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Impact of Rhizobium, PSB, and Phosphorus on Chickpea (*Cicer arietinum* L.) Growth and Yield in Humid South-Eastern Plains Region of Rajasthan

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Abstract:

Pulses are integral to sustainable farming systems due to their dual role in improving soil fertility and supplying dietary protein. Chickpea (*Cicer arietinum* L.), a major rabi pulse crop in India, contributes significantly to protein nutrition and soil enrichment through biological nitrogen fixation. However, declining per capita availability of pulse protein highlights the need for improved production strategies. Phosphorus deficiency and low soil organic matter in Rajasthan constrain chickpea productivity, while biofertilizers such as Rhizobium and phosphate-solubilizing bacteria (PSB) offer eco-friendly solutions.

A field experiment was conducted during Rabi 2024–25 at the Agricultural Research Farm, Career Point University, Kota, to evaluate the impact of Rhizobium, PSB, and phosphorus fertilization on chickpea growth, yield, nutrient uptake, and economics in the humid south-eastern plains of Rajasthan. The experiment, laid out in a randomized block design with different treatment combinations, showed that phosphorus application up to 30 kg P_2O_5 ha^{-1} significantly enhanced plant height, branching, nodulation, dry matter, pods per plant, seed yield, and seed protein content. Similarly, seed inoculation with Rhizobium + PSB produced synergistic effects on growth and yield attributes, nutrient uptake, and profitability compared with single inoculations and control. The combined application of bio-fertilizers with moderate phosphorus fertilization emerged as a cost-effective and sustainable approach for improving chickpea productivity and soil health in phosphorus-deficient soils.

Keywords: Chickpea, Phosphorus fertilization, growth and yield, nutrient uptake, bio-fertilizers

1 Introduction:

Pulses form an essential component of farming systems worldwide due to their vital role in maintaining soil health and productivity. They are incorporated into crop rotations as main crops, catch crops, cover crops, green manure, and intercrops practices that sustain soil biological activity and fertility. Pulses also serve as a major source of dietary protein for large populations. However, the per capita availability of pulse protein has been declining sharply. In 2019, the availability was only 42 g per capita per day far below the Indian Council of Medical Research (ICMR) recommended minimum of 84 g contributing to malnutrition amidst a growing population (Anonymous, 2020). This underscores the urgent need to enhance pulse production to meet the rising protein demand.

Among pulses, chickpea (*Cicer arietinum* L.) is one of the most important rabi crops, valued for its rich nutrient profile, including iron, niacin, vitamin C, and B-complex vitamins. Its leaves contain malic acid, which aids in gastrointestinal health and blood purification. In India, chickpea cultivation spans 7.84 million hectares with an average productivity of 798 kg ha^{-1}, yielding an estimated 11.02 million metric tonnes (Anonymous, 2019–20). Rajasthan ranks as the second-largest producer after Madhya Pradesh, with 12.60 lakh hectares under cultivation, producing 9.80 lakh tonnes at an average productivity of 778 kg ha^{-1} (Anonymous, 2019–20).

Rajasthan's soils are typically low in organic matter and nitrogen. The use of biofertilizers has proven effective in enhancing fertilizer efficiency under such conditions. In particular, Rhizobium inoculation increases the population of beneficial microbes in the rhizosphere, thereby improving biological nitrogen fixation and promoting plant growth. Studies show that Rhizobium-inoculated plots produce higher seed yields than uninoculated controls. Moreover, Rhizobium works symbiotically with legume roots, improving soil fertility and offering a cost-effective alternative to synthetic nitrogen fertilizers.

Phosphorus, a crucial plant nutrient, is largely present in insoluble forms, limiting its direct uptake by plants. Only about 25% of water-soluble phosphate applied in a season is absorbed by crops, while the remainder becomes unavailable by converting into insoluble forms (Verma,1993). To address this challenge, phosphorus-solubilizing microorganisms (PSM) are introduced into the soil to release phosphate from insoluble sources, desorb fixed phosphates, and improve the efficiency of phosphatic fertilizers (Gaind & Gaur, 1991). Phosphorus-

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solubilizing bacteria secrete organic acids that solubilize unavailable phosphorus, making it accessible to plants.

