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Response of temperature on growth, quality, yield attributing characters and yield of maize: A review

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Abstract

Because of global land surface warming, extreme temperature events are expected to occur more often and more intensely, affecting the growth and development of the major cereal crops in several ways, thus affecting the production component of food security. In this study, we have identified maize crop responses to temperature in different, but consistent, phenological phases and development stages. A literature review and data compilation of scientific articles have determined the key temperature thresholds and response to extreme temperature effects for maize crop, complementing an earlier study on wheat. Lethal temperatures and cardinal temperatures, together have been identified for phenological phases and development stages. Following the methodology of previous work, we have collected and analysed temperature effect on growth stages of crop. Our summary shows that cardinal temperatures are conservative between studies and are seemingly well defined. Anthesis and ripening are the most sensitive temperature stages in maize. We call for further studies of the effects of transgressing threshold temperatures so such responses can be included into crop impact and adaptation models.

Keywords: Maize, temperature, CO_2, climate change

Introduction

Maize (*Zea mays* L.) is grown throughout the world and as such is subject to a wide variety of climates and potential scenarios of climate change. Production area continues to increase in response to the increased demand for corn grain and the production per unit area (yield) has continued to increase due to enhanced technology. Corn is a grain crop with both food and feed uses and variation in production at the local scale can have major impact on local economies and local food supplies as well as world food security. It also serves as feed for poultry and as raw material for the brewing industry, for making malt drinks. Maize are mainly grown in summer but improved cultivars are mostly day neutrals and can be grown thought the year. It is found that without implementing adaptation strategies there would be a loss in yield in both temperate and tropical regions with only 2 °C of warming. However, yields are low due to high temperature at tasseling and silking stages. It is rarely grown in area where the average summer temperature is less than 19 °C and mean night summer temperature is less than 13 °C. Minimum temperature for germination is 10 °C and the optimum is 30 °C to 35 °C under adequate moisture. The predominant maize growing states that contributes more than 80% of the total maize production are Andhra Pradesh (20.9%), Karnataka (16.5%), Rajasthan (9.9%), Maharashtra (9.1%), Bihar (8.9%), Uttar Pradesh (6.1%), Madhya Pradesh (5.7%), Himachal Pradesh (4.4%). Hence, the maize has emerged as important crop in the non-traditional regions i.e, peninsular India as the state like Andhra Pradesh which ranks 5th in area (0.79 m ha) has recorded the highest production (4.14 m t) and productivity (5.26 t ha^{-1}) in the country although the productivity in some of the districts of Andhra Pradesh is more or equal to the USA.

Climate change impacts on agricultural productivity are linked to the positive effects of increasing carbon dioxide (CO2), negative effects of increasing temperatures, and variable effects of precipitation timing and amounts. Projections of crop productivity under scenarios of climate change have ranged from less than 5% with temperature increases of less than 1 °C (Hatfield *et al*. 2011) [21] to a decrease of more than 50% in maize. In addition, the review by Hatfield *et al*. (2011) [21] summarized that rising temperatures increase the rate of phenological development, leading to a smaller plant and reduced productivity because of the shortened growth cycle. One of the most vulnerable stages of plant development to temperature stress is the pollination phase because of pollen's sensitivity to extreme temperatures. In recent years, global warming has gained considerable attention by experts throughout the world to see how the rapidly changing climate is affecting crop growths and what the possible solutions to minimize its influence are. Such future global warming also reflects the changes in predicted climate variables (Pachauri and Meyer, 2014) [38]. Crop yields directly correlate with climate variables, and they can bring positive or negative impacts on the agriculture yield. The increase in temperature may have a severe negative effect on crop yields, which may lead to decreased crop yields around the world (Lobell and Schlenker, 2011) [33].

