

CLIMATE-SMART FINGER MILLET PRODUCTION THROUGH SYSTEM OF FINGER MILLET INTENSIFICATION, NANO FERTILIZERS AND MORINGA SEED PRIMING

Indianraj, N^{1*}, A.L. Narayanan², Santosh Kumar Meena³, L. Aruna⁴, S. Mala⁵, S. Nadaradjan⁶

^{1*}Ph.D. Scholar, Department of Agronomy, Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Karaikal, Puducherry, India, Email ID: indianrajagri5243@gmail.com. Orcid ID: 0000-0002-3532-8079

²Professor, Department of Agronomy, PAJANCOA & RI, Karaikal, Puducherry, India, Email ID: alnarayanan69@gmail.com

³Assistant Professor, Department of Agronomy, PAJANCOA & RI, Karaikal, Puducherry, India, Email ID: jharwal_santosh777@yahoo.co.in

⁴Professor, Department of Soil Science and Agrl. Chemistry, PAJANCOA & RI, Karaikal, Puducherry, India, Email ID: marunassac@gmail.com

⁵Professor, Department of Agronomy, PAJANCOA & RI, Karaikal, Puducherry, India, Email ID: malapjn2020@gmail.com

⁶Professor, Department of Plant breeding and Genetics, PAJANCOA & RI, Karaikal, Puducherry, India, Email ID: nadaradjans@gmail.com

ABSTRACT

Finger millet (*Eleusine coracana* L. Gaertn.) is an important climate-resilient cereal with considerable potential for sustainable food and nutritional security. However, improving productivity under changing climatic conditions requires the integration of efficient crop establishment, improved nutrient-use efficiency and biologically based crop growth-promoting approaches. A field experiment was conducted during Kharif 2025 at the Agronomy Farms, Department of Agronomy, Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Karaikal, Puducherry, to evaluate the combined influence of the System of Finger Millet Intensification (SFMI), nano fertilizers and 2% moringa leaf extract (MLE) seed priming on productivity and profitability of finger millet. The experiment comprised factorial treatment combinations arranged in a Factorial Randomized Block Design (FRBD) with three replications. Among the treatments evaluated, the combination of SFMI with 2% MLE seed priming and foliar application of Nano Urea Plus (20% N, w/v) and Nano DAP (8% N and 16% P, w/v) at 4% concentration, applied twice at flowering and 15 days after the first spray, recorded superior yield attributes. The treatment recorded 6.32 productive tillers m⁻², 9.12 cm and a test weight of 3.85 g. The same treatment produced the highest grain yield of 2,529 kg ha⁻¹ and straw yield of 4,176.4 kg ha⁻¹, with a net return of ₹63,334 ha⁻¹ and a benefit-cost ratio of 2.94. Weather analysis further indicated that temperature, rainfall, relative humidity and evaporation, together with derived agrometeorological indices, influenced crop productivity. The recorded values of diurnal variation in temperature (DVT), growing degree days (GDD), heliothermal units (HTU), photothermal units (PTU) and heat use efficiency (HUE) were 12.8°C, 688.7°C day, 6547.21 degree hours, 8453.49 degree hours and 4.2 g m⁻² day⁻¹, respectively. The results indicate that integrating SFMI, MLE seed priming and foliar nano-fertilizer application has considerable potential as a climate-smart production strategy for improving finger millet productivity and farm profitability under the environmental conditions of Karaikal.

KEYWORDS: Climate-smart agriculture, finger millet, *Eleusine coracana*, System of Finger Millet Intensification, moringa leaf extract, nano fertilizer, Nano Urea Plus, Nano DAP, agrometeorological indices.

