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Effect of Biofertilizers and Growth Promoting Microorganisms on Productivity and Profitability of Mungbean [*(Vigna radiata* (L.) Wilczek] under Mungbean-Wheat Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

A field experiment was conducted during *Kharif* 2022 and 2023 at Dr. BRC Agricultural Research Station (ARS), Mandor, Rajasthan, to evaluate the effect of biofertilisers and growth-promoting microorganisms on growth, yield, and profitability of mungbean *(Vigna radiata* (L.) Wilczek*, var.* GM-4) under the mungbean–wheat cropping system. The experiment was laid out in a Randomised Block Design with ten treatments and three replications. Treatments consisted of different combinations of the recommended dose of fertilisers and seed inoculation, soil application, or combined seed and soil application of *Rhizobium* and phosphate-solubilising bacteria (PSB). The results indicated that growth parameters, yield attributes, grain yield, biological yield, and economic returns were significantly influenced by the treatments. The greatest numerical plant heights at 30 DAS (46.8 cm)

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and 45 DAS (55.9 cm) were recorded under T_{10}, while T_5 recorded comparable values of 45.8 and 55.3 cm, respectively. The highest numbers of pods per plant (39.6) and seeds per pod (13.5), dry matter production (3.50 t ha^{-1}), and test weight (48.1 g) were observed under T_5, whereas the highest numerical chlorophyll content (4.00 mg g^{-1}) was recorded under T_{10}. The highest grain yield (pooled: 1458 kg ha^{-1}) and net return (₹98,855 ha^{-1}) were recorded with 100% RDF (T_5), whereas 75% RDF combined with seed and soil application of *Rhizobium* + PSB (T_{10}) produced a pooled grain yield of 1400 kg ha^{-1} and a B:C ratio of 4.41, remaining statistically at par with T_5. Thus, integrated use of biofertilisers with 75% RDF can reduce fertiliser requirement without significant yield loss and improve profitability.

Keywords: Rhizobium; Chlorophyll, biofertiliser; seed inoculation; soil application; phosphate-solubilising bacteria.

1. Introduction

Mungbean [*Vigna radiata* (L.) Wilczek] holds a significant position as a versatile leguminous pulse crop cultivated worldwide for its nutritional and economic value (Kebede, 2021). It has been successfully adapted to diverse agro-climatic zones in India, serving various purposes as a vegetable, pulse, fodder, and green manure crop (Banotra *et al.*, 2021; Kumawat *et al.*, 2022), while also contributing to soil fertility restoration through its inherent biological nitrogen fixation mechanism (Bahadari *et al.*, 2020). Despite its adaptability, mungbean productivity remains low because of suboptimal management practices, inherent factors, and physiological intricacies (Athnere *et al.*, 2021). The mungbean–wheat cropping system is widely practised in north-western India, particularly in Rajasthan, where mungbean serves as a short-duration legume during the kharif season, followed by wheat during the *rabi* season. The inclusion of mungbean in this cropping system enhances soil fertility through biological nitrogen fixation, improves nutrient cycling, and contributes residual nitrogen to the succeeding wheat crop, thereby reducing fertiliser requirements and improving system productivity (Ghosh *et al.*, 2007; Raiger *et al.*, 2011). The combined use of *Rhizobium* and phosphate-solubilising bacteria (PSB) along with balanced fertiliser application has been reported to improve growth, yield, nutrient uptake, and soil health in legume-based cropping systems (Dhakal *et al.*, 2016; Gorade *et al.*, 2014; Mahdi *et al.*, 2010). However, information on integrated nutrient management involving reduced fertiliser doses with biofertilisers under the mungbean–wheat cropping system of western Rajasthan remains limited. Therefore, the present investigation was undertaken to evaluate the effect of different combinations of chemical fertilisers and biofertilisers on the growth, yield, nutrient uptake, economics, and soil fertility of mungbean under the mungbean–wheat cropping system. The growing demand for food production has led to extensive use of chemical fertilisers, particularly nitrogen and phosphorus fertilisers. Although these fertilisers have contributed substantially to increased agricultural productivity, their indiscriminate use has resulted in nutrient imbalance, declining soil organic matter, deterioration of soil biological activity, groundwater contamination, and increased production costs (Tilman *et al.*, 2002; Bhattacharyya *et al.*, 2015). Continuous dependence on chemical fertilisers without adequate replenishment of soil organic matter has adversely affected soil health and sustainability of agricultural production systems (Lal, 2004). The combined application of *Rhizobium* and PSB has received considerable attention because these microorganisms complement each other's activities. While *Rhizobium* enhances nitrogen availability, PSB improves phosphorus nutrition, leading to better root development, increased chlorophyll synthesis, improved photosynthetic efficiency, and enhanced yield attributes (Bhattacharyya & Jha, 2012; Dhakal *et al.*, 2016). Integrated use of biofertilisers with reduced doses of chemical fertilisers has been recognised as an environmentally friendly and economically viable approach to sustainable nutrient management (Mahdi *et al.*, 2010).

