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Genetic assessment of terminal heat tolerance mechanisms in summer quality protein maize during grain filling in Gajapati district: A review

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Abstract
Terminal heat stress may impact grain quality during the critical fill period in warmer weather. Environmental conditions trigger widespread transformations within plants, affecting their growth patterns and possibly causing substantial financial losses. Gaining insight into the intricate details of heat stress's underlying biology will aid in overcoming these obstacles. By setting temperature milestones, we can determine the probability of transgressing them, essential for comprehensive climate change hazard appraisal. Armed with multiple strategies to combat harsh environmental situations, plants are resilient. After stress, heat shock proteins are generated, and their manufacturing depends on transcription factors. Prolonged exposure to elevated temperatures (HT) generates dangerous ROS, capable of altering or destroying vital cellular structures. Stress's impact on biology and physiology enlists numerous allies to counteract damage; these include antioxidants, transporters, Osmo comparative molecules, heat shock proteins, plus governing mRNA phrase designers. By delving into the molecular details of these pathways, our investigation sheds light on how they adapt under terminal heat conditions, highlighting strategies employed by plants to enhance resistance. Using the previously mentioned studies, we hope to identify and map genes or QTLs responsible for terminal heat tolerance. This information will help inform marker-assisted selection practices to improve terminal heat tolerance traits, while simultaneously advancing research into fundamental genomic elements influencing these qualities. By doing this, we aim to create advanced crops with increased resistance to extreme summer temperatures and increase the output quality of protein maize during hotter seasons.

Keywords: Terminal heat stress, quality protein maize, heat shock proteins, thermotolerance

Introduction

Despite adapting well to various environments, maize yields suffer under diverse abiotic and biotic limitations. One crucial aspect of the physical setting that affects crop output worldwide is elevated temperature stress. From the start of the present century, atmospheric temperature increases have occurred, and these elevations are slated to persist thanks to climate alterations. According to (Farooq *et al*. 2011) [21], these extreme fluctuations can lead to stressful conditions during critical phases like breeding or crop development. Should the average temp of the chilliest mo reach 17.5C, it results in terminal warmth stress; otherwise known as persistent warmth pressure once this mark has been hit. Certain temperature levels surpassed over time lead to heat stress, causing permanent damage to growing crops.

Temperature constraints define maize production; ideal conditions are neither too hot nor too dry. These three variables heavily influence how efficiently maize crops absorb water during a rainstorm. Enhanced evapotranspiration occurs because increased moisture content results from heat-induced intensified soil dryness and vegetal foliation (maize leaves). In diverse climate settings, temperature conditions serve as a determinant factor in evaluating maize resilience; whether exceptionally cool (-40 °C) or oppressively warm (exceeding >68 °C), temperature parameters decide productivity levels. Shorter exposure intervals do not drastically hinder crop growth while extended durations pose significant threats to quality preservation. Extreme temperatures beyond four weeks cause irreversible damage, while prolonged periods above 43 °C lead to total yield decline. Temperature extremes often hinder yield production throughout these crucial phases. According to (Porter, 2005; Wahid *et al*. 2007) [36, 51], global warming causes abrupt modifications in maize plants.

On the flip side, extremely hot temperatures between 45 °C-48 °C during reproduction cause anxiety about regulating crops' development and, ultimately, harvests. (Khatib & Paulsen, 1999; Ulukan, 2009; Rahman *et al.* 2013) [1, 53, 54] Temperature levels beyond the preferred range drastically impair plant progress and output, as observed by Compos *et al*. (2004) [14]. Higher temperatures pose the potential for diverse changes within plant structures, with consequences on total plant development and profitability. Consequences of this nature might lead to notable decreases in economic output (Badu-Apraku *et al*. 1983) [7].

To address the issue of unpredictable temperature spikes during maize cultivation, we must choose between improving existing species heat resilience or switching to diverse types accustomed to sweltering environments. Given this scenario, our key objective is twofold: mitigate the impact of climate change on crop yields while also finding ways to enhance future output through advanced heat-tolerant varieties. Especially in places like South Asia, with unsustainable farming practices set to face dire consequences of climate change shortly, such endeavors hold immense significance. Noteworthy observations result from research recorded via: IPCC (2007) [27], databases. In collaboration with Zaidi and Cairns (2011) [52], genetic material from heat-resistant varieties found in Asia and beyond are being combined to produce lines capable of yielding novel heat-tolerant strains. Increased knowledge about the effects of heat stress on maize phenology lies at the forefront of enhancing maize resistance. To overcome heat challenges, these adaptable crops recover equilibrium and mend damaged components, paving way for continued prosperity.