INTRODUCTION

Agriculture is increasingly exposed to climate-related stresses, including changes in temperature, rainfall variability, moisture stress and other weather extremes. These challenges create a need for production systems that simultaneously improve productivity, strengthen resilience and reduce the environmental burden associated with agricultural production. Climate-smart agriculture is broadly based on three interconnected objectives: sustainably increasing productivity and incomes, enhancing resilience and adaptation to climate change, and contributing to mitigation of greenhouse-gas emissions where possible (FAO, 2013; FAO, 2015). Finger millet (*Eleusine coracana* L. Gaertn.) is particularly relevant in this context because of its adaptability to relatively harsh production environments and its nutritional importance. The crop is recognized for its climate resilience, nutritional value and potential contribution to sustainable food systems. Recent reviews have emphasized the ability of finger millet to contribute to food and nutritional security while maintaining productivity under environments where major cereal crops can face greater climatic constraints (Kaur *et al.*, 2024).

Despite its resilience, productivity of finger millet depends considerably on crop establishment, nutrient availability and weather conditions during critical growth stages. Nitrogen is one of the important nutrients determining crop growth and yield, and improving nitrogen-use efficiency is therefore an important component of sustainable finger millet production. Foliar nutrition using nano-fertilizers has received increasing attention because nutrient delivery through leaves can supplement soil-applied nutrients during periods of high crop

demand. Recent field studies have demonstrated the potential of nano urea in finger millet. Soundarya *et al.* (2024) reported improvements in growth, yield and nutrient uptake with foliar application of nano urea under appropriate nitrogen management. Similarly, a field experiment conducted at Karaikal reported that combining conventional nitrogen with liquid nano urea improved finger millet yield and nitrogen-use efficiency (Rajeshwari *et al.*, 2025). Plant-based biostimulants provide another potential component of climate-smart nutrient management. Moringa leaf extract (MLE) contains minerals, amino acids, proteins, phenolic compounds and plant growth-promoting substances, including cytokinins and other phytoactive compounds. Reviews of MLE applications have reported positive effects on seed germination, root development, plant growth, nutrient-use efficiency and yield in several crops, particularly when plants are exposed to environmental stresses (Merwad *et al.*, 2022). The System of Finger Millet Intensification (SFMI) represents an approach aimed at improving crop establishment and resource utilization through modifications in crop establishment and plant management. Integration of improved establishment practices with biological stimulation and efficient foliar nutrient supplementation may provide a more comprehensive strategy than relying on any single intervention. Therefore, the present investigation was undertaken to evaluate the combined effect of SFMI, 2% MLE seed priming and foliar application of nano fertilizers on finger millet productivity, profitability and weather-related performance under the agro-environmental conditions of Karaikal.

2. MATERIALS AND METHODS

A field experiment was conducted during Kharif 2025 at the Agronomy Farms, Department of Agronomy, Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA & RI), Karaikal, Puducherry, India. The experiment was conducted to evaluate climate-smart production technologies involving SFMI, nano fertilizers and MLE seed priming in finger millet. The experimental location represents the coastal agro-environmental conditions of the Karaikal region. The experiment consisted of factorial treatment combinations involving the production system, MLE seed priming and foliar nano-fertilizer treatments. The treatments were arranged in a Factorial Randomized Block Design (FRBD) with three replications. Treatment effects were evaluated using the appropriate analysis of variance for the experimental design. The original experimental dataset should be used to report standard error, critical difference, coefficient of variation and interaction effects.

3. RESULTS AND DISCUSSION

3.1 Effect of integrated climate-smart management on yield attributes and yield

3.1.1. Productive tillers

The integrated treatment comprising SFMI, 2% MLE seed priming and combined foliar application of Nano Urea Plus and Nano DAP produced the superior yield attributes among the treatments evaluated. The treatment recorded 6.32 productive tillers m⁻².

Improved crop establishment and resource utilization under an intensification-based production system can promote better plant growth and reproductive development. The beneficial response may have been further supported by MLE seed priming, which is associated with improved germination, root development and physiological activity. Moringa leaf extract contains several bioactive compounds, including plant growth-promoting substances, nutrients and antioxidants, which can contribute to improved early crop establishment and subsequent growth (Merwad *et al.*, 2022).

