

Growth and Yield Response of Superior Rice Varieties under Different Biofertilizer Rates in Lowland Rice Fields

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Abstract

Efforts to increase rice productivity through a sustainable and environmentally friendly approach are using biofertilizers. The biofertilizer contains beneficial microorganisms that play an essential role in promoting plant growth and increasing rice yield. This study aimed to investigate the potential of biofertilizers and evaluate the performance of superior rice varieties by applying several rates of biofertilizers in lowland rice fields for enhancing growth and yield. A split-plot design was laid out using a randomized complete block design with three replications. The main plot consisted of superior rice varieties, including "Inpari 30", "Inpari 32", "Inpari 36", and "Inpari 42", while the subplot involved biofertilizer rates of 0, 400, and 800 g.ha⁻¹. The utilization of biofertilizer contributed to the improvement of seedling height and root length. Applying biofertilizer increased plant height, panicle length, the number of grains per panicle, the number of filled grains per panicle, and the percentage of filled grains, while decreasing the number of unfilled grains per panicle. The application of biofertilizer at a rate of 400 g.ha⁻¹ significantly improved grain yields for "Inpari 30", "Inpari 32", and "Inpari 36". However, "Inpari 42" required a higher biofertilizer rate of 800 g.ha⁻¹ to produce high grain yields. The grain yield of superior rice varieties increased by 10%-21.6% with the application of biofertilizer. The findings of this study may provide recommendations for applying biofertilizers to enhance grain yields of several superior rice varieties in specific lowland rice field agroecosystems.

Keywords: beneficial microorganisms, grain yields, "Inpari 42", panicle length, plant height

Introduction

Rice is the most important staple crop, supporting millions of people in Indonesia. Its vital role in food security and nutrition underscores the importance of optimizing rice cultivation methods. However, the cultivation of this essential grain often relies on conventional farming practices that can be resource-intensive and environmentally detrimental. As a strategic food crop commodity in Indonesia, the government continues to increase rice production and productivity to meet domestic needs, which aligns with the country's growing population. However, it remains unable to meet the domestic rice market's needs. One strategy to increase national rice productivity is through intensification and extensification (expanding rice planting areas). Increasing rice production through extensification is quite challenging to achieve in the short term, and this is also hindered by the rapid growth of residential areas. Agricultural intensification is one method that can be chosen. One aspect of concern in intensification is optimizing superior rice varieties by applying biofertilizers, thereby enhancing rice productivity. Biofertilizers are diverse products containing living or dormant microorganisms, including bacteria, fungi, and other beneficial microorganisms (Choudhary and Yadav, 2021). The microorganisms in the biofertilizer increase the availability of nutrients through natural processes, including phosphorus, potassium, and zinc solubilization, nitrogen fixation, secretion of phytohormones, various hydrolytic enzymes, and safeguarding plants against harmful pathogens and stress conditions (Seenivasagan and Babalola, 2021; Chaudhary et al., 2022). In the face of mounting agricultural challenges, biofertilizers have emerged as a beacon of hope for rice cultivation, offering sustainable and eco-friendly alternatives to traditional fertilizer methods.

The cultivation of rice crops is particularly demanding in terms of nutrients, especially nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and other essential nutrients. Traditional approaches to meet these nutrient needs have often relied on chemical fertilizers, which can lead to soil degradation, water pollution, and increased greenhouse gas emissions (Sembiring et al., 2021). In contrast, biofertilizers tailored for rice crops harness the power of beneficial microorganisms to enhance nutrient availability, improve soil health, and promote sustainable rice cultivation (Jirakkakul et al., 2023). In the quest for enhanced rice production, biofertilizers have emerged as a transformative tool, offering sustainable and eco-friendly solutions to address the unique nutrient requirements of rice crops. Biofertilizer positively affects crop production by conserving soil health and building soil fertility, as it does not contain any chemicals detrimental to the living soil (Sarker et al., 2018; O'Callaghan et al., 2022). Microbial biofertilizers are essential in maintaining soil fertility by improving soil particles and structure (Rashid et al., 2016). Furthermore, biofertilizers can maintain the balance and sustainability of agricultural land ecosystems; hence, agricultural land can be used sustainably to produce safe and healthy food for public health (Martínez-Alcántara et al., 2016).

The biofertilizers provide nutrients in sufficient amounts for healthy plant growth and development, are eco-friendly, non-toxic, and renewable sources of crop nutrients, and reduce production costs (Nosheen et al., 2021; Chaudhary et al., 2022). The potential of biofertilizers in enhancing crop growth and yield, while reducing the need for chemical fertilizers, has been reported by many researchers (Roy and Srivastava, 2011; Moe et al., 2019). It is confirmed that biofertilizers could overcome agricultural production issues due to their ability to cater to the appropriate nutrients required by crops without side effects on the environment and increasing harvest yield (Moreno et al., 2017). Biofertilizer possesses specific characteristics, including facilitating the absorption of nutrients by plants, reducing the risk of nutrient loss, and the presence of microorganisms, which provide the necessary nutrients for rapid plant growth (Jones et al., 2013). According to Schütz et al. (2018), the inoculation of biofertilizers could increase yield by 16.2% compared to the control.

