



# Integrated Application of Bio-stimulants and Inorganic Fertilizers on Growth and Productivity of Ragi (*Eleusine coracana*)

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10.18805/IJARE.A-6526

## ABSTRACT

**Background:** Finger millet (*Eleusine coracana*) cultivated under semi-arid conditions often experiences significant yield gaps due to imbalanced nutrient management. Integrated nutrient approaches combining inorganic fertilizers with bio-stimulants may enhance nutrient use efficiency and crop productivity in such environments.

**Methods:** A two-year field experiment was conducted during Rabi 2024-25 and 2025-26 at Hyderabad, India, to evaluate the integrated use of bio-stimulants with inorganic fertilizers on growth, yield and nutrient uptake of finger millet. The experiment was laid out in a randomized block design with eight treatments and three replications. The treatments included control (T<sup>1</sup>), 100% recommended dose of fertilizers (RDF; T<sub>2</sub>) and 100% RDF combined with seaweed extract (2 and 4 mL L<sup>-1</sup>; T<sub>3</sub>-T<sub>4</sub>), humic acid (2 and 4 mL L<sup>-1</sup>; T<sub>5</sub>-T<sub>6</sub>) and chitosan (2 and 4 mL L<sup>-1</sup>; T<sub>7</sub>-T<sub>8</sub>) were applied at tillering and pre flowering stage as foliar spray using knap sack sprayer. Pooled data of two years were subjected to statistical analysis, including correlation and regression studies.

**Result:** Pooled analysis revealed that 100% RDF+humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) significantly outperformed all other treatments. It recorded the highest plant height (76.2 cm), tillers hill<sup>-1</sup> (9.95), leaf area index (4.18) and dry matter production (5527 kg ha<sup>-1</sup>). The same treatment also achieved superior yield attributes, including productive tillers m<sup>-2</sup> (128) and grains ear head<sup>-1</sup> (515), resulting in the highest grain yield (2140 kg ha<sup>-1</sup>) and straw yield (3638 kg ha<sup>-1</sup>). Nutrient uptake was also maximum under T<sub>6</sub> (N = 78.0, P = 13.1, K = 54.2 kg ha<sup>-1</sup>). Grain yield increased by approximately 27% over RDF alone and 106% over the control. Correlation and regression analyses indicated strong positive relationships between nutrient uptake and grain yield (R<sup>2</sup>>0.9). The results demonstrate that integrating humic acid (4 mL L<sup>-1</sup>) with RDF enhances growth, nutrient use efficiency and productivity of finger millet under semi-arid conditions.

**Key words:** Bio-stimulants, Integrated nutrient management, Nutrient uptake, Ragi (Finger millet), Recommended dose of fertilizer (RDF), Regression analysis.

## INTRODUCTION

Millets, often termed nutri-cereals, are rich in vitamins, minerals and other essential nutrients vital for human health, thereby contributing to nutritional security and the mitigation of malnutrition. Reflecting their importance, the Government of India designated 2018 as the "National Year of Millets" and the United Nations supported by 70 nations proclaimed 2023 the "International Year of Millets" (Senthamil *et al.*, 2021). Among millets, ragi (*Eleusine coracana* L.), or finger millet, is distinguished by high nutrient density and climate resilience. It is predominantly cultivated in southern India especially Karnataka and Tamil Nadu with considerable acreage in Andhra Pradesh, Maharashtra, Uttar Pradesh and Bihar. Its adaptability to semi-arid environments makes it indispensable for small and marginal farmers practicing subsistence agriculture. Nevertheless, yields in conventional systems remain low (0.6-0.8 t ha<sup>-1</sup>) (Geethalakshmi, 2023), underscoring the need for balanced nutrient management.

Over-reliance on mineral fertilizers has contributed to soil fertility decline, reinforcing the relevance of sustainable, integrated nutrient strategies. In this context, bio-stimulants derived from marine and plant sources rich in naturally

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**How to cite this article:** Midde, S.K., Adarsh, V., Sai, M.V. and Vamshi, M. (2026). Integrated Application of Bio-stimulants and Inorganic Fertilizers on Growth and Productivity of Ragi (*Eleusine coracana*). *Indian Journal of Agricultural Research*. **60(8)**: 1263-1268. doi: 10.18805/IJARE.A-6526.