Low phosphorus availability is a major factor limiting productivity in phosphorus-deficient areas. Although chickpea is capable of fixing atmospheric nitrogen through symbiosis with Rhizobium, phosphorus remains a critical nutrient for its growth and yield. Despite its importance, research on chickpea nutrition particularly phosphorus management has been relatively limited. Phosphorus is indispensable for forming plant cell structures such as mitochondria, chloroplasts, and cell membranes. It also plays a vital role in the synthesis of nucleotides, nucleic acids, coenzymes, and high-energy compounds like ADP and ATP, which drive plant metabolic processes. For legumes, adequate phosphorus supply is even more crucial than nitrogen because efficient nitrogen fixation depends on healthy root systems and active nodulation both promoted by phosphorus. Adequate phosphorus enhances root development, nodulation, growth, yield, crop quality, and disease resistance. Its benefits extend beyond the current crop, enriching soil nitrogen levels and improving the productivity of subsequent non-legume crops. Phosphorus also supports energy transfer, carbohydrate and fat metabolism, and cellular respiration. By stimulating cell division and early root formation, it improves plant vigor and reduces lodging risk. Thus, phosphorus management is essential for achieving higher productivity and quality while maintaining soil health for future cropping.

2. Review of Literature:

The study entitled "Impact of rhizobium, PSB, and Phosphorus on Chickpea (*Cicer arietinum* L.) Growth and Yield in Humid South-Eastern Plains Region of Rajasthan" was conducted at the Agricultural Research Farm, Career Point University, Kota.

2.1 Effect of Phosphorus:

Plant Growth:

Several studies have consistently shown that phosphorus application improves chickpea growth parameters such as plant height, number of branches, leaf area index (LAI), dry matter accumulation, nodulation, and nodule dry weight. Significant improvements have been reported up to 60 kg P_2O_5 ha^{-1}, with some responses observed even at higher doses (Sharma *et al*. 1995).

2.2 Yield and Yield Attributes:

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Application of phosphorus markedly increases pods per plant, seeds per pod, test weight, and grain and straw yields of chickpea. Most studies observed significant responses up to 40–60 kg P_2O_5 ha^{-1}, though responses often plateau beyond this level (Kumpawat & Manohar 1994; Meena *et al*. 2001).

2.3 Nutrient Content and Uptake:

Phosphorus fertilization significantly enhances N and P uptake as well as protein content in chickpea seeds. Uptake generally increases with P levels up to 60–80 kg P_2O_5 ha^{-1}, improving seed quality and soil nutrient status (Singh *et al*. 1997; Meena *et al*. 2004).

2.4 Effect of Biofertilizers:

Growth Attributes:

Seed inoculation with Rhizobium, PSB, or their combination significantly improves chickpea growth enhancing plant height, number of branches, LAI, nodulation, and dry matter accumulation compared with uninoculated control. Dual inoculation (Rhizobium + PSB) generally outperforms single inoculations (Shivakumar *et al*. 2004).

2.5 Yield and Yield Attributes:

Combined inoculation with Rhizobium + PSB increases pods per plant, seeds per pod, test weight, grain and straw yields of chickpea over uninoculated control. In many cases, dual inoculation with moderate P fertilization achieves yields comparable to higher P levels without inoculation (Shinde & Saraf 1994; Meena *et al*. 2001; Singh *et al*. 2006).

2.6 Nutrient Content and Uptake:

Seed inoculation with Rhizobium + PSB significantly enhances nitrogen and phosphorus uptake and improves seed protein content and quality attributes. This effect is consistently reported across chickpea, lentil, and pea crops (Meena 1997; Jat & Ahalawat 2004; Thenua *et al*. 2010).

3. Materials and Methods:

The field experiment entitled "Impact of Rhizobium, PSB, and Phosphorus on Chickpea (*Cicer arietinum* L.) Growth and Yield in Humid South-Eastern Plains Region of Rajasthan" was conducted during the Rabi season of 2024–25 at the Agricultural Research Farm, Career Point University, Kota.

