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Performance of finger millet genotypes under terminal heat stress as influenced by plant growth regulators

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Abstract

Terminal heat stress is an important constraint to finger millet productivity, particularly during reproductive and grain-filling stages. The present study was conducted to evaluate the response of diverse finger millet genotypes to terminal heat stress and to assess the effectiveness of plant growth regulators (PGRs) in improving growth and yield performance. Fifteen finger millet genotypes were evaluated under terminal heat stress with salicylic acid (SA) @ 100 mg L⁻¹, gibberellic acid (GA₃) @ 100 mg L⁻¹ and an untreated control. Pooled analysis revealed significant genotypic variation for plant stand establishment, plant height, seed yield, biological yield and harvest index. G7 (SKMFM3014) recorded the maximum plant stand establishment (24.37 plants m⁻²), followed by G5 (KMR708) (23.68 plants m⁻²), whereas G13 (WWN35) recorded the minimum (17.95 plants m⁻²). G1 (IIMRFM3996) recorded the maximum plant height at harvest (92.09 cm), while G7 (SKMFM3014) recorded the minimum (72.43 cm). The highest seed yield was recorded in G10 (CFMV-1) (5306.89 kg ha⁻¹), which was at par with G1 (IIMRFM3996) (5208.88 kg ha⁻¹), whereas G7 recorded the lowest seed yield (4131.72 kg ha⁻¹). G1 recorded the maximum biological yield (16177.99 kg ha⁻¹), while G7 recorded the minimum (12359.02 kg ha⁻¹). G3 (WN1585) recorded the highest harvest index (33.68%), followed by G8 (VL376) (32.65%) and G7 (SKMFM3014) (32.27%). Among PGR treatments, GA₃ @ 100 mg L⁻¹ recorded the maximum plant height (86.64 cm), seed yield (5117.71 kg ha⁻¹), biological yield (15874.31 kg ha⁻¹) and harvest index (36.91%), followed by SA @ 100 mg L⁻¹ with seed yield of 4780.80 kg ha⁻¹, biological yield of 14781.40 kg ha⁻¹ and harvest index of 32.56%. The untreated control recorded the minimum seed yield (4303.54 kg ha⁻¹), biological yield (13382.10 kg ha⁻¹) and harvest index (26.45%). Overall, G10 (CFMV-1) and G1 (IIMRFM3996) demonstrated superior productivity under terminal heat stress, while GA₃ @ 100 mg L⁻¹ was the most effective PGR for improving growth, biomass production, grain yield and harvest efficiency.

Keywords: Finger millet, terminal heat stress, genotype variability, gibberellic acid, salicylic acid, growth regulators

Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn.) is an important climate-resilient small millet cultivated primarily in the semi-arid and sub-humid regions of Africa and Asia. It is valued for its adaptability to diverse agro-ecological conditions, comparatively low input requirement, and high nutritional quality. The grain is particularly rich in calcium, dietary fibre, essential amino acids and other bioactive compounds, making it an important component of food and nutritional security. In India, finger millet is an important cereal crop for rainfed and marginal production systems, where its ability to withstand moisture limitation and other environmental stresses provides an advantage over several major cereals. However, increasing temperature associated with climate change poses a significant threat to finger millet productivity. High temperature, particularly during the reproductive and grain-filling phases, can adversely affect crop establishment, phenological development, canopy development, photosynthetic activity, biomass accumulation, reproductive processes and grain formation. Terminal heat stress may accelerate crop development and senescence, shorten the effective grain-filling period and disrupt the balance between assimilate production and reproductive sink demand (Aidoo *et al*, 2016) [1]. The resulting reduction in pollen viability, assimilate translocation and grain development can ultimately lead to

considerable losses in seed yield. The magnitude of these effects varies among genotypes because of differences in their morphological, physiological and biochemical mechanisms of heat adaptation.

Genotypic variability is therefore an important resource for improving finger millet performance under terminal heat stress. Genotypes capable of maintaining plant growth, canopy function, chlorophyll content, membrane stability and reproductive development under high temperature are more likely to sustain biomass production and grain yield. Traits such as plant stand establishment, plant height, tiller production, ear-head development, seed formation and harvest index provide important indicators of the ability of genotypes to tolerate or escape terminal heat stress. Identification of superior genotypes based on integrated performance of these traits is consequently essential for developing heat-resilient finger millet production systems (Aparna *et al*, 2017) ^[3].