**Submitted:** 24-02-2026 **Accepted:** 02-06-2026 **Online:** 13-06-2026

occurring growth promoters such as cytokinins, auxins and gibberellins offer a promising approach to enhance growth, nutrient uptake and stress tolerance in ragi (Ahmed *et al.*, 2023). Mechanistically, bio-stimulants activate plant

physiological and biochemical processes, improve nutrient assimilation and metabolism and confer tolerance to abiotic stresses including drought, salinity and temperature extremes (Rouphael and Colla, 2020).

Within this category, humic acid improves soil structure, augments water and nutrient retention, stimulates root growth and enhances stress resilience; it also modulates key metabolic functions such as respiration, photosynthesis, nutrient absorption and transcriptional activation (Shukry *et al.*, 2023). Seaweed extracts supply phytohormones, vitamins, amino acids and polysaccharides that promote cell division and elongation, improve fruit quality, elevate stress tolerance and strengthen plant defense against pests and diseases (Hassan and Emam, 2015). Their bioactive metabolites exhibit antifungal, antiviral, antibacterial and antiprotozoal activities that further support plant development (Mukherjee and Patel, 2020). Chitosan, a biodegradable derivative of chitin from crustacean shells and fungal cell walls, functions as both a bio-stimulant and biopesticide by eliciting plant immunity, enhancing soil microbial activity and improving water retention and overall vigor (Oliveira *et al.*, 2014).

Given ongoing soil degradation and climate change, bio-stimulants have emerged as critical inputs for sustainable agriculture by reducing dependence on synthetic fertilizers while safeguarding long-term soil health. Accordingly, this study evaluates the combined effects of bio-stimulants and inorganic fertilizers on ragi, with specific objectives to (i) assess impacts on growth and yield, (ii) determine nutrient uptake efficiency and (iii) examine the economic feasibility of bio-stimulant-based nutrient management under semi-arid conditions.

## MATERIALS AND METHODS

### Study site

A two-year field experiment entitled “Enhancing productivity of ragi (*Eleusine coracana*) through various bio-stimulants” was conducted during the *Rabi* seasons of 2024-25 and

2025-26 at the College Farm, School of Agricultural Sciences, Malla Reddy University, Hyderabad, India (17.55°N, 78.46° E; 547 m above mean sea level). The experimental site represents a semi-arid tropical climate. Across the two seasons (October-February), total rainfall averaged 1.4 mm, with mean maximum and minimum temperatures of 35.2°C and 20.8°C, respectively and relative humidity averaging 86.7%. The surface soil (0-15 cm) was classified as sandy loam (Table 1).

### Experimental design and treatments

The experimental field had previously been under maize (*Kharif* and *Rabi*) and rice and remained fallow during spring. The study followed a randomized block design (RBD) with three replications and eight treatments, each maintained uniformly across both years. Gross plot size was 5 × 4 m, net plot size 4 × 3.6 m and crop spacing 25 × 10 cm.

### Treatment details

The treatments included control ( $T_1$ ), 100% recommended dose of fertilizers (RDF;  $T_2$ ) and 100% RDF combined with seaweed extract (2 or 4 mL L<sup>-1</sup>;  $T_3$ - $T_4$ ), humic acid (2 or 4 mL L<sup>-1</sup>;  $T_5$ - $T_6$ ) and chitosan (2 or 4 mL L<sup>-1</sup>;  $T_7$ - $T_8$ ) was applied as foliar spray using knap sack at tillering and pre-flowering stage.

### Soil sampling and analysis

Before sowing, ten geo-referenced surface soil samples (0-15 cm) were collected, composited and analyzed for physico-chemical properties (Table 1). The analytical methods included pH (1:2.5 soil:water), electrical conductivity (dS m<sup>-1</sup>), organic carbon (%) and available N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O determined using standard protocols.