Adopting techniques like crossbreeding allows scientists to generate resilient crops suitable for hot climates. To create a maize hybrid resilient against terminal heat stress, critical traits linked to thermotolerance require identification first. Heat resilience determines which parent lines create adaptable maize hybrids for hot climates.

Limit of terminal heat stress in spring Quality Protein Maize

Daily average temperatures represent the onset of slowed plant development once they reach this level. Significant temperature alterations affect seed germination dramatically. Few plant varieties can tolerate extreme heat during seedling stages (Buriro *et al*. 2011) [10]. During spring maize's grain-filling period, excessive heat can cause a slower filling pace and abbreviated time frame, ultimately impacting grain weight. Temperature exceedances beyond 35 °C undermine maize pollen's vitality according to Herrero & Johnson (1980) [23], Schoper *et al.* (1987) [39]. According to Crafts Brandner and Salvucci (2002) [13], photosynthesis in maize leaves spans a temperature range of 33 °C to 38 °C.

In their study Jones *et al*. (1984), [28] highlighted how imperative the environmental conditions were regarding maize's endosperm cell division process during this period. The difference between 30 °C and 35 °C becomes apparent when evaluating kernel growth rate (capacity) and eventual kernel dimensions. A pivotal finding presented in 2001 by Commuri and Jones indicated that elevated temperatures above 30 degrees Celsius negatively affect corn kernel development, leading to diminished agricultural output and revenue. Prior to and during the critical period of anthesis, maize is exceptionally sensitive to hot and unfavorable weather conditions. Of specific concern is how higher temperatures affect pollination. Up to 51% fewer germinated pollen grains were observed under temperatures above 32 °C (Schoper *et al*. 1987) [39]. In semiarid tropical environments, continuous exposure to 38 °C renders maize pollen unable to germinate (Carberry *et al*. 1989) [11].

For maize plants belonging to the C4 category, temperature has complex effects with benefits & drawbacks. This optimal temperature window prompts enhanced photosynthesis activity in maize plants, fostering swift progress. However, the optimal temperature range (-5 °C to 32 °C) has a considerable impact on plant growth, as indicated by research conducted by Steven *et al.* [40] (year). Increased flower abortions, decreased seed production, disturbed photosynthesis and modified plant development—all signs of heat stresses effects, observed here (Ristic *et al.* 2009) [55] - once the process of fertilization has begun, developing kernels become entirely beholden to the photosynthesising power of their parent plants According to Steven *et al.* (2002) [40], temperature thresholds above 30 °C significantly impede Rubisco function in maize, resulting in altered photosynthetic processes with consequences for grain maturity duration and seed size.

Corn reproduction benefits from temperatures beyond ideal levels, resulting in higher yield. Based on Shaw's research (1983), there exists a negative correlation between temperature deviations and grain productivity. Although peak maize productivity lies within 20 °C's grasp, this temperature limit also leads to substantially reduced harvests per Thompson's research (1986) [43]. Photosynthetic activity in maize increases significantly with rising temperature within the range of 32 °C observed by Duncan and Hesketh (1968) [19], Hofstra and Hesketh (1968) [19]. Therefore, the decreased yield is unlikely caused solely by limited access to photochemical energy sources. Heat stress during grain filling is probably causing internal changes in the kernel that contribute to yield loss. Research has shown that thermal stress affects kernel growth in grain cultivation according to (Keeling & Greaves 1990) [29]; meanwhile, experiments demonstrate this sensitivity via *in vitro* culture techniques employed by Jones *et al*. (1984) [28], and also highlighted by Major & Schaalje (1985) [56]. According to various studies, including those conducted by Badu-Apraku *et al*., Jones *et al*., 1984 [28] Major and Schaalje, Tollenaar and Bruulsema, Tashiro and Wardlaw, and Muchow, rising temperature triggers increased kernel growth before decreasing the time needed for dry matter buildup.