Maize crop provides 19.5% of global caloric intake from all sources (Watto *et al*. 2018) [61]. Furthermore, it has also become an important industrial commodity. However, temperature extremes (occurrence of high and low temperatures during the growth period) are threatening the yield sustainability of maize. It is projected that until 2050, 45% of the global maize production area is likely to face a mean episode of five days of the maximum temperature more than 35 °C during the reproductive stage annually (Gourdji *et al*. 2013) [18]. This is important to note as a mere 1 °C rise in mean seasonal temperature can cut the economic yield of maize crop by 3–13% (Izaurralde *et al*. 2011) [26]. A high temperature at critical development stages may also deteriorate the quality of maize grains (Siebers *et al*. 2017) [49]. Low temperature negatively affects gaseous exchange, water use efficiency, morphology, and physiology (Hussain *et al*. 2019) [23, 24]. Farmers sow maize early to escape heat stress at the reproductive stage, but plants are exposed to low soil temperature (below 10 °C) during early seedling establishment. During this phase, soil temperature strongly impacts leaf development as the shoot apex is positioned very near to the soil surface. Therefore, to cope with temperature extremes in maize production, a comprehensive set of adjustments in cultural as well as in molecular techniques (such as breeding climate resilient genotypes) and an improved understanding of the genetic, physiological, and molecular responses to temperature extremes are needed. Many morphological and physiological perturbations, resulting in stunted plant growth and reduced grain yields (Rafique at al., 2019) [40]. Temperatures above the threshold for various metabolic, biochemical, and physiological processes result in imbalance for these activities and activate the innate plant defence system (Zafar *et al*. 2020) [67]. Temperature extremes alter the photosynthetic process, damage the biological membranes, affect nutrient uptake, and limit the functioning of various enzymes in maize plants. Stunted growth and low photosynthetic rates cause impairment in overall maize performance.

The objective of this study is to investigate the responses of maize phenology, yield-related traits, and yield to elevated air temperature conditions. This paper therefore provides a review based upon some of these relevant scientific literatures.

Climatic requirements

Maize is a plant that has a good adaptability to intense lighting conditions and high daytime temperatures with low photo responsiveness. The main climatic factor of corn is temperature. The thermal requirements of the plant are relatively high throughout the vegetation period, although they are quite different from one vegetation stage to another. The optimum maize growth temperature is 28-30 °C, but it also uses moderate temperatures. Cofas and Elena (2018) [8] reported that in the growth, blooming and grain filling phases the temperatures of 10 °C cause plant growth to cease, yellowing or whitening of the plant also the very high temperatures above 32 °C are considered as critical temperatures for corn. Through the sweat process, the plant loses a very large amount of water, dehydrating, even if the plant has a reservoir of water in the soil. At higher temperatures (48 °C for 6 hours) and under relatively low humidity conditions (below 30%) the maize plant is irreversibly dry. As it advances in vegetation, the requirements of maize are rising as against temperature. At temperature greater than 37 °C the growth rate of maize plants is reduced, the growing season is prolonged and the production decreases. Oluwaranti *et al*. (2015) [37] concluded that development rate from sowing to flowering (days to 50% tasseling, anthesis and silking) was affected mainly by high temperature. They have also indicated that temperature, photoperiod and heat units are the major climatic factors affecting days to flowering in maize. Days to flowering increases as temperature, heat units and photoperiod increases and declines as these climatic factors decreases. Theoretically, delayed planting in the early season should reduce the number of days to flowering while in the late season, it should delay flowering. The base temperature of 8 °C is used for all phenological phases except seedling emergence. Kiniry (1996) [28] reported that high temperature cut-off is activated at 34 °C, and values are decreased linearly from their maximum at 34 °C to zero at 44 °C. Du Plesis (2003) [13] reported that if minimum air temperature of 10 to 15 °C is maintained for seven successive days, germination should proceed normally. Virtually no germination or growth takes place below 10 °C. Planting should be scheduled such that the most heat and water sensitive growth stage of maize (i.e. the flowering stage) does not coincide with midsummer droughts. Farooq *et al*. (2009) [16] reported that low temperature stress, characterized by plant exposure to a temperature range below 10 °C for a sufficient duration, can interrupt the normal process of crop growth, starting from the early seedling stage to the later reproductive stages

