RESEARCH ARTICLE

Impact of Bio Fertilizer Levels and Phosphorus Nutrient Performance in Black Gram (*Vigna mungo* L. Hepper) Under Sustainable Agriculture

Dharam Veer, Khalid Habib* and Saba Siddique

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Abstract

The field study conducted at Departmental Research Farm, Integral University, Lucknow, evaluated the impact of biofertilizer levels and phosphorus nutrient on black gram (*Vigna mungo* L. Hepper) during the *Kharif* seasons of 2022-2023 and 2023-2024. The application of 60 kg P_2O_5 ha^{-1} resulted in the highest chlorophyll content (2.42 mg/g), protein content (22.84%), and carbohydrate content (59.62%) in black gram. The soil pH was recorded as 7.66, electrical conductivity (EC) as 0.26 dSm-1, and organic carbon (OC) as 0.39%, indicating favourable soil conditions. Significant increases were also observed in nitrogen (124.8), phosphorus (19.13) and potassium (285.76) levels (as kg per hectare) due to different treatments across both years. The biofertilizer levels with 60 kg P_2O_5 ha^{-1}, recorded maximum grain and straw yields, biological yield, and harvest index. It also resulted in higher gross returns, net returns, and benefit-cost ratio treatment T_{15} followed closely in performance. The study underscores the effectiveness of combining adequate phosphorus fertilization (specifically 60 kg P_2O_5 ha^{-1}) with appropriate biofertilizer levels (especially PSB + Rhizobium) for maximizing yield and economic returns in black gram cultivation under sustainable agriculture practices. These findings provide valuable insights for optimizing nutrient management strategies in similar agricultural contexts.

Keywords: *Rhizobium*, *PSB*, Phosphorus, Black gram and Yield.

Highlights

The influence of bio-fertilizer levels on phosphorus enhancing nutrient performance in black gram cultivation.

The combined application of biofertilizers and phosphorus nutrients appears to have a synergistic effect, significantly enhancing black gram growth and development.

Evaluates the impact of bio-fertilizer treatments on microbial population and soil health in sustainable agriculture practices.

Assesses the potential of bio-fertilizers and phosphorus to enhance sustainability in black gram production.

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Introduction

Crop development is aided by living microorganisms known as bio-fertilizers. They can help maintain the soil's fertility, nutrient availability, and higher yields from agriculture. Two typical biological fertilizers used for black gram are vesicular-arbuscular mycorrhizal fungus (VAM) and phosphorus-solubilizing bacteria (PSB). In the framework of sustainable agriculture, this study investigates the effects of soil phosphorus nutrient availability and biofertilizer levels on black gram yield. It is planted in Uttar Pradesh over an area of 6.99 lakh ha^{-1}, producing 2.19 lakh tonnes and 501 kg per ha^{-1} (Anonymous, 2022). Black gram contains about carbohydrate 60% and fat 1.3% reached of phosphoric acid. Black gram contributes 13% in the total pulse area and 10% to the total pulse production of India. It is a short-duration pulse crop that contains 25 percent protein of high digestibility and has an appreciable amount of riboflavin and thiamine (Lokhande 2018). The results showed that the application of P and biofertilizer significantly increased the output of black gram. The concurrent use of 60 kg P_2O_5 ha^{-1}. A study stated that the combined application of phosphorus-solubilizing bacterial strain and bio-organic phosphate effectively enhanced the grain yield by about 54.3 and 83.3%, respectively. They also enhanced the population of phosphorus-solubilizing bacteria, organic matter, and phosphorus content in the soil, resulting in a higher wheat yield under dry conditions with a limited fertilization input by Bilal *et al.* (2021). These acids cause the pH to drop and dissolve phosphates in their bound forms. A few hydroxyl acids can form chelates with iron and calcium, which can effectively solubilize and use phosphates, according to (Venkatarao *et al.*, 2017). The ability of microorganisms to convert insoluble phosphorus to a soluble form, like orthophosphate, was an important trait in plant growth-promoting bacteria for increasing plant yields. The inoculation of P-solubilizing microorganisms was an efficient technique because it can increase phosphorus availability in the soil (Sanjotha and Manawadi, 2016).

Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Lucknow, Uttar Pradesh, India.

***Corresponding author:** Khalid Habib, Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Lucknow, Uttar Pradesh, India., Email: khalidh@iul.ac.in

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Materials And Methods

A field study was conducted at Agronomy Research Farm Integral Institute of Agricultural Science and Technology (IIAST), Integral University, Lucknow. During *kharif* season 2022-2023 and 2023-2024 to, evaluate the impact of biofertilizer levels and phosphorus nutrient performance in black gram (*Vigna mungo* L. Hepper) under sustainable agriculture. The experiment consists of 16 treatment combinations with some phosphorus levels (Control, 15, 30, 60 kg P_2O_5 ha^{-1}) and biofertilizer (control, PSB, *Rhizobium*, PSB + *Rhizobium*), which were laid out in factorial randomized block design with three replications. There are 16 treatments *viz.* 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*), 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). and Each plot is 3.0 × 4.0 (12 m^2) in size. 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 15 kg/hac seed rate. The economics of various treatments was calculated by converting the total yield (grain + straw) into money value. The cost of cultivation was computed on the prevailing market of expenditure. Net income was calculated by the following formulae: Net income (Rs. ha^{-1}) = Gross income (Rs. ha^{-1}) - cost of cultivation (Rs. ha^{-1}). The benefit-cost ratio was calculated by dividing the net return by the cost of cultivation of the individual treatment combination. The data recorded on various parameters were subjected to statistical analysis following the analysis of variance technique and were tested at 5% significance level to interpret the significant differences. Weeding, watering, and insecticide spraying during cross-cultural activities were carried out when necessary. The yield, nutritional content and absorption, and physio-chemical parameters were noted at the appropriate phases.

Results And Discussion

The effect of bio-fertilizers and phosphorus levels on quality attributes of black gram

The chlorophyll content (mg/g), protein content (%), and carbohydrates content (%) in biofertilizer levels *Rhizobium* with PSB inoculation exhibited a remarkable increase, with chlorophyll levels reaching (2.37, 2.39 and 2.38 mg/g), (22.68, 22.86 22.77%) and (59.10, 59.57 and 59.34%) in the 2022-2023 and 2023-2024 year and the pooled data as presented in (Table 1) emphasized the significant impact of bio-fertilizer levels. Interestingly, it was the phosphorus level, specifically treatment T_{16} involving the application of (60 kg ha^{-1} P_2O_5), which demonstrated the most substantial effect. The chlorophyll content (mg/g), protein content (%) and carbohydrate content (%) in this treatment registered at (2.41, 2.43, and 2.42 mg/g), (22.75, 22.93 and 22.84%) and (59.38, 59.85 and 59.62%) with the pooled data in both year, showcasing a consistently high level of chlorophyll production. Remarkably, this performance

Table 1: The effect of bio-fertilizers and phosphorus levels on the quality attributes of black gram grown in Lucknow during 2022-23 and 2023-24 under wet conditions

Treatments	*Quality attributes*								
	Chlorophyll content (mg/g)			*Protein content (%)*			*Carbohydrates content (%)*		
	2022-23	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*
Bio-fertilizer (BF)									
Control	2.16	2.18	2.17	22.25	22.43	22.34	58.03	58.49	58.26
Rhizobium inoculation	2.27	2.29	2.28	22.30	22.48	22.39	58.28	58.74	58.51
PSB inoculation	2.32	2.34	2.33	22.58	22.76	22.67	58.88	59.35	59.12
Rhizobium with PSB inoculation	2.37	2.39	2.38	22.68	22.86	22.77	59.10	59.57	59.34
SE(m)±	0.04	0.04	0.0283	0.50	0.52	0.358	1.11	1.18	0.809
CD (p = 0.05)	0.12	0.12	0.12	1.437	1.488	2.181	3.204	3.404	4.806
Phosphorus levels (kg ha^{-1}) (P)									
Control	2.11	2.13	2.12	22.08	22.26	22.17	57.60	58.06	57.83
15	2.32	2.34	2.33	22.58	22.76	22.67	58.90	59.37	59.14
30	2.27	2.29	2.28	22.40	22.58	22.49	58.40	58.87	58.64
60	2.41	2.43	2.42	22.75	22.93	22.84	59.38	59.85	59.62
SE(m)±	0.04	0.04	0.0283	0.50	0.52	0.358	1.11	1.18	0.809
CD (p = 0.05)	0.12	0.12	0.080	NS	NS	NS	NS	NS	NS