The improved reproductive development under combined nano-nutrient application may also be associated with improved nutrient availability during the reproductive phase. Nitrogen and phosphorus are particularly important for photosynthetic activity, assimilate production, reproductive development and grain formation. Field studies in finger millet have shown positive responses to foliar nano urea under suitable nitrogen management (Soundarya *et al.*, 2024).

3.1.2 Finger length and test weight

The integrated treatment recorded a finger length of 9.12 cm and test weight of 3.85 g. These results indicate that the treatment combination supported both reproductive growth and grain development.

Finger millet yield is determined by the interaction of yield components rather than by a single trait. Adequate nutrient availability during reproductive development can maintain photosynthetic activity and assimilate supply to developing grains. The combined application of Nano Urea Plus and Nano DAP may therefore have provided supplementary nitrogen and phosphorus at an important stage of crop development.

The observed response is consistent with previous research showing that nano-fertilizer-based nutrient supplementation can improve crop growth and productivity when appropriately integrated with conventional nutrient management. In finger millet, foliar nano urea application has been reported to improve plant height, tiller production, dry matter accumulation and grain yield (Soundarya *et al.*, 2024).

Table 1 : Effect of SFMI, Nano fertilizers and seed priming on yield and yield attributes of Finger millet

Treatments	Productive tillers	Finger length (cm)	Test weight (g)	Grain yield (Kg/ha)	Straw yield (Kg/ha)
Main factor					
M1: CT	6.06	8.18	3.43	2204	3653.8
M2: SFMI	6.32	8.93	3.68	2447	4034.1

S. Ed	0.13	0.004	0.03	67.5	112.8
CD	0.26	NS	NS	138	230.4
Sub factor					
S1: SP MLE	6.20	8.53	3.50	2250	3715
S2: SP MLE + NUP	6.27	8.83	3.68	2385	3935
S3: SP MLE + NDAP	6.25	8.73	3.63	2350	3880
S4: SP MLE + NUP+ NDAP	6.32	9.12	3.85	2529	4176.4
S5: WSP	6.07	8.23	3.30	2150	3560
S6: WSP MLE + NUP	6.12	8.43	3.48	2300	3810
S7: WSP MLE + NDAP	6.10	8.33	3.43	2260	3740
S8: WSP MLE + NUP+ NDAP	6.18	8.63	3.58	2380	3935
S. Ed	0.26	0.008	0.10	135	225.6
CD	0.53	NS	NS	276	460.7
Interaction (M X S)					
S. Ed	0.37	0.01	0.21	190.9	318.6
CD	0.75	NS	NS	390	650.6

M- Method of planting; S- Seed Priming practices; CT- Conventional Transplanting; SFMI- System of Finger Millet Intensification; SP- Seed Priming; WSP- Without Seed Priming; MLE- Moringa Leaf Extract; NUP- Nano Urea Plus; NDAP- Nano Di-Ammonium Phosphate.

3.1.3 Grain yield

The highest grain yield of 2,529 kg ha⁻¹ was recorded with the integrated SFMI + 2% MLE seed priming + Nano Urea Plus + Nano DAP treatment. This indicates that simultaneous improvement of crop establishment, biological stimulation and foliar nutrient supply can contribute to improved grain productivity.

The yield advantage can be physiologically interpreted as the combined outcome of better crop establishment, improved nutrient availability and greater reproductive sink development. SFMI may improve plant establishment and resource-use efficiency, while MLE seed priming can promote early physiological activity. Foliar application of nitrogen and phosphorus during flowering and subsequent crop development may support continued photosynthesis and grain filling.

The result is also comparable in direction with previous research on nano-nutrient management in finger millet. Rajeshwari *et al.* (2025) reported that integrated conventional nitrogen and liquid nano urea application improved grain yield and nitrogen-use efficiency compared with conventional nitrogen alone. However, the magnitude of response should be interpreted specifically for the present Karaikal experiment because nano-fertilizer responses can vary with genotype, soil fertility, weather, nutrient management and application timing.