Superior rice varieties, often characterized by their increased yield potential, disease resistance, and higher nutritional content, require a higher level of nutrient support. In the pursuit of feeding an ever-growing global population and ensuring food security,

developing superior rice varieties has been a key focus of agricultural innovation. These high-yielding rice strains promise increased productivity and enhanced nutritional value (Purwanto et al., 2020). However, to achieve its full potential, it is essential to adopt sustainable and environmentally friendly approaches to nourish these exceptional rice crops. This is where biofertilizers step in as a transformative solution. Traditionally, these needs have been met through synthetic fertilizers, which, over time, can deplete soil fertility and harm the ecosystem. Biofertilizers, tailored explicitly for superior rice varieties, harness the power of beneficial microorganisms to provide essential nutrients while safeguarding soil health and minimizing ecological impact. The Indonesian Agency for Agricultural Research and Development (IAARD) has found Agrimeth biofertilizers through the National Leading Biofertilizer Consortium. This biofertilizer contained several beneficial microorganisms for crops, i.e., *Bradyrhizobium japonicum*, *Rhizobium japonicum*, *Azotobacter* sp., *Bacillus* sp., and *Methylobacterium* sp. packaged in a powder carrier (Purwani et al., 2018; Ikhwan et al., 2022). However, the required levels of biofertilizers and their ability to improve rice production, incorporated with a superior rice variety in the lowland agroecosystem, need further exploration. Therefore, the study was undertaken to investigate the potential of biofertilizers for increasing rice grain yield in lowland rice fields and to evaluate the response and performance of selected superior rice varieties to the application of biofertilizers.

Materials and Methods

Study Site and Climate Conditions

The study was conducted on farmers' lowland rice fields in Binuang District, Polewali Mandar Regency, West Sulawesi Province, Indonesia, during the dry season from June to September 2019. The experimental field was at an altitude of ± 14 m above sea level. Based on the climate data from the Meteorological, Climatological, and Geophysical Agency Station, the annual rainfall at the study site in 2019 was 1,241 mm, corresponding to 122 rainy days. During the study period, the average monthly rainfall and number of rainy days were 63.5 mm and seven days, respectively. The dry season lasted three months, from July to September 2019, with an average monthly rainfall of <100 mm. The lowest rainfall recorded during the growing season was 14 mm in July 2019. Rainfall and rainy days during the growing season in 2019 are presented in Figure 1.

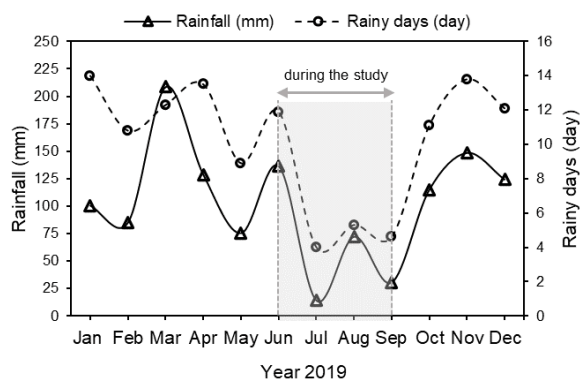


Figure 1. Rainfall and rainy days at the study site.

Experimental Design and Field Preparation

A split-plot design was arranged in a randomized complete block design with three replications. The main plot consisted of four superior rice varieties: “Inpari 30”, “Inpari 32”, “Inpari 36”, and “Inpari 42”. The subplot consisted of biofertilizer application at three rate levels: 0 (without biofertilizer), 400 g.ha⁻¹, and 800 g.ha⁻¹. Agrimeth biofertilizer was used in this experiment. The number of experimental units was 36 plots.

Land preparation and tillage were done before planting. The land was plowed first by using a tractor. Next, the land is harrowed and leveled. Every time it was plowed, the land was flooded and left temporarily. The process lasted for approximately one week.

The seeds were soaked for approximately 24 hours and then drained. One hectare of rice field requires around 25 kg of seeds (Yuliyasari et al., 2023). Biofertilizer was applied thoroughly as a seed treatment before sowing, according to the procedure outlined by Husnain et al. (2016). Nurseries are prepared with a 5 m x 1.5 m size for each plot. The 21 day old seedlings were transplanted to the rice field. Three seedlings were planted per hill using the square planting system (tile) with a spacing of 25 cm x 25 cm, resulting in a plant density of approximately 160,000 plants.ha⁻¹. The inorganic fertilizer was applied at a dose of urea 150 kg.ha⁻¹ and NPK Phonska 300 kg.ha⁻¹ at 11 and 36 days after transplanting (DAT), with a rate of each application equal to half of the total dose for the growing season. All plots were maintained under non-water-limiting conditions (flood-irrigated) and protected from weeds, pests, and diseases throughout the plot. The irrigation water was drained out from the plots 15 days before harvesting.

Data Collection and Statistical Analysis

In the nursery, the seedlings were randomly

measured for plant height once a week until they were transplanted into the field. The roots of the seedlings were carefully cleaned with water, and their lengths were recorded. When harvesting, five rice hills were randomly selected from each plot to measure the morphological traits (plant height and number of tillers), yield components (number of productive tillers, panicle length, panicle density, number of filled grains per panicle, number of unfilled grains per panicle, total number of grains per panicle (filled + unfilled grains), percentage of filled grains, and 1000 grain weight), and grain yield per hectare. The crop cut sample was harvested in each plot, measuring 6.25 m² (2.5 m x 2.5 m). Grains were separated from the straw, cleaned, and sun-dried until the moisture content reached ±14%. Finally, grain yield was weighed and converted to units per hectare.