Recent mungbean evidence indicates that combining *Rhizobium* and phosphate-solubilising bacteria (PSB) with organic nutrient inputs can improve plant NPK uptake and post-harvest soil nutrient availability (Kalson *et al.*, 2025). Integrated combinations of mineral fertiliser and organic nutrient sources have also improved nutrient content and uptake in green gram, indicating potential for input-efficient nutrient strategies (Kamal *et al.*, 2026). Field evidence in mungbean further indicates strain-specific responses, with *Rhizobium phaseoli* increasing biological nitrogen fixation and *Bacillus subtilis* increasing plant nitrogen accumulation and dry matter, whereas yield was not significantly affected in that study (Pataczek *et al.*, 2024). Screening of mungbean nodule bacteria from arid Rajasthan identified drought-tolerant isolates with nitrogen-fixing and phosphate-solubilising traits and plant-growth effects under water deficit, underscoring the importance of locally adapted inoculants in arid environments (Mondal & Gera, 2024). Recent field research has also shown that the response of mungbean to biological fertilisers can depend on the broader management system, including tillage and organic nutrient inputs, supporting context-specific evaluation of microbial nutrient-management strategies (Shahsavari *et al.*, 2025).

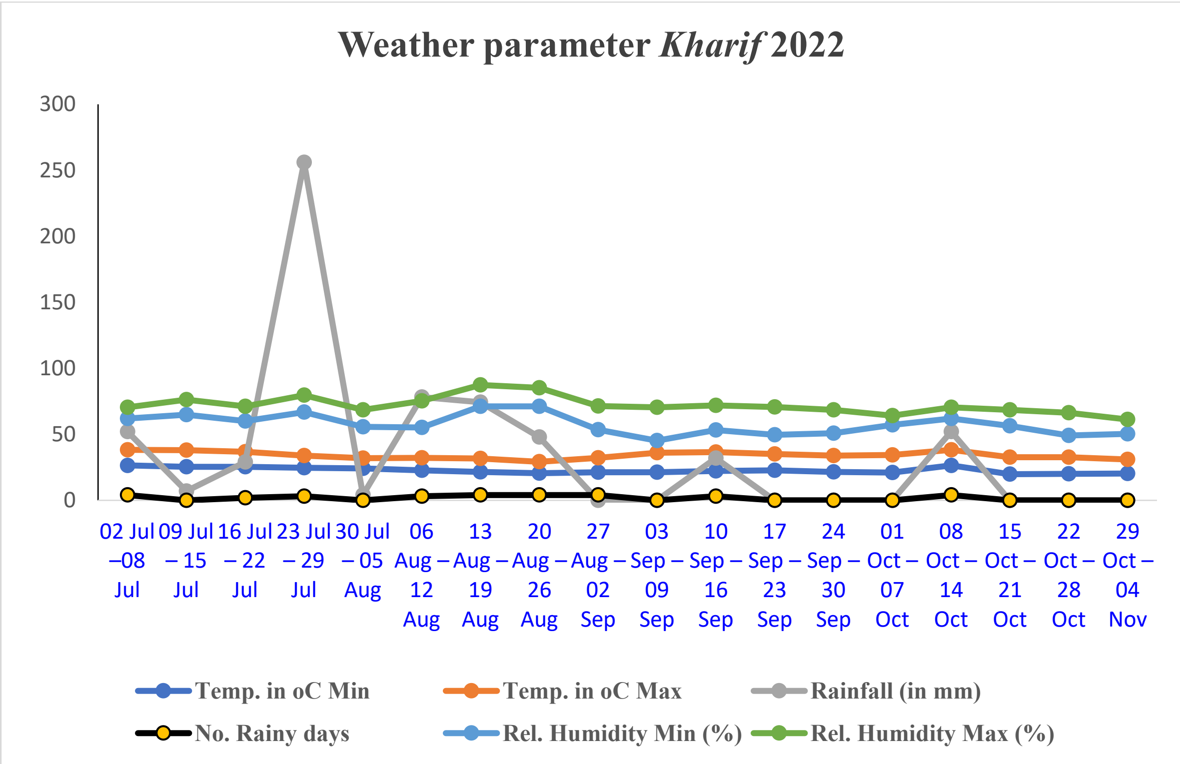
Despite these advances, evidence remains limited on whether reduced recommended fertiliser doses combined with both seed and soil application of *Rhizobium* + PSB can sustain mungbean growth, yield, and profitability within the mungbean–wheat cropping system under western Rajasthan conditions.

