RESEARCH ARTICLE

Biochemical Effects of *Rhizobium* and Phosphate Solubilizing Bacteria on Growth and Yield of Black Gram (*Vigna mungo* L.)

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DOI: 10.18811/ijpen.v10i03.14

Abstract

A field study conducted at Integral University, Lucknow, during the kharif seasons of 2022–2023 and 2023–2024 evaluated the biochemical effects of *Rhizobium* and phosphate-solubilizing bacteria on black gram (*Vigna mungo* L.). The experiment included three replications and sixteen treatments to assess their impact on various growth parameters and yield. Significant findings included the highest values for plant population (59.15 m^{-2}), plant height (40.31 cm), number of branches (13.34 $plant^{-1}$), and number of nodules $plant^{-1}$ (60.60). Notably, treatments combining 60 kg ha^{-1} of *Rhizobium* and phosphate-solubilizing bacteria showed promising results, yielding highest fresh weight of nodules (957.51), pods $plant^{-1}$ (68.67), seeds pod^{-1} (8.5), grain yield (12.32 q ha^{-1}), straw yield (25.92 q ha^{-1}), 1000-grain weight (39.31), and harvest index (33.26%). Additionally, applying 60 kg P_2O_5 ha^{-1} demonstrated superior yield performance, comparable to 30 kg P_2O_5 ha^{-1}.

Keywords: *Rhizobium*, Phosphorus solubilizing bacteria, Phosphorus, Black Gram.

Highlights

- Provides insights into optimizing black gram cultivation through sustainable biochemical interventions.
- It highlights the importance of nutrient uptake efficiency, a critical factor for plant health and yield of black gram.
- It emphasizes the long-term impact on soil health and sustainability, crucial for agricultural practices.
- Examines how phosphorus supplementation interacts with *Rhizobium* and PSB inoculation to influence black gram productivity.
- The influence of bio-fertilizer levels on phosphorus enhancing growth performance in black gram cultivation

International Journal of Plant and Environment (2024); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

A bacteria called *Rhizobium leguminosarum* coexists with legumes in a mutualistic symbiotic relationship. This means that the bacterium and the legume plant benefit from each other. The bacterium provides the plant with nitrogen, which is a nutrient that plants require in order to flourish. In return, the plant provides the bacterium with a home and a source of energy. *R. leguminosarum* is able to fix nitrogen from the air.

This method transforms air nitrogen into a form that plants can utilize. Nitrogen fixation is an important process for agriculture, as it helps to increase crop yields. (Herridge, 2013). Black gram is a leguminous plant belonging to the *Fabaceae* family. They are an excellent source of Protein, fiber, and other nutrients. It can be used for human consumption, animal feed, or as green manure to improve soil fertility.

The usage of bio-fertilizer may be more crucial for improving phosphorus use efficiency. Indian soils have low to medium levels of phosphate and nitrogen that are readily available with the intention of boosting their population in the rhizosphere, *Rhizobium* is introduced into pulse seeds in order to significantly enhance the amount of microbiologically fixed nitrogen for plant growth. Bio-fertilizers like *Rhizobium* and phosphate solubilizing bacteria play an important role in increasing the availability of nitrogen and phosphorus through an increase in biological fixation of atmospheric nitrogen and enhanced phosphorus availability to the crop. (Divyanshi *et al.,* 2020). The synthesis of rhizobia nod factors required by the root nodules and the rhizobia that will eventually colonize them was important for the identification of leguminous crops. (Via *et al.,* 2016). Microorganisms of the *Rhizobium* and phosphate solubilizing bacteria (PSB) types can be employed to increase leguminous crop production. A bacterium called *Rhizobium* collaborates symbiotically with legumes. Due to this connection, the legume may fix nitrogen from the air, a crucial component that is frequently deficient in the soil. PSBs are bacteria that may saturate insoluble forms of phosphorus, increasing their availability to plants (Meera *et al.,* 2022). It has been demonstrated that the use of *Rhizobium* and PSB enhances the growth, production, and nutritional value of black gram. *Rhizobium* and PSB were applied in an Indian study, and the results showed a 20% increase in grain yield and 15% rise in the protein content of black gram. Usually, grain legumes are grown on marginal land, and poor yields in such soils are partly due to a lack of effective and specific strains of *Rhizobium* in the rhizosphere in soil (Dongare *et al.*, 2016). The use of organic manures, inorganic manures and biofertilizers can enhance the production potential of this crop. Although chemical fertilizers play a crucial role in meeting the nutrient requirement of the crop, persistent nutrient depletion is posing a greater threat to