The recorded data were analyzed statistically using analysis of variance (ANOVA) at a significance level of p<0.05. Trait means were compared using Fisher’s Least Significant Difference (LSD) test at the 5% level. The association between morpho-agronomic traits was estimated using Pearson’s correlation analysis at a significance level of p<0.05. All statistical analyses were processed using the R program version 4.3.1 (<http://www.r-project.org/>) and RStudio version 2023.06.0+421 (<https://posit.co/>).

Results and Discussion

Morphological Traits of Rice Seedlings

The initial stage of plant growth, during the seedling phase, is critical when rice seedlings are planted in the rice field. The biofertilizer application did not significantly affect rice seedling height seven days after sowing (DAS). However, at 14 and 21 DAS, the plant height of rice seedlings significantly increased with biofertilizer (Figure 2). The response of seedling height at 7 DAS was not significantly different among all treatments (0, 400, and 800 g.ha⁻¹), with the mean seedling height ranging from 12.47 cm to 13.43 cm. The seedling’s heights at 14 and 21 DAS showed a similar pattern. The seedling’s height at a rate of 400 g.ha⁻¹ was higher than without biofertilizer (control), but was not significantly different at a rate of 800 g.ha⁻¹. This indicated that the demand for biofertilizer was relatively high at the seedling stage, resulting in a continuous increase in seedling height with increasing biofertilizer doses. Applying biofertilizer at a rate of 400 g.ha⁻¹ could increase the seedlings’ height at 14 and 21 DAS by 7.9% and 5.9%, respectively. The increase in seedling height growth may be attributed to the activity of rhizobacteria, such as *Methylobacterium* sp., in this biofertilizer. *Methylobacterium* sp. is

typically found in the phyllosphere; however, several other species have been isolated from roots, shoots, seeds, and seedlings (Jorge et al., 2019; Jirakkakul et al., 2023). Their role has been reported to be plant growth-promoting (Grossi et al., 2020).

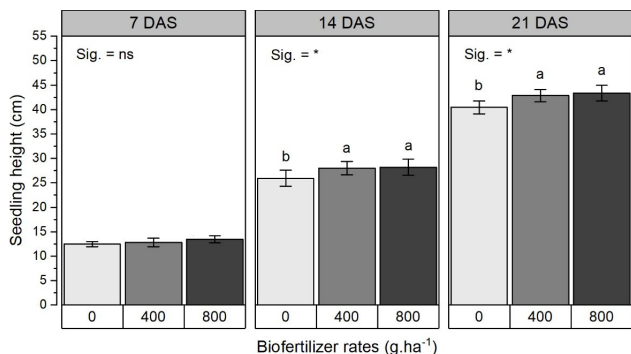


Figure 2. Rice seedlings' height at 7–21 days after sowing at several rates of biofertilizer. Mean values above the bar followed by the same letters are not significantly different, according to Fisher's LSD test at the 5% level.

The seedling's root length was significantly affected by applying biofertilizer at 21 DAS (Figure 3). The highest root growth of rice seedlings was found at a biofertilizer rate of 800 g.ha⁻¹. At this rate, the seedlings had the longest roots compared to other treatments. The application of biofertilizer at a rate of 800 g.ha⁻¹ increased the root length of seedlings by 14.8%. Meanwhile, a biofertilizer rate of 400 g.ha⁻¹ did not increase the root length of the seedlings. There was no significant difference between the application of 400 g.ha⁻¹ biofertilizer and without biofertilizer (control).

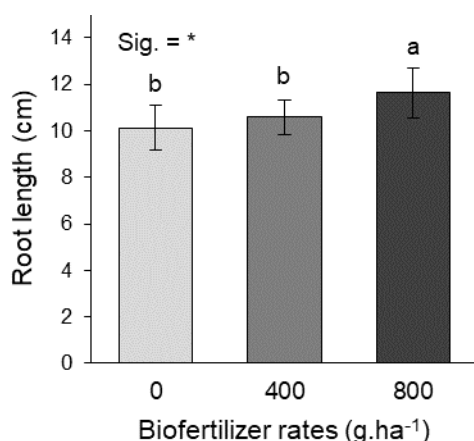


Figure 3. Root length of rice seedling at 21 days after sowing under different rates of biofertilizer. Mean values above the bar followed by the same letters are not significantly different, according to Fisher's LSD test at the 5% level.