High temperatures cause a reduction in yield. They also shorten kernel filling. Low temperatures have the opposite effect. They increase yield while also shortening kernel filling. A study by Brooking in 1993 [57] noted a decline in kernel filling rate under 13.5 °C. He also found a linear response between 13 °C to 32 °C. The research by Muchow in 1990 along with Tollenaar & Bruulsema in 1988 revealed a growth rate of 0.3 mg kernel-1 day-1 °C-1 from 10 °C to 32 °C. Smith discovered in 1996 [42] that pollination temperatures of 35 °C during the grain filling phases can lower grain yield. It can plummet by 101 kg ha per day. A rise from 22 °C to 28 °C during the grain filling phase is alarming as well. It may result in production losses ranging from 10 to 42%. This was proven by Lobell & Burke in

2010 [33]. Similar results were found by Rowhani *et al*. in 2011 [38]. Cairns *et al*. confirmed this in 2013.

Summer maize responses to terminal heat stress

High temperature stress hampers plant growth worldwide. This stress impacts all aspects of plant metabolism. Multiple metabolic activities become sensitive under this stress. Heat stress is also linked to the study fields of morphological responses. The same goes for physiological responses. Biochemical responses are also part of this study.

A range of molecular techniques are now in use. These techniques target high temperature tolerance in plants. Heat stress affects the processes of a plant. This includes germination. It also covers growth. Development too is included. The same goes for reproduction. Yield is not exempted from the effects of heat stress. Hasanuzzaman *et al*. gave insights into this in 2013 [25-26]. Lobell *et al*. have been studying this since 1980.

Plant morphology and physiology under heat stress

Increased radiation levels coupled with high temperatures impose limitations on plant growth in tropical climates. Such conditions result in scorching of plant parts. Scorched parts include leaves twigs branches as well as stems. There is also early aging of leaves which typically fall off prematurely. Growth of shoots as well as roots are obstructed. Fruits sustain damage. All these lead to a reduction in crop yields.

In the case of maize grain filling during active periods is reduced when heated. This leads to substantial weight loss of kernels during the reproductive phase. Maize coleoptiles growth is restricted at 40 degrees Celsius but incited at 45 degrees Celsius under diurnal fluctuating temperatures. High temperatures are responsible for a lower shoot dry mass. There is a decreased relative growth rate. Also noted is a diminished net assimilation rate in maize pearl millet as well as sugar cane. However leaf expansion remains largely unaffected. Key impact on shoot growth due to high temperatures is considerable decrease in beginning internode length. It often leads to plant mortality. Heat stress leads to an extended grain filling duration. However the starch protein as well as oil contents of the maize kernels decrease.

Heat stress triggers a loss of cell water content. Consequently cell size decreases along with reduced cellular proliferation. Heat stress circumstances significantly decrease relative growth rate in maize as well as millet due to reduction in the net absorption rate. Noticeable morphological changes under heat stress include leaf scalding tassel blast early leaf aging inhibition of root as well as shoot growth fruit color changes along with signs of damage. Varied plant species showing significant drop in floral bud along with flower abortion can be seen under heat stress circumstances. Heat stress can disrupt cell division in male as well as female plant organs. It can impede pollen tube germination. Heat stress also alters growth patterns of an ovule. In case of fertilization it reduces the number of pollen per silk. It causes stigmatic deviations. It also adjusts the style position.

Heat stress creates unfavorable conditions for the growth of endosperm. The proembryo faces a similar impact. The growth of a barren embryo can also get compromised. Research shows that plant reactions to high temperatures vary. They are dependent upon plant species. They also rely on phonological phases. High temperatures greatly affect reproductive processes in various plants. Fertilization becomes tricky. Post-fertilization processes become challenging. This leads to lower crop yield. Stressful conditions impact the physiology of the plant as well. Extreme circumstances lead to reduced cell size. The stomata close. Stomatal density increases. Even the trichome density is not spared. Shoot xylem vessels get impacted. So do the root xylem vessels. The same applies to modifications in different plant parts. Leaf thickness changes. The size of epidermis alters. Changes occur even in the mesophyll tissues within a leaf.