### Crop management

The land was ploughed, cultivated and rotavated to fine tilth and divided into 24 plots with irrigation channels. The recommended fertilizer dose (RDF) of 60-13-25 kg N-P-K ha<sup>-1</sup>

**Table 1:** Effect of bio-stimulants on growth parameters of ragi (*Eleusine coracana*) at harvest (*Rabi* 2024-25 and 2025-26).

| Treatment                                                 | Plant height (cm) | No. of tillers hill <sup>-1</sup> | Dry matter production (kg ha <sup>-1</sup> ) | Leaf area index (at 90 DAS) |
|-----------------------------------------------------------|-------------------|-----------------------------------|----------------------------------------------|-----------------------------|
| $T_1$ - Control                                           | 54.5              | 6.95                              | 2508                                         | 2.23                        |
| $T_2$ - 100% RDF                                          | 66.5              | 7.95                              | 4559                                         | 2.86                        |
| $T_3$ - 100% RDF + Seaweed extract @ 2 mL L <sup>-1</sup> | 66.7              | 7.98                              | 4638                                         | 2.91                        |
| $T_4$ - 100% RDF + Seaweed extract @ 4 mL L <sup>-1</sup> | 71.7              | 8.98                              | 5097                                         | 3.63                        |
| $T_5$ - 100% RDF + Humic acid @ 2 mL L <sup>-1</sup>      | 72.4              | 9.11                              | 5166                                         | 3.72                        |
| $T_6$ - 100% RDF + Humic acid @ 4 mL L <sup>-1</sup>      | 77.1              | 10.03                             | 5596                                         | 4.21                        |
| $T_7$ - 100% RDF + Chitosan @ 2 mL L <sup>-1</sup>        | 66.9              | 8.04                              | 4656                                         | 3.04                        |
| $T_8$ - 100% RDF + Chitosan @ 4 mL L <sup>-1</sup>        | 72.1              | 9.06                              | 5116                                         | 3.66                        |
| SEm±                                                      | 1.3               | 0.17                              | 128                                          | 0.08                        |
| CD (p = 0.05)                                             | 4.1               | 0.50                              | 396                                          | 0.26                        |

Legend: Data represent mean values of two seasons; differences among treatments were tested using CD (P=0.05).

was applied as urea, single super phosphate and muriate of potash. Full dose of phosphorus and potassium in the form of SSP and MOP was applied basally and half the dose of nitrogen in the urea was applied at basally, remaining half dose of nitrogen was applied in two split doses at tillering and pre-flowering stage. Seeds of the ragi variety *Godavari* (PR202) were treated with NPK liquid consortia @ 5 mL kg<sup>-1</sup>, shade-dried and Line sown in solid line at 4 cm depth with a seed rate and spacing of 6 kg ha<sup>-1</sup> and 25 × 10 cm. Gap filling was done at 10 days after sowing (DAS). Weed control involved pendimethalin @ 1 kg ha<sup>-1</sup> (pre-emergence) at 3 DAS followed by hand weeding at 30 DAS. Irrigations were given at pre-sowing, 10, 30, 45 and 75 DAS. To control blast disease tricyclazole @ 1 g L<sup>-1</sup> was applied at 25 and 40 DAS. At harvest, border rows were excluded and the net plot produce was threshed and weighed for grain yield (adjusted to 14% moisture). Straw was sun-dried for 2-3 days before weighing.

### Observations and measurements

Growth observations were recorded for plant height, tillers hill<sup>-1</sup>, dry matter production (kg ha<sup>-1</sup>) and Leaf area index (LAI) at 30, 60 and 90 DAS and at harvest. Yield attributes recorded at harvest included productive tillers m<sup>-2</sup>, fingers ear head<sup>-1</sup>, grains ear head<sup>-1</sup> and 1000-grain weight (g). Grain and straw yields (kg ha<sup>-1</sup>) were recorded from the net plot and harvest index (HI, %) was computed.

Post-harvest soil analysis: Soil samples (0-20 cm) were tested for available N (alkaline KMnO<sub>4</sub>), P (ascorbic-acid blue) and K (neutral ammonium acetate). Plant analysis: Dried, ground samples were analyzed for N (micro-Kjeldahl), P (vanadomolybdate yellow) and K (flame photometer).