1.1 Objective

The present study therefore aimed to evaluate the effects of graded fertiliser levels combined with seed and/or soil application of *Rhizobium* + PSB on the growth, yield, nutrient uptake, economics, and soil fertility of mungbean under the mungbean–wheat cropping system.

2. Materials and Methods

The field experiment was conducted during the *Kharif* seasons of 2022 and 2023 at Dr. BRC Agricultural Research Station, Mandor, Jodhpur, Rajasthan, to evaluate the effect of biofertilisers and growth-promoting microorganisms on growth, yield, and profitability of mungbean (*Vigna radiata* (L.) Wilczek, *var*. GM-4) under the mungbean–wheat cropping system. The experimental



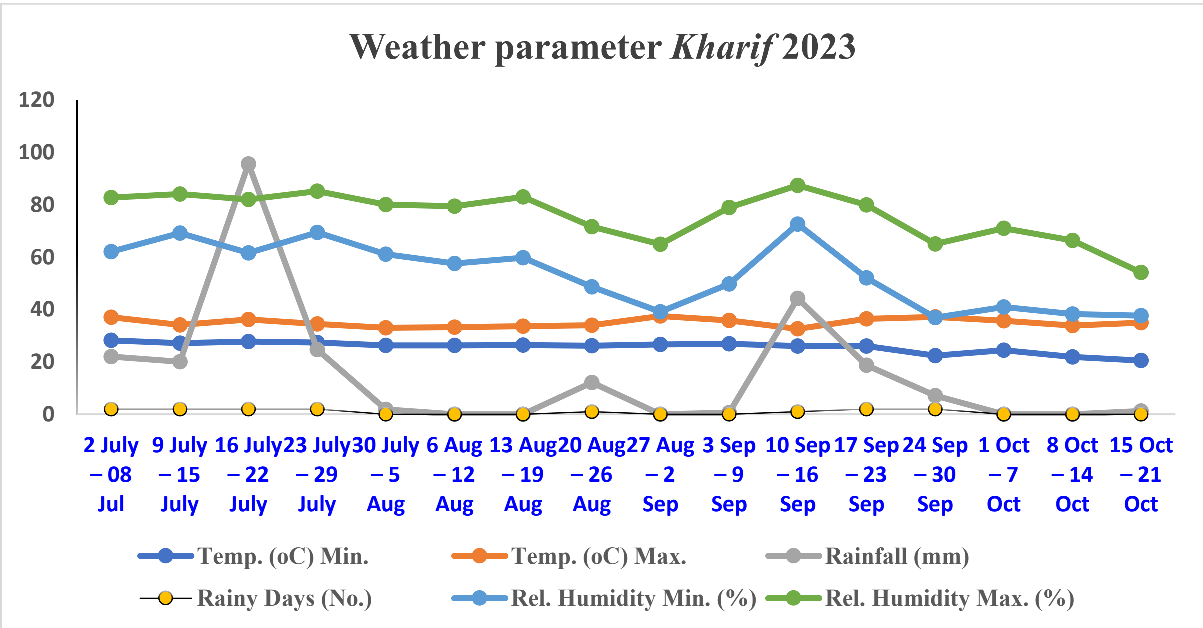


Fig. 1. Meterological parameter during crop season

field was located between 26°15′ N and 26°45′ N latitude and 73°00′ E and 73°29′ E longitude, at an altitude of 231 m above mean sea level. The research station is located within agro-climatic zone Ia, classified as the arid western plains zone of Rajasthan. The region receives an average annual rainfall of approximately 367 mm (CV 52%), of which the majority (85 to 90%) occurs from June to September during the kharif season under the influence of the south-west monsoon. Fig. 1 illustrates the weather parameters recorded during the crop season (*Kharif* 2022 and *Kharif* 2023). The experimental soil was loamy sand in texture and slightly alkaline in reaction (pH 8.29), with an electrical conductivity (EC) of 0.30 dS m^{-1}, low organic carbon (0.22%), and low available nitrogen (155 kg ha^{-1}). However, it contained medium levels of available phosphorus (19.2 kg P ha^{-1}) and high available potassium (350 kg K_2O ha^{-1}). The experiment was laid out in a Randomised Block Design (RBD) comprising ten treatments and three replications. Each experimental plot measured 3.0 m × 4.0 m with a crop geometry of 30 cm × 10 cm. The treatments included T_1 (Control), T_2 (seed treatment with *Rhizobium* + PSB), T_3 (soil treatment with *Rhizobium* + PSB), T_4 (combined seed and soil treatment with *Rhizobium* + PSB), T_5 (100% recommended dose of fertilisers, RDF), T_6 (75% RDF + seed treatment with *Rhizobium* + PSB), T_7 (75% RDF + soil treatment with *Rhizobium* + PSB), T_8 (50% RDF + seed treatment with *Rhizobium* + PSB), T_9 (50% RDF + soil treatment with *Rhizobium* + PSB), and T_{10} (75% RDF + combined seed and soil treatment with *Rhizobium* + PSB). The biofertiliser cultures were applied as seed inoculation and soil application according to recommended procedures. The crop was sown during the second week of July and harvested during October in both years. Recommended agronomic practices regarding irrigation, weed management, and plant protection were followed uniformly for all treatments. Observations on plant height at 30 and 45 DAS, number of branches per plant, pods per plant, seeds per pod, dry matter production, chlorophyll content, test weight, grain yield, biological yield, gross returns, net returns, and benefit-cost ratio were recorded. Statistical analysis involved pooling the mean values from the three replications in each year. These pooled mean values were subjected to statistical analysis using SAS software by one-way analysis of variance (ANOVA).

