage and high temperatures persist close to the anthesis stage, the highest yield losses occur (van der Velde et al., 2011). agricultural management and adaptable genotypes need to be part of any successful adaptation strategy, but this strategy can only be put into action on a regional or even a local scale.

Selecting or breeding varieties that are more tolerant to severe occurrences but also suited to a broad range of circumstances is vital to prevent yield losses since cultivars adapted exclusively to extreme drought and heat

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diminish their yield. This might be accomplished by combining genetic alterations targeting enzymes that govern the photosynthetic process with those targeting stomatal density and opening.

One optimistic approach to craft climate-resistant maize types includes utilizing genetic engineering and advanced biotechnological techniques. Genetic engineering permits scientists to insert certain genes into maize plants that grant them resistance to heat, drought, and other environmental stressors. Scientists target crucial genes linked to stress tolerance, intending to shape maize varieties capable of flourishing amid climate changes. These varieties aim to sustain yields and safeguard food security (Hickey et al., 2019). These novel techniques offer a bright outlook for the future of maize cultivation in an evolving climate, where heat-resistant maize varieties can assume a crucial role in securing global food production and sustainability.

However, some obstacles prevent these suggested techniques from being put into action. Limited access to resources and technology in some areas might pose problems for farmers looking to embrace cutting-edge agricultural approaches. A lack of understanding of the risks involved and the efficacy of such interventions prevents the implementation of adaptive management approaches for reducing heat stress. Socioeconomic factors like poverty and gender inequities may make it more difficult to employ adaptive management measures to reduce the effects of heat stress on maize yield.

The outcomes of this study hold significant ramifications for the prospects of maize cultivation and the worldwide sustenance of food supplies. The impact of climate change on regions where maize is a primary crop may intensify food insecurity due to the adverse consequences of heat stress. The frequency and severity of this condition are predicted to increase. Given the impending effects of climate change, it is crucial to implement adaptive management measures immediately to guarantee sustainable maize farming and food security.

1.12. Conclusion

In conclusion, the impact of climate change on growing maize is evident, especially in areas prone to heat stress and lack of rain. Environmental pressures, like hotter temperatures and changes in rain patterns, significantly affect the growth and yield of crops. Maize, a major global food crop, faces significant challenges due to the increasing heat stress linked to climate change. This stress results in lower harvests, poorer grain quality, and higher vulnerability to pests and diseases. Yet, experts are actively tackling these issues using various strategies. Countries like Pakistan, which heavily rely on maize for food and economic stability, face severe threats from climate change. Heat stress hurts maize growth, development, and output, impacting farmers of all sizes. Additionally, maize is used for making things like biofuels and biodegradable plastics, supporting global sustainability goals. Yet, heat stress's negative impacts on maize challenge these industries, too.

Addressing temperature-related challenges in corn necessitates the development of heat-resilient varieties using both conventional and biotechnological means. Nonetheless, these methods come with hurdles such as restricted genetic diversity, substantial costs, and the incorporation of several characteristics. Intense climatic disturbances, encompassing droughts and elevated heat, notably impact corn productivity. This underscores the imperative of adopting efficient tactics to address these issues. Given escalating temperatures and shifting weather trends, the upcoming phases of corn cultivation demand adaptive solutions. These encompass innovative cultivation practices, enhanced irrigation strategies, and comprehensive pest and disease management. The ultimate goal of these techniques is to strengthen corn's resilience against temperature-related stress, ensure safe food provision, promote economic progression and aid in global climate change mitigation endeavors. It's vital that researchers, decision-makers, and all involved parties collaborate to pinpoint effective strategies and guarantee the longevity of corn cultivation in an evolving environment.