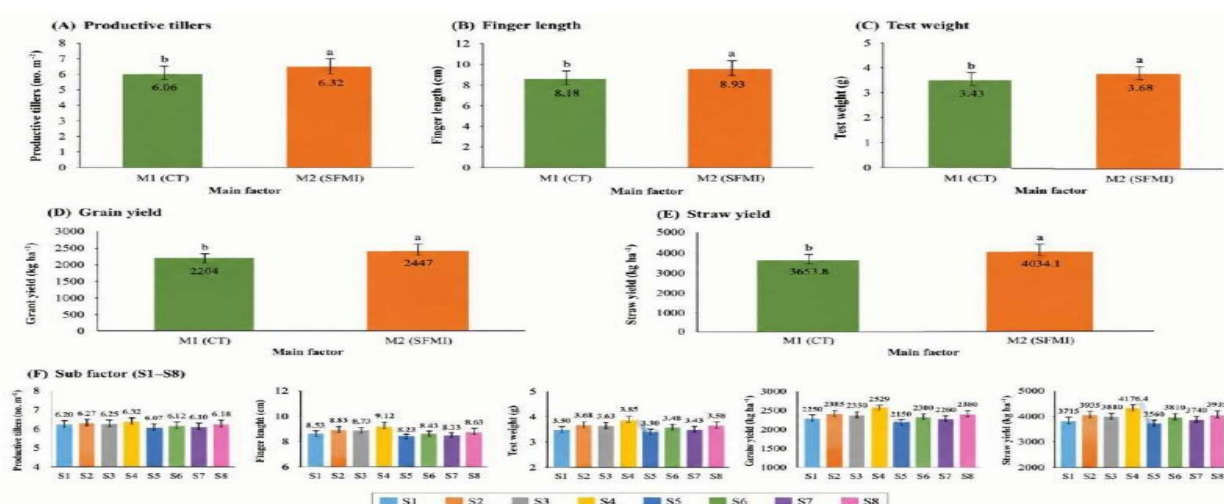


Fig. 1. Effect of main factors (M1 and M2) and sub factors (S1-S8) on yield and its attributes in finger millet. Bars represent mean values $\pm$ standard error. Different letters indicate significant differences at $p \leq 0.05$ (DMRT).

3.1.4 Straw yield

The highest straw yield of 4,176.4 kg ha⁻¹ was obtained with the same integrated treatment. Higher straw production reflects greater overall vegetative biomass production and may be associated with enhanced nutrient acquisition and crop growth.

The simultaneous improvement in productive tillers, earheads and grain yield suggests that the treatment did not merely promote vegetative growth but maintained crop development through the reproductive phase. Such

balanced biomass production is desirable in climate-smart production systems because improved resource capture can contribute to higher productivity per unit area (Fageria and Baligar, 2005).

3.2 Effect of integrated climate-smart management on Economic performance

The integrated treatment recorded the highest net return of ₹63,334 ha⁻¹ and a benefit-cost ratio of 2.94. Economic performance is an essential component of climate-smart agriculture because a technology must not only improve biological productivity but also provide adequate economic incentives for farmers. FAO describes climate-smart agriculture as an approach that seeks to increase productivity and incomes while simultaneously improving resilience to climate change.

The higher net return obtained in the present study can be attributed primarily to the higher grain and straw yields achieved under the integrated treatment. The benefit-cost ratio of 2.94 indicates favourable economic returns under the conditions of the experiment.

3.3 Effect of integrated climate-smart management on Weather variables and finger millet productivity

Weather conditions play an important role in determining crop growth, phenological development and yield. The present study considered temperature, rainfall, relative humidity and evaporation as direct weather variables and evaluated their relationship with finger millet productivity.

The results indicated that weather variables influenced crop performance. Such a response is expected because temperature determines the rate of physiological development, while rainfall and atmospheric moisture affect water availability and transpiration. Evaporation provides an indication of atmospheric evaporative demand and therefore helps explain crop water requirements.