3. Results and Discussion

3.1 Effect of Biofertilisers and Growth-promoting Microorganisms on Growth and Yield Attributes of Mungbean

The growth of mungbean was significantly influenced by different combinations of inorganic fertilisers and biofertilisers. The pooled data indicated that integrated nutrient management improved plant height, number of branches per plant, chlorophyll content, and dry matter production compared with the control. These beneficial effects may be attributed to improved biological nitrogen fixation, enhanced phosphorus solubilisation, increased nutrient uptake, and better root development due to the combined activity of *Rhizobium* and phosphate-solubilising bacteria (PSB).

3.2 Plant Height, Number of Branches per Plant, Dry Matter Production and Chlorophyll Content

Plant height is an important indicator of vegetative growth and reflects the availability of nutrients during crop development. The data presented in Table 1 showed that plant height increased progressively with crop age under all treatments. At 30 DAS, plant height ranged from 39.2 cm in the control (T_1) to 46.8 cm under T_{10}. Likewise, at 45 DAS, the greatest numerical plant height (55.9 cm) was recorded under 75% RDF + combined seed and soil application of *Rhizobium* + PSB (T_{10}), while T_5 recorded 55.3 cm; the differences were non-significant. Branch production increased considerably with biofertiliser application. The control treatment produced only 6.2 branches per plant, whereas the maximum value (7.4 branches per plant) was recorded under 100% RDF (T_5). Treatment T_{10} also produced 7.3 branches per plant and was statistically comparable with T_5, as presented in Table 1. Dry matter production represents the cumulative growth of the crop and reflects efficient utilisation of nutrients. The data revealed significant variation among treatments. Table 1 showed that the highest dry matter production (3.50 t ha^{-1}) was recorded under 100% RDF, followed by 3.40 t ha^{-1} under T_{10}. The control produced only 2.80 t ha^{-1}. Chlorophyll content is closely associated with photosynthetic efficiency and crop productivity. The highest numerical chlorophyll content (4.00 mg g^{-1}) was recorded under T_{10}, while T_5 recorded 3.90 mg g^{-1}, as shown in Table 1. Similar findings have been reported by Debbarma *et al.* (2020), Dhakal *et al.* (2016), Gorade *et al.* (2014), Meena *et al.* (2020), and Bhattacharyya and Jha (2012), who observed significant improvement in plant height, number of branches per plant, dry matter production, and chlorophyll content following inoculation with *Rhizobium* and PSB.

