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INFLUENCE OF GIBBERELIC ACID AND SALICYLIC ACID ON PHENOPHASIC TRANSITIONS AND YIELD EFFICIENCY OF FINGER MILLET GENOTYPES

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ABSTRACT

The phenological responsiveness and yield dynamics of finger millet (*Eleusine coracana* L.) under high temperature is vital for developing climate resilient crop management strategies. A field experiment was conducted to evaluate the influence of plant growth regulators (PGRs) on the phenological transitions, seed yield, and harvest index of diverse finger millet genotypes under thermal stress. The experimental design comprised 15 genotypes (G1 to G15) and three PGR treatments: T1 (Control), T2 [Salicylic acid (SA) @ 100 mg/L], and T3 [Gibberellic acid (GA₃) @ 100 mg/L]. The results revealed significant ($p \geq 0.05$) variation among genotypes and PGR treatments across most phenological phases and yield attributes. Genotypic duration varied substantially; genotype G10 (CFMV-1) exhibited the longest life cycle, requiring maximum days to reach tillering (29.94 DAS), flag leaf emergence (52.06 DAS), ear head emergence (64.89 DAS), physiological maturity (105.33 DAS), and harvest maturity (116.78 DAS). Conversely, genotype G7 (SKMFM3014) demonstrated a short duration, maturing in 100.56 DAS and indicating an inherent terminal heat escape strategy. While PGR treatments had a non-significant effect on early tillering initiation, exogenous GA₃ application (T3) significantly accelerated post-vegetative development, advancing flag leaf emergence (45.83 DAS), ear head emergence (53.64 DAS), and harvest maturity (104.64 DAS) compared to untreated control T1 (112.56 DAS). Growth regulator treatments also significantly enhanced yield parameters under thermal stress. Foliar application of GA₃ (T3) recorded the highest seed yield (5117.71 kg ha⁻¹) and harvest index (36.91%), followed by SA treatment T2 (4780.80 kg ha⁻¹ and 32.56%), whereas T1 (Control) yielded the lowest (4303.54 kg ha⁻¹ and 26.45%). These results demonstrate that exogenous application of GA₃ and SA effectively mitigates high temperature stress by synchronizing phenological maturation, enhancing source to sink assimilate partitioning, and optimizing yield productivity in finger millet.

Key words: Finger millet, Thermal stress, Gibberellic acid, Salicylic acid

Introduction

Finger millet [*Eleusine coracana* (L.) Gaertn.] is an important climate-resilient small millet crop widely cultivated across the semi-arid tropics owing to its adaptability to diverse agro-ecological conditions, superior nutritional quality, high dietary fibre, and rich mineral composition. In India, finger millet occupies an important position among nutri-cereals under the *Shree Anna* group and contributes substantially to food and nutritional

security, particularly in rainfed and resource-constrained production systems. During 2023–24, finger millet was cultivated over approximately 10.37 lakh hectares in India, with a production of about 13.86 lakh tonnes and average productivity of 1,336 kg ha⁻¹. In Madhya Pradesh, the crop occupied approximately 1.65 lakh hectares, producing about 1.47 lakh tonnes with a productivity of nearly 892 kg ha⁻¹. Major finger millet-producing regions include Karnataka, Tamil Nadu, Maharashtra,

Uttarakhand, and Odisha, while Madhya Pradesh has considerable scope for productivity enhancement through improved genotypes and appropriate agronomic interventions. The relatively lower productivity under several rainfed production environments highlights the need for management strategies capable of sustaining crop productivity under increasing climatic variability.

Despite its inherent adaptability to marginal environments, finger millet productivity is increasingly constrained by global climate warming, particularly high-temperature stress during critical developmental stages. Knowledge of phenological progression and its variability under high-temperature environments is vital for establishing timely and efficient crop management strategies. The crop progresses through distinct phenophases including tillering, flag leaf emergence, ear head emergence, milking, dough stage, physiological maturity, and harvest maturity, and the duration of these stages is strongly governed by temperature and thermal-time accumulation. Elevated temperatures can accelerate developmental processes, alter crop duration, impair reproductive development, hasten leaf senescence, and reduce the effective period available for biomass accumulation and grain filling, ultimately affecting grain weight and yield stability (Hatfield and Prueger, 2015).