Germination and seedling growth

Du plesis (2003) [13] suggested that maize is a warm weather crop and is not grown in areas where the mean daily temperature is less than 19 °C or where the mean of the summer months is less than 23 °C. Although the minimum temperature for germination is 10 °C, germination will be faster and less variable at soil temperatures of 16 to 18 °C. At 20 °C, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately 32 °C. Pollen production and/or viability have been highlighted as major factors responsible for reduced fertilisation under high temperatures. Pollen produced under high temperature has reduced viability and *in vitro* germination. Additionally, high temperatures are responsible for reduced pollen water potential, quantity of the pollen shed and pollen tube germination (Dupuis and Dumas, 1990) [14]. Elevated temperatures also negatively affect the seedling and vegetative stages. During the autotrophic phase of germination, plant energy is directly affected by soil temperature (Stone, 2001) [52]. High temperature reduces both seedling percentage and growth (Weaich *et al*. 1996) [62]. In maize, seedling growth is maximized at a soil temperature of 26 °C and above this temperature, root and shoot mass both decline by 10% for each degree increase until 35 °C when growth is severely retarded (Walker, 1969) [58]. Reduced seedling growth has been suggested to be associated with poor reserve mobilization, with reduced protein synthesis observed in seedlings grown under elevated temperatures (Riley, 1981) [42]. Seedlings growing in high soil temperatures are likely to suffer further damage as the associated slower growth rate delays canopy closure, consequently reducing soil shading. Blacklow (1972) [4] reported that the rates of elongation were greatest at about 30 °C and effectively ceased at lowest of 9 °C and highest of 40 °C temperature. The time for initiation of a radicle and a shoot decreased to a minimum at 30 °C with the radicle preceding the shoot. Chen *et al*. (2012) [6] reported that low temperature in maize seedlings significantly limits germination and seedlings' growth and destabilizes the antioxidant defence mechanism. A temperature around 8 to 10 °C delays seedling emergence and causes a reduction in the root / shoot ratio and chlorophyll content during the early growth cycle in maize (Bano *et al*. 2015) [2], whereas a temperature from 4 to 10 °C may suppress chlorophyll synthesis and causes a severe reduction in photosystem II (PS II) activity (Riva *et al*. 2016) [43].

Leaf development and Flowering

Djanaguiraman *et al*. (2020) [11] reported that high-temperature stress during the flowering or grain filling stages of wheat reduced the photosynthetic rate, increased the damage to the thylakoid membrane, and decreased yield by 29% and 44%, respectively. Gabaldón *et al*. (2018) [17] found that the critical maximum temperature at flowering ranged from 32–35 °C for maize and, at temperatures above 35 °C, the reproductive organs develop poorly, pollination and fertilization cannot proceed normally, and grain filling and the seed-setting rate decrease, which ultimately leads to reduced production.

Wang *et al*. (2019) [12] reported that when the night time temperature was 26 °C at the flowering stage, no significant effects on maize seed set and grain yield were found, but as night temperature reached up to 30 °C, maize seed set and grain yield were dramatically reduced. The percentage of flowering tassels was significantly higher at 26 °C and 30 °C than in the control, especially on the tassel branches. The percentage of flowering tassels on the main stem was more than 40% at 26 °C and more than 71% at 30 °C. On the tassel branches, the percentage of flowering tassels was significantly higher under HNT than under controlled temperature. The high night temperature (HNT) treatments attained 100% flowering 1–2 days earlier compared with the controlled temperature. HDT has little effects on silking time, but advanced tasseling and pollen shedding time (Edreira *et al*. 2011, Lizaso *et al*. 2018) [15, 31, 32]. However, HNT resulted in a shorter pollen shedding duration in maize through accelerating tassel inflorescences flowering rate. HNT also has a larger effect on male flowering than female flowering in maize (Djanaguiraman *et al*. 2017, Wang *et al*. 2019) [12, 59, 60] by reducing the number of pollen grains shed. Neiff *et al*. (2016) [36] research shows that temperature ranging from 33 to 36 ◦C during pre-and post-flowering regimes of maize, respectively, reduce the CO2 exchange rate (~17%), crop growth rate (17–29%), grain number (7–45%), and grain yield (10–45%). Leaf development becomes slow in cold-stressed plants due to a prolonged cell cycle and decreased rate of mitosis.