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How to cite this article: Veer, D., Rao, PS and Habib, K. (2024). Biochemical Effects of *Rhizobium* and Phosphate Solubilizing Bacteria on Growth and Yield of Black Gram (*Vigna mungo* L.). International Journal of Plant and Environment. 10(3), 124-130.

Submitted: 06/01/2024 **Accepted:** 26/06/2024 **Published:** 30/11/2024

sustainable agriculture. (Behera *et al.,* 2022). Numerous bacteria, fungi, and actinomycetes have the potential to dissolve bound phosphates in soil. By using PSB more frequently, you can also lessen the environmental damage that heavy use of chemical fertilizer causes.

Material And Methods

A field study conducted at Integral University, Lucknow, during the kharif seasons of 2022–2023 and 2023–2024 evaluated the biochemical effects of *Rhizobium* and phosphate-solubilizing bacteria on black gram (*Vigna mungo* L.). Three replications, sixteen treatments and a completely factorial randomised design were used to set up the experiment. Each plot is 3.0 × 4.0 metres in size. The treatments were T_1 (control) T_2 (15 kg ha^{-1} P_2O_5 + control) T_3 (30 kg ha^{-1} P_2O_5 + control) T_4 (60 kg ha^{-1} P_2O_5 + control) T_5 (Control + *Rhizobium* seed inoculation), T_6 (15 kg ha^{-1} P_2O_5 + *Rhizobium* soil treatment), T_7 (30 kg ha^{-1} P_2O_5 + *Rhizobium* inoculation), T_8 (60 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB seed inoculation), T_9 (Control + PSB inoculation), T_{10} (15 kg ha^{-1} P_2O_5 +PSB inoculation), T_{11} (30 kg ha^{-1} P_2O_5 + PSB inoculation), T_{12} (60 kg ha^{-1} P_2O_5 +PSB inoculation) T_{13} (Control + *Rhizobium* with PSB inoculation), T_{14} (15 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB inoculation), T_{15} (30 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB inoculation) and T_{16} (60 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB inoculation). All the recommended cultural practices and plant protection measures were followed throughout the experimental periods. The height of the plant, number of branches, effective nodules, dry matter, test weight, pod plant^{-1}, yield and yield contributing characters were recorded from all plots at pertinent stages. All obtained data from the experiment were statistically analyzed by analysis of variance (ANOVA). The water was consumed in a quantity that would sufficiently moisten the seed. One packet of *Rhizobium* culture was added to this mixture and thoroughly stirred. The seed had been covered with the prepared slurry. The seeds were then immediately sowed after drying in the shade. Similar manual mixing was done to incorporate PSB into the soil, *Rhizobium*, or both. Azad U-3, a black gram cultivar, was sown at a rate of 15 kg ha^{-1}.

Results And Discussion

Growth parameters

Effect of phosphorus levels on plant population (m^{-1}) of black gram its attributes

According to studies, the black gram plant population is significantly impacted by phosphorus levels. The number of plants (m^{-1}) increased as phosphorus levels, according to a study by (Kachave *et al.,* 2018). Data represented in (Table 1) the highest plant population was observed to increase the phosphorus level of T_{16} (60 kg ha^{-1}+*Rhizobium* with PSB inoculation). The observed maximum initial plant population (59.00, 57.80 and 58.4 m^{-2}) in the years 2022-2023 and 2023-2024 and in the pooled results. The lowest final plant population (48.60, 47.90 m^{-2} and 48.25) was obtained across both years, and the pooled results, as presented in (Table 1) emphasized the significant impact of biofertilizer levels. These results are in agreement with the findings of earlier research workers (Singh *et al.,* 2020). Phosphorus levels play a pivotal role in influencing the plant population of black gram, as evidenced by studies. (Chhatwani *et al.,* 2022; Singh *et al.,* 2021; and Mohasin *et al.,* 2022) emphasizing the vital connection between phosphorus levels and black gram plant populations.