REFERENCES

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H. and Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environmental Science and Pollution Research, 29. https://doi.org/10.1007/s11356-022-19718-6

Adam, D. (2021). How far will global population rise? Researchers can't agree. Nature, 597(7877), 462–465. https://doi.org/10.1038/d41586-021-02522-6

Ainsworth, E. A. and Rogers, A. (2007). The response of photosynthesis and stomatal conductance to rising [CO2]: mechanisms and environmental interactions. Plant, Cell & Environment, 30(3), 258–270. https://doi.org/10.1111/j.1365-3040.2007.01641.x

Ajani, A. and Van der Geest, K. (2021). Climate change in rural Pakistan: evidence and experiences from a people-centered perspective. Sustainability Science, 16(6), 1999–2011. https://doi.org/10.1007/s11625-021-01036-4

Ali, F. and Yan, J. (2012). Disease resistance in maize and the role of molecular breeding in defending against global threat. Journal of Integrative Plant Biology, 54(3), 134-151.

Ali, S., Liu, Y., Ishaq, M., Shah, T., Abdullah, Ilyas, A. and Din, I. (2017). Climate Change and Its Impact on the Yield of Major Food Crops: Evidence from Pakistan. Foods, 6(6), 39. https://doi.org/10.3390/foods6060039

Ambaye, T. G., Vaccari, M., Bonilla-Petriciolet, A., Prasad, S., van Hullebusch, E. D. and Rtimi, S. (2021). Emerging technologies for biofuel production: A critical review on recent progress, challenges and perspectives. Journal of Environmental Management, 290, 112627. https://doi.org/10.1016/j.jenvman.2021.112627

Antonucci, G., Croci, M., Miras-Moreno, B., Fracasso, A. and Amaducci, S. (2021). Integration of gas exchange with metabolomics: high-throughput phenotyping methods for screening biostimulant-elicited beneficial responses to short-term water deficit. Frontiers in Plant Science, 12, 1002.

Badu-Apraku, Á., Hunter, R. B. and Tollenaar, M. (1983). Effect of temperature during grain filling on whole plant and grain yield in maize (Zea mays L.). Canadian Journal of Plant Science, 63(2), 357-363.

Balla, K., Rakszegi, M., Li, Z., Bekes, F., Bencze, S. and Veisz, O. (2011). Quality of winter wheat in relation to heat and drought shock after anthesis. Czech Journal of Food Sciences, 29(2), 117-128.

Boyer, J. S. (1982). Plant Productivity and Environment. *Science*, *218*(4571), 443–448. https://doi.org/10.1126/science.218.4571.443

Brilhaus, D., Bräutigam, A., Mettler-Altmann, T., Winter, K. and Weber, A. P. (2016). Reversible burst of transcriptional changes during induction of crassulacean acid metabolism in Talinum triangulare. Plant Physiology, 170(1), 102-122.

Cairns, J. E., Crossa, J., Zaidi, P. H., Grudloyma, P., Sanchez, C., Araus, J. L. and Atlin, G. N. (2013). Identification of drought, heat, and combined drought and heat tolerant donors in maize. Crop Science, 53(4), 1335-1346.

Cassia, R., Nocioni, M., Correa-Aragunde, N. and Lamattina, L. (2018). Climate Change and the Impact of Greenhouse Gasses: CO2 and NO, Friends and Foes of Plant Oxidative Stress. Frontiers in Plant Science, 9(273). https://doi.org/10.3389/fpls.2018.00273

Chaudhry, Q., Mahmood, A. and Hyder, K. (2019). Effect of Temperature Rise on Crop Growth & Productivity. Pakistan Journal of Meteorology, 8, 15. http://www.pmd.gov.pk/rnd/rnd_files/vol8_issue15/5_Effect%20of%20Temperature%20Rise%20on%20Crop%20Growth.pdf

Chaves, M. M., Flexas, J. and Pinheiro, C. (2008). Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. Annals of Botany, 103(4), 551–560. https://doi.org/10.1093/aob/mcn125

Chen, Y., Zhang, Z. and Tao, F. (2018). Impacts of climate change and climate extremes on major crops productivity in China at a global warming of 1.5 and 2.0 °C. Earth System Dynamics (Online), 9(2). https://doi.org/10.5194/esd-9-543-2018