Among phenological transitions, the reproductive window extending from ear head emergence through grain filling represents the most critical phase for determining spikelet fertility, assimilate mobilization, grain development, and final seed yield. High-temperature stress during flowering and grain filling can impair sink capacity, accelerate canopy senescence, disturb assimilate translocation, and shorten the effective grain-filling period, thereby increasing the risk of yield reduction. Consequently, precise characterization of phenological responses and appropriate stress mitigation strategies are essential for maintaining reproductive efficiency under terminal heat stress (Srinithi *et al.*, 2023). Substantial genotypic variation exists among finger millet germplasm in phenological development and response to thermal stress. Long-duration genotypes generally require greater thermal time to complete vegetative and reproductive development, whereas short-duration genotypes complete their life cycle rapidly and may utilize early maturity as a stress-escape mechanism against late-season terminal heat (Pradhan *et al.*, 2019).

The contrasting relationship between crop duration and heat adaptation makes identification of suitable genotypes particularly important under terminal heat stress. Although early maturity can enable plants to escape severe late-season temperature stress, a shorter

developmental period may also restrict biomass accumulation and grain-filling duration. Conversely, long-duration genotypes may have greater opportunity for vegetative growth, reproductive development, and assimilate accumulation but may experience prolonged exposure to terminal heat. Therefore, phenological duration needs to be evaluated together with seed yield and biomass partitioning efficiency to identify genotypes possessing a favourable balance between heat escape and productivity. Harvest index, which reflects the proportion of accumulated biomass converted into economic yield, provides an additional indicator of reproductive partitioning efficiency under stress (Reynolds *et al.*, 2016).

To counteract heat-induced physiological injury, exogenous application of plant growth regulators (PGRs) has emerged as a promising strategy for modifying crop development and improving source–sink relationships. Gibberellic acid (GA_3) promotes cell division, internodal elongation, leaf expansion, assimilate partitioning, and reproductive development and can facilitate timely panicle or ear head emergence and reproductive maturation under stress conditions (Ashwini *et al.*, 2021). Exogenous GA_3 may therefore help regulate crop duration and synchronize vegetative-to-reproductive transitions, thereby improving the coordination between source development and reproductive sink establishment. Previous studies have demonstrated beneficial effects of GA_3 in promoting tissue development, reproductive transition and assimilate partitioning under adverse environmental conditions (Kumar *et al.*, 2018).

Concurrently, salicylic acid (SA) functions as an important stress-signalling molecule and antioxidant elicitor involved in the regulation of plant responses to high temperature. Exogenous SA can enhance antioxidant defence, stabilize cellular membranes, maintain chlorophyll concentration, delay premature senescence, and preserve photosynthetic activity under elevated temperature conditions (Sairam *et al.*, 1994). Such protective effects can support reproductive development and sustain assimilate availability during grain filling. While early vegetative processes such as tillering initiation may be strongly influenced by genotype and prevailing environmental conditions, hormonal regulation becomes increasingly important during reproductive development and grain filling through its effects on stress responses, assimilate mobilization and developmental coordination.

Thermal stress during reproductive development can suppress dry matter accumulation, restrict sink development, increase reproductive losses, and ultimately reduce seed yield and harvest index (Chauhan *et al.*,

2019; Pushpalatha *et al.*, 2020; Suresh *et al.*, 2021). Genotypes capable of maintaining efficient biomass partitioning towards reproductive sinks may therefore possess an adaptive advantage under terminal heat conditions. At the same time, hormonal regulation through GA₃ and SA can potentially sustain functional canopy activity, improve source–sink coordination, reduce reproductive injury, and preserve seed yield under high temperature. The beneficial effects of hormonal regulation on crop development, assimilate partitioning and stress resilience have been reported by Srinithi *et al.*, (2023).

Materials and Methods

A field experiment was conducted during the rabi seasons of 2023–24 and 2024–25 in a Factorial Randomized Block Design (RBD) with three replications at the Department of Plant Physiology, JNKVV, Jabalpur, MP, evaluating 15 finger millet genotypes (G1 to G15) and three plant growth regulator treatments: T1 (Control water spray), T2 (Salicylic Acid @ 100 mg L⁻¹), and T3 (Gibberellic Acid @ 100 mg L⁻¹) applied at the vegetative and flowering stages. Observations were systematically recorded in days after sowing (DAS) for critical phenological stages including days to tillering, flag leaf emergence, ear head emergence, milking, dough, physiological maturity, and harvest maturity when 50% of plants per plot attained the respective stage. Economic seed yield was recorded at harvest and converted to kg ha⁻¹, while the harvest index (%) was computed as the ratio of economic yield to total biological yield. The experimental data from both years were pooled and subjected to two-way Analysis of Variance (ANOVA) using R software, with treatment mean comparisons evaluated at a 5% level of significance ($p \geq 0.05$).