Effect of phosphorus on plant growth characteristics, including plant height and number of branches

The maximum plant height was recorded with the application of 60 kg P_2O_5 ha^{-1} (39.93, 40.70, and 40.31 cm) at harvest stages observed in the year 2022-2023 and 2023-2024 individual who was at par with 30 kg P_2O_5 ha^{-1} and in bio-fertilizer PSB + *Rhizobium* have got maximum and in treatment combination T_8- 60 kg P_2O_5 + PSB + *Rhizobium* which was statistically at par with T_{15}- 30 kg P_2O_5 + PSB + *Rhizobium* and significantly superior over rest of the treatments. (Gangaraju *et al.,* 2019). The minimum plant height was recorded with the phosphorus level zero and bio-fertilizer PSB and in treatment combination T_1 (control). The entire crop growing with height (15.10 and 15.40 cm) at 30 days after sowing (DAS), Plant height increased significantly with increasing levels of phosphorus up to 60 kg P_2O_5 ha^{-1}, which was at par with 30 kg P_2O_5 ha^{-1} and superior over rest of the doses of phosphorus (Table 1) during both of the year 2022-2023 and 2023-2024. This stark contrast further underscores the importance of appropriate nutrient and microbial management for optimizing plant growth and development. Similar outcomes were discovered for a number of branches plant^{-1}, values as (13.20, 13.48 and 13.34) at the harvest stage in the years 2022-2023 and 2023-2024 and in the pooled results, respectively was, recorded with treatment T_{16} which remained statistically on at par with another treatment. *Rhizobium* with PSB inoculation, which may maintain a favorable equilibrium between the applied nutrients in the plant for its optimum growth while elongation and chlorophyll production, in turn, improve the branches plant^{-1}, was observed to significantly increase plant height. The similar result was found by (Kant *et al.,* 2016; Shekhawat *et al.,* 2017; Jitender *et al.,* 2016; Chaudhary *et al.*, 2016; Kumari *et al.*, 2020; Bhadauria *et al.,* 2019 and Philip *et al.,* 2021). The growth characteristics of the urd bean were greatly enhanced by the use of fertilizers and inoculants. Effective portioning and inoculants may have contributed to the increase in dry matter production brought on by fertilization and inoculants.

Effects of Rhizobium and PSB on the development of nodule plant^{-1} physical characteristics

In a recent research study, intriguing findings emerged regarding legume nodulation and nitrogen fixation. The study delved into the impact of phosphorus on these crucial processes. The results, particularly those observed in treatment T_{16} (comprising 60 kg ha^{-1} of phosphorus, along with *Rhizobium* and PSB inoculation), The research indicated a substantial increase in the number of nodules per plant in phosphorus, up to 30 days after sowing (DAS). Interestingly, when the plants reached the harvest stage (10.60 and 10.80 plant^{-1}), the lowest number of nodules per plant was observed in the control group, where biofertilizers were used at their standard level (10.7 plant^{-1}). This contrast highlighted the pivotal role of phosphorus supplementation, particularly in the form of treatment T_{16} (60 kg ha^{-1}+ *Rhizobium* with PSB inoculation).