Hussain *et al*. (2006) [25] reported that maize leaf growth increases at temperatures ranging from 10 °C to 35 °C, while it starts declining at temperatures more than 35 °C. Higher leaf area production in the north experiment compared to rest of the field could explain by the lower radiation and temperature of the site, which would result in different pattern of assimilation portioning targeted to maximize radiation interception (Vos *et al*. 2005) [57].

Pollens growth

The negative effects of high temperatures during the grain-filling period were attributed to pollen survivability and the efficiency of the grain-filling process. Pollen viability significantly reduced when the night-time temperature reached 30 °C, which is consistent with the results in rice (Mohammed and Tarpley 2009). The tapetum layer is a rich source of sugars, feeding the

developing pollen, and the disruption of the tapetum function under heat stress can affect pollen grain wall (Parish *et al*. 2012). Disruption of sugar metabolism under heat stress is a key factor that reduces pollen viability in many crops (Sato *et al*. 2006, Echer *et al*. 2014). However, neither soluble sugar content nor starch content in the pollen reduced under HNT. Interestingly, in the study conducted by Wang *et al*. (2019) [59, 60] shows that HNT decreased soluble sugar content in anther, and more ^{13}C isotopes were transported to the pollen when night temperature was 30 °C. On the basis of these findings, we proposed that HNT accelerated sugar transport from the tapetum to pollen to offset the negative effects on pollen. Survival of pollen are sensitive to temperature, e.g., temperatures exceeding 35 °C have been proven detrimental to pollen viability.

Kernel and tassel development

Cheik and Jones (1996) reported that long-term heat stress during early stages of kernel development disrupts endosperm development and leads to abortion or premature cessation of growth. Furthermore, they have shown that even a brief period of high temperature (i.e. 4 d at 35 °C) can hamper subsequent kernel development. These data suggest that the duration of heat stress determines the extent of the thermally induced perturbation of kernel development, since kernels exposed to short-term heat stress showed partial recovery but inhibition of kernel growth was irreversible following long-term heat stress. Barnabas *et al*. (2008) [3] reported that elevated temperature at the reproductive developmental stage reduces pollen shedding, pollen viability, and pollination efficiency, and affects kernel development, resulting in a reduction in seed set, kernel size, and kernel weight. Hatfield (2016) [19] shows that exposure to maize hybrids to temperatures above 30 °C during the pollination stage reduces the kernel number. High temperature during the reproductive phase is associated with a decrease in yield due to a decrease in the number of grains and kernel weight. Cicchino *et al*. (2010) [7] reported that reduction in kernel number between 52 and 61% for plants exposed to heat. Among the morphological responses by stressed maize plants, low temperature stress causes abnormal tassel growth in maize (Hayashi *et al*. 2015) [22], thus affecting the pollination and grain filling processes.

Photosynthesis

Steven *et al*. (2002) [51] reported that photosynthetic apparatus of maize is very much sensitive to high temperature stress. Photosynthesis efficiency reduces beyond 38 °C and severe inhibition occurs due to rapid increase in temperature. Heat-stressed maize plants are unable to convert photosynthates into starch in pollens. Thus, a decrease in pollen numbers, viability, and starch synthesis contribute to the distorting fertilization process Wang *et al*. (2019) [59, 60].

Grain filling

Notably, a high temperature at the grain filling phase reduces amyloplast biogenesis and endosperm cell division, causing a decrease in the grain size (Shim *et al*. 2017) [48]. Heat stress more than 30 °C limits the enzyme activities and impairs starch accumulation during the grain filling and hardening process. Hussain *et al*. (2019) [23, 24] reported that low temperature weakens the seedling and may also cease the grain filling prematurely at the end of the growth cycle. Low temperature stress at grain filling can alter the starch composition in grains by reducing the amylose content, ultimately decreasing water solubility and starch swelling power and increasing gelatinization temperatures (Lu *et al*. 2016). Using crop production and meteorological records, Thomson (1966) [53] showed that a 6 °C increase in temperature during the grain filling period resulted in a 10% yield loss in the US Corn Belt.