Roots had an essential role in uptaking nutrients for the plant. The demand for nutrients such as N is needed at the early growth stage of rice crops, but the plant roots are too small (Liu et al., 2016). Microorganisms in biofertilizers play an important role in providing essential nutrients for the growth of rice seedling roots. Microorganisms in biofertilizers accelerate the decomposition of organic matter in the soil and release nutrients in a form that is readily available to plant roots (Cai et al., 2014). The use of biofertilizers helps minimize nutrient loss. According to Samijan et al. (2023), the Agrimeth biofertilizer increased the population of nitrogen-fixing and phosphate-solubilizing bacteria. Biofertilizers based on microbial strains that exert phosphate-solubilizing activity and possess the ability to fix nitrogen are promising approaches to increasing phosphorus and nitrogen availability in soil (Barea, 2015). The role of microorganisms in biofertilizers, such as *Bacillus* sp. and *Azotobacter* sp., is to mobilize essential nutritional elements from unusable forms to usable forms (Singh et al., 2015). The nutrients released have a positive effect on other microorganisms and soil bacteria, thereby increasing plant nutrient uptake (Molla et al., 2012). This biofertilizer inoculation ultimately increases shoot and root growth (Rodríguez and Fraga, 1999). The plant with an extensive root system may have resulted in favorable nutrient uptake, supporting various molecular responses to biofertilizer, which ultimately led to enhanced plant growth and grain yield.

Plant Growth

Optimal rice growth is determined by better morphological traits, such as plant height and the number of tillers. Based on the analysis of variance, the average plant height did not show any significant differences among cultivars tested at the tillering stage. Furthermore, the different cultivars did not have different numbers of tillers per hill in this study. The average plant height significantly differed at the harvesting stage. The highest plant height was found in "Inpari 32" (111.73 cm), followed by "Inpari 30" (103.31 cm) and "Inpari 36" (100.53 cm). The "Inpari 42" tended to have a lower average plant height than other cultivars. The average plant height of the "Inpari 42" variety was 98.58 cm, which is 13% lower than that of the "Inpari 32" variety (Table 1). This suggests that plant height is primarily determined by genetic factors, as reported by numerous researchers (Anwar et al., 2010; Sarker et al., 2018).

The biofertilizer significantly affected plant height at the harvesting stage, but didn't affect tillering at the same stage (Table 1). A significant increase in plant height was observed when biofertilizer was applied

at a rate of 800 g.ha⁻¹. The plant height increased by 2.9% with this rate of biofertilizer compared to without biofertilizer. This result was not significantly different from the biofertilizer application at a rate of 400 g.ha⁻¹. Meanwhile, biofertilizer treatment did not influence the number of tillers per hill. Application of biofertilizer up to 800 g.ha⁻¹ did not show a significant difference in the number of tillers per hill. Apart from that, there was no interaction effect between cultivar and biofertilizer on plant height and number of tillers per hill. According to Khan (2018), the highest plant height was found in rice crops inoculated with microorganisms as biofertilizers. Symbiotic microorganisms in biofertilizers help improve nutrition and rice growth (Oladele and Awodun, 2014). The biofertilizers contain *Bacillus* sp., *Methylobacterium* sp., *Azotobacter* sp., *Rhizobium* sp., and *Bradyrhizobium* sp., known as plant growth-promoting rhizobacteria (PGPR) that can produce phytohormones (Shahwar et al., 2023). Plant hormones play a crucial role in plant growth and development, being secreted by plants and microorganisms (Sokolova et al., 2011). These bacteria stimulate plant growth through both indirect and direct mechanisms, including providing plants with specific compounds, water, and nutrients, as well as protecting them against harmful pests and diseases (O’Callaghan et al., 2022). The mechanisms directly acquire N, P, K, S, and other essential nutrients and operate indirectly by reducing the inhibitory impact of various pathogens on crop growth and development, functioning as biocontrol agents (Olanrewaju et al., 2017). The mechanisms responsible for these beneficial effects vary significantly, and a single microorganism

can utilize multiple mechanisms to promote plant growth. Moreover, they can also synthesize growth substances such as indole acetic acid (IAA), gibberellins, cytokinin, and other phytohormones (Hussain and Hasnain, 2009; Al Ali et al., 2021; Shahwar et al., 2023), which help enhance plant height (Singh et al., 2015).

Yield Components

Yield components, such as the number of productive tillers, panicle length, panicle density, total number of grains (filled grains plus unfilled grains), and 1000 grain weight, are important characters that are directly or indirectly related to grain yield. These characters usually tend to vary among cultivars. The genetic factors of individual crops can determine this, and environmental factors also influence them. Additionally, environmental conditions will impact the response of several yield components, including the use of biofertilizers. The response of yield components to biofertilizer can be different for each character. Based on the analysis of variance, the cultivars used were significantly different in all rice yield components. At the same time, the biofertilizer treatment affected several traits, including panicle length, total number of grains per panicle, number of filled grains per panicle, number of unfilled grains per panicle, and percentage of filled grains. The effect of the interaction between cultivar and biofertilizer was only observed in the characters of the number of unfilled grains per hill and the percentage of filled grains. At the same time, there is no interaction on the character of other yield components (Table 2).

Table 1. Effect of cultivar and biofertilizer treatment on the plant height and tiller number

Treatment	Plant height (cm)		Number of tillers per hill
	Tillering	Harvesting	
Cultivar			
“Inpari 30”	70.78	103.31 ^b	24.16
“Inpari 32”	71.78	111.73 ^a	27.58
“Inpari 36”	74.78	100.53 ^{bc}	25.33
“Inpari 42”	66.89	98.58 ^c	29.27
Biofertilizer (g.ha⁻¹)			
0	70.40	101.95 ^b	27.23
400	71.45	103.75 ^{ab}	26.12
800	71.32	104.92 ^a	26.40
Cultivar (V)	ns	**	ns
Biofertilizer (B)	ns	*	ns
V × B	ns	ns	ns

Note: Mean values within a column followed by the same letters are not significantly different according to Fisher’s LSD test at the 5% level. **: p<0.01, *: p<0.05, ns: not significant.

