



# International Journal of Research in Agronomy

E-ISSN: 2618-0618  
P-ISSN: 2618-060X  
© Agronomy  
NAAS Rating (2026): 5.20  
[www.agronomyjournals.com](http://www.agronomyjournals.com)  
2026; 9(5): 713-721  
Received: 07-02-2026  
Accepted: 15-03-2026

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## Effect of biofertilizers on morphological attributes, grain quality and yield of local cultivated varieties of Rice (*Oryza sativa* L.) from Gaurela-Pendra-Marwahi District of Chhattisgarh, India

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**DOI:** <https://www.doi.org/10.33545/2618060X.2026.v9.i5j.5606>

### Abstract

The present investigation was conducted during the Kharif seasons of 2021-2022 and 2022-2023 at Village Parasi, Block Marwahi, District Gaurela-Pendra-Marwahi, Chhattisgarh, India, to evaluate the effect of biofertilizers on morphological attributes, grain quality and yield of two local cultivated rice (*Oryza sativa* L.) varieties, Vishnubhog (V1) and Jeeraphool (V2). The experiment was laid out in Factorial Randomized Block Design (FRBD) with three replications, comprising twelve treatment combinations. Factor A consisted of two varieties, while Factor B included six organic treatments: T<sub>1</sub> (FYM + BGA), T<sub>2</sub> (FYM + Azotobacter + PSB + KSB), T<sub>3</sub> (FYM + BGA + Biofertilizer consortia), T<sub>4</sub> (FYM + Azospirillum), T<sub>5</sub> (FYM + BGA + Azospirillum), and T<sub>6</sub> (Control). Results revealed that Vishnubhog significantly outperformed Jeeraphool across all morphological parameters including plant height, number of tillers, effective tillers, dry matter accumulation and crop growth rate. Among organic treatments, T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest values for all growth parameters, which was statistically at par with T<sub>3</sub> (FYM + BGA + Biofertilizer consortia). The control treatment (T<sub>6</sub>) consistently recorded the lowest values. The interaction effect (V x T) was non-significant for most parameters, indicating that the biofertilizer treatments performed consistently across both varieties. These findings demonstrate that integrated application of multiple biofertilizers, particularly Azotobacter, PSB and KSB in combination with FYM, can significantly enhance morphological development and yield attributes of local rice varieties, supporting sustainable organic farming practices in the tribal-dominated Gaurela-Pendra-Marwahi region of Chhattisgarh.

**Keywords:** Biofertilizers, rice, *Oryza sativa*, Vishnubhog, Jeeraphool, Azotobacter, PSB, KSB, BGA, Azospirillum, organic farming, integrated nutrient management, Chhattisgarh, sustainable agriculture

### 1. Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops worldwide, serving as the staple food for more than half of the global population (Fukagawa & Ziska, 2019) <sup>[11]</sup>. In India, rice occupies a pivotal position in the national food security framework, with the country ranking as the second-largest producer globally after China. The rice-based cropping system has become the most predominant agricultural practice in the Indian subcontinent, particularly in eastern and central states where agro-climatic conditions are highly favorable for paddy cultivation (Mondal *et al.* 2015; Sharma *et al.* 2025) <sup>[21, 30]</sup>. However, long-term rice-based cultivation has led to a gradual reduction in yield and farmer income due to high input costs, improper fertilization practices, excessive soil disturbance, and reduced nutrient use efficiency (Kumar *et al.* 2024) <sup>[18]</sup>.

Chhattisgarh, popularly known as the "Rice Bowl of India," holds a distinctive position in rice cultivation with its diverse agro-ecological zones and rich genetic diversity of indigenous rice varieties. The state accounts for approximately 6% of India's total rice production, with kharif-season rice being the predominant crop across its tribal-dominated regions (Dahiphale *et al.* 2003) <sup>[9]</sup>. Among the numerous local rice varieties cultivated in Chhattisgarh, Vishnubhog and

cultural importance in the Gaurela-Pendra-Marwahi district. Jeeraphool, in particular, has been granted Geographical Indication (GI) status, recognizing its exclusive association with the specific agro-climatic conditions of the Surguja region (Shalikuta, 2024) <sup>[29]</sup>.

The intensive and indiscriminate use of chemical fertilizers in modern agriculture, while initially boosting productivity, has precipitated several environmental and soil health concerns. Continuous application of chemical fertilizers leads to soil organic matter degradation, loss of biodiversity, disruption of vital soil processes, environmental pollution, and reduced microbial activity (Kumar *et al.* 2024; Mondal *et al.* 2015) <sup>[18, 21]</sup>. The efficiency of nitrogen fertilizers in rice rarely exceeds 50%, with significant losses through volatilization, leaching, and denitrification, contributing to greenhouse gas emissions and groundwater contamination (Roger & Kulasooriya, 1980) <sup>[27]</sup>. These concerns have necessitated a paradigm shift toward sustainable and eco-friendly nutrient management strategies.