Plant growth regulators (PGRs) offer an additional approach for mitigating the adverse effects of high temperature. Gibberellic acid (GA₃) plays a major role in cell elongation, plant growth and developmental regulation and may improve crop performance under stress by promoting vegetative growth and facilitating assimilate movement toward reproductive organs. Salicylic acid (SA), in contrast, functions as an important signalling molecule involved in plant defence and stress acclimation. Exogenous application of SA has been associated with improved photosynthetic stability, antioxidant defence, membrane integrity and reproductive performance under abiotic stress. Thus, appropriate PGR application may strengthen the physiological capacity of finger millet plants to withstand

terminal heat stress and sustain yield formation.

Although considerable efforts have been made to understand heat stress responses in cereals, information on the comparative performance of diverse finger millet genotypes and the effectiveness of PGRs in alleviating terminal heat stress remains comparatively limited. In particular, an integrated assessment linking genotype-dependent growth responses with biomass production, seed yield and harvest efficiency can provide valuable information for identifying suitable genetic resources and management strategies.

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 morphological stages including plant stand establishment and plant height attained at 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 ($p \geq 0.05$).

Table 1: Effect of Genotypes and Plant Growth Regulators on Morphological characters and yield of Finger Millet under terminal heat stress

Treatments	Plant stand establishment sq.m	Plant height (cm) at Harvest	Seed yield kg/plant	Biological yield Kg/ha	Harvest Index (%)
Factor 1 (Genotypes)					
G1 (IIMRFM3996)	20.56	92.09	5208.88	16178	31.96
G2 (OEB605)	20.65	80.16	4905.61	15891	32.15
G3 (WN1585)	18.33	76.43	4267.33	13390	33.68
G4 (CFMV-2)	20.16	75.33	4380.50	13575	31.13
G5 (KMR708)	23.68	76.64	4315.46	13163	31.45
G6 (GPU107)	19.74	83.69	5063.23	15839	31.86
G7 (SKMFM3014)	24.37	72.43	4131.72	12359	32.27
G8 (VL376)	21.58	80.89	4933.40	14847	32.65
G9 (KFMG2115)	22.64	76.64	4644.12	14777	31.32
G10 (CFMV-1)	20.39	89.49	5306.89	16033	31.71
G11 (KMR716)	23.60	83.77	5056.71	16099	32.07
G12 (VR-1192)	20.77	80.75	4706.37	14615	32.10
G13 (WWN35)	17.95	85.18	4859.34	15084	32.17
G14 (IIMRFM3799)	22.52	83.78	5034.30	15233	31.33
G15 (BR-9)	18.84	72.44	4196.34	13106	31.72
SEm±	0.39	0.89	69.71	352.92	0.40
CD (0.05)	1.10	2.50	195.92	991.87	1.12
CV%	5.58	3.56	4.86	7.91	4.50
Factor 2 (PGRs)					
T ₁ (Control)	21.00	74.85	4303.54	13382	26.45
T ₂ (SA @ 100 mg/L)	20.99	80.45	4780.80	14781	32.56
T ₃ (GA @ 100 mg/L)	21.17	86.64	5117.71	15874	36.91
SEm±	0.17	0.40	31.18	157.83	0.18
CD (0.05)	NS	1.12	87.62	443.58	0.50