The number of productive tillers per hill was significantly different among cultivars but not among biofertilizer applications. The same response was found in panicle density and 1000 grain weight, where biofertilizer treatment did not influence these characters. “Inpari 32” had more productive tillers per hill than “Inpari 30” and “Inpari 36”, which were not significantly different from “Inpari 42”. However, “Inpari 32” had a lower panicle length, number of filled grains per hill, and total number of grains per hill than “Inpari 30” and “Inpari 42”. “Inpari 30” and “Inpari 42” exhibited similar characteristics in terms of the total number of grains per hill and the number of filled grains per hill (Table 2). “Inpari 42” had the highest panicle density (8.34 panicles.cm⁻¹) compared to other varieties. However, this variety tends to have a lower 1000 grain weight (21.66 g). “Inpari 36” had a low average number of filled grains per panicle (107.99 grains), but the average number of unfilled grains per panicle was the highest (53.70 grains). Additionally, the percentage of filled grains produced by this variety was lower than that of other varieties.

The application of biofertilizer significantly affected the panicle length, the number of filled grains per panicle, the number of unfilled grains per panicle, the total number of grains per panicle, and the percentage of filled grains. There were significant differences in these characters with various rates of biofertilizer treatment. However, biofertilizer application did not affect the number of productive tillers per hill, panicle density, and 1000 grain weight (Table 2). There were no significant differences in

biofertilizer treatments at rates up to 800 g.ha⁻¹ on these characters. Applying biofertilizer at a rate of 400 g.ha⁻¹ could improve panicle length and the total number of grains per panicle by 4.1% and 14.7%, respectively, compared to the control (without biofertilizer). Enhancing the rate of biofertilizer to 800 g.ha⁻¹ was not significantly different from the rate of 400 g.ha⁻¹ for these two characters. The same response was found in the number of filled grains per panicle. An increase in the average number of filled grains per panicle was observed when applying biofertilizer at a rate of 800 g.ha⁻¹. Still, this result was not significantly different from that obtained at a rate of 400 g.ha⁻¹. The average number of filled grains per panicle was 139.83 grains with the application of biofertilizer at a rate of 400 g.ha⁻¹. According to Singh et al. (2015), the improvement of grain number due to biofertilizer inoculant may not be solely caused by nitrogen fixation or phosphate solubilization. Some other factors include the release of growth-promoting substances and the proliferation of beneficial microorganisms in the rhizosphere. Solubilizing inorganic phosphate in the soil makes it available to plants and increases the number of grains per panicle.

There was an interaction effect between the application of biofertilizer and the use of rice cultivars on the number of unfilled grains per panicle (Figure 4) and the percentage of filled grains (Figure 5). This means that each superior rice variety responded differently to the application of biofertilizer. “Inpari

Table 2. Effect of cultivar and biofertilizer treatment on rice yield components

Treatment	NPT	PL	PD	TNG	NFG	NUG	PFG	TGW
Cultivar								
“Inpari 30”	19.16 ^b	23.66 ^a	7.33 ^b	173.87 ^{ab}	148.58 ^a	25.29 ^b	85.29 ^a	25.96 ^a
“Inpari 32”	24.18 ^a	20.68 ^c	6.89 ^b	142.42 ^c	122.52 ^b	19.90 ^b	85.89 ^a	25.99 ^a
“Inpari 36”	19.69 ^b	23.48 ^{ab}	6.88 ^b	161.69 ^{bc}	107.99 ^b	53.70 ^a	66.33 ^b	22.03 ^b
“Inpari 42”	21.42 ^{ab}	22.92 ^b	8.34 ^a	191.84 ^a	166.40 ^a	25.44 ^b	86.51 ^a	21.66 ^b
Biofertilizer (g.ha ⁻¹)								
0	21.88	22.11 ^b	6.85	151.85 ^b	121.74 ^b	30.11 ^b	79.52 ^b	23.95
400	20.92	23.02 ^a	7.56	174.19 ^a	139.83 ^{ab}	34.36 ^a	80.44 ^{ab}	24.05
800	20.53	22.93 ^a	7.67	176.33 ^a	147.54 ^a	28.78 ^b	83.06 ^a	23.73
Cultivar (V)	*	**	*	**	**	**	**	**
Biofertilizer (B)	ns	*	ns	*	*	*	*	ns
V × B	ns	ns	ns	ns	ns	**	*	ns

Note: Mean values within a column followed by the same letters are not significantly different according to Fisher’s LSD test at the 5% level. **: p<0.01, *: p<0.05, ns: not significant. NPT: number of productive tillers per hill, PL: panicle length (cm), PD: panicle density (grains.cm⁻¹), TNG: total number of grains per panicle, NFG: number of filled grains per panicle, NUG: number of unfilled grains per panicle, PFG: percentage of filled grains (%), TGW: 1000 grain weight (g).