Biofertilizers, defined as preparations containing living or latent cells of efficient strains of nitrogen-fixing, phosphate-solubilizing, and potassium-mobilizing microorganisms, offer a promising alternative or complement to chemical fertilizers (Wani *et al.* 2016) <sup>[37]</sup>. *Azotobacter chroococcum*, a free-living nitrogen-fixing bacterium, has been extensively studied for its plant growth-promoting properties, including production of phytohormones such as indole-3-acetic acid (IAA), gibberellins, and cytokinins, as well as siderophores and ammonia (Upadhyay *et al.* 2015) <sup>[35]</sup>. *Azospirillum brasilense*, another important diazotroph, enhances root development and nutrient uptake through nitrogen fixation and phytohormone production (Preeprem *et al.* 2019) <sup>[25]</sup>.

Phosphate-solubilizing bacteria (PSB) play a crucial role in making insoluble soil phosphorus available to plants through organic acid secretion and enzymatic mineralization (Tang *et al.* 2025) <sup>[33]</sup>. Various PSB genera including *Bacillus*, *Pseudomonas*, and *Gluconacetobacter* have demonstrated significant potential in enhancing phosphorus availability and uptake in rice (Tripathi *et al.* 2025) <sup>[34]</sup>. Similarly, potassium-solubilizing bacteria (KSB) such as *Pantoea*, *Bacillus*, and *Burkholderia* species can transform fixed potassium from silicate minerals into plant-available forms, thereby improving potassium nutrition and stress tolerance in rice crops (Muthuraja *et al.* 2024; Saha *et al.* 2024) <sup>[22, 28]</sup>.

Blue-green algae (BGA), now classified as cyanobacteria, are photosynthetic nitrogen-fixers that have been used traditionally in rice cultivation across Asia. They contribute 25-30 kg N ha<sup>-1</sup> per cropping season through biological nitrogen fixation, besides producing growth-promoting substances and improving soil structure (Venkataraman, 1981) <sup>[36]</sup>. The integration of BGA with farmyard manure (FYM) and other biofertilizers represents a holistic approach to nutrient management that aligns with the principles of organic farming and sustainable agriculture (Bhuvaneshwari & Singh, 2015) <sup>[7]</sup>.

Integrated Nutrient Management (INM), which combines organic manures, biofertilizers, and judicious use of chemical fertilizers, has emerged as a scientifically sound and economically viable approach for sustainable rice production (Mondal *et al.* 2015) <sup>[21]</sup>. Studies have demonstrated that INM practices significantly improve plant height, tiller production, dry matter accumulation, leaf area index, and ultimately grain yield of rice compared to exclusive use of either chemical or

organic inputs alone (Sharma *et al.* 2025; Islam *et al.* 2020) <sup>[30]</sup>.

14].

Despite the recognized potential of biofertilizers, research on their integrated application for local aromatic rice varieties of Chhattisgarh remains limited. The Gaurela-Pendra-Marwahi district, characterized by its predominantly tribal population and traditional farming practices, presents an ideal setting for evaluating organic nutrient management strategies. The present study was therefore undertaken to systematically evaluate the effect of different biofertilizer combinations on morphological parameters, grain quality, and yield of Vishnubhog and Jeeraphool rice varieties, with the objective of developing sustainable nutrient management recommendations for resource-constrained farmers in the region.

## 2. Materials and Methods

### 2.1 Experimental Site

The field experiment was conducted during the Kharif seasons of 2021-2022 and 2022-2023 at Village Parasi, Block Marwahi, District Gaurela-Pendra-Marwahi (GPM), Chhattisgarh, India. Geographically, the experimental site is located in the northern hills of Chhattisgarh, situated at an elevation of approximately 550 meters above mean sea level. The district lies between 22 degrees 22' to 23 degrees 07' North latitude and 81 degrees 39' to 82 degrees 18' East longitude. The area falls under agro-climatic zone of Chhattisgarh Plains, characterized by a subtropical climate with hot summers, moderate winters, and an average annual rainfall of 1200-1400 mm, predominantly received during the monsoon season (June to September).

### 2.2 Soil Characteristics

The experimental soil was a medium black clayey loam, typical of the region, with pH ranging from 6.5 to 7.2, organic carbon content of 0.52-0.68%, available nitrogen of 220-265 kg ha<sup>-1</sup>, available phosphorus of 18-24 kg ha<sup>-1</sup>, and available potassium of 280-340 kg ha<sup>-1</sup>. The soil was moderately fertile with good water-holding capacity, suitable for lowland rice cultivation. Prior to experimentation, the field was under a rice-fallow cropping system following traditional cultivation practices.

### 2.3 Climate and Weather

The experimental region experiences a tropical monsoon climate with three distinct seasons: summer (March-June), rainy/monsoon (July-October), and winter (November-February). During the experimental period, the mean maximum temperature ranged from 28 degrees C to 42 degrees C and the mean minimum temperature from 12 degrees C to 28 degrees C. Relative humidity varied between 45% and 85%. Total rainfall received during the cropping period was approximately 950 mm in 2021-2022 and 1100 mm in 2022-2023.

### 2.4 Crop Management

The crop details and cultural operations followed during the experiment are presented in Table 1. Healthy seeds of selected rice varieties were cleaned, treated, and raised in well-prepared nursery beds. Seedlings of appropriate age (25-30 days) were carefully uprooted and transplanted into the main field at 20 cm x 10 cm spacing. Standard agronomic practices including weeding, irrigation, and plant protection measures were followed uniformly across all treatments as per recommendations for the region.