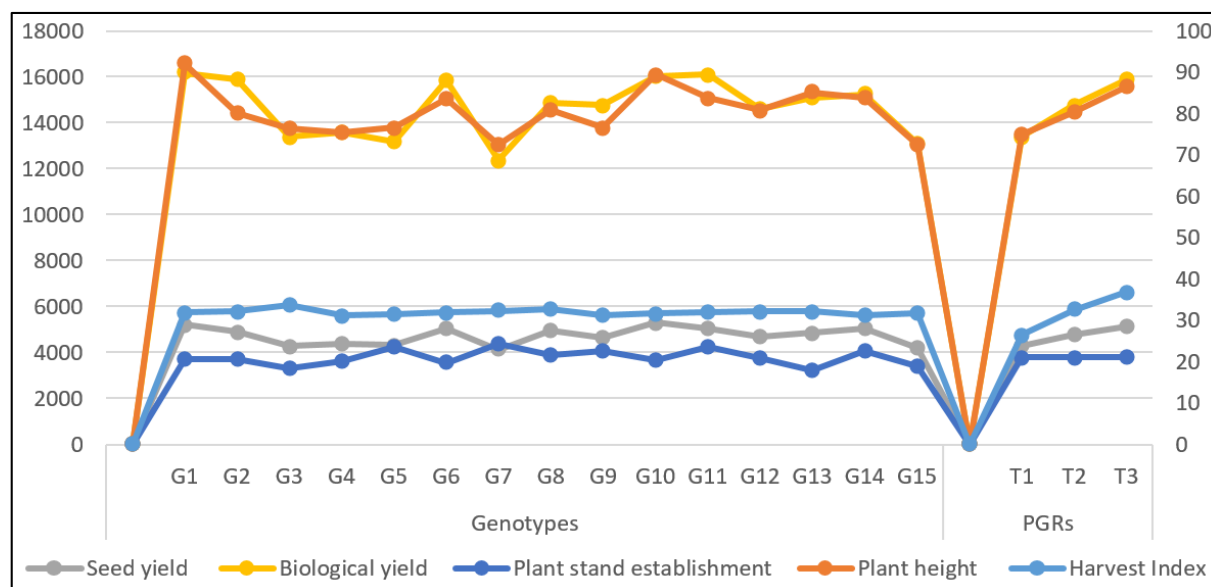


Fig 1: Effect of Genotypes and Plant Growth Regulators on Morphological characters and yield of Finger Millet under terminal heat stress

Results and Discussion

The results revealed a significant genotypic variation in plant stand establishment and plant height at harvest, indicating differential adaptation of finger millet genotypes to terminal heat stress. Genotype G7 (SKMFM3014) recorded the highest plant stand establishment, followed by G5 (KMR708), whereas G13 (WWN35) showed the poorest establishment, remaining statistically at par with G3 (WN1585) and G15 (BR-9). The relatively better establishment of G7 under terminal heat stress suggests greater early-stage adaptability and seedling survival; however, its subsequent growth and productivity did not correspond to its superior plant stand. This was evident from its comparatively shorter plant stature and lower seed and biological yield. Such differential responses indicate that successful establishment under heat stress alone may not ensure sustained vegetative growth and reproductive productivity, as later developmental stages are strongly influenced by the ability of genotypes to maintain photosynthetic activity, assimilate production and effective partitioning under elevated temperature.

Significant differences among genotypes for plant height at harvest further demonstrated variation in vegetative growth under terminal heat stress. G1 (IIMRFM3996) recorded the maximum plant height, followed by G10 (CFMV-1), whereas G7 (SKMFM3014) and G15 (BR-9) remained the shortest. The greater plant stature of G1 and G10 was associated with their superior biological productivity, particularly in the case of G1, suggesting greater biomass accumulation and maintenance of vegetative growth under stress. In contrast, the shorter stature of G7 was accompanied by reduced biological and seed yield, despite its superior plant establishment. Terminal heat stress can accelerate developmental progression, restrict leaf expansion and reduce assimilate accumulation, ultimately limiting biomass production and reproductive development. Genotypic differences in maintaining canopy growth and assimilate production under high temperature therefore play an important role in determining final productivity (Reynolds *et al.*, 2016) [6].

Seed yield represented the cumulative outcome of genotypic differences in establishment, vegetative growth, reproductive development and assimilate partitioning under

terminal heat stress. G10 (CFMV-1) recorded the highest seed yield and remained statistically at par with G1 (IIMRFM3996), followed by G6 (GPU107), demonstrating their superior capacity to sustain reproductive productivity under heat stress. G1 also recorded the highest biological yield, statistically comparable with G11 (KMR716), G10 (CFMV-1) and G2 (OEB605), indicating greater dry matter production in these genotypes. In contrast, G7 (SKMFM3014) recorded the lowest seed yield as well as the lowest biological yield, followed by G15 (BR-9) and G5 (KMR708). Thus, the high plant stand observed in G7 did not translate into greater biomass accumulation or grain productivity, suggesting limitations in subsequent vegetative growth, assimilate production or reproductive sink development under terminal heat stress. Heat stress during reproductive development can impair pollen viability, reduce sink strength, accelerate leaf senescence and restrict the accumulation and translocation of assimilates toward developing grains, thereby reducing final yield (Reynolds *et al.*, 2016) [6].