was both highly non-significant at par when compared to the control group. These findings are consistent with the results suggested by (Gebremariam *et al.,* 2021; Selvakumar *et al.*, 2012; Veer *et al.,* 2022; Sasidhar *et al.,* 2022; and Ghannam *et al.*, 2022)

The effect of bio-fertilizers and phosphorus levels on status of soil at harvest stage

The P^H, EC (dSm^{-1}), and OC (%) in biofertilizer levels, *Rhizobium* with PSB inoculation exhibited a remarkable increase, with various parameters of soil status at harvest stage reaching (7.7, 7.62 and 7.66), (0.26, 0.27 and 0.26 dSm^{-1}) and (0.4, 0.39 and 0.39%) in the 2022-2023 and 2023-2024 year and in the pooled data as presented in (Table 2) emphasized the significant impact of biofertilizer levels. Interestingly, it was the phosphorus level, specifically treatment T_{16} involving the application of (60 kg ha^{-1} P_2O_5), which demonstrated the most substantial effect. The P^H, EC (dSm^{-1}), and OC (%) in this treatment registered at (7.7, 7.62 and 7.6), (0.26, 0.27 dSm^{-1} and 0.26) and (0.4, 0.39 and 0.39%) with the pooled data in both year, showcasing a consistently high level of the different parameter of soil at harvest stage. Remarkably, this performance was both highly non-significant at par compared to the control group. These findings are consistent with results suggested by (Jangin *et al.*, 2017; Berger *et al.*, 2013; Bhadauria *et al.*, 2019; and Mohasin *et al.,* 2022).

The effect of bio-fertilizers and phosphorus levels on nutrient status of soil at harvest

The average nitrogen (kg ha^{-1}), average phosphorus (kg ha^{-1}) and potassium (kg ha^{-1}). bio fertilizer levels *Rhizobium* with PSB inoculation exhibited a remarkable increase, reaching (124.57, 124.94 and 124.76 kg ha^{-1}), (19.09, 19.17 and 19.13 kg ha^{-1}) and (284.90, 286.60 and 285.75 kg ha^{-1}) in the 2022-2023 and 2023-2024 year and in the pooled data soil status at harvest stage. These findings were consistent across both years and the pooled results at par control, as presented in (Table 3) emphasized the non-significant impact of biofertilizer levels. These findings are consistent with the results suggested by (Khuntia *et al.,* 2022; Singh *et al.,* 2022; Hakim *et al.,* 2021; and Bhadauriya *et al.,* 2019). Interestingly, it was the phosphorus level, specifically treatment T_{16} involving the application of (60 kg ha^{-1} $P_2O_{5)}$, which demonstrated the most substantial effect. The average nitrogen (kg ha^{-1}), average phosphorus (kg ha^{-1}) and potassium (kg ha^{-1}) in this treatment registered at (124.67, 125.04 and 124.86 kg ha^{-1}), (19.09, 19.17 and 19.13 kg ha^{-1}) and (284.91, 286.61 and 285.76 kg ha^{-1}) in the 2022-2023 and 2023-2024 year, showcasing a consistently high level of potassium at harvest stage. This performance was highly non-significant at par when compared to the 30 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB inoculation. These findings are consistent with the results suggested by (Chetan *et al.,* 2017; Kant *et al.*, 2017; Sood *et al.,* 2023; Jamir *et al.,* 2022; and Bhadauria *et al.*, 2019).