3.3 Effect on Yield Attributes

The number of pods per plant increased significantly with fertiliser and biofertiliser application. The control produced only 27.2 pods per plant, whereas 100% RDF (T_5) recorded the highest value (39.6 pods per plant). Treatment T_{10} recorded 39.3 pods per plant and remained statistically at par with T_5. The maximum number of seeds per pod (13.5) was recorded under T_5, followed by 12.9 seeds per pod under T_{10}. The control recorded only 9.4 seeds per pod. The maximum test weight (48.1 g) was observed under 100% RDF, while T_{10} recorded 47.5 g. The increase in test weight reflects improved grain filling due to better nutrient availability and photosynthate accumulation. These improvements have also been associated with the production of plant growth regulators such as indole acetic acid (IAA), gibberellins, and cytokinins by rhizosphere microorganisms, which promote reproductive development (Bhattacharyya & Jha, 2012; Dhakal *et al.*, 2016; Gorade *et al.*, 2014; Kaur & Sharma, 2017).

3.4 Effect of Biofertilisers and Growth-promoting Microorganisms on Yield and Economics of Mungbean

Grain yield is the ultimate expression of the interaction between vegetative growth and reproductive development. Table 2 showed that the pooled grain yield varied from 958 kg ha^{-1} in the control to 1458 kg ha^{-1} under T_5. Treatment T_{10} produced 1400 kg ha^{-1}, which remained statistically at par with T_5. Similarly, biological yield increased from 3077 kg ha^{-1} under the control to 4219 kg ha^{-1} under T_5, while T_{10} produced 4118 kg ha^{-1}. The higher grain yield under integrated nutrient management resulted from increased pods per plant, higher seeds per pod, greater test weight, improved nutrient uptake, and enhanced photosynthetic efficiency. Biofertilisers improved nitrogen fixation and phosphorus availability, which supported both vegetative and reproductive growth. Similar conclusions were reported by Debbarma *et al.* (2020), Dhakal *et al.* (2016), Gorade *et al.* (2014), Kumar *et al.* (2017), and Raiger *et al.* (2011).

Economic analysis revealed that integrated nutrient management significantly improved profitability. The highest gross return (₹126,405 ha^{-1}), net return (₹98,855 ha^{-1}), and benefit-cost ratio (4.59) were recorded under 100% RDF (T_5). Treatment T_{10} produced gross returns of ₹121,534 ha^{-1}, net returns of ₹93,964 ha^{-1}, and a B:C ratio of 4.41, while reducing fertiliser use by 25%,

Table 1. Effect of biofertilizers and growth promoting microorganism on growth and yield attributes of mungbean

Treatment	Plant height at 30 DAS (cm)	Plant height at 45 DAS (cm)	Branches / plant	Pods/ Plant	Seeds /Pod	Dry matter production (t/ha)	Chlorophyll content (mg/g)	Test weight (g)	H.I. (%)
T_1: Control	39.2	47.7	6.2	27.2	9.4	2.80	2.70	44.2	29.4
T_2: Seed treatment with Rhizobium+ PSB culture	41.8	50.4	6.3	29.2	10.5	3.00	2.90	45.0	29.9
T_3: Soil treatment with Rhizobium+ PSB culture	40.6	49.2	6.3	29.0	10.0	3.00	2.90	44.6	29.4
T_4: Combined treatment seed and soil with Rhizobium+ PSB culture	42.1	50.7	6.4	31.0	10.9	3.10	3.00	45.2	30.6
T_5: 100% RDF	45.8	55.3	7.4	39.6	13.5	3.50	3.90	48.1	32.5
T_6:75% RDF + Seed treatment with Rhizobium+ PSB culture	45.2	54.3	7.3	38.0	12.1	3.40	3.80	46.9	31.7
T_7: 75% RDF+ Soil treatment with Rhizobium+ PSB culture	45.2	54.0	7.2	37.5	11.8	3.30	3.70	47.0	32.1
T_8:50% RDF+ Seed treatment with Rhizobium+ PSB culture	43.5	52.8	6.8	34.9	11.5	3.20	3.60	46.1	31.2
T_9: 50% RDF+ Soil treatment with Rhizobium+ PSB culture	42.9	52.7	6.6	33.6	11.4	3.10	3.60	45.8	31.3
T_{10}:75% RDF+ combined treatment seed and soil with Rhizobium+ PSB culture	46.8	55.9	7.3	39.3	12.9	3.40	4.00	47.5	32.0
SEm±	**2.16**	**2.58**	**0.39**	**1.95**	**0.54**	**0.13**	**0.18**	**1.03**	**1.75**
CD (5%)	**NS**	**NS**	**NS**	**5.79**	**1.61**	**0.38**	**0.54**	**3.06**	**5.19**