Chen, Y., Zhang, Z., Tao, F., Palosuo, T. and Rötter, R. P. (2018). Impacts of heat stress on leaf area index and growth duration of winter wheat in the North China Plain. Field Crops Research, 222, 230–237. https://doi.org/10.1016/j.fcr.2017.06.007

Ciais, P., Reichstein, M., Viovy, N., Granier, A., Ogée, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, Chr., Carrara, A., Chevallier, F., De Noblet, N., Friend, A. D., Friedlingstein, P., Grünwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G. and Loustau, D. (2005). Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature, 437(7058), 529–533. https://doi.org/10.1038/nature03972

Curtis, O. F. (1936). Transpiration and the Cooling of Leaves. American Journal of Botany, 23(1), 7–10. https://doi.org/10.2307/2436384

Cutler, S. R., Rodriguez, P. L., Finkelstein, R. R. and Abrams, S. R. (2010). Abscisic Acid: Emergence of a Core Signaling Network. Annual Review of Plant Biology, 61(1), 651–679. https://doi.org/10.1146/annurev-arplant-042809-112122

Dakora, F. D., Matiru, V. N. and Kanu, A. S. (2015). Rhizosphere ecology of lumichrome and riboflavin, two bacterial signal molecules eliciting developmental changes in plants. Frontiers in Plant Science, 6. https://doi.org/10.3389/fpls.2015.00700

Dar, Z. A., Dar, S. A., Khan, J. A., Lone, A. A., Langyan, S., Lone, B. A. and Ansari, M. J. (2021). Identification for surrogate drought tolerance in maize inbred lines utilizing high-throughput phenomics approach. Plos one, 16(7), e0254318.

El-Sappah, A. H., Rather, S. A., Wani, S. H., Elrys, A. S., Bilal, M., Huang, Q., Dar, Z. A., Elashtokhy, M. M. A., Soaud, N., Koul, M., Mir, R. R., Yan, K., Li, J., El-Tarabily, K. A. and Abbas, M. (2022). Heat Stress-Mediated Constraints in Maize (*Zea mays*) Production: Challenges and Solutions. Frontiers in Plant Science, 13. https://doi.org/10.3389/fpls.2022.879366

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. Food Security. https://doi.org/10.1007/s12571-022-01288-7

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Saud, S., Ihsan, M. Z., Alharby, H., Wu, C., Wang, D. and Huang, J. (2017). Crop Production under Drought and Heat Stress: Plant Responses and Management Options. Frontiers in Plant Science, 8. https://doi.org/10.3389/fpls.2017.01147

Gachoki, P., Muraya, M. and Njoroge, G. (2022). Features Selection in Statistical Classification of High Dimensional Image Derived Maize (Zea Mays L.) Phenomic Data.

Gillani, S. F., Rasheed, A., Majeed, Y., Tariq, H. and Yunling, P. (2021). Recent advancements on use of CRISPR/Cas9 in maize yield and quality improvement. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 49(3), 12459-12459.

Gonzalez, M. E. and Barrett, D. M. (2010). Thermal, High Pressure, and Electric Field Processing Effects on Plant Cell Membrane Integrity and Relevance to Fruit and Vegetable Quality. Journal of Food Science, 75(7), R121–R130. https://doi.org/10.1111/j.1750-3841.2010.01763.x

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K. and Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1554), 2973–2989. https://doi.org/10.1098/rstb.2010.0158

Gupta, A., Rico-Medina, A. and Caño-Delgado, A. I. (2020). The physiology of plant responses to drought. Science, 368(6488), 266–269. https://doi.org/10.1126/science.aaz7614

Halubok, M. and Yang, Z.-L. (2020). Estimating Crop and Grass Productivity over the United States Using Satellite Solar-Induced Chlorophyll Fluorescence, Precipitation and Soil Moisture Data. Remote Sensing, 12(20), 3434. https://doi.org/10.3390/rs12203434

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Hatfield, J. L. and Dold, C. (2018). Climate change impacts on corn phenology and productivity. *Corn: Production and human Health in Changing Climate*, *95*.