Economics

Data (Table 4) revealed that the maximum cost of cultivation (Rs. 37913 and 44913 ha^{-1} during 2022-2023 and 2023-2024, respectively) was incurred in the treatment T_{16}- 60 kg P_2O_5 ha^{-1} with PSB + *Rhizobium*, while the lowest cost of cultivation of system (Rs. 33736 and 40736 ha^{-1} during 2022-2023 and 2023-2024 respectively) was associated with T_1- Control + PSB. The maximum gross return was calculated in (Rs. 136497 and 133471.5 ha^{-1} and The highest net income of (Rs. 19584 and 88558.5 during 2022-2023 and 2023-2024 respectively) T_{16}- 60 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB, followed by T_{15} - 30 kg P_2O_5 ha^{-1} *Rhizobium* with PSB.

The highest grain yield of green gram. Similarly, the maximum benefit-cost ratio was also observed with T_{16} (2.60,

Table 2: The effect of bio-fertilizers and phosphorus levels on soil status at harvest grown Lucknow during 2022-23 and 2023-24 under wet conditions

Treatments	*Soil status at harvest*								
	pH			*EC (dSm^{-1})*			*OC (%)*		
	2022-23	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*
Bio-fertilizer levels									
Control	7.72	7.62	7.67	0.27	0.27	0.27	0.38	0.383	0.3815
Rhizobium inoculation	7.72	7.63	7.675	0.27	0.27	0.27	0.39	0.386	0.388
PSB inoculation	7.7	7.63	7.665	0.26	0.86	0.56	0.4	0.391	0.3955
Rhizobium with PSB inoculation	7.7	7.62	7.66	0.26	0.27	0.265	0.4	0.391	0.3955
SE(m)±	0.149	0.157	0.157	0.005	0.004	0.005	0.007	0.009	0.008
CD (p = 0.05)	0.423	0.450	0.648	0.017	0.016	0.025	0.026	0.026	0.039
Phosphorus levels (kg ha^{-1})									
Control	7.73	7.63	7.68	0.27	0.27	0.27	0.38	0.378	0.379
15	7.71	7.62	7.665	0.27	0.87	0.57	0.39	0.388	0.389
30	7.71	7.62	7.665	0.26	0.27	0.265	0.4	0.391	0.3955
60	7.7	7.62	7.66	0.26	0.27	0.265	0.4	0.393	0.3965
SE(m)±	0.149	0.157	0.157	0.005	0.004	0.005	0.007	0.009	0.008
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: The effect of bio-fertilizers and phosphorus levels on the nutrient status of soil at harvest grown Lucknow during 2022-23 and 2023-24 under wet conditions

Treatments	*Nutrient status of soil at harvest*								
	Av N (kg ha^{-1})			*Av P (kg ha^{-1})*			*Av K (kg ha^{-1})*		
	2022-23	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*	*2022-23*	*2023-24*	*Pooled*
Bio-fertilizer levels									
Control	124.04	124.41	124.23	18.93	19.08	19.01	283.47	285.17	284.32
Rhizobium inoculation	124.35	124.72	124.54	19.04	19.13	19.09	284.22	285.92	285.07
PSB inoculation	124.32	124.69	124.51	19.08	19.14	19.11	284.46	286.16	285.31
Rhizobium with PSB inoculation	124.57	124.94	124.76	19.09	19.17	19.13	284.90	286.60	285.75
SE(m)±	2.78	2.36	2.361	0.40	0.42	0.419	5.82	5.77	5.768
CD (p = 0.05)	8.040	6.820	11.45	1.165	1.211	1.77	16.801	16.660	25.13
Phosphorus levels (kg ha^{-1})									
Control	123.77	124.14	123.96	18.93	19.04	18.99	282.92	284.61	283.77
15	124.25	124.62	124.44	19.04	19.11	19.08	284.05	285.74	284.90
30	124.60	124.97	124.79	19.08	19.19	19.14	285.17	286.88	286.03
60	124.67	125.04	124.86	19.09	19.17	19.13	284.91	286.61	285.76
SE(m)±	2.78	2.36	2.361	0.40	0.42	0.419	5.82	5.77	5.768
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Cost of cultivation of black gram based on prevailing rates during 2022-23 and 2023-24 for one-hectare area