36”, with different levels of biofertilizer, had the highest average number of unfilled grains per panicle, with a lower percentage of filled grains than other cultivars. However, increasing the rate of biofertilizer in this cultivar did not significantly affect these two characters, with no significant increase observed up to a rate of 800 g.ha⁻¹. The lowest number of unfilled grains per panicle was observed in “Inpari 32” with biofertilizer treatment at a rate of 800 g.ha⁻¹. This treatment of biofertilizer rate reduced the number of unfilled grains per panicle compared to the control (without biofertilizer). On the other hand, the percentage of filled grains increased with the application of biofertilizer. The percentage of filled grains increased by 7.7% in this cultivar.

Grain Yield

The interaction between biofertilizer and cultivar had a significant effect on grain yield. The grain yield of the superior rice variety showed significant differences with the application of biofertilizer (Figure 6). In “Inpari 32”, the biofertilizer application with a rate of 400 g.ha⁻¹ obtained the highest grain yield (7.6 t.ha⁻¹). The grain yield was not significantly different from “Inpari 30” at the same rate. In “Inpari 30” and “Inpari 32”, applying biofertilizer at a rate of 400 g.ha⁻¹ could increase grain yield by ±0.7-0.8 t.ha⁻¹ or 10%-12% higher than without biofertilizer. In contrast, the lowest grain yield (5.3 t.ha⁻¹) was observed in “Inpari 36” without biofertilizer treatment compared to the other treatments. In “Inpari 36”, applying biofertilizer at a rate of 400 g.ha⁻¹ could

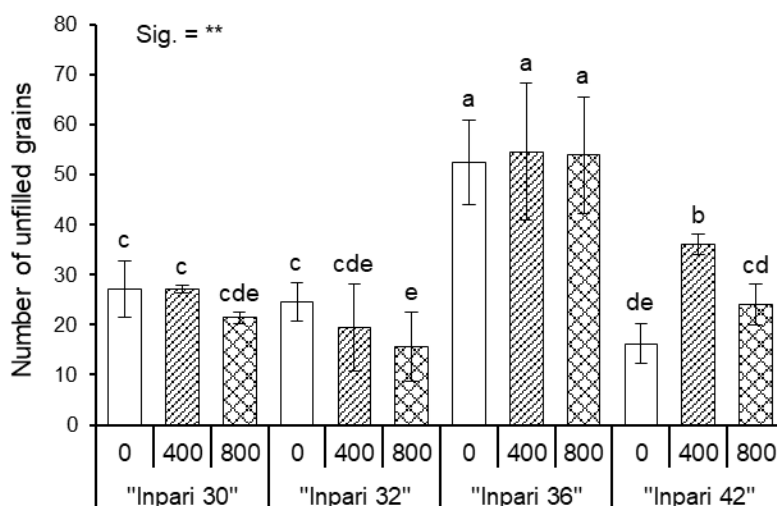


Figure 4. Number of unfilled grains per panicle for several superior rice varieties under different rates of biofertilizer. Mean values above the bar followed by the same letters are not significantly different according to Fisher's LSD test at the 5% level.

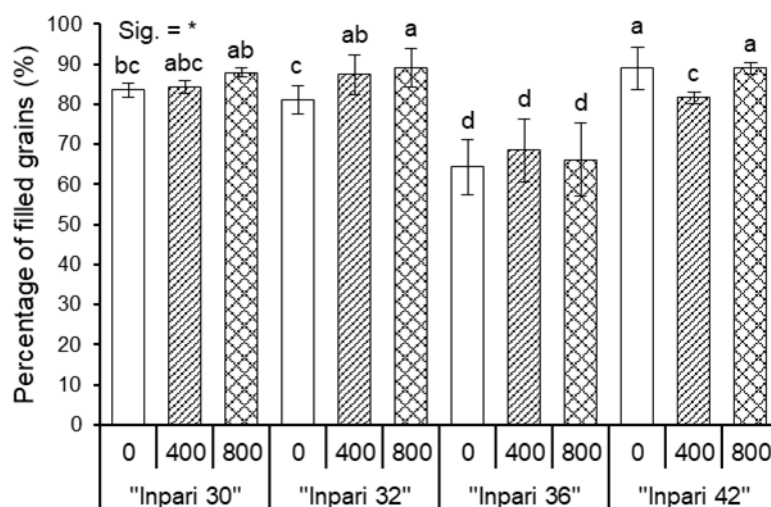


Figure 5. Percentage of filled grains for several superior rice varieties under different rates of biofertilizer. Mean values above the bar followed by the same letters are not significantly different according to Fisher's LSD test at the 5% level.

increase grain yield by 1.1 t.ha⁻¹ or 21.6% compared to the control (without biofertilizer). The results of this study are similar to those reported by Arafah (2017) and Nurkhaida et al. (2021).