**Table 1:** Crop details and experimental parameters

| Parameter             | : | Details                                  |
|-----------------------|---|------------------------------------------|
| Crop                  | : | Rice ( <i>Oryza sativa</i> L.)           |
| Variety               | : | Vishnubhog and Jeeraphool                |
| Year                  | : | 2021-2022 and 2022-2023                  |
| Sowing date           | : | 28 June 2022                             |
| Transplanting         | : | 18 July 2022                             |
| Season                | : | Kharif                                   |
| Design                | : | Factorial Randomized Block Design (FRBD) |
| Replications          | : | 03                                       |
| Treatments            | : | 12 (2 varieties x 6 organic treatments)  |
| Gross plot size       | : | 4.00 m x 3.00 m                          |
| Net plot size         | : | 3.40 m x 2.60 m                          |
| Irrigation            | : | As per requirement                       |
| Seed rate             | : | 25 kg ha <sup>-1</sup>                   |
| Spacing (Row x Plant) | : | 20 cm x 10 cm                            |

### 2.5 Biofertilizer Application

The biofertilizers were obtained from certified microbial culture production units. *Azotobacter chroococcum* (10<sup>8</sup> CFU ml ha<sup>-1</sup>), *Azospirillum brasilense* (10<sup>8</sup> CFU ml ha<sup>-1</sup>), Phosphate Solubilizing Bacteria - *Bacillus megaterium* (10<sup>8</sup> CFU ml ha<sup>-1</sup>), Potassium Solubilizing Bacteria - *Frateuria aurantia* (10<sup>8</sup> CFU ml ha<sup>-1</sup>), and BGA (mixed culture of *Aulosira*, *Anabaena*, and *Tolypothrix*) were applied as per treatment specifications. The biofertilizer consortia contained a balanced mixture of N-fixers, P-solubilizers, and K-mobilizers. FYM was applied as basal 15 days before transplanting and incorporated into the soil. Biofertilizers were applied as soil treatment at the time of transplanting.

### 2.6 Observations Recorded

Morphological observations were recorded at 30, 60, 90 days after transplanting (DAT) and at harvest. The parameters recorded included plant height (cm), number of tillers per square meter, number of effective tillers per square meter, dry matter accumulation (g plant ha<sup>-1</sup>), and crop growth rate (g plant ha<sup>-1</sup> day ha<sup>-1</sup>). Plant height was measured from the ground level to the tip of the tallest leaf using a meter scale. Tillers were counted from randomly selected one-meter row length in each plot and expressed per square meter. Dry matter accumulation was determined by oven-drying plant samples at 65 degrees C to constant weight. Crop growth rate was calculated using the formula:  $CGR = (W_2 - W_1) / (T_2 - T_1)$ , where W1 and W2 are dry weights at times T<sub>1</sub> and T<sub>2</sub> respectively.

### 2.7 Statistical Analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for Factorial Randomized Block Design as described by Gomez and Gomez (1984) [13]. The significance of treatment effects was tested using F-test at 5% probability level. Critical difference (CD) at P=0.05 was calculated for comparing treatment means whenever the treatment effect was found significant. Standard error of mean (SEm±) was also computed for all parameters.

## 3. Results

### 3.1 Plant Height (cm) at 30, 60, 90 DAT and at Harvest

Plant height at different growth stages was significantly influenced by both variety and organic treatments (Table 2). Data analysis revealed significant differences between the two varieties at all growth stages during both years and in the pooled mean.

### 3.1.1 Effect of Variety

Vishnubhog (V1) consistently recorded significantly higher plant height compared to Jeeraphool (V2) across all growth stages. At 30 DAT, Vishnubhog recorded plant heights of 66.77 cm (2021-22), 68.98 cm (2022-23), and a pooled mean of 67.87 cm, while Jeeraphool recorded 49.68 cm, 51.89 cm, and 50.78 cm respectively. The difference between varieties became more pronounced at later growth stages. At 90 DAT, Vishnubhog attained 126.08 cm (2021-22), 128.86 cm (2022-23), and 127.47 cm (pooled), compared to 103.46 cm, 106.24 cm, and 104.85 cm for Jeeraphool. At harvest, the values were 133.45 cm, 136.18 cm, and 134.82 cm for Vishnubhog versus 124.48 cm, 127.22 cm, and 125.85 cm for Jeeraphool.

### 3.1.2 Effect of Organic Treatment

Among organic treatments, T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest plant height at all growth stages and

years, which was statistically at par with T<sub>3</sub> (FYM + BGA + Biofertilizer consortia). At 30 DAT, T<sub>2</sub> recorded 64.94 cm (2021-22), 67.14 cm (2022-23), and 66.04 cm (pooled), while T<sub>3</sub> recorded 61.98 cm, 64.19 cm, and 63.09 cm. The control treatment (T<sub>6</sub>) consistently recorded the lowest plant height: 51.71 cm, 53.92 cm, and 52.81 cm at 30 DAT. At harvest, T<sub>2</sub> recorded 132.14 cm, 134.87 cm, and 133.51 cm, while T<sub>6</sub> recorded 125.22 cm, 127.95 cm, and 126.58 cm.

### 3.1.3 Interaction Effect (V x T)

The interaction effect between variety and organic treatment was non-significant for plant height at most growth stages, except at 90 DAT pooled mean where it was significant. The combination V1T<sub>2</sub> (Vishnubhog with FYM + Azotobacter + PSB + KSB) produced the tallest plants at all stages, recording 72.63 cm, 106.52 cm, 131.99 cm, and 136.43 cm at 30, 60, 90 DAT and harvest respectively during 2021-22.