Result and Discussion

Pooled analysis revealed significant genotypic variation in the duration of phenological stages, indicating substantial genetic differences in developmental rate and thermal responsiveness among the finger millet genotypes. Genotype G10 (CFMV-1) consistently required the longest duration to attain tillering, flag leaf emergence, ear head emergence, milking, dough, physiological maturity and harvest maturity, followed generally by G1 (IIMRFM3996). In contrast, G7 (SKMFM3014) consistently exhibited the earliest progression through the major phenological stages, while G3 (WN1585) and G15 (BR-9) were also comparatively early at specific stages. The consistent differences among genotypes indicate that crop duration was predominantly influenced by genetic constitution and genotype-specific

responses to the prevailing thermal environment. Longer-duration genotypes may maintain vegetative and reproductive development for an extended period, whereas early-maturing genotypes complete their life cycle more rapidly and may thereby possess an advantage for escaping terminal heat stress. Similar genetic variation in phenological development and crop duration among finger millet genotypes was reported by Dhanakodi (1988). The observed variation also agrees with the concept that phenological adjustment is an important component of crop adaptation to high-temperature environments, particularly where terminal heat can progressively reduce the effective reproductive and grain-filling period.

The effect of plant growth regulators was non-significant for days to tillering, suggesting that initiation of early vegetative tillering was relatively less responsive to the applied PGRs and was primarily governed by genotype and prevailing environmental conditions. Although T2 (SA @ 100 mg L⁻¹) recorded a marginally greater duration to tillering, the differences among T1, T2 and T3 were statistically non-significant. This indicates that exogenous hormonal regulation had comparatively limited influence on the onset of tillering under the experimental conditions. Similar observations regarding the variable response of early tillering to gibberellin application have been reported by Datta and Nanda (1978). Nevertheless, the reported enhancement of early vigour and maintenance of tiller development through SA and GA₃ under stress conditions suggests that PGRs may influence subsequent plant establishment and tiller survival even when their effect on the initial timing of tillering is not statistically significant (Ashwini *et al.*, 2021).

From flag leaf emergence onwards, PGR effects became significant and a clear developmental response was observed. The untreated control (T1) consistently required the longest duration to reach flag leaf emergence, ear head emergence, milking, dough stage, physiological maturity and harvest maturity, whereas GA₃ application

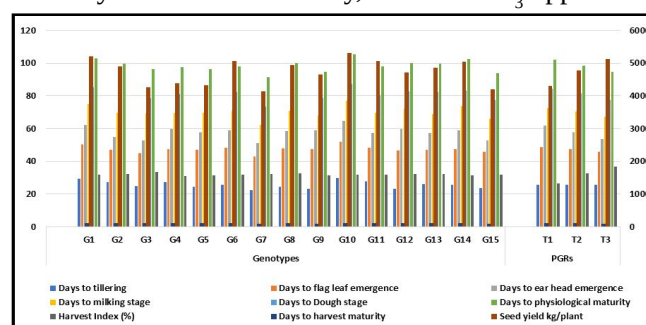


Fig. 1: Effect of Genotypes and Plant Growth Regulators on Phenological characters and yield of Finger Millet under terminal heat stress.

whereas G7 (SKMFM3014) and G15 (BR-9) reached maturity comparatively earlier. This demonstrates that the differences observed during early and reproductive development were ultimately expressed in total crop duration. Early completion of the life cycle may be advantageous under terminal heat because it allows reproductive development and grain maturation to be completed before the most severe late-season thermal conditions. However, the yield results indicate that earliness alone did not determine productivity, as the late-maturing G10 recorded the highest seed yield. Thus, the adaptive value of early maturity must be considered together with the genotype's ability to maintain reproductive development, biomass accumulation and efficient assimilate partitioning under heat stress. The importance of coordinating maturity duration with assimilate mobilization and stress adaptation has similarly been emphasized by Jayalakshmi *et al.*, (2010).

The differences in phenological behaviour were reflected in final productivity. Significant genotypic variation was observed for seed yield, with G10 (CFMV-1) recording the highest seed yield and remaining statistically at par with G1 (IIMRFM3996), followed by G6 (GPU107). In contrast, G7 (SKMFM3014), despite being the earliest genotype across most phenological stages, recorded the lowest seed yield and was statistically at par with G15 (BR-9), G3 (WN1585) and G5 (KMR708). This contrasting response demonstrates that early maturity provided a potential heat-escape mechanism but did not necessarily translate into maximum productivity. G10 may have benefited from a longer period for biomass production, reproductive development and assimilate accumulation, enabling greater grain production despite its longer crop duration. Conversely, the shorter developmental period of G7 may have restricted the time available for biomass accumulation and grain filling, resulting in lower final seed yield. Thus, under the conditions of the present experiment, productive adaptation to terminal heat appears to depend not only on rapid maturity but also on the ability to sustain physiological activity and assimilate supply during reproductive development.