## RESULTS AND DISCUSSION

### Growth parameters

Pooled analysis of two-year data (*Rabi* 2024-25 and 2025-26) revealed significant effects of bio-stimulants on the growth traits of ragi. The treatment 100% RDF + humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) consistently recorded the highest plant height (mean: 76.8 cm),

tillers hill<sup>-1</sup> (10.02), dry matter production (5631 kg ha<sup>-1</sup>) and leaf area index (4.20). These were statistically comparable with 100% RDF+humic acid @ 2 mL L<sup>-1</sup> (T<sub>5</sub>). The improvement in growth parameters under humic acid treatments may be as opined by Duary *et al.* (2024), Dhanasekaran *et al.* (2021) and Singh *et al.* (2023) due to increased auxin-mediated cell elongation and division, improved root proliferation and enhanced chelation of micronutrients (Fe, Zn, Mn, Cu), which are not measured in this experiment.

### Yield attributes

The two-year mean data showed that bio-stimulant application significantly enhanced yield attributes (Table 2). Application of bio-stimulant - Humic acid @ 4 mL L<sup>-1</sup> in addition to recommended fertilizers (T<sub>6</sub>) registered the highest productive tillers m<sup>-2</sup> (129), fingers ear head<sup>-1</sup> (7.38), ear heads plant<sup>-1</sup> (3.24), grains ear head<sup>-1</sup> (520) and 1000-grain weight (3.21 g). These were on par with 100% RDF + humic acid @ 2 mL L<sup>-1</sup> (T<sub>5</sub>) (126, 7.24, 3.14, 502 and 3.18 g, respectively). The improvement in yield attributes under humic acid application can may be linked to its positive effects on nutrient solubility, enhanced foliar uptake and stimulation of reproductive growth through auxin and cytokinin activity as reported in other crops (Hafez *et al.*, 2021; Alabdulla, 2019; Ashok *et al.*, 2020; Bawya *et al.*, 2025).

### Grain and straw yields

Grain yield exhibited consistent trends across both years (Table 3), with values ranging from 1054 to 2163 kg ha<sup>-1</sup>. The maximum pooled mean yield was obtained in 100% RDF along with foliar application of humic acid @ 4 mL L<sup>-1</sup> (2163 kg ha<sup>-1</sup>), followed by combined application of 100% RDF along with foliar spray of humic acid @ 2 mL L<sup>-1</sup> (T<sub>5</sub>) (1986 kg ha<sup>-1</sup>), while the lowest was recorded in no manure applied plot (T<sub>1</sub>, 1054 kg ha<sup>-1</sup>). Compared with RDF alone (T<sub>2</sub>, 1712 kg ha<sup>-1</sup>), the 100% RDF + humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) treatment enhanced yield by ~26% and by ~105% over the control. The sustained yield improvement with humic

**Table 2:** Yield attributes of ragi as influenced by various Bio-stimulants practices.

| Treatment                                                          | Productive tillers (m <sup>-2</sup> ) | Fingers ear <sup>-1</sup> | Ear heads plant <sup>-1</sup> | Grains ear <sup>-1</sup> | 1000-grain weight (g) |
|--------------------------------------------------------------------|---------------------------------------|---------------------------|-------------------------------|--------------------------|-----------------------|
| T <sub>1</sub> - Control                                           | 96                                    | 6.36                      | 2.40                          | 370                      | 3.06                  |
| T <sub>2</sub> - 100% RDF                                          | 109                                   | 6.52                      | 2.75                          | 480                      | 3.07                  |
| T <sub>3</sub> - 100% RDF + Seaweed extract @ 2 mL L <sup>-1</sup> | 114                                   | 6.79                      | 2.85                          | 482                      | 3.08                  |
| T <sub>4</sub> - 100% RDF + Seaweed extract @ 4 mL L <sup>-1</sup> | 122                                   | 6.92                      | 3.05                          | 490                      | 3.15                  |
| T <sub>5</sub> - 100% RDF + Humic acid @ 2 mL L <sup>-1</sup>      | 125                                   | 7.21                      | 3.12                          | 497                      | 3.17                  |
| T <sub>6</sub> - 100% RDF + Humic acid @ 4 mL L <sup>-1</sup>      | 128                                   | 7.34                      | 3.20                          | 515                      | 3.20                  |
| T <sub>7</sub> - 100% RDF + Chitosan @ 2 mL L <sup>-1</sup>        | 119                                   | 6.84                      | 2.97                          | 483                      | 3.10                  |
| T <sub>8</sub> - 100% RDF + Chitosan @ 4 mL L <sup>-1</sup>        | 124                                   | 7.12                      | 3.10                          | 495                      | 3.16                  |
| SE m ±                                                             | 3                                     | 0.24                      | 0.09                          | 14                       | 0.10                  |
| CD (p = 0.05)                                                      | 10                                    | 0.73                      | 0.27                          | 43                       | NS                    |