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3.1 Site and Soil:

The experimental farm lies in the Humid South-Eastern Plain Zone (Zone V) of Rajasthan at 25°11′N latitude, 75°54′E longitude and 273 m MSL, about 40 km from Kota railway station. The soil was clay-loam, alkaline, low in organic carbon and nitrogen, medium in phosphorus, and high in potassium. Composite soil samples (0–15 cm) were analyzed before sowing.

3.2 Weather:

During crop growth, weekly mean maximum temperatures ranged from 22.9–41.3°C and minimum from 3.5–23.3°C; mean relative humidity was 69.18% with 0.3 mm rainfall recorded during the 50th meteorological week. Weather data were obtained from the Meteorological Observatory, Ummedganj, Kota.

3.4 Experimental Design and Treatments:

The experiment was laid out in a Randomized Block Design with three replications. Treatments consisted of different combinations of Rhizobium, phosphate-solubilizing bacteria (PSB), and phosphorus levels.

3.5 Crop and Agronomic Practices:

Chickpea variety GNG-663 (semi-spreading, wilt and pod borer tolerant, 150 days duration, 20–24 q ha^{-1} potential yield) was sown on 2nd November 2024 at 80 kg seed ha^{-1}, 30 cm row spacing and 5 cm depth. Basal dose of 20 kg N ha^{-1} through urea and phosphorus through SSP as per treatments was applied. Seeds were inoculated with Rhizobium and PSB as per treatment. Standard field operations were followed: cross-ploughing, planking, thinning at 20 DAS, manual weeding at 30 and 45 DAS, three irrigations through sprinkler system, and timely harvesting and threshing.

3.6 Observations Recorded:

Growth parameters (plant stand, plant height, branches, nodules, dry matter, chlorophyll content) were measured on five tagged plants per plot at periodic intervals. Yield attributes (pods $plant^{-1}$, seeds pod^{-1}, test weight) and yields (seed, straw, biological) were recorded at harvest. Harvest index was calculated as per Singh and Stoskhopf (1971).

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3.7 Chemical Analysis and Economics:

Nitrogen, phosphorus and protein content in seed and straw were estimated using standard methods and nutrient uptake computed. Net returns (₹ ha^{-1}) and benefit cost ratio were calculated from prevailing market prices of inputs and outputs to identify the most profitable treatment.

3.8 Statistical Analysis:

Data were analyzed using Analysis of Variance (ANOVA) as per Gomez and Gomez (1984). Significance was tested at 5% level and critical differences (CD) calculated accordingly.

4. Results and Discussion:

The findings of the field experiment entitled "Impact of Rhizobium, PSB, and Phosphorus on Chickpea (*Cicer arietinum* L.) Growth and Yield in Humid South-Eastern Plains Region of Rajasthan" are presented in the previous chapter. This section discusses only the significant variations observed in the data. Where possible, the results have been compared with those of earlier studies. Since information on the effect of bio-fertilizers on chickpea is limited, results from similar crops have also been considered for better understanding.

4.1 Effect of Phosphorus:

4.1.1 Growth Parameters:

Phosphorus is an essential nutrient for all living organisms. It plays a major role in energy conservation and transfer within plant cells, especially in biological energy transformations.

In this study, applying phosphorus up to 30 kg P_2O_5 ha^{-1} significantly improved plant height (at 30 DAS and harvest), dry matter accumulation per plant (at 60, 90 DAS and harvest), number of branches per plant (at 60 DAS and harvest), and number of root nodules per plant (at 40 and 60 DAS). This improvement may be due to phosphorus promoting root growth, nodule formation, and nitrogen fixation by supplying more assimilates to the roots. As the experimental soil was low in available phosphorus, application up to 30 kg P_2O_5 ha^{-1} met the crop's nutrient requirement.

Phosphorus forms part of high-energy phosphate molecules like ATP and ADP, which act as "energy currency" in plants. It also influences photosynthesis, protein and phospholipid synthesis, nucleic acid formation, membrane transport, energy transfer, and cell division. The

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higher phosphorus availability improved nutrient uptake, which in turn enhanced root and shoot growth, nodulation, plant height, branching, and dry matter accumulation. These findings are consistent with Kasturikrishna and Ahalawat (1999), Jat and Ahalawat (2004), Meena *et al*. (2004) and Thenua *et al*. (2010).