Harvest index further revealed differences in the efficiency of biomass partitioning toward reproductive sinks. G3 (WN1585) recorded the highest harvest index, remaining at par with G8 (VL376), followed by G7 (SKMFM3014), despite these genotypes not being among the highest seed-yielding genotypes. This indicates that a relatively greater proportion of the biomass produced by these genotypes was ultimately allocated toward grain production. In particular, the contrasting response of G3, which exhibited relatively low seed and biological yield but the highest harvest index, suggests efficient biomass partitioning rather than high biomass production. Such a distinction is important under terminal heat stress because yield performance may depend both on the amount of biomass produced and on the efficiency with which that biomass is transferred to reproductive sinks. Efficient source-sink regulation and maintenance of reproductive development under stress can therefore contribute to improved harvest efficiency (Reynolds *et al.*, 2016) [6].

Growth regulator application substantially improved crop productivity under terminal heat stress. GA₃ @ 100 mg/L (T₃) produced the greatest plant height at harvest, followed by SA @ 100 mg/L (T₂), whereas the untreated control

recorded the shortest plants. The enhancement in plant growth under GA₃ may be associated with stimulation of cell elongation and improved vegetative growth, which can contribute to greater assimilatory surface and dry matter accumulation. More importantly, T₃ produced the highest seed yield and biological yield, followed by T₂, while the control recorded the lowest values. These results demonstrate that exogenous growth regulator application alleviated the adverse effects of terminal heat stress and improved the conversion of available assimilates into biomass and grain yield. The positive response to GA₃ may be attributed to improved source-sink relationships, enhanced assimilate translocation and maintenance of active growth during reproductive development (Dawood *et al.*, 2012; Sathishkumar *et al.*, 2020; Ashwini *et al.*, 2021) [5, 7, 4]. The improvement in productivity under SA application further indicates its role in enhancing crop tolerance to high-temperature stress. SA can support the stability of photosynthetic machinery, improve cellular protection and reduce the adverse effects of oxidative stress, thereby facilitating continued assimilate production and reproductive development under elevated temperature. The higher seed and biological yields under T₂ compared with the untreated control suggest that SA helped maintain productive growth during terminal heat stress. Similar beneficial effects of SA in maintaining photosynthetic activity, reducing reproductive damage and improving yield-related traits under stress conditions have been reported by Ali *et al.* (2013) [2] and Srinithi *et al.* (2023) [8, 9]. A similar trend was observed for harvest index, with T₃ recording the highest value, followed by T₂, while the untreated control recorded the lowest harvest index. The higher harvest index under GA₃ indicates not only increased biomass production but also more efficient allocation of assimilates toward the reproductive sinks. The simultaneous improvement in biological yield, seed yield and harvest index under GA₃ suggests that its beneficial effect extended beyond vegetative growth to improved source-sink coordination and reproductive partitioning. SA also improved harvest efficiency relative to the control, although its response remained lower than that of GA₃.

Conclusion

The study revealed significant genotypic variation in finger millet growth and productivity under terminal heat stress. G7 (SKMFM3014) showed the highest plant stand establishment but recorded comparatively lower plant height, seed yield and biological yield, indicating that better establishment alone did not ensure higher productivity. G10 (CFMV-1) recorded the highest seed yield, while G1 (IIMRFM3996) produced the highest biological yield and G3 (WN1585) exhibited the highest harvest index. Among the PGR treatments, GA₃ @ 100 mg L⁻¹ consistently performed best for improving plant height, seed yield, biological yield and harvest index, followed by SA @ 100 mg L⁻¹, whereas the control recorded the lowest performance. Overall, G1 (IIMRFM3996) and G10 (CFMV-1) showed greater yield potential, and application of GA₃ @ 100 mg L⁻¹ proved effective for enhancing finger millet productivity under terminal heat stress.

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