Hickey, L. T., Hafeez, N. A., Robinson, H., Jackson, S. A., Leal-Bertioli, S. C., Tester, M., ... & Wulff, B. B. (2019). Breeding crops to feed 10 billion. Nature Biotechnology, 37(7), 744-754.

Huan, Y. A. N. G., Gu, X. T., Ding, M. Q., Lu, W. P. and Lu, D. L. (2020). Weakened carbon and nitrogen metabolisms under post-silking heat stress reduce the yield and dry matter accumulation in waxy maize. Journal of Integrative Agriculture, 19(1), 78-88.

Hussain, H. A., Men, S., Hussain, S., Chen, Y., Ali, S., Zhang, S., Zhang, K., Li, Y., Xu, Q., Liao, C. and Wang, L. (2019). Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. Scientific Reports, 9(1), 3890. https://doi.org/10.1038/s41598-019-40362-7

Jamil, M., Shakeel, I., Ullah, H., Ahmad, M., Ullah, S., Rasool, I., Tahir, M., Gull, J., Jabeen, N. and Ali, M. (2022). Livestock in Pakistan: An Insight into Climate Changes and Impacts. Journal of Bioresource Management, 9(4). https://corescholar.libraries.wright.edu/jbm/vol9/iss4/10/

Kamara, A. Y., Menkir, A., Badu-Apraku, B. and Ibikunle, O. (2003). The influence of drought stress on growth, yield and yield components of selected maize genotypes. The Journal of Agricultural Science, 141(1), 43-50.

Kharin, V. V., Zwiers, F. W., Zhang, X. and Hegerl, G. C. (2007). Changes in Temperature and Precipitation Extremes in the IPCC Ensemble of Global Coupled Model Simulations. Journal of Climate, 20(8), 1419–1444. https://doi.org/10.1175/jcli4066.1

Killi, D., Bussotti, F., Raschi, A. and Haworth, M. (2016). Adaptation to high temperature mitigates the impact of water deficit during combined heat and drought stress in C3 sunflower and C4 maize varieties with contrasting drought tolerance. Physiologia Plantarum, 159(2), 130–147. https://doi.org/10.1111/ppl.12490

Klopfenstein, T. J., Erickson, G. E. and Berger, L. L. (2013). Maize is a critically important source of food, feed, energy and forage in the USA. Field Crops Research, 153, 5–11. https://doi.org/10.1016/j.fcr.2012.11.006

Kulkarni, M., Soolanayakanahally, R., Ogawa, S., Uga, Y., Selvaraj, M. G. and Kagale, S. (2017). Drought Response in Wheat: Key Genes and Regulatory Mechanisms Controlling Root System Architecture and Transpiration Efficiency. Frontiers in Chemistry, 5. https://doi.org/10.3389/fchem.2017.00106

Kwak, J. M. (2003). NADPH oxidase AtrbohD and AtrbohF genes function in ROS-dependent ABA signaling in Arabidopsis. The EMBO Journal, 22(11), 2623–2633. https://doi.org/10.1093/emboj/cdg277

Lafitte, H. R., Yongsheng, G., Yan, S. and Li, Z. K. (2007). Whole plant responses, key processes, and adaptation to drought stress: the case of rice. Journal of Experimental Botany, 58(2), 169-175.

Li, Z., Liu, P., Zhang, X., Zhang, Y., Ma, L., Liu, M. and Shen, Y. (2020). Genome-wide association studies and QTL mapping uncover the genetic architecture of ear tip-barrenness in maize. Physiologia Plantarum, 170(1), 27-39.

Lipiec, J., Doussan, C., Nosalewicz, A. and Kondracka, K. (2013). Effect of drought and heat stresses on plant growth and yield: a review. International Agrophysics, 27(4), 463–477. https://doi.org/10.2478/intag-2013-0017

Lobell, D. B. and Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. Environmental Research Letters, 2(1), 014002.