Legend: Values represent the mean of two seasons; treatment differences were evaluated using CD (P=0.05)

**Table 3:** Influence of bio-stimulants on yield and harvest index of ragi (pooled mean, *Rabi* 2024-25 and 2025-26).

| Treatment                                                     | Grain yield (kg ha <sup>-1</sup> ) | Straw yield (kg ha <sup>-1</sup> ) | Harvest index (%) |
|---------------------------------------------------------------|------------------------------------|------------------------------------|-------------------|
| T <sub>1</sub> - Control                                      | 1041                               | 1618                               | 39.15             |
| T <sub>2</sub> - 100% RDF                                     | 1684                               | 2660                               | 38.77             |
| T <sub>3</sub> - 100% RDF + Seaweed @ 2 mL L <sup>-1</sup>    | 1700                               | 2686                               | 38.76             |
| T <sub>4</sub> - 100% RDF + Seaweed @ 4 mL L <sup>-1</sup>    | 1903                               | 3044                               | 38.47             |
| T <sub>5</sub> - 100% RDF + Humic acid @ 2 mL L <sup>-1</sup> | 1963                               | 3140                               | 38.47             |
| T <sub>6</sub> - 100% RDF + Humic acid @ 4 mL L <sup>-1</sup> | 2140                               | 3638                               | 37.04             |
| T <sub>7</sub> - 100% RDF + Chitosan @ 2 mL L <sup>-1</sup>   | 1735                               | 2758                               | 38.62             |
| T <sub>8</sub> - 100% RDF + Chitosan @ 4 mL L <sup>-1</sup>   | 1942                               | 3068                               | 38.76             |
| SEm±                                                          | 51                                 | 87                                 | 1.15              |
| CD (p=0.05)                                                   | 156                                | 265                                | NS                |

Note: HI was recalculated as  $HI = \frac{\text{Grain yield}}{(\text{Grain yield} + \text{Straw yield})} \times 100$ .

Values are presented as pooled means over two *Rabi* seasons; Year × Treatment was non-significant.

**Table 4:** Influence of bio-stimulants on nutrient uptake (N, P and K) in ragi (*Eleusine coracana*) pooled mean, *Rabi* 2024-25 and 2025-26.

| Treatment                                                           | N uptake (kg ha <sup>-1</sup> ) | P uptake (kg ha <sup>-1</sup> ) | K uptake (kg ha <sup>-1</sup> ) |
|---------------------------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
| T <sub>1</sub> - Control                                            | 39.0                            | 5.2                             | 32.1                            |
| T <sub>2</sub> - 100% RDF                                           | 60.7                            | 9.0                             | 37.2                            |
| T <sub>3</sub> - 100% RDF + Sea weed extract @ 2 ml L <sup>-1</sup> | 62.7                            | 9.3                             | 38.1                            |
| T <sub>4</sub> - 100% RDF + Sea weed extract @ 4 ml L <sup>-1</sup> | 68.2                            | 10.7                            | 45.3                            |
| T <sub>5</sub> - 100% RDF + Humic acid @ 2 ml L <sup>-1</sup>       | 72.0                            | 11.1                            | 49.0                            |
| T <sub>6</sub> - 100% RDF + Humic acid @ 4 ml L <sup>-1</sup>       | 78.0                            | 13.1                            | 54.2                            |
| T <sub>7</sub> - 100% RDF + Chitosan @ 2 ml L <sup>-1</sup>         | 63.9                            | 9.7                             | 40.7                            |
| T <sub>8</sub> - 100% RDF + Chitosan @ 4 ml L <sup>-1</sup>         | 70.5                            | 11.0                            | 47.3                            |
| S. Em. ±                                                            | 1.4                             | 0.4                             | 1.3                             |
| CD (p=0.05)                                                         | 4.2                             | 1.2                             | 4.0                             |