**Table 2:** Effect of biofertilizers on plant height (cm) at 30, 60, 90 DAT and at harvest of local cultivated varieties of rice

| Treatment                          | 2021-22 30 DAT | 2021-22 60 DAT | 2021-22 90 DAT | 2021-22 Harvest | 2022-23 30 DAT | 2022-23 60 DAT |
|------------------------------------|----------------|----------------|----------------|-----------------|----------------|----------------|
| V1: Vishnubhog                     | 66.77          | 98.57          | 126.08         | 133.45          | 68.98          | 101.15         |
| V2: Jeeraphool                     | 49.68          | 71.23          | 103.46         | 124.48          | 51.89          | 73.81          |
| SEm±                               | 0.62           | 1.34           | 1.36           | 0.93            | 0.65           | 1.33           |
| CD (P=0.05)                        | 1.81           | 3.93           | 3.97           | 2.71            | 1.92           | 3.90           |
| T <sub>2</sub> : FYM+Azoto+PSB+KSB | 64.94          | 96.14          | 124.79         | 132.14          | 67.14          | 98.72          |
| T <sub>3</sub> : FYM+BGA+Consortia | 61.98          | 91.56          | 120.96         | 131.24          | 64.19          | 94.14          |
| T <sub>6</sub> : Control           | 51.71          | 73.38          | 106.31         | 125.22          | 53.92          | 75.96          |
| SEm±                               | 1.07           | 2.32           | 2.35           | 1.60            | 1.13           | 2.30           |
| CD (P=0.05)                        | 3.14           | 6.81           | 6.88           | 4.70            | 3.32           | 6.75           |

**Note:** V x T interaction was non-significant. Complete data available upon request.

### 3.2 Number of Tillers at 30, 60, 90 DAT

The number of tillers per square meter is a critical growth parameter that directly influences the final yield potential of rice. The data presented in Table 3 indicate that both variety and organic treatments exerted significant effects on tiller production at all growth stages.

#### 3.2.1 Effect of Variety

Vishnubhog (V1) produced significantly more tillers than Jeeraphool (V2) at all growth stages. At 30 DAT, Vishnubhog recorded 7.57, 8.65, and 8.11 tillers during 2021-22, 2022-23, and pooled respectively, compared to 5.08, 6.17, and 5.62 for Jeeraphool. The difference widened at 60 DAT, with Vishnubhog recording 17.42, 18.46, and 17.94 tillers versus 15.64, 16.67, and 16.15 for Jeeraphool. At 90 DAT, the corresponding values were 20.21, 20.44, and 20.32 for Vishnubhog compared to 18.19, 18.65, and 18.42 for Jeeraphool.

#### 3.2.2 Effect of Organic Treatment

Treatment T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest number of tillers at all growth stages, which was statistically at par with T<sub>3</sub> (FYM + BGA + Biofertilizer consortia). At 30 DAT, T<sub>2</sub> recorded 7.30, 8.38, and 7.84 tillers, while T<sub>3</sub> recorded 6.91, 8.00, and 7.45. The control (T<sub>6</sub>) recorded the lowest values: 5.34, 7.63, and 7.08 at 30 DAT. At 90 DAT, T<sub>2</sub> maintained its superiority with 20.11, 20.38, and 20.25 tillers compared to 18.20, 18.50, and 18.35 for T<sub>6</sub>.

#### 3.2.3 Interaction Effect (V x T)

The interaction between variety and organic treatment was non-significant for tiller production at all growth stages, indicating that the response to biofertilizer treatments was consistent across both varieties. However, numerically, the combination V1T<sub>2</sub> consistently produced the maximum number of tillers at all stages.

**Table 3:** Effect of biofertilizers on number of tillers at 30, 60, 90 DAT of local cultivated varieties of rice

| Treatment                          | 2021-22 30 DAT | 2021-22 60 DAT | 2021-22 90 DAT | 2022-23 30 DAT | 2022-23 60 DAT | 2022-23 90 DAT |
|------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| V1: Vishnubhog                     | 7.57           | 17.42          | 20.21          | 8.65           | 18.46          | 20.44          |
| V2: Jeeraphool                     | 5.08           | 15.64          | 18.19          | 6.17           | 16.67          | 18.65          |
| SEm±                               | 0.11           | 0.08           | 0.09           | 0.12           | 0.09           | 0.10           |
| CD (P=0.05)                        | 0.31           | 0.25           | 0.28           | 0.35           | 0.27           | 0.30           |
| T <sub>2</sub> : FYM+Azoto+PSB+KSB | 7.30           | 17.39          | 20.11          | 8.38           | 18.34          | 20.38          |
| T <sub>3</sub> : FYM+BGA+Consortia | 6.91           | 17.10          | 19.85          | 8.00           | 18.10          | 20.15          |
| T <sub>6</sub> : Control           | 5.34           | 15.63          | 18.20          | 6.43           | 16.67          | 18.50          |
| SEm±                               | 0.19           | 0.15           | 0.16           | 0.21           | 0.16           | 0.18           |
| CD (P=0.05)                        | 0.54           | 0.43           | 0.48           | 0.61           | 0.47           | 0.52           |

**Note:** V x T interaction was non-significant. Complete data available upon request.

### 3.3 Number of Effective Tillers

Effective tillers, defined as tillers bearing productive panicles, represent the actual yield-contributing component of the rice crop. The data on effective tillers are presented in Table 4.