Lobell, D. B. and Gourdji, S. M. (2012). The influence of climate change on global crop productivity. Plant Physiology, 160(4), 1686-1697.

Lobell, D. B., Bänziger, M., Magorokosho, C. and Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change, 1(1), 42–45. https://doi.org/10.1038/nclimate1043

Lobell, D. B., Hammer, G. L., McLean, G., Messina, C., Roberts, M. J. and Schlenker, W. (2013). The critical role of extreme heat for maize production in the United States. Nature Climate Change, 3(5), 497–501. https://doi.org/10.1038/nclimate1832

Lobell, D. B., Schlenker, W. and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science, 333(6042), 616-620.

Martinez-Feria, R. A. and Basso, B. (2020). Unstable crop yields reveal opportunities for site-specific adaptations to climate variability. Scientific Reports, 10(1), 2885.

Masson-Delmotte, V. (2018). Global warming of 1.5° c: An IPCC Special Report on impacts of global warming of 1.5° c above pre-industrial levels and related global greenhouse gas emission pathways, in the contex of strengthening the global response to the thereat of blimate change, sustainable development, and efforts to eradicate poverty. *(No Title)*.

Matsuoka, Y., Vigouroux, Y., Goodman, M. M., Sanchez G., J., Buckler, E. and Doebley, J. (2002). A single domestication for maize shown by multilocus microsatellite genotyping. Proceedings of the National Academy of Sciences, 99(9), 6080–6084. https://doi.org/10.1073/pnas.052125199

Mazahery-Laghab, H., Nouri, F. and Zare Abianeh, H. (2003). Effects of the reduction of drought stress using supplementary irrigation for sunflower (Helianthus annuus) in dry farming conditions. *Horticulture*.

Miller, G., Suzuki, N., Ciftci-Yilmaz, S. and Mittler, R. (2010). Reactive oxygen species homeostasis and signalling during drought and salinity stresses. Plant, Cell & Environment, 33(4), 453–467. https://doi.org/10.1111/j.1365-3040.2009.02041.x

Moreau, L., Charcosset, A. and Gallais, A. (2004). Experimental evaluation of several cycles of marker-assisted selection in maize. Euphytica, 137(1), 111-118.

Nayyar, H., Kaur, S., Singh, S. and Upadhyaya, H. D. (2006). Differential sensitivity of Desi (small-seeded) and Kabuli (large-seeded) chickpea genotypes to water stress during seed filling: effects on accumulation of seed reserves and yield. Journal of the Science of Food and Agriculture, 86(13), 2076-2082.

Nelson, T. and Dengler, N. (1997). Leaf Vascular Pattern Formation. The Plant Cell, 1121–1135. https://doi.org/10.1105/tpc.9.7.1121

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Obeng-Bio, E., Badu-Apraku, B., Ifie, B. E., Danquah, A., Blay, E. T. and Annor, B. (2019). Genetic analysis of grain yield and agronomic traits of early provitamin A quality protein maize inbred lines in contrasting environments. The Journal of Agricultural Science, 157(5), 413-433.

OECD-FAO Agricultural Outlook 2021-2030. (2021). In *OECD-FAO Agricultural Outlook*. OECD. https://doi.org/10.1787/19428846-en

Paterniani, E. (1990). Maize breeding in the tropics. Critical Reviews in Plant Sciences, 9(2), 125-154.

Pereira, A. (2016). Plant Abiotic Stress Challenges from the Changing Environment. Frontiers in Plant Science, 7. https://doi.org/10.3389/fpls.2016.01123

Prasanna, B. M. (2014, October). Maize research-for-development scenario: challenges and opportunities for Asia. In *12th Asian maize conference and expert consultation on maize for food, feed and nutritional security, book of extended summaries* (Vol. 30, pp. 2-11).