Growth regulator application significantly improved seed yield, with T3 (GA_3 @ 100 mg L⁻¹) recording the highest productivity, followed by T2 (SA @ 100 mg L⁻¹), while the untreated control recorded the lowest seed yield. The superior performance of GA_3 suggests that regulation of plant growth and reproductive development contributed to improved conversion of accumulated biomass into grain yield. GA_3 -mediated enhancement of tissue development, reproductive growth and source-to-sink translocation may have promoted better assimilate

allocation towards developing ear heads and grains. The response is consistent with reports that GA_3 can improve source-sink relationships and assimilate partitioning under stress conditions (Dawood *et al.*, 2012; Ashwini *et al.*, 2021; Sathishkumar *et al.*, 2020). The positive response under SA further indicates that mitigation of heat-induced oxidative damage and preservation of photosynthetic machinery can contribute to yield maintenance under thermal stress (Ali *et al.*, 2013; Srinithi *et al.*, 2023).

Harvest index provided additional evidence of differences in biomass partitioning among the genotypes. G3 (WN1585) recorded the highest harvest index and was at par with G8 (VL376), followed by G7 (SKMFM3014). The comparatively high harvest index of G3, despite its relatively low seed yield, suggests that a greater proportion of the biomass produced by this genotype was allocated towards reproductive sinks. This distinction is important because harvest index reflects partitioning efficiency rather than absolute productivity; consequently, a genotype may exhibit efficient biomass partitioning without necessarily producing the greatest total seed yield. Similar relationships between biomass allocation, sink development and yield formation under stress have been highlighted by Reynolds *et al.*, (2016).

A pronounced PGR effect was also evident for harvest index. GA_3 treatment recorded the highest harvest index, followed by SA, whereas the control recorded the lowest value. The increase in harvest index under GA_3 indicates more effective partitioning of assimilates towards reproductive structures and grain formation, complementing its positive effect on seed yield. SA also improved harvest index relative to the untreated control, which may be associated with better maintenance of photosynthetic activity, membrane stability and reproductive sink development under terminal heat. Thus, the combined response of seed yield and harvest index demonstrates that PGR application, particularly GA_3 , improved not only overall productivity but also the efficiency with which available biomass was partitioned into economic yield.

These results demonstrate a strong interaction between genotype specific phenological behaviour and PGR-mediated developmental regulation under terminal heat stress. G10 (CFMV-1) and G1 (IIMRFM3996) exhibited longer crop durations and superior seed-yield performance, whereas G7 (SKMFM3014) showed pronounced earliness but comparatively lower productivity. Among the PGR treatments, GA_3 @ 100 mg L⁻¹ consistently accelerated phenological development after tillering and simultaneously improved seed yield and harvest index, while SA @ 100 mg L⁻¹ provided an intermediate but beneficial response. These findings

indicate that successful adaptation to terminal heat stress requires an appropriate balance between crop duration, reproductive development, assimilate accumulation and biomass partitioning. The superior performance of GA₃ suggests that targeted hormonal regulation can help synchronize crop development and improve productivity under high-temperature conditions, while genotypic variation provides an important resource for identifying cultivars capable of combining desirable maturity duration with high yield potential.

Conclusion

The present study demonstrates that terminal heat stress significantly alters the phenological progression and yield productivity of finger millet, while exogenous application of plant growth regulators serves as an effective agronomic strategy to mitigate thermal injury. Substantial genotypic diversity was observed across developmental stages, with long duration genotypes requiring greater thermal time across all phenophases to achieve superior overall yield output, whereas short duration genotypes exhibited an effective heat escape mechanism by rapidly completing their life cycle. Exogenous hormonal interventions significantly modulated post-vegetative transitions without altering early tillering initiation, as foliar application of gibberellic acid consistently accelerated reproductive development and advanced harvest maturity while maximizing seed yield and harvest index through enhanced source to sink assimilate partitioning. Concurrently, salicylic acid application provided balanced physiological protection by sustaining functional canopy duration, maintaining membrane stability, and protecting reproductive organs against elevated temperatures. Ultimately, combining high-yielding genotypes with targeted growth regulator applications particularly gibberellic acid and salicylic acid offers a robust and sustainable approach to synchronizing crop maturity, safeguarding reproductive efficiency, and optimizing finger millet productivity under high-temperature climate scenarios in semi-arid regions.

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