#### 3.3.1 Effect of Variety

Vishnubhog recorded significantly higher number of effective tillers compared to Jeeraphool across both years. The values were 14.44 (2021-22), 15.51 (2022-23), and 14.97 (pooled) for Vishnubhog versus 11.23, 12.30, and 11.76 for Jeeraphool. The higher effective tiller count in Vishnubhog contributed to its superior yield potential.

#### 3.3.2 Effect of Organic Treatment

Treatment T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest number of effective tillers: 14.52 (2021-22), 15.59 (2022-23), and 15.05 (pooled), which was statistically at par with T<sub>3</sub> (13.66, 14.73, 14.19) and T<sub>5</sub> (13.11, 14.17, 13.64). The control (T<sub>6</sub>) recorded the lowest values: 11.21, 12.29, and 11.75 effective tillers.

#### 3.3.3 Interaction Effect (V x T)

The interaction effect between variety and organic treatment was non-significant for effective tillers, though the combination V1T<sub>2</sub> numerically recorded the highest values (16.41, 17.49, and 16.95 respectively).

**Table 4:** Effect of biofertilizers on number of effective tillers of local cultivated varieties of rice

| Treatment                             | 2021-22 | 2022-23 | Pooled Mean | CD (P=0.05) |
|---------------------------------------|---------|---------|-------------|-------------|
| V1: Vishnubhog                        | 14.44   | 15.51   | 14.97       | 0.73        |
| V2: Jeeraphool                        | 11.23   | 12.30   | 11.76       | -           |
| T <sub>2</sub> : FYM+Azoto+PSB+KSB    | 14.52   | 15.59   | 15.05       | 1.26        |
| T <sub>3</sub> : FYM+BGA+Consortia    | 13.66   | 14.73   | 14.19       | -           |
| T <sub>5</sub> : FYM+BGA+Azospirillum | 13.11   | 14.17   | 13.64       | -           |
| T <sub>6</sub> : Control              | 11.21   | 12.29   | 11.75       | -           |

### 3.4 Dry Matter Accumulation at 30, 60, 90 DAT and at Harvest

Dry matter accumulation (DMA) is an important physiological parameter reflecting the photosynthetic efficiency and overall biomass production capacity of the crop. The DMA data are presented in Table 5.

#### 3.4.1 Effect of Variety

Vishnubhog exhibited significantly higher dry matter accumulation than Jeeraphool at all growth stages. At 30 DAT, DMA values for Vishnubhog were 7.50 g (2021-22), 8.28 g (2022-23), and 7.89 g (pooled), compared to 5.07 g, 5.88 g, and 5.48 g for Jeeraphool. At harvest, the values were 41.94 g, 43.82 g, and 42.88 g for Vishnubhog versus 35.83 g, 37.70 g, and 36.76 g for Jeeraphool.

#### 3.4.2 Effect of Organic Treatment

Treatment T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest DMA at all growth stages, which was statistically at par with T<sub>3</sub> (FYM + BGA + Biofertilizer consortia) and T<sub>5</sub> (FYM + BGA + Azospirillum). At 30 DAT, T<sub>2</sub> recorded 7.13 g, 7.88 g, and 7.50 g, while the control (T<sub>6</sub>) recorded 5.34 g, 6.15 g, and 5.75 g. At harvest, T<sub>2</sub> recorded 41.51 g, 43.39 g, and 42.45 g, compared to 36.35 g, 38.22 g, and 37.29 g for T<sub>6</sub>.

#### 3.4.3 Interaction Effect (V x T)

The interaction effect was non-significant for DMA at most growth stages, except at 90 DAT (2021-22) where it was significant. The combination V1T<sub>2</sub> consistently produced the highest DMA values across all stages.

**Table 5:** Effect of biofertilizers on dry matter accumulation (g plant ha<sup>-1</sup>) at 30, 60, 90 DAT and at harvest of local cultivated varieties of rice

| Treatment                          | 2021-22 30 DAT | 2021-22 60 DAT | 2021-22 90 DAT | 2021-22 Harvest | 2022-23 30 DAT | 2022-23 60 DAT |
|------------------------------------|----------------|----------------|----------------|-----------------|----------------|----------------|
| V1: Vishnubhog                     | 7.50           | 16.05          | 26.15          | 41.94           | 8.28           | 17.12          |
| V2: Jeeraphool                     | 5.07           | 13.61          | 21.97          | 35.83           | 5.88           | 14.69          |
| SEm±                               | 0.14           | 0.29           | 0.49           | 0.41            | 0.12           | 0.29           |
| CD (P=0.05)                        | 0.41           | 0.86           | 1.43           | 1.20            | 0.36           | 0.86           |
| T <sub>2</sub> : FYM+Azoto+PSB+KSB | 7.13           | 15.94          | 25.78          | 41.51           | 7.88           | 16.98          |
| T <sub>3</sub> : FYM+BGA+Consortia | 6.79           | 15.63          | 25.27          | 40.22           | 7.60           | 16.72          |
| T <sub>6</sub> : Control           | 5.34           | 13.78          | 22.20          | 36.35           | 6.15           | 14.86          |
| SEm±                               | 0.24           | 0.51           | 0.84           | 0.71            | 0.21           | 0.51           |
| CD (P=0.05)                        | 0.71           | 1.49           | 2.47           | 2.08            | 0.62           | 1.48           |

**Note:** V x T interaction non-significant except at 90 DAT (2021-22). Complete data available upon request.

### 3.5 Crop Growth Rate (CGR) at 0-30, 30-60, 60-90 DAT and 90-Harvest

Crop growth rate represents the rate of biomass accumulation per unit time and is a key indicator of crop vigor and productivity. The CGR data are presented in Table 6.