The average grain yield of "Inpari 30" and "Inpari 32", with this rate of biofertilizer, was not significantly different from that of the application of biofertilizer at a rate of 800 g.ha⁻¹. A similar response to this biofertilizer treatment was also found in "Inpari 36". The higher rate of biofertilizer, at 800 g.ha⁻¹, did not significantly enhance grain yield. There was no significant difference in grain yield even though the rate of biofertilizer was improved (up to twofold). However, in "Inpari 42", applying biofertilizer at 400 g.ha⁻¹ did not increase grain yield. A significant increase in grain yield for this cultivar was obtained by applying biofertilizer at a rate of 800 g.ha⁻¹. This biofertilizer rate increased the grain yield of this cultivar by 0.8 t.ha⁻¹, or 12.6% higher than without biofertilizer. Treatment with biofertilizer has enhanced the quality of root growth by producing bioactive substances, such as hormones and enzymes, thereby facilitating the plant's nutrient uptake to a greater extent. As a result, this led to improved chlorophyll content, enhanced photosynthesis, and increased carbohydrate synthesis, ultimately enhancing rice grain yield (Noraida and Hisyamuddin, 2021). The role of microorganisms within biofertilizers, such as *Rhizobium* sp. and *Bradyrhizobium* sp., is direct, as they fix nitrogen or secrete plant hormones (Fahde et al., 2023). According to Sammauria et al. (2020), inoculating rice seeds with different *Rhizobium* strains at varying nitrogen levels increased straw yield by 4% to 19% and grain yield by 8% to 22%. Other studies have also reported by Husna et al. (2021) where there was an increase in rice grain yield by 0.32 t.ha⁻¹ by

using microorganisms in biofertilizers, which play an important role as phosphate-solubilizing and nitrogen-fixing bacteria, such as *Bacillus* sp. Furthermore, applying this bacterium could enhance bacterial populations, improve soil biological properties, and increase the availability of phosphorus in the soil.

Correlation Among Traits

The study of the relationship between morpho-agronomic characters is crucial in identifying traits that can potentially enhance rice grain yield. Associations between these characters can be computed based on the results of correlation analysis (Saleh et al., 2020). A higher Pearson's correlation coefficient value typically indicates a stronger association among variables. On the other hand, the lower the association among characters, the lower the Pearson's correlation coefficient value. This method is most often used to analyze relationships among traits (Kozak et al., 2012). Figure 7 illustrates the relationship among the morpho-agronomic characters of superior rice varieties. The results of the correlation analysis showed that several characters were significantly correlated with rice grain yield. These characters include plant height, the number of filled grains per panicle, the number of unfilled grains per panicle, and the percentage of filled grains.

The plant height had a highly significant and positive correlation with the number of productive tillers per hill ($r = 0.464^{**}$), 1000 grain weight ($r = 0.556^{**}$), and grain yield ($r = 0.428^{**}$). Otherwise, the plant height showed a significant and negative correlation between panicle length ($r = -0.627^{**}$), total number of grains per panicle ($r = -0.497^{**}$), and number of unfilled grains per panicle ($r = -0.332^*$). The correlation between the

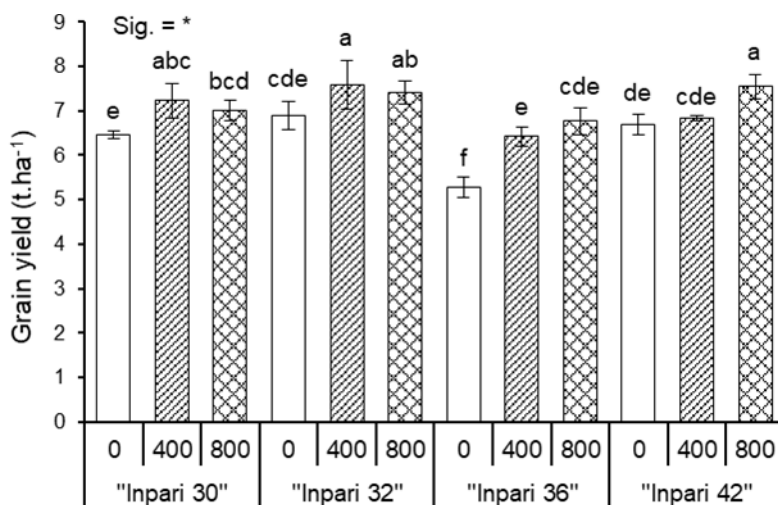


Figure 6. Grain yield of superior rice varieties under different rates of biofertilizer. Mean values above the bar followed by the same letters are not significantly different according to Fisher's LSD test at the 5% level.