The rhizome also experiences changes. The size of the pith changes. The cortex sees changes. So do the aerenchyma tissues. Similar changes occur in root tissues too. Generally heat exerts significant pressure on anatomical structures. This pressure is not limited to tissue or cellular levels alone. It extends to sub-cellular levels too. Severe temperature stress could cause poor plant growth. It could also limit productivity. Phenotypic alterations in plants help us comprehend plant-stress relations better. Maize yield for instance is comprehended through a combination of yield components. These are kernal number as well as individual kernal weight. They are heavily affected by environmental conditions during flowering stage. Grain-filling period is highly sensitive to such conditions too. Reproductive organs are prone to heat stress injury more than other organs. They have a much lower threshold for temperature stress-related injury.

High temperatures can reduce yield during the reproductive phase. They do this by lowering both kernal number and weight. Overheating can reduce the amount of kernels. This is due to a decrease in fertility. Abnormal development of male reproductive tissues is largely responsible. These tissues are particularly susceptible to heat. High temperatures can render pollen inviable. They can also hinder germination. Mismatched timing of anthesis also contributes to less fertilised ovules. This discrepancy is affected by both drought stress.

Heat stress early on can hinder endosperm formation. This can cause abortion or untimely growth arrest. Sustained heat stress over a week can lead to a significant drop in kernal abortion. Short-term heat stress has less impact. Kernal weight hinges on biomass accumulation during the grain-filling period. This process depends on the growth rate of the kernal.It also depends on the amount of effective filling time. Both factors react to temperature. Also important is the availability of assimilates. Heat stress during this stage can cut short the duration of grain filling. This can inhibit endosperm cell growth. It can stop amyloplast biogenesis as well. It can affect assimilates availability. This all contributes to final kernal weight being lower.Heat stress affects ultimate weight more if it occurs during the first half of grain filling. This impact is greater in temperate hybrids than in tropical ones.

Anthesis -silking interval (ASI) Chapman *et al*. in 1997 [12] reported that high yielding plants typically had short ASI. They also noticed an increase in ear per plant notably in drought environments. Similarly in 2003 Betran *et al.* [9] discovered short ASI to be associated with high grain yields. The grain yield difference under drought was linked with reduced ASI. Boonpradub along with Senthong noted in 2001 that ASI had a negative correlation with kernel yield under dry regime. According to Cicchino *et al*. in 2010 [10] high temperature conditions extend anthesis silking interval when large time gaps exist between anthesis to tassing in maize.

Tassel blast was found to be negatively and highly significantly correlated with grain yield and positive significant association between leaf firing in maize (Hussain *et al.* 2006) [24].

Leaf firing Chen *et al.* (2010) [16] reported that under high temperature stress condition leaf firing reduces photosynthetic apparatus. Significant reduction in yield per plant with increase in percent leaf firing and days to flowering and reduction in chlorophyll fluorescence and number of tassel branches in heat stress were also reported by Bai (2003) [9].

Silk receptivity (%) Kernel number per cob determines maize output. Maize benefits from ample pollen at silking time. Adequate pollen is less than 3000 grains per silk. That quantity is optimum for kernel production. Maximum grain yield needs minimum pollen density. This is a finding documented by Westgate *et al.* in 2003 [49]. Kernel set in maize relates to silk elongation. Silk receptivity duration also plays part in it. Kernel s*et al*so affects grain yield. Anderson *et al*. documented this in 2004.Campos *et al.* studied this in 2004. They found grain yield rises in adverse drought conditions. This is due to increased yield potential. Rapid silk exertion also contributes to it. Barrenness is less during these periods. This happens even at a lower rate than under optimal conditions. It aids the selection of heat stress tolerant genotypes. This happens in heat stress breeding.

Leaf senescence (%) Lobell *et al.* in 2012 [35] identified that senescence limits grain filling. Senescence also affects grain yields under heat stress. Kamara *et al*. in 2003 [20] found no significant correlation between leaf dead score and grain yield. Instead they found a strong link between leaf dead score with LAI. This relationship underscores the importance of green area. It directly relates to the chlorophyll content. The chlorophyll content facilitates photosynthesis. It also sustains high grain yield during periods of drought. Delayed senescence is an important secondary trait for plants. It signifies the plant's green nature. High levels of leaf chlorophyll during late grain filling is beneficial during stress as per Zaidi *et al*. in 2011 [11].