#### 3.5.1 Effect of Variety

Vishnubhog exhibited higher CGR than Jeeraphool at most growth intervals. At 0-30 DAT, CGR values for Vishnubhog were 0.25, 0.28, and 0.26 g plant ha<sup>-1</sup> day ha<sup>-1</sup> (2021-22, 2022-23, pooled), compared to 0.17, 0.20, and 0.18 for Jeeraphool. At 60-90 DAT, the values were 0.34, 0.37, and 0.35 for Vishnubhog versus 0.28, 0.31, and 0.29 for Jeeraphool. At 90-

harvest, CGR values were 0.53, 0.52, and 0.52 for Vishnubhog compared to 0.46, 0.46, and 0.46 for Jeeraphool.

#### 3.5.2 Effect of Organic Treatment

Treatment T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) recorded the highest CGR across all growth intervals, followed closely by T<sub>3</sub>. At 0-30 DAT, T<sub>2</sub> recorded 0.24, 0.26, and 0.25 g plant ha<sup>-1</sup> day ha<sup>-1</sup>, while T<sub>6</sub> (control) recorded 0.18, 0.21, and 0.19. At the 90-harvest stage, T<sub>2</sub> recorded 0.52, 0.52, and 0.52 compared to 0.47, 0.47, and 0.47 for T<sub>6</sub>.

#### 3.5.3 Interaction Effect (V x T)

The interaction between variety and organic treatment was non-

significant for CGR at all growth intervals, though V1T<sub>2</sub> consistently produced the highest values, particularly at 90-

harvest where it recorded 0.54-0.55 g plant ha<sup>-1</sup> day ha<sup>-1</sup>.

**Table 6:** Effect of biofertilizers on crop growth rate (CGR) (g plant ha<sup>-1</sup> day ha<sup>-1</sup>) at different growth intervals of local cultivated varieties of rice

| Treatment                          | 2021-22 0-30 | 2021-22 30-60 | 2021-22 60-90 | 2021-22 90-Harv | 2022-23 0-30 | 2022-23 30-60 |
|------------------------------------|--------------|---------------|---------------|-----------------|--------------|---------------|
| V1: Vishnubhog                     | 0.25         | 0.28          | 0.34          | 0.53            | 0.28         | 0.29          |
| V2: Jeeraphool                     | 0.17         | 0.28          | 0.28          | 0.46            | 0.20         | 0.29          |
| SEm±                               | 0.005        | 0.006         | 0.009         | 0.008           | 0.004        | 0.007         |
| CD (P=0.05)                        | 0.014        | NS            | 0.027         | 0.023           | 0.012        | NS            |
| T <sub>2</sub> : FYM+Azoto+PSB+KSB | 0.24         | 0.29          | 0.33          | 0.52            | 0.26         | 0.30          |
| T <sub>3</sub> : FYM+BGA+Consortia | 0.23         | 0.29          | 0.32          | 0.50            | 0.25         | 0.30          |
| T <sub>6</sub> : Control           | 0.18         | 0.28          | 0.28          | 0.47            | 0.21         | 0.29          |
| SEm±                               | 0.008        | 0.011         | 0.016         | 0.014           | 0.007        | 0.012         |
| CD (P=0.05)                        | 0.024        | NS            | NS            | NS              | 0.021        | NS            |

**Note:** CGR = Crop Growth Rate (g plant ha<sup>-1</sup> day ha<sup>-1</sup>). V x T interaction non-significant.

#### 4. Discussion

The present investigation was undertaken to evaluate the effect of integrated biofertilizer application on morphological attributes of two local rice varieties, Vishnubhog and Jeeraphool, under the agro-climatic conditions of Gaurela-Pendra-Marwahi district, Chhattisgarh. The results clearly demonstrate that both variety and organic treatments significantly influenced all morphological parameters studied, while their interaction was largely non-significant.

##### 4.1 Plant Height

The significant variation in plant height between Vishnubhog and Jeeraphool can be attributed to their inherent genetic differences. Vishnubhog, being a relatively taller variety, possesses greater internodal elongation capacity and more efficient nutrient translocation mechanisms. These findings are consistent with those of Bera *et al.* (2024) [5], who reported that plant height is a genetically controlled trait influenced by the variety's capacity for cell division and elongation. The taller stature of Vishnubhog (134.82 cm at harvest) compared to Jeeraphool (125.85 cm) reflects the former's superior vegetative vigor and biomass production potential.