Table 1: Combined effect of bio-fertilizers and phosphorus on plant population (m^{-2}) and plant height (cm) of Black gram

Treatments	*Plant population*						*Plant height (cm)*								
	Initial			*Final*			*30 DAS*			*60 DAS*			*At harvest*		
	2022-23	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*
Bio-fertilizer levels															
Control	56.50	55.375	55.9375	47.00	46.33	46.665	15.30	15.60	15.45	30.88	31.50	31.19	34.63	35.30	34.965
Rhizobium inoculation	57.50	56.35	56.925	47.80	47.10	47.45	15.80	15.70	15.75	34.40	34.28	34.34	38.55	38.40	38.475
PSB inoculation	58.75	57.58	58.165	48.55	47.85	48.2	15.40	16.10	15.75	33.60	35.08	34.34	37.65	39.33	38.49
Rhizobium with PSB inoculation	59.75	58.55	59.15	49.45	48.75	49.1	15.90	16.20	16.05	35.15	35.83	35.49	39.40	40.18	39.79
SE(m)+	1.334	1.327	1.3305	0.956	0.845	0.9005	0.340	0.353	0.3465	0.606	0.687	0.458	0.840	0.790	0.789
CD (p = 0.05)	3.854	3.833	5.770	2.762	2.440	3.982	0.983	1.020	1.493	1.752	1.983	1.295	2.425	2.281	2.280
Phosphorus levels (kg ha^{-1})															
Control	57.50	56.35	56.925	47.70	47.03	47.365	15.10	15.40	15.25	30.40	31.00	30.7	34.10	34.78	34.44
15	57.25	56.13	56.69	47.70	47.00	47.35	15.40	15.70	15.55	33.20	33.88	33.54	37.20	37.95	37.575
30	58.75	57.58	58.165	48.80	48.10	48.45	15.90	16.20	16.05	34.80	35.48	35.14	39.00	39.78	39.39
60	59.00	57.80	58.4	48.60	47.90	48.25	16.00	16.30	16.15	35.63	36.33	35.98	39.93	40.70	40.315
SE(m)+	1.334	1.327	1.3305	0.956	0.845	0.9005	0.340	0.353	0.3465	0.606	0.687	0.458	0.840	0.790	0.789
CD (p=0.05)	3.854	3.833	5.770	2.762	2.440	3.982	0.983	1.020	1.493	1.752	1.983	1.295	2.425	2.281	2.280

Table 2: Effect of bio-fertilizers and phosphorus levels on number of branches $plant^{-1}$ and number of nodules $plant^{-1}$ of black gram at different stages

Treatments	*Number of branch $plant^{-1}$*									*Number of nodules $plant^{-1}$*								
	30 DAS			*60 DAS*			*At harvest*			*30 DAS*			*60 DAS*			*At harvest*		
	2022-23	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*
Bio-fertilizer levels																		
Control	4.08	4.18	4.13	9.60	9.80	9.7	10.55	10.75	10.65	49.20	50.18	49.69	34.38	35.08	34.73	10.60	10.80	10.7
Rhizobium inoculation	4.50	4.60	4.55	10.73	10.93	10.83	11.78	12.00	11.89	55.05	56.15	55.6	38.50	39.30	38.9	11.98	12.23	12.105
PSB inoculation	4.65	4.75	4.7	10.98	11.18	11.08	12.13	12.38	12.255	53.88	54.95	54.415	36.88	37.58	37.23	11.43	11.65	11.54
Rhizobium with PSB inoculation	4.83	4.93	4.88	11.50	11.73	11.615	12.65	12.90	12.775	56.50	57.65	57.075	39.55	40.35	39.95	12.30	12.55	12.425
SE(m)+	0.090	0.094	0.065	0.201	0.224	0.150	0.259	0.244	0.177	1.112	1.121	0.789	0.735	0.714	0.512	0.246	0.281	0.186
CD (p=0.05)	0.260	0.272	0.184	0.582	0.646	0.425	0.747	0.704	0.502	3.211	3.237	2.232	2.122	2.062	1.448	0.710	0.812	0.528
Phosphorus levels (kg ha^{-1})																		
Control	4.00	4.10	4.05	9.30	9.50	9.4	10.23	10.43	10.33	45.68	46.58	46.13	31.90	32.55	32.225	9.88	10.08	9.98
15	4.38	4.48	4.43	10.35	10.55	10.45	11.38	11.58	11.48	52.40	53.48	52.94	36.63	37.38	37.005	11.35	11.55	11.45
30	4.68	4.78	4.73	11.18	11.38	11.28	12.30	12.55	12.425	56.55	57.68	57.115	38.83	39.58	39.205	12.05	12.30	12.175
60	5.00	5.10	5.05	11.98	12.20	12.09	13.20	13.48	13.34	60.00	61.20	60.6	41.95	42.80	42.375	13.03	13.30	13.165
SE(m)+	0.090	0.094	0.065	0.201	0.224	0.150	0.259	0.244	0.177	1.112	1.121	0.789	0.735	0.714	0.512	0.246	0.281	0.186
CD (p=0.05)	0.260	0.272	0.184	0.582	0.646	0.425	0.747	0.704	0.502	3.211	3.237	2.232	2.122	2.062	1.448	0.710	0.812	0.528