Quality

High-temperature stress induces cellular changes leading to over-production of highly reactive oxygen species which damages macromolecules and cell organelles, eventually resulting in cell death. Yadav *et al*. (2021) [64] reported that elevated temperature in free air decreases the crude protein content by 8.1% in HQPM-1 and by 12.5% in PMH-1. They also reported that Carbohydrate content of grains increased in HQPM-1 (4.6%) and PMH-1 (15.5%) under the elevated temperature as compared to the ambient treatment. Lysine is an important α amino acid that is needed for the biosynthesis of proteins. It ranges from 0.27 to 0.28% under elevated temperature. Lysine contents of maize grains decreased under elevated temperature by 3.7–8.4% over the ambient treatment in both HQPM-1 and PMH-1 maize cultivars, Yadav *et al*. (2021) [64]. Further Dalei *et al*. (2013) [10] reported that heat stress during grain filling stage increased protein content, starch granule size, abnormal granule numbers and iodine binding capacity. These effects were more severe when heat stress was introduced at early development stage than at late grain filling stage. The peak intensities and crystallinities were decreased when plants were exposed to high temperature at early development stage. Lu *et al*. (2014) [35] results showed that high temperature affects the physicochemical properties (starch, protein, and soluble sugar contents) of waxy maize during the grain filling process, resulting in grains with substandard quality. Plants exposed to high temperature had low starch content, and high protein and soluble sugar contents at maturity. Starch iodine binding capacity and granule size were increased by heat stress at all grain-filling stages. High-temperature stress led to an increase in the level of glutathione in all the genotypes, the glutathione S-transferase activity increased significantly under heat stress (Tiwari and Yadav, 2020) [55]. A survey of 11 enzymes done by Wilhelm *et al*. (1999) [63] of sugar and starch metabolism extracted from developing endosperm in maize revealed that ADP glucose pyrophosphorylase, glucokinase, sucrose synthase, and soluble starch synthase were most sensitive to the high temperature treatment.

Growth and Development

Effects of increased temperatures have shown a large degree of variation with projections of reduced production by less than 5% with temperature increases of 1 °C (Hatfield *et al*. 2011) [21] to over 50% with 4 °C increases (Schlenker and Roberts, 2009) [45, 46]. Cárcova and Otegui (2001) [5] shows in their work that heat stress also disturbs the normal physiological processes required for optimal maize growth and development. Reduced biomass assimilation and grain abortion are the key physiological processes resulting in reduced grain number in heat-stressed plants. This result was supported by (Edreira *et al*. 2011) [15]. Heat stress up to 36 °C significantly decreased the radiation use efficiency (Cicchino *et al*. 2010) [7] and less active nitrogen and carbon metabolisms contribute to a decrease in dry matter accumulation (Yang *et al*. 2019) [65]. Temperatures below 15 °C during the late reproductive stage reduce the activities of the photosynthetic apparatus as well as rates of sucrose phosphate synthase, phosphoenolpyruvate carboxylase, and sucrose synthase. It tends to destabilize the assimilation process, resulting in impaired grain quality with substandard-quality components and poor physical grain texture. Heat stress during late vegetative growth and the silking pollination periods had severe negative effects on kernel set and final grain yield of maize crops. The larger biomass in stems when the condition were hottest suggested that the shorter grain filling duration might have limited assimilate mobilization to the sinks. High day temperature has little effects on silking time, but advanced tasseling and pollen shedding time (Edreira *et al*. 2011, Lizaso *et al*. 2018) [15, 31, 32]. However, high night temperature resulted in a shorter pollen shedding duration in maize through accelerating tassel inflorescences flowering rate. Similar changes in flowering pattern were also induced by high day temperature (Wang *et al*. 2019) [59, 60]. Liy *et al*. (2016) [30] reported that low temperature stress significantly decreases the plant height and total crop biomass of maize.