Table 2. Effect of biofertilizers and growth promoting microorganism on yield and economics of mungbean

Treatment	Grain yield (kg/ha)			Biological yield (kg/ha)	Gross return (₹./ha)	Net return (₹./ha)	B:C ratio
	2022	2023	Pooled				
T_1: Control	980	937	958	3077	83896	58396	3.29
T_2: Seed treatment with Rhizobium+ PSB culture	1059	976	1017	3201	88846	63326	3.48
T_3: Soil treatment with Rhizobium+ PSB culture	1035	951	993	3185	86890	61190	3.38
T_4: Combined treatment seed and soil with Rhizobium+ PSB culture	1099	994	1046	3233	91178	65458	3.55
T_5: 100% RDF	1490	1426	1458	4219	126405	98855	4.59
T_6: 75% RDF + Seed treatment with Rhizobium+ PSB culture	1403	1333	1368	4078	118935	91585	4.35
T_7: 75% RDF + Soil treatment with Rhizobium+ PSB culture	1383	1311	1347	3963	116965	89415	4.24
T_8: 50% RDF + Seed treatment with Rhizobium+ PSB culture	1259	1193	1226	3694	106691	79951	3.99
T_9: 50% RDF+ Soil treatment with Rhizobium+ PSB culture	1240	1174	1207	3635	105023	78083	3.90
T_{10}: 75% RDF+ Combined treatment seed and soil with Rhizobium+ PSB culture	1427	1372	1400	4118	121534	93964	4.41
SEm±	**68.04**	**60.03**	**62.3**	**157**	**-**	**-**	**-**
CD at 5 %	**202**	**178**	**185.1**	**467**	**-**	**-**	**-**

as shown in Table 2. This demonstrates that biofertiliser inoculation can lower input costs without a significant reduction in productivity, making this approach a sustainable and economically attractive option for farmers. Similar economic advantages of integrated nutrient management have been reported by Aulakh and Grant (2008), Debbarma *et al.* (2020), Kaur and Sharma (2017), Kumar *et al.* (2017), and Meena *et al.* (2020).

Overall, the results indicate that integrated use of *Rhizobium*, PSB, and reduced chemical fertiliser doses is an effective strategy for sustaining crop productivity, improving nutrient use efficiency, enhancing soil fertility, and increasing farmers' income under the arid and semi-arid conditions of Rajasthan.

4. Conclusions

The two-year field evaluation showed that mungbean growth, yield attributes, yield, and economic performance responded to the combined use of fertilisers and biofertilisers under the mungbean–wheat cropping system. Full RDF (T_5) produced the highest pooled grain yield (1458 kg ha^{-1}), gross return (₹126,405 ha^{-1}), net return (₹98,855 ha^{-1}), and B:C ratio (4.59). However, 75% RDF combined with seed and soil application of *Rhizobium* + PSB (T_{10}) produced a pooled grain yield of 1400 kg ha^{-1} and a B:C ratio of 4.41, with grain yield statistically at par with T_5. T_{10} also recorded the greatest numerical plant heights at 30 and 45 DAS and the highest chlorophyll content, while T_5 recorded the highest pods per plant, seeds per pod, dry matter production, and test weight. Therefore, the findings support 75% RDF with combined seed and soil inoculation of *Rhizobium* and PSB as a potential nutrient-management option for reducing chemical fertiliser use by 25% without a significant reduction in mungbean grain yield under the conditions of this study.

5. Limitation

The findings are based on field experiments conducted over two kharif seasons at a single research station in western Rajasthan under the specific soil and agro-climatic conditions described in the manuscript. Consequently, the observed treatment responses and economic outcomes should be interpreted within these conditions. Validation across additional locations, seasons, soil types, and production environments would be useful before extending the findings beyond comparable mungbean–wheat systems.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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