The data suggests that phosphorus is crucial for optimal nodulation and nitrogen fixation in legumes. Specifically, the highest number of nodules per plant was observed with phosphorus treatment, showing significant increases of 60.00, 61.20 and 60.60 nodules per plant at 30 days after sowing (DAS) across the years 2022-2023 and 2023-2024, as well as in pooled results. The following figures, Figs 1 (A, B and C), present in methodological data. This underscores phosphorus's essential role in enhancing nodulation and subsequent plant development treatment T_{16} consistently produced the highest number of nodules per plant in both individual years and the combined data. These findings are presented in (Table 2) it's important to note that the results are in alignment with the findings reported by (Kumar *et al.,* 2018 and Jangir *et al*., 2017). This might be due to more solubility of phosphorus, which increased the availability of phosphorus to plant. There was enough photosynthesis to support metabolic activity the formation of nodule in greater numbers. Similar results on such character have been reported by (Tiwari *et al*., 2022; Rekha *et al.,* 2018 Bhadauria *et al.,* 2019; Veer *et al*., 2022; Rani *et al*., 2016; and Venkatarao *et al.,* (2017).

Number of pods plant^{-1}

When the major effect of the *Rhizobium* with PSB inoculation to seeds was examined, it was discovered that there were more pods in plant^{-1} than usual changed ($p = 0.05$) accordingly mean value over treatment. Additionally, the analysis of variance revealed that the plant strains recorded the greatest mean value in T_{16} (60 kg ha^{-1}+ *Rhizobium* with PSB inoculation). Highest plant pod per plant (68, 69.35 and 68.67 pod plant^{-1}) in both year and pooled results, respectively, comparing the number of pods to the control (60.25, 61.45 and 60.85 plant^{-1}). 60 DAS When phosphorus was applied, compared to control plots, more pods were produced per plant and the highest number of pods per plant (68.00) was noted at a phosphorus dose of 60 kg ha^{-1}. Superior in a big way to control. A minimum number of pods per plant observed (56.90, 58.05 and 57.47 pod plant^{-1}) were noted as being under control. (Sahu *et al*., 2019) suggested enhancing efficient stages of crop, such as the number of pods plant^{-1}, the interaction impact of *Rhizobium* and PSB inoculation to the seeds and different phosphorus levels was not statistically significant. The plant strains recorded the greatest mean value in bio-fertilizer (8.28, 8.45 and 8.36 seed pods^{-1}), compared to the control (7.48, 7.63 and 7.55 seeds pod^{-1}) in pooled results of two years. Phosphorus application increased the number of seeds pod^{-1}, and the highest number of seeds plant^{-1} (8.40, 8.6 and 8.5 seeds pods^{-1}) was noted at a phosphorus dose of 60 kg ha^{-1}. Superior in a big way to control. (7.10, 7.20 and 7.15 seeds pod^{-1}) in pooled results of two years of the minimum quantity of seeds was noted under monitoring. The findings were backed up by the results of (Kant *et al*., 2016; Diwakar*et al*., 2021; Joharika *et al.,* 2023; Swamy *et al.,* 2020 and Nissa *et. al.,* 2017).