Yield and its components

Environmental factors, especially temperature during the period of seed development and maturation affectes yield and yield components. Grain yield decreases when yield formation operations are conducted earlier than normal. Controlled environment studies have confirmed the effect of high temperatures on corn with temperatures greater than or equal to 3 °C above normal temperatures showing maize yield reductions of over 50% in grain yield (Hatfield and Prueger, 2015) [20]. Maize yields have been shown to have an optimum growing temperature of 29 °C and 30 °C, respectively; temperatures above this limit resulted in decline of yield (Schlenker and Roberts, 2009) [45, 46]. Exposure to temperatures above 30 °C damaged cell division and amyloplast replication in maize kernels which reduced the size of the grain sink and ultimately yield (Commuri and Jones, 2001) [9]. Khodarahmpour and Choukan (2011) [27] observed reduction of grain yield up to 70% under heat stress might be due to low pollen viability, silk receptivity and longer ASI duration in heat stressed condition. High temperature has adverse effect on the growth and development of plants (Noohi *et al*. 2009) and the yield may be reduced by 101 kg ha^{-1} day^{-1} when the temperature reaches up to 35 °C during pollination and grain filling stage (Smith, 1996) [50]. Ramadoss *et al*. (2016) [41] reported that lower grain yield, grain numbers and harvest Index were recorded in the sowing treatment where extreme air temperatures (more than 38 °C) coincided with anthesis. Lizaso *et al*. (2018) [31, 32] shows that air temperature above 35 °C suppresses maize ovary fertilization and the grain filling process, which is directly associated with the final grain yield. Heat stress during the reproductive phase causes parchedness of silks, pollens' sterility, and poor seed setting, resulting in drastic yield reduction (Sanchez *et al*. 2014 and Lesk *et al*. 2016) [44, 29]. Productivity loss at the reproductive phase due to heat stress is also linked with a decrease in the number of grains and their weight Tian *et al.* (2019) [54]. The day-time temperature of 35 °C in waxy maize reduced the grain yields by up to 31% due to decreased grain number and grain weight (yang *et al*. 2018). Sub-optimal temperatures can cause a serious yield reduction if occurring at critical reproductive stages, as plants assign more than 50% of their photosynthates to develop grains during this phase until physiological maturity. This study conducted by Qaisar *et al.* (2020) [39] showed that future maize yields negatively correlated with increased temperatures in Shaanxi Province. With an average 1 °C increase in the temperature, the maize yields decreased by 9%. However, elevated CO2 concentrations reduced the severe effects of temperatures on the maize yields. At a high temperature of 35 °C, maize yield reduces by 9% with a one-inch reduction in rainfall. Dale, (1983) concluded that maize yields to be negatively correlated with accumulated degrees of daily maximum temperatures above 32 °C during the grain filling period. It is estimated that corn yields would decrease by nearly 15% in temperate regions with a 4 °C increase.

Analysis of more than 20,000 historical maize trial yields in Africa over an eight year period combined with weather data shows that for every degree day above 30 °C grain yield was reduced by 1% and 1.7% under optimal rainfed and drought conditions, respectively (Lobell *et al.* 2011) [33, 34]. High daytime temperatures (above 32 °C) raise plant tissue temperatures above threshold levels, damaging yield influencing mechanisms (Hall 2001). Grain yield, seed set and kernel number in maize decreased by 23.8, 20.3 and 25.1%, respectively, at 30 °C night temperature compared with the control.

Conclusion

This study investigated the observed climate-induced and cultivar-induced changes in summer maize phenology over the past. The results showed that climate warming could accelerate crop growth and shorten the length of the growing period. Summer maize production is adapting to ongoing climate change by adoption of cultivars with longer growing and more longer growing cultivar should be adapt in the future. The current knowledge about future climate projections and its impact on maize production has been reviewed in this paper. Although variations existed within most of the future climate projections, the common agreement was that temperatures will keep on rising.

Increased water and heat stress on maize plants were revealed to be the primary reasons for the projected decline. Also, pests and diseases of the maize plant are likely to be enhanced by the future climate projections and thus will cause considerable damage to the crop. Areas suitable for the cultivation of maize are likely to decrease. Due to the impact of temperature on the yields of maize, many farmers have adopted numerous adaptation measures. These include changes in the planting dates, cultivating varieties with heat tolerant abilities. Others are inclusion of tree crops on farmlands and diversification of crops and livelihood activities. For future climate scenario, there were suggestions to enhance irrigation facilities in farmland activities and to concentrate maize production around the semi-deciduous rainforest zone, though this area will be less affected compared to the other agro ecological zones.

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