Ranum, P., Peña-Rosas, J. P. and Garcia-Casal, M. N. (2014). Global maize production, utilization, and consumption. Annals of the New York Academy of Sciences, 1312(1), 105–112. https://doi.org/10.1111/nyas.12396

Rehman, A., Jingdong, L., Shahzad, B., Chandio, A. A., Hussain, I., Nabi, G. and Iqbal, M. S. (2015). Economic perspectives of major field crops of Pakistan: An empirical study. Pacific Science Review B: Humanities and Social Sciences, 1(3), 145–158. https://doi.org/10.1016/j.psrb.2016.09.002

Ribaut, J. M. and Ragot, M. (2007). Marker-assisted selection to improve drought adaptation in maize: the backcross approach, perspectives, limitations, and alternatives. Journal of Experimental Botany, 58(2), 351-360.

Rizhsky, L. (2004). When Defense Pathways Collide. The Response of Arabidopsis to a Combination of Drought and Heat Stress. Plant Physiology, 134(4), 1683–1696. https://doi.org/10.1104/pp.103.033431

Rojas, M., Lambert, F., Ramirez-Villegas, J. and Challinor, A. J. (2019). Emergence of robust precipitation changes across crop production areas in the 21st century. Proceedings of the National Academy of Sciences, 116(14), 6673–6678. https://doi.org/10.1073/pnas.1811463116

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., Khabarov, N., Neumann, K., Piontek, F., Pugh, T. A. M., Schmid, E., Stehfest, E., Yang, H. and Jones, J. W. (2013). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proceedings of the National Academy of Sciences, 111(9), 3268–3273. https://doi.org/10.1073/pnas.1222463110

Rouf Shah, T., Prasad, K. and Kumar, P. (2016). Maize - A potential source of human nutrition and health: A review. Cogent Food & Agriculture, 2(1). https://doi.org/10.1080/23311932.2016.1166995

Samarah, N. H., Mullen, R. E., Cianzio, S. R. and Scott, P. (2006). Dehydrin-Like Proteins in Soybean Seeds in Response to Drought Stress during Seed Filling. Crop Science, 46(5), 2141-2150.

Schauberger, B., Archontoulis, S., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Elliott, J., Folberth, C., Khabarov, N., Müller, C., Pugh, T. A. M., Rolinski, S., Schaphoff, S., Schmid, E., Wang, X., Schlenker, W. and Frieler, K. (2017). Consistent negative response of US crops to high temperatures in observations and crop models. Nature Communications, 8(1). https://doi.org/10.1038/ncomms13931

Settles, A. M., Holding, D. R., Tan, B. C., Latshaw, S. P., Liu, J., Suzuki, M. and McCarty, D. R. (2007). Sequence-indexed mutations in maize using the UniformMu transposon-tagging population. BMC Genomics, 8(1), 1-12.

Shrestha, S., Mahat, J., Shrestha, J., K.C., M. and Paudel, K. (2022). Influence of high-temperature stress on rice growth and development. A review. Heliyon, 8(12), e12651. https://doi.org/10.1016/j.heliyon.2022.e12651

Syed, A., Raza, T., Bhatti, T. T. and Eash, N. S. (2022). Climate Impacts on the agricultural sector of Pakistan: Risks and solutions. Environmental Challenges, 6, 100433. https://doi.org/10.1016/j.envc.2021.100433

Tariq, M. and Iqbal, H. (2010). Maize in Pakistan -An Overview. National Science, 44, 757–763. https://www.thaiscience.info/Journals/Article/TKJN/10641540.pdf

Tian, X., Matsui, T., Li, S., Yoshimoto, M., Kobayasi, K. and Hasegawa, T. (2010). Heat-induced floret sterility of hybrid rice (Oryza sativa L.) cultivars under humid and low wind conditionsin the field of Jianghan Basin, China. Plant Production Science, 13(3), 243-251.