The significant enhancement of plant height under T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) and T<sub>3</sub> (FYM + BGA + Biofertilizer consortia) treatments can be attributed to the synergistic action of multiple plant growth-promoting microorganisms. Azotobacter produces phytohormones including IAA, gibberellins, and cytokinins that stimulate cell division and elongation (Wani *et al.* 2016; Upadhyay *et al.* 2015) [37, 35]. The combined application of PSB and KSB ensures adequate phosphorus and potassium availability, which are essential for energy metabolism, protein synthesis, and osmotic regulation in plant cells (Tang *et al.* 2025; Muthuraja *et al.* 2024) [33, 22]. Similar results were reported by Mondal *et al.* (2015) [21], who observed that integrated nutrient management with biofertilizers significantly increased plant height of hybrid rice compared to control treatments.

##### 4.2 Tillering Behavior

Tiller production is a crucial determinant of rice yield potential, as it establishes the foundation for panicle number and ultimately grain yield. The superior tiller production in Vishnubhog compared to Jeeraphool can be attributed to genetic differences in tillering potential and nutrient use efficiency. These findings align with those of Tripathi *et al.* (2025) [34], who reported significant varietal differences in tiller production among rice cultivars.

The significantly higher number of tillers under T<sub>2</sub> treatment can

be explained by the multi-mechanism growth promotion exerted by the microbial consortium. Azotobacter fixes atmospheric nitrogen and produces growth hormones that stimulate axillary bud development (Chennappa *et al.* 2016) [8]. PSB solubilizes insoluble phosphorus, making it available for ATP synthesis and energy transfer processes critical for tiller initiation (Tripathi *et al.* 2025) [34]. KSB mobilizes potassium, which regulates enzyme activation, protein synthesis, and photosynthate translocation to developing tillers (Saha *et al.* 2024) [28]. The cumulative effect of these mechanisms resulted in 10.8% higher tillers at 90 DAT in T<sub>2</sub> compared to control.

The non-significant interaction between variety and treatment for tillering indicates that both varieties responded similarly to biofertilizer application, suggesting that the beneficial effects of the microbial consortium are consistent across different genetic backgrounds. This is particularly important for recommending integrated nutrient management practices for diverse rice varieties in the region.

##### 4.3 Effective Tillers and Yield Components

The number of effective tillers directly correlates with grain yield potential, as each productive tiller contributes a panicle to the final harvest. The superiority of Vishnubhog in producing effective tillers reflects its better sink capacity and nutrient partitioning efficiency. Among treatments, T<sub>2</sub> recorded 28.1% more effective tillers than the control, which can be attributed to the improved nitrogen, phosphorus, and potassium nutrition provided by the microbial consortium.

The findings corroborate those of Sharma *et al.* (2025) [30], who reported that integrated nutrient management with biofertilizers significantly increased productive tillers in rice. The enhanced availability of nutrients through microbial solubilization and mineralization processes likely reduced tiller mortality during the transition from vegetative to reproductive phase, resulting in higher retention of productive tillers.

##### 4.4 Dry Matter Accumulation and Crop Growth Rate

Dry matter accumulation is a cumulative measure of photosynthetic efficiency and represents the total biomass produced by the crop. The significantly higher DMA in Vishnubhog reflects its greater leaf area, higher photosynthetic rate, and more efficient source-sink relationship. The treatment effects on DMA were more pronounced at later growth stages, indicating that sustained nutrient availability through biofertilizer action is critical during the grain-filling period.

The superior performance of T<sub>2</sub> in terms of DMA and CGR can be attributed to the complementary action of N-fixation, P-solubilization, and K-mobilization. Azotobacter ensures

continuous nitrogen supply for chlorophyll synthesis and photosynthetic machinery maintenance (Upadhyay *et al.* 2015)<sup>[35]</sup>. PSB enhances phosphorus availability for ATP synthesis and Calvin cycle operations (Rasul *et al.* 2024)<sup>[26]</sup>. KSB improves potassium nutrition, which is essential for stomatal regulation, enzyme activation, and photosynthate translocation (Muthuraja *et al.* 2024)<sup>[22]</sup>. The combined effect of these mechanisms resulted in 13.8% higher DMA at harvest in T<sub>2</sub> compared to control.

The crop growth rate data revealed that the maximum growth rate occurred during the 90-harvest interval, coinciding with the grain-filling period. This observation is consistent with the findings of Tripathi *et al.* (2025)<sup>[34]</sup>, who reported that CGR peaks during the reproductive phase when photosynthate demand is highest. The maintenance of higher CGR under biofertilizer treatments during this critical period ensures adequate assimilate supply for grain development, ultimately contributing to higher grain yield.

#### 4.5 Comparative Efficacy of Biofertilizer Treatments

Among the six organic treatments evaluated, T<sub>2</sub> (FYM + Azotobacter + PSB + KSB) and T<sub>3</sub> (FYM + BGA + Biofertilizer consortia) emerged as the most effective treatments, recording statistically comparable values for all parameters. The superiority of T<sub>2</sub> can be attributed to the multi-strain microbial consortium that addresses all three major nutrient requirements (N, P, K) simultaneously. The functional compatibility between Azotobacter, PSB, and KSB creates a synergistic microenvironment in the rhizosphere that enhances overall nutrient availability and uptake.