Finger millet is generally considered a climate-resilient crop, but resilience does not mean complete immunity to climatic stress. Recent research has shown that drought and low nitrogen can interact to reduce finger millet yield potential, particularly when stress occurs during important reproductive stages. Consequently, climate-smart agronomic interventions should focus not only on the inherent resilience of the crop but also on improving its ability to utilize available resources efficiently under variable weather conditions.

3.3.1. Derived agrometeorological indices

The treatment comprising SFMI + 2% MLE seed priming + Nano Urea Plus and Nano DAP @ 4% each, applied twice at flowering and 15 days later, recorded DVT was 12.8°C, while cumulative GDD, HTU and PTU were 688.7°C day, 6547.21 degree hours and 8453.49 degree hours, respectively. The recorded HUE was 4.2 g m⁻² day⁻¹.

Growing degree days provide an estimate of thermal accumulation and are useful for describing crop development in relation to temperature. HTU combines accumulated heat units with bright sunshine hours, while PTU integrates thermal accumulation with photoperiodic conditions. These agrometeorological indices are useful for assessing crop phenology, growth and productivity under varying weather conditions (Rajput *et al.*, 1987; Mavi & Tupper, 2004). HUE provides an indication of biomass or productivity obtained per unit of accumulated thermal resource.

The observed association of these indices with crop productivity emphasizes the importance of considering both agronomic management and weather conditions when evaluating climate-smart production systems. A productive treatment under a particular environment may respond differently under another combination of temperature, radiation, rainfall and humidity. Therefore, future research should evaluate SFMI, MLE and nano-fertilizer combinations across multiple seasons and locations to determine their stability under contrasting weather environments.

4. Climate-smart significance of the integrated approach

The present study demonstrates the potential of integrating three complementary approaches: improved crop establishment through SFMI, biological stimulation through MLE seed priming and targeted nutrient supplementation through nano fertilizers.

The importance of this integration lies in the fact that climate-smart agriculture is not necessarily a single input or technology. Rather, it involves combining production practices that improve productivity and resilience while promoting efficient resource utilization. FAO emphasizes that climate-smart agriculture is location-specific and involves selecting production systems that respond effectively to local climate-related challenges.

MLE offers a plant-derived biostimulant option that can complement mineral nutrition. Moringa leaf extract contains phytohormones, antioxidants, minerals and other bioactive compounds that may promote plant growth, nutrient utilization and tolerance to abiotic stresses, supporting its potential role as a sustainable component of integrated crop management (Rady *et al.*, 2022).

Nano fertilizers may provide an additional strategy for improving nutrient-use efficiency through foliar nutrient delivery. Foliar application of nanofertilizers can facilitate rapid nutrient absorption and may improve nutrient-use efficiency compared with conventional nutrient application; however, their performance is influenced by crop, environment, formulation and application conditions (Verma *et al.*, 2023). However, their effectiveness should not be generalized across all crops and environments. Recent literature also emphasizes the need for multi-location and multi-season studies to evaluate their long-term agronomic and environmental effects. Thus, the integrated treatment identified in the present study should be considered a promising climate-smart management package for finger millet under Karaikal conditions rather than as a universally optimum treatment.

5. CONCLUSION

The field experiment conducted during Kharif 2025 at PAJANCOA & RI, Karaikal demonstrated the potential of integrating System of Finger Millet Intensification with 2% Moringa Leaf Extract seed priming and foliar nano-fertilizer application for improving finger millet productivity and profitability. The treatment comprising SFMI + 2% MLE seed priming + Nano Urea Plus and Nano DAP @ 4% each, applied twice at flowering and 15 days later, recorded the superior yield attributes, with 6.32 productive tillers m⁻², 9.12 cm finger length, and 4.0 g test weight. The treatment produced the highest grain yield (2,529 kg ha⁻¹), straw yield (4,176.4 kg ha⁻¹), net return (₹63,334 ha⁻¹) and benefit-cost ratio (2.94).