Utsumi, Y., Utsumi, C., Tanaka, M., Ha, C. V., Takahashi, S., Matsui, A., Matsunaga, T. M., Matsunaga, S., Kanno, Y., Seo, M., Okamoto, Y., Moriya, E. and Seki, M. (2019). Acetic Acid Treatment Enhances Drought Avoidance in Cassava (Manihot esculenta Crantz). Frontiers in Plant Science, 10. https://doi.org/10.3389/fpls.2019.00521

Van der Velde, M., Tubiello, F. N., Vrieling, A. and Bouraoui, F. (2011). Impacts of extreme weather on wheat and maize in France: evaluating regional crop simulations against observed data. Climatic Change, 113(3-4), 751–765. https://doi.org/10.1007/s10584-011-0368-2

Vogel, E., Donat, M. G., Alexander, L. V., Meinshausen, M., Ray, D. K., Karoly, D., Meinshausen, N. and Frieler, K. (2019). The effects of climate extremes on global agricultural yields. Environmental Research Letters, 14(5), 054010. https://doi.org/10.1088/1748-9326/ab154b

Waha, K., Müller, C. and Rolinski, S. (2013). Separate and combined effects of temperature and precipitation change on maize yields in sub-Saharan Africa for mid- to late-21st century. Global and Planetary Change, 106, 1–12. https://doi.org/10.1016/j.gloplacha.2013.02.009

Waqas, M. A., Wang, X., Zafar, S. A., Noor, M. A., Hussain, H. A., Azher Nawaz, M. and Farooq, M. (2021). Thermal Stresses in Maize: Effects and Management Strategies. Plants, 10(2), 293. https://doi.org/10.3390/plants10020293

Webber, H., Ewert, F., Olesen, J. E., Müller, C., Fronzek, S., Ruane, A. C., Bourgault, M., Martre, P., Ababaei, B., Bindi, M., Ferrise, R., Finger, R., Fodor, N., Gabaldón-Leal, C., Gaiser, T., Jabloun, M., Kersebaum, K.-C., Lizaso, J. I., Lorite, I. J. and Manceau, L. (2018). Diverging importance of drought stress for maize and winter wheat in Europe. Nature Communications, 9(1). https://doi.org/10.1038/s41467-018-06525-2

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Weiß, T. M., Zhu, X., Leiser, W. L., Li, D., Liu, W., Schipprack, W. and Würschum, T. (2022). Unraveling the potential of phenomic selection within and among diverse breeding material of maize (Zea mays L.). *G3*, *12*(3), jkab445.

Xiao, L., Yobi, A., Koster, K. L., He, Y. and Oliver, M. J. (2018). Desiccation tolerance in Physcomitrella patens: rate of dehydration and the involvement of endogenous abscisic acid (ABA). Plant, Cell & Environment, 41(1), 275-284.

Xiao, Y., Liu, H., Wu, L., Warburton, M. and Yan, J. (2017). Genome-wide association studies in maize: praise and stargaze. Molecular Plant, 10(3), 359-374.

Xiong, L., Ishitani, M., Lee, H. and Zhu, J. K. (2001). The Arabidopsis LOS5/ABA3 locus encodes a molybdenum cofactor sulfurase and modulates cold stress–and osmotic stress–responsive gene expression. The Plant Cell, 13(9), 2063-2083.

Yu, C., Miao, R. and Khanna, M. (2021). Maladaptation of U.S. corn and soybeans to a changing climate. Scientific Reports, 11(1), 12351. https://doi.org/10.1038/s41598-021-91192-5

Zargar, S. M., Gupta, N., Nazir, M., Mahajan, R., Malik, F. A., Sofi, N. R., Shikari, A. B. and Salgotra, R. K. (2017). Impact of drought on photosynthesis: Molecular perspective. Plant Gene, 11, 154–159. https://doi.org/10.1016/j.plgene.2017.04.003

Zhao, X., Luo, L., Cao, Y., Liu, Y., Li, Y., Wu, W. and Lin, H. (2018). Genome-wide association analysis and QTL mapping reveal the genetic control of cadmium accumulation in maize leaf. BMC Genomics, 19(1), 1-13.