Crop maturity days Grain filling duration time between heading date to physiological maturity and rate no significant association with grain yield in most of cases. But under water deficient condition during maturities it was associated with increases yield in cereals (Talbert *et al*. 2001) [44].

Chlorophyll content Grain yield was significantly correlated with chlorophyll content and EPP under severe drought stress condition (Betran *et al.* 2003a) [9]. The association between leaf injury and low chlorophyll content in maize plants (Liu and Huang 2000) [31].

Plant height Reduction of rate of growth of first internode of plan under the heat stress condition which initial step of plant height development in maize and that determine plant height in maturity (Weaich *et al*. 1996) [46].

Number of kernel per ear Under heat stress condition in corn kernel number loss due to kernel abortion due to pollen viability and pollination dynamics which ultimate limit the crop production (Cicchino *et al.* 2010b) [18].

Grain yield Khodarahmpour *et al.* (2011) [31] reported that Maize inbred lines reduced grain yield up to 70% in high temperature condition. Pollen viability under the same conditions was associated with a lower grain yield according to Rowhani *et al*. (2011) [38]. Thompson (1986) [43] identified grain filling as a sensitive stage of corn under heat stress. Heat stress also has a variable effect on grain yield depending on the crop stage. Pre-anthesis stress contributes to barrenness in plants while other effects include lowered absorption of fertilized structure. Altered ear growth rate also leads to fewer kernels affecting overall yield as observed by Cicchino *et al.* (2010b) [18].

Molecular and Biotechnological strategies

Breeding approaches aim to enhance wild species. These processes make elite or domesticated breeding lines. These lines introduce novel alleles into desired crops. High-temperature tolerance is a difficult trait. It is polygenic. It is also influenced by the environment. The genetics behind it are less understood. Selecting for such tolerance is complex. This task is made difficult by environmental factors. Biotic stresses could also affect it. More accurate greenhouse experiments are needed. Rice researchers need additional tools. These tools will help identify the genes linked with HTS tolerance. The genome sequence has its advantages. It is well-annotated. It aids in significant advances in this genomics field.

Marker assisted selection (MAS) is efficient. Genomic selection (GS) is also effective. They are used for the development of new cultivars. These tools have potential advantages. They can be compared to marker-assisted back-crossing. This method requires knowledge about genetic markers. MAS breeding is common in the private sector. Reports of its use in the public sector are limited. The GS method is comprehensive. It predicts the breeding value of an individual in a population. In general GS tools can easily predict monogenic or less complex traits. Stress responses are more complex traits. These traits are hard to estimate by the genomic estimated breeding value. This value is also known as GEBV. Heat-stress tolerance is a focus with a quantitative hereditary characteristic. MAS seems to be a highly efficient method for plant breeding. Jain *et al*. in 2014 saw improvements in drought plus heat tolerance in wheat after using MAS.

The International Maize & Wheat Improvement Center has started using this method in maize. Efforts towards achieving heat-stress tolerance are still early. The complexity of this trait makes it challenging to get suitable breeding material. This includes inbred lines plus commercial hybrids. Identifying the genetic resources for heat-stress tolerance may accelerate the progress. Screening a large population that spans various development stages might also help. This idea is supported by Wahid *et al*. in 2007 [51]. An advanced molecular breeding approach might be beneficial. It can provide data contributing to the development of maize plants tolerant to heat stress.

Conclusion and future prospects

Summer Quality Protein maize has low terminal heat tolerance. This fact limits output during grain filling. Terminal heat stress often negatively impacts plant growth. These effects are most pronounced in reproductive growth. Some effects include oxidative damage. Also notable are infrastructure changes in tissues. Cell organelle instability also occurs. Plant responses to this stress are a focus of recent studies. However understanding these responses poses numerous challenges. Plants often produce antioxidants under high temperature conditions. Field experiments can be useful to observe these stress responses. They can help farmers adapt their practices. An understanding of tolerance mechanisms can aid in the development of heat resistant plants. One must also consider the implications of global warming. Plant tolerance is reliant on the proper genes. Terminal heat stress management deserves further attention. In addition to this molecular cloning as well as gene characterization are crucial.

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