The observed relationships between weather parameters, derived agrometeorological indices and crop productivity further indicate that climate variability should be incorporated into the evaluation of finger millet production technologies. Overall, the integration of SFMI, MLE seed priming and nano-fertilizer-based foliar nutrition represents a promising climate-smart production strategy for enhancing productivity and economic returns of finger millet under the Karaikal agro-environment.

Nevertheless, multi-season and multi-location experiments involving complete statistical datasets are required to validate the stability, nutrient-use efficiency, environmental benefits and economic feasibility of this integrated technology under diverse agro-climatic conditions.

Conflict of interest

All authors declare that there is no conflict of interest.

REFERENCES

1. Fageria, N. K., and Baligar, V. C. 2005. Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy*, 88, 97–185. [https://doi.org/10.1016/S0065-2113\(05\)88004-6](https://doi.org/10.1016/S0065-2113(05)88004-6).
2. FAO. 2013. *Climate-Smart Agriculture Sourcebook*. Food and Agriculture Organization of the United Nations, Rome, Italy.
3. FAO. 2015. *Climate-smart agriculture: What is it? Why is it needed?* Food and Agriculture Organization of the United Nations.
4. Kaur, S., Kumari, A., Seem and K., Kaur, G., 2024. Finger millet (*Eleusine coracana* L.): From staple to superfood—a comprehensive review on nutritional, bioactive, industrial, and climate resilience potential. *Planta*, 260, 75. <https://doi.org/10.1007/s00425-024-04502-2>
5. Mavi, H. S., & Tupper, G. J. 2004. *Agrometeorology: Principles and applications of climate studies in agriculture*. Food Products Press.
6. Merwad, A. M. A., Desoky, E.-S. M., and Rady, M. M. 2022. Assessing the usefulness of *Moringa oleifera* leaf extract as a biostimulant to supplement synthetic fertilizers: A review. *Plants*, 11.
7. Rady, M. M., Abd El-Mageed, T. A., Abdurrahman, H. A., and Bhavanasi, R. 2022. Assessing the usefulness of *Moringa oleifera* leaf extract as a biostimulant to supplement synthetic fertilizers: A review. *Plants*, 11(17), 2214. <https://doi.org/10.3390/plants11172214>
8. Rajeshwari, S., Narayanan, V., Sridevi, V., Nadarajan, S., and Pushparaj, S. 2025. Effect of liquid nanourea application on yield, post-harvest plant and soil nutrient status in finger millet (*Eleusine coracana* L.) production. *Journal of Advances in Biology & Biotechnology*, 28(3), 474–480. <https://doi.org/10.9734/jabb/2025/v28i32107>
9. Rajput, R. P., Deshmukh, S. G., & Paradkar, V. K. 1987. Accumulated heat units and phenology relationships in wheat. *Journal of Agricultural Science*, 109(1), 123–127.
10. Samanta, S., Maitra, S., Shankar, T., Gaikwad, D., Sagar, L., Panda, M., and Samui, S. 2022. Comparative performance of foliar application of urea and nano urea on finger millet (*Eleusine coracana* L. Gaertn.). *Crop Research*, 57, 166–170. <https://doi.org/10.31830/2454-1761.2022.025>
11. Soundarya, Gaddi, A. K., Veeresh, H., Ravi, S., Srinivasa, D. K., and Ajaya Kumar, M. Y. 2024. Effect of nano urea on growth, yield and nutrient uptake of finger millet (*Eleusine coracana* L.). *International Journal of Plant & Soil Science*, 36(9), 660–667. <https://doi.org/10.9734/ijpss/2024/v36i95014>
12. Verma, K. K., Song, X.-P., Tian, D.-D., Guo, D.-J., Chen, Z.-L., Zhong, C.-S., and Lin, X.-Y. (2023). Recent trends in foliar nanofertilizers: A review. *Nanomaterials*, 13(21), 2906. <https://doi.org/10.3390/nano13212906>