(A) (B) (C)

Fig. 1: Effect of Rhizobium, PSB and Phosphorus on Black Gram: (A) Black Gram Crop (B) Black Gram without Rhizobium & PSB (C) Black Gram with Rhizobium & PSB

Test Weight of 1000 grains

The Table 3 indicates that different treatments had minimal effects on the 1000-grain weight. The highest grain weights were observed with *Rhizobium* and PSB inoculation, showing values around 38.33 to 38.59. Plants with no treatments (control) had slightly lower grain weights, ranging from 37.98 to 38.24. Phosphorus application at 60 kg ha^{-1} resulted in the highest grain weights, reaching up to 39.45. In summary, phosphorus fertilization improved grain weight more than other treatments, while control plants had the lowest weights.

Grain yield (q/ha)

According to data on grain yield presented in Table 3, several treatments had a discernible effect on the test crop grain output. The data clearly show that *Rhizobium* with PSB inoculation treatment had the highest grain yield (12.70, 12.96 and 12.83 q ha^{-1}) under the bio-fertilizers levels of both years. This was considerably higher than the therapy under control.

Grain yield after phosphorus treatment as compared to control plots, and the highest grain yield (12.80, 11.84 and 12.32 q ha^{-1}) grain yield recorded during the year 2022-2023 and 2023-2024 and in pooled results. was seen at a phosphorus dosage of 60 kg ha^{-1} under treatment T_{16} (60 kg ha^{-1}+ *Rhizobium* with PSB inoculation). Substantially better than the control. Under supervision, a minimum grain production of (10.20, 10.40 and 10.3 q ha^{-1}) was found. For grain yield, the interaction between *Rhizobium*, PSB inoculation, and phosphorus level was not important. These results are in agreement with the findings of earlier research workers by (Meena *et al.,* 2022 and Jayshree *et al.,* 2021).

Straw Yield (q/ha)

The data indicates that treatments involving Rhizobium and PSB inoculation resulted in the highest straw yields, with values of (25.65, 25.85 and 25.75 q ha^{-1}) across two years and pooled results. These treatments performed significantly better than the un-inoculated control. Additionally, phosphorus application increased straw yield compared to control plots, with the highest yields of 25.81, 26.03, and 25.92 q ha^{-1} observed with a phosphorus dose of 60 kg ha^{-1} combined with Rhizobium and PSB inoculation (T_{16}). Overall, the treatments with phosphorus and inoculation yielded more than the minimum straw yields of 20.83 and 21.00 q ha^{-1} observed under standard conditions. (Shah *et al.,* 2022 and Khan *et al*., 2017) The results showed that the plant PSB and *Rhizobium* inoculations had significantly higher growth, yield, and nutritional quality compared to the inoculation seed. There were more nodules on the inoculated seed., more leaves, and tiller stems. They also produced more pods and grains, and the grains had a higher protein content.

Table 3: Effect of bio-fertilizers and phosphorus levels on yield attributes and harvest index of Black gram