T<sub>3</sub>, containing BGA and biofertilizer consortia, also performed exceptionally well. BGA contributes through atmospheric nitrogen fixation (25-30 kg N ha<sup>-1</sup>), production of growth-promoting substances, and improvement of soil physical properties (Venkataraman, 1981; Bhuvaneshwari & Singh, 2015)<sup>[36, 7]</sup>. The biofertilizer consortia in T<sub>3</sub> likely contained compatible strains of N-fixers, P-solubilizers, and K-mobilizers that complemented the BGA action. These findings support the observations of Singh and Singh (1986)<sup>[31]</sup> and Adhikari *et al.* (2020)<sup>[1]</sup> regarding the beneficial effects of BGA integration in rice cultivation systems.

T<sub>4</sub> (FYM + Azospirillum) and T<sub>5</sub> (FYM + BGA + Azospirillum) recorded intermediate values, reflecting the growth-promoting effects of Azospirillum through nitrogen fixation and phytohormone production (Preeprem *et al.* 2019)<sup>[25]</sup>. However, the absence of PSB and KSB in these treatments limited their effectiveness compared to T<sub>2</sub> and T<sub>3</sub>. T<sub>1</sub> (FYM + BGA) recorded lower values than T<sub>2</sub> and T<sub>3</sub>, suggesting that while BGA alone provides nitrogen benefits, the integrated supply of all major nutrients through multiple microbial agents is more effective.

#### 4.6 Regional Relevance and Practical Implications

The findings of this study hold significant practical relevance for the tribal-dominated Gaurela-Pendra-Marwahi region, where chemical fertilizer use is limited due to economic constraints and transportation difficulties. The demonstrated efficacy of biofertilizer-based nutrient management offers a low-cost, environmentally sustainable alternative that can be readily adopted by resource-poor farmers. The use of locally available FYM combined with commercial biofertilizer formulations represents a practical approach that aligns with traditional farming practices while incorporating scientific nutrient management principles.

The non-significant interaction between variety and treatment

suggests that the recommended biofertilizer combinations can be confidently applied to different local rice varieties without genotype-specific adjustments. This simplifies extension recommendations and facilitates large-scale adoption. The 20-30% improvement in morphological parameters observed under optimal biofertilizer treatments can translate to proportionate yield gains, significantly enhancing food security and livelihoods in the region.

Furthermore, the adoption of biofertilizer-based integrated nutrient management contributes to soil health improvement through enhanced microbial diversity, increased organic matter content, and better soil structure. These benefits are cumulative and long-lasting, supporting the sustainability of rice-based cropping systems in the region. The findings support the national mandate for reducing chemical fertilizer dependency and promoting organic farming under programs such as Paramparagat Krishi Vikas Yojana (PKVY) and Mission Organic Value Chain Development.

#### 5. Conclusion

The present investigation conclusively demonstrates that integrated application of biofertilizers significantly enhances morphological development, grain quality, and yield potential of local rice varieties Vishnubhog and Jeeraphool cultivated in the Gaurela-Pendra-Marwahi district of Chhattisgarh. The key findings are summarized as follows:

1. Vishnubhog significantly outperformed Jeeraphool across all morphological parameters including plant height (134.82 vs. 125.85 cm at harvest), number of tillers (20.32 vs. 18.42 at 90 DAT), effective tillers (14.97 vs. 11.76), dry matter accumulation (42.88 vs. 36.76 g plant ha<sup>-1</sup> at harvest), and crop growth rate (0.52 vs. 0.46 g plant ha<sup>-1</sup> day ha<sup>-1</sup> at 90-harvest), reflecting its superior genetic potential for vegetative growth and biomass production.
2. Among organic treatments, T<sub>2</sub> (FYM @ 10 t ha ha<sup>-1</sup> + Azotobacter @ 1250 ml ha ha<sup>-1</sup> + PSB @ 1250 ml ha ha<sup>-1</sup> + KSB @ 1250 ml ha ha<sup>-1</sup>) recorded the highest values for all parameters, which was statistically at par with T<sub>3</sub> (FYM @ 10 t ha ha<sup>-1</sup> + BGA @ 1250 ml ha ha<sup>-1</sup> + Biofertilizer consortia @ 1250 ml ha ha<sup>-1</sup>). The superiority of T<sub>2</sub> can be attributed to the synergistic action of nitrogen fixation, phosphate solubilization, and potassium mobilization by the microbial consortium.
3. The control treatment (T<sub>6</sub>) consistently recorded the lowest values for all parameters, emphasizing the importance of external nutrient supplementation for realizing the yield potential of local rice varieties in the relatively nutrient-poor soils of the region.
4. The interaction effect between variety and organic treatment was non-significant for most parameters, indicating that biofertilizer treatments performed consistently across both varieties and can be recommended for diverse rice cultivars in the region.

Based on these findings, it is recommended that farmers in the Gaurela-Pendra-Marwahi region adopt integrated biofertilizer application, particularly T<sub>2</sub> or T<sub>3</sub>, for enhancing productivity of local rice varieties in a sustainable and economically viable manner. Future research should focus on multi-location validation, economic analysis, and long-term effects on soil health and biodiversity.

#### Acknowledgments

The authors are grateful to the authorities of Govt. D.B. Girls

P.G. College, Raipur, and Pandit Ravishankar Shukla University, Raipur, for providing necessary facilities and support to conduct this research. Sincere thanks are extended to the Department of Agronomy, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, for technical guidance and laboratory support throughout the investigation. The authors also acknowledge the cooperation of local farmers at Village Parasi, Block Marwahi, District Gaurela-Pendra-Marwahi, for providing their experimental fields and valuable traditional knowledge about local rice varieties.

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