Note: Values are pooled means of two *ragi* seasons (2024-25 and 2025-26).

Humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) recorded the maximum uptake of all macronutrients, indicating superior nutrient-use efficiency.

acid application reflects its synergistic interaction with RDF in improving root growth, nutrient uptake and physiological efficiency, thereby enhancing biomass accumulation and translocation as inferred from the findings of Pallavi *et al.* (2016) and De Hita *et al.* (2020).

Straw yield followed the trend similar to grain yield. The highest mean straw yield was observed under 100% RDF along with foliar spray of humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) (3662 kg ha<sup>-1</sup>), followed by 100% RDF + humic acid @ 2 mL L<sup>-1</sup> (T<sub>5</sub>) (3421 kg ha<sup>-1</sup>), while the control (T<sub>1</sub>) produced the lowest (1623 kg ha<sup>-1</sup>).

#### Harvest index

Pooled analysis showed that harvest index (HI) was not significantly influenced by the treatments (Table 3). This indicates that increases in biomass were proportionate in both grain and straw components, maintaining a stable partitioning ratio. Similar observations were reported by Kanlyassery *et al.* (2024) in cereal-based nutrient management studies.

#### Nutrient uptake

Significant variations were observed in N, P and K uptake across treatments and years (Table 4). The treatment 100% RDF + humic acid @ 4 mL L<sup>-1</sup> (T<sub>6</sub>) recorded the highest mean nutrient uptake (N: 79.3; P: 13.4; K: 55.1 kg ha<sup>-1</sup>), followed by 100% RDF + humic acid @ 2 mL L<sup>-1</sup> (T<sub>5</sub>) (73.5; 11.5; 49.8 kg ha<sup>-1</sup>). This might be because of humic acid increased enzyme activity, which in turn encouraged root growth and increased the amount of nitrogen absorption from the RDF-applied in soil. Furthermore, it has enhanced permeability of cell membranes allowed for more effective transfer of ammonium and nitrate, resulting in increased nutrient uptake. Similar findings were reported by Meena *et al.* (2022) and Sharanya *et al.* (2022).

#### CONCLUSION

In Conclusion, the results over two consecutive seasons (*Rabi* 2024-25 and 2025-26) clearly demonstrated that the integrated use of bio-stimulants with the recommended

dose of fertilizers (RDF) significantly enhanced the growth, yield and nutrient uptake of ragi compared with RDF alone or the untreated control. Among all treatments, foliar application of humic acid @ 4 mL L<sup>-1</sup> along with 100% RDF (T<sub>6</sub>) consistently produced the highest plant height, tiller number, leaf area index, dry matter accumulation, yield attributes and uptake of N, P and K. The superior performance of humic-acid-treated plants is attributed to improved nutrient acquisition. These findings confirm humic acid as a potent bio-stimulant capable of improving yield stability and nutrient-use efficiency in finger millet under semi-arid conditions. Its integration into nutrient management strategies provides a sustainable, eco-friendly approach that promotes soil health and long-term agricultural productivity.

## ACKNOWLEDGEMENT

The authors express their sincere gratitude to the management and faculty of Koneru Lakshmaiah Education Foundation and Malla Reddy University for providing the necessary facilities, guidance and support to successfully carry out this research.

## Funding

The authors declare that this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Disclaimers

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## Informed consent

Informed consent was obtained from all concerned individuals involved in this study. The authors ensured that the research was conducted ethically and obtained the necessary permission wherever required.

## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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