Treatments	Yield attributes									Yield (q/ha) and Harvest Index (%)								
	Number of pods $plant^{-1}$			Number of grain $plant^{-1}$			1000- grain weight			Grain yield (q/ha)			Straw yield (q/ha)			Harvest index (%)		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Bio-fertilizer levels																		
Control	60.25	61.45	60.85	7.48	7.63	7.555	37.98	38.24	38.11	10.49	10.70	10.595	21.35	21.55	21.45	32.91	33.17	33.04
Rhizobium inoculation	64.1	65.4	64.75	7.93	8.1	8.015	38.18	38.44	38.31	11.51	11.74	11.625	23.39	23.57	23.48	32.98	33.24	33.11
PSB inoculation	62.15	63.38	62.765	7.68	7.85	7.765	38.08	38.34	38.21	12.31	12.56	12.435	24.89	25.08	24.985	33.09	33.36	33.225
Rhizobium with PSB inoculation	66.78	68.1	67.44	8.28	8.45	8.365	38.33	38.59	38.46	12.70	12.96	12.83	25.65	25.85	25.75	33.11	33.38	33.245
SE(m)+	1.156	1.205	0.835	0.133	0.154	0.101	0.844	0.793	0.579	0.184	0.188	0.131	0.402	0.414	0.288	0.689	0.727	0.708
CD (p=0.05)	3.34	3.481	2.362	0.384	0.444	0.287	2.437	2.292	1.638	0.531	0.544	0.372	1.162	1.195	0.816	1.991	2.099	1.0495
Phosphorus levels (kg ha^{-1})																		
Control	56.9	58.05	57.475	7.1	7.2	7.15	36.95	37.21	37.08	10.20	10.40	10.3	20.83	21.00	20.915	32.87	33.13	33
15	62.75	64	63.375	7.75	7.93	7.84	37.65	37.91	37.78	11.60	12.66	12.13	25.11	25.32	25.215	33.07	33.33	33.2
30	65.63	66.93	66.28	8.1	8.3	8.2	38.78	39.05	38.915	12.41	11.84	12.125	23.52	23.71	23.615	33.03	33.29	33.16
60	68	69.35	68.675	8.4	8.6	8.5	39.18	39.45	39.315	12.80	11.84	12.32	25.81	26.03	25.92	33.13	33.40	33.265
SE(m)+	1.156	1.205	0.835	0.133	0.154	0.101	0.844	0.793	0.579	0.184	0.188	0.131	0.402	0.414	0.288	0.689	0.727	0.708
CD (p=0.05)	3.34	3.481	2.362	0.384	0.444	0.287	2.437	2.292	1.638	0.531	0.544	0.372	1.162	1.195	0.816	1.991	2.099	1.0495

Harvest Index (%)

The maximum harvest index was recorded with the application of 60 kg P_2O_5 ha^{-1} (33.13, 33.40 and 33.26%) pooled data observed in the year 2022-2023 and 2023-2024 individual who was at par with 30 kg P_2O_5 ha^{-1} and in bio-fertilizer PSB + *Rhizobium* have got maximum and in treatment combination T_{16}- 60 kg P_2O_5 + PSB + *Rhizobium* which was statistically at par with T_{15}- 30 kg P_2O_5 + PSB + *Rhizobium* and significantly superior over rest of the treatments. The findings of earlier research workers (Kumar *et al.,* 2014 and Rao *et al.,* 2023) observed slight improvement in see due to combined inoculation of Rhizobium. Further, higher values of harvest index observed phosphorus with rhizobium +PSB inoculation meant the analysis of more photosynthesis and their translocation the seed. The yield attributes viz. pod per plant and seeds per pod showed very little improvement in rhizobium + PSB inoculation than inculcation separately.

Conclusion

Based on the study, the combination of Rhizobium, PSB, and 60 kg P_2O_5 ha^{-1} (T_{16}) demonstrated superior growth and yield characteristics in black gram. It showed maximum plant population, height, branches per plant, nodules per plant, yield attributes, and harvest index. This treatment, along with T_{15}, effectively reduced phosphorus fertilizer requirements and enhanced native phosphate availability. Further trials are recommended to validate these findings, based on experiments conducted during 2022–2024 with black gram variety Azad U-3.

Acknowledgments

The authors and co-authors are greatly appreciative to writing the research paper and the Integral Institute of Agricultural Science and Technology (IIAST) for their laboratory facilities support for the research work and for providing the manuscript communication number (MCN) IU/R & D/2024-MCN0002515. Thankful for the support of from research station and departments in providing meteorological data.

Authors Contribution

Research planning of study, review and editing of Dr. Sandeep Kumar Diwakar Conceptualization of idea & supervision of the study. Assistant Professor and Review editing of Krishna Kumar and correction as per suggestion from reviewer and editor correction as per suggestion from reviewer and editor. S.K.D and S.K. conceptualization of idea and writing the original draft of manuscript and collection of review literature and compilation.

Conflict Of Interest

The author declares that there is no conflict of interest.

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