Treatment	*Cost of Cultivation (Rs.)*		*Treatment cost (Rs.)*		*Total cost of Cultivation (Rs.)*		*Gross return (Rs.)*		*Net Return (Rs.)*		*B:C ratio*		
	2022	*2023*	*2022*	*2023*	*2022*	*2023*	*2022*	*2023*	*2022*	*2023*	*2022*	*2023*	*Pooled*
T_1	33736	40736	00	00	33736	40736	89860	87765	56124	47029	1.66	1.15	1.41
T_2	33736	40736	650	650	34386	41386	98725	96450	64339	55064	1.87	1.33	1.60
T_3	33736	40736	700	700	34436	41436	105595	103153.5	71159	61717.5	2.06	1.49	1.77
T_4	33736	40736	1025	1025	34761	41761	108550	106074	73789	64313	2.12	1.54	1.83
T_5	33736	40736	788	788	34524	41524	102986	107022	68462	65498	1.98	1.58	1.78
T_6	33736	40736	1438	1438	35174	42174	112772	117112.5	77598	74938.5	2.20	1.78	1.99
T_7	33736	40736	1488	1488	35224	42224	120625	125274	85401	83050	2.42	1.97	2.19
T_8	33736	40736	1813	1813	35549	42549	124567	129139.5	89018	86590.5	2.50	2.04	2.27
T_9	33736	40736	1576	1576	35312	42312	108805	99940.5	73493	57628.5	2.08	1.36	1.72
T_{10}	33736	40736	2226	2226	35962	42962	119052	109449	83090	66487	2.31	1.55	1.93
T_{11}	33736	40736	2276	2276	36012	43012	127325	117076.5	91313	74064.5	2.53	1.72	2.13
T_{12}	33736	40736	2601	2601	36337	43337	131265	120939	94928	77602	2.61	1.79	2.20
T_{13}	33736	40736	3152	3152	36888	43888	112390	109906.5	75502	66018.5	2.04	1.50	1.77
T_{14}	33736	40736	3802	3802	37538	44538	123767	120960	86229	76422	2.29	1.72	2.00
T_{15}	33736	40736	3852	3852	37588	44588	132090	129130.5	94502	84542.5	2.51	1.90	2.20
T_{16}	33736	40736	4177	4177	37913	44913	136497	133471.5	98584	88558.5	2.60	1.97	2.29

1.97, and 2.29 pooled) followed by T_{15} (2.51, 1.90, and 2.2. pooled) during both the years 2022-2023 and 2023-2024, respectively. The minimum (1.66, 1.15, and 1.41 pooled) benefit-cost ratio was recorded in T_1 during 2022-2023 and 2023-2024, respectively. The results showed that the combined use of 60 kg P_2O_5 ha^{-1} with PSB + *Rhizobium* is more profitable in black gram cultivation (Kumar *et al.,* 2013; Bilal *et al.,* 2021; Yadav *et al.,* 2021; Rohan *et al.,* 2022; and Pongener *et al.,* 2022). Observed that the net returns and benefit-cost ratio were higher when the seed was inoculated with PSB + *Rhizobium* over control.

Conclusion

Base on this study, treatment T_{16} (60 kg ha^{-1} P_2O_5 + *Rhizobium* with PSB inoculation) emerges as highly effective in improving soil nutrient availability and physicochemical properties. It demonstrates superior results compared to other treatments, including the control, by enhancing chlorophyll content, protein, and carbohydrate levels, thereby indicating its potential for sustainable and productive black gram cultivation practices. The combined biofertilizers and phosphorus fertilization with dual seed inoculation of *Rhizobium* and PSB, stands out as an effective strategy to improve soil fertility, enhance plant nutrition, and potentially optimize agricultural productivity while minimizing environmental impacts.

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Authors Contribution

Dr. Deepak Kumar and Ashish Kumar are involved in the complete writing of the article. Deepak Kumar was also involved in the overall formatting and editing, critical revision of tables and graphs, and improvement of the article.

Conflict of Interest

The author declares that there is no conflict of interest.

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