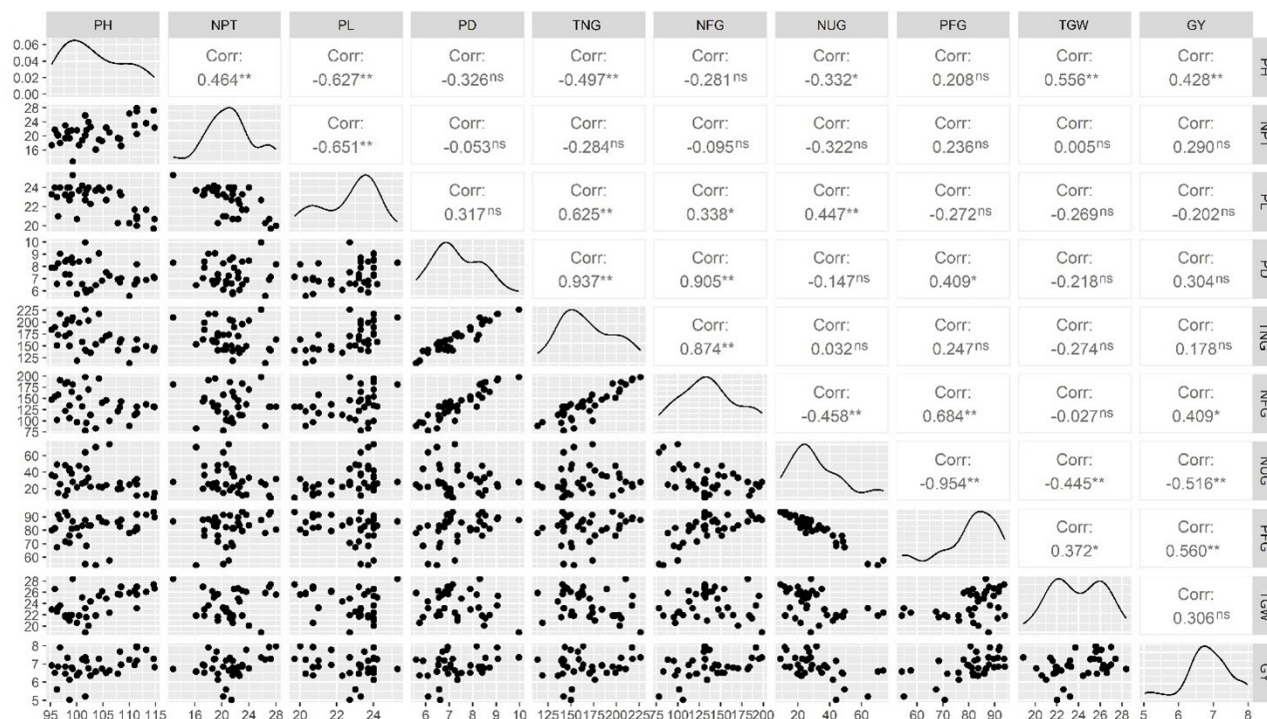


Figure 7. Pearson's correlation coefficient among grain yields and its component characters in four superior rice varieties. **: significant at $p < 0.01$, *: significant at $p < 0.05$, ns: not significant. PH: plant height, NPT: number of productive tillers per hill, PL: panicle length, PD: panicle density, TNG: total number of grains per panicle, NFG: number of filled grains per panicle, NUG: number of unfilled grains per panicle, PFG: percentage of filled grains, TGW: 1000 grain weight, GY: grain yield ($t \cdot ha^{-1}$).

number of productive tillers per hill and panicle length was highly significant and negative ($r = -0.651^{**}$). The panicle length showed a significant and positive correlation between the total number of grains per panicle ($r = 0.625^{**}$), the number of filled grains per panicle ($r = 0.338^*$), and the number of unfilled grains per panicle ($r = 0.447^{**}$). Grain yield had a significant positive correlation with the number of filled grains per panicle ($r = 0.409^*$) and the percentage of filled grains ($r = 0.560^{**}$). This means that grain yield will improve with increasing the number of filled grains per panicle and the percentage of filled grains. Conversely, grain yield will decrease with a larger number of unfilled grains. Results revealed a highly significant and negative correlation between the number of unfilled grains per panicle and grain yield ($r = -0.516^{**}$). According to Purwanto et al. (2020), a higher number of unfilled grains per panicle would reduce grain yields, while high grain yields were achieved by increasing the percentage of filled grains.

Each cultivar's characteristics may differ, including grain yield and its components. For the four superior rice varieties in this study, characters associated with grain yield required special attention, particularly plant height, the number of filled grains per panicle, the number of unfilled grains per panicle, and the percentage of filled grains. These characters were

essential factors in increasing rice grain yield. This study showed that biofertilizers influenced these traits and significantly increased rice grain yield. Microorganisms within biofertilizers play a crucial role in a complex mechanism between plant genetics and the environment (O'Callaghan et al., 2022), enabling the achievement of the yield potential of superior rice varieties.

Conclusions

The use of biofertilizer contributes to improved growth and development of rice seedlings, characterized by increased seedling height and root length. Applying biofertilizer at a rate of $400 \text{ g} \cdot \text{ha}^{-1}$ has the potential to enhance grain yield and its yield components for "Inpari 30", "Inpari 32", and "Inpari 36". Meanwhile, for "Inpari 42", the biofertilizer rate of $800 \text{ g} \cdot \text{ha}^{-1}$ is required to achieve higher grain yields. Biofertilizers could increase the grain yield of superior rice varieties by 10%-21.6%. The average rice grain yields produced were $7.2 \text{ t} \cdot \text{ha}^{-1}$ for "Inpari 30", $7.5 \text{ t} \cdot \text{ha}^{-1}$ for "Inpari 32", $6.4 \text{ t} \cdot \text{ha}^{-1}$ for "Inpari 36", and $7.5 \text{ t} \cdot \text{ha}^{-1}$ for "Inpari 42". The appropriate biofertilizer rate may vary depending on specific land conditions and soil fertility. Further research should focus on exploring the effects of biofertilizers under varying soil conditions or their long-term impacts on soil health.

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