4.1.2 Yield and Yield Attributes:

Application of 30 kg P_2O_5 ha^{-1} significantly increased pods per plant, seeds per pod, seed yield, straw yield, biological yield, and 100-seed weight. Phosphorus regulates photosynthesis and carbohydrate metabolism, which are especially important during the reproductive stage.

Better growth (plant height, branches, dry matter, nodulation) under adequate phosphorus supply led to more photosynthates and nutrients for reproductive structures. This favored yield attributes such as pods per plant, seeds per pod, and test weight. These results agree with Kumpawat and Manohar (1994a), Lakpale *et al*. (2003) and Kumar and Singh (2004).

Seed yield increases were mainly due to improved growth and yield components. A positive correlation between seed yield and yield attribute further confirms the role of phosphorus in maximizing chickpea productivity. Straw and biological yields also rose because of better vegetative growth and nutrient uptake from an extensive root system. Similar findings were reported by Jat and Ahalawat (2004), Solanki and Sahu (2007) and Singh and Chauhan (2005).

4.1.3 Quality Parameters:

Protein content in seeds increased significantly with phosphorus application up to 30 kg P_2O_5 ha^{-1}. Improved root development and rhizobium activity enhanced nitrogen utilization, leading to higher seed nitrogen content. Since protein content depends on nitrogen content, phosphorus also indirectly supports protein synthesis.

4.1.4 Nutrient Content and Uptake:

Nitrogen content and uptake in seed and straw, as well as total nitrogen uptake at harvest, increased significantly with 30 kg P_2O_5 ha^{-1}. Phosphorus content in seed and straw increased up to 30 kg P_2O_5 ha^{-1}, while phosphorus uptake (seed, straw, and total) increased up to 45 kg P_2O_5 ha^{-1}. This may be due to improved rhizosphere conditions and enhanced translocation of nitrogen and phosphorus to pods and seeds. Higher yields and nutrient content together

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resulted in greater total uptake of N and P. These results agree with Bhal *et al*. (1997), Kasturikrishna and Ahalawat (1999), Jat and Ahalawat (2004) and Tiwari *et al*. (2005).

4.1.5 Economics:

Phosphorus application up to 30 kg P_2O_5 ha^{-1} produced higher net returns (₹14,293 and ₹18,290) and B:C ratios (2.33 and 2.66) compared with control and 15 kg P_2O_5 ha^{-1} respectively. This increase in net return reflects the higher seed and straw yields obtained at this rate.

4.2 Effect of Bio-fertilizers:

4.2.1 Growth Parameters:

Seed inoculation with Rhizobium, PSB, and Rhizobium + PSB significantly increased plant height, dry matter per plant (at 60, 90 DAS and harvest), number of root nodules (at 40 and 60 DAS), and branches per plant at harvest. Rhizobium + PSB inoculation showed the highest plant height at harvest. Rhizobium and PSB inoculation individually increased nodules significantly but remained statistically at par.

This improvement is linked to the enhanced nutritional environment and physiological processes promoted by microbial inoculation. Rhizobium fixes atmospheric nitrogen in association with the plant, while PSB solubilizes unavailable phosphorus by releasing organic acids such as citric, oxalic, malic, and others. Combined Rhizobium + PSB inoculation proved most effective for plant height, branches, nodules, and dry matter at almost all growth stages. Dual inoculation improves both N_2 and P status of the soil and may also produce plant growth regulators like auxins, IAA, and gibberellins. Increased nodulation could be due to close association and synergistic activities of the two microbes. These findings align with Jat and Ahalawat (2004), Shivakumar *et al*. (2004), Tyagi *et al*. (2003) and Karale and Kulkarni (2005).

4.2.2 Yield Attributes and Yield:

Seed treatment with Rhizobium, PSB, and Rhizobium + PSB significantly improved pods per plant, seed yield, straw yield, and biological yield compared with the uninoculated control. Rhizobium improved root nodulation and nutrient availability, leading to better flowering, pod formation, and seed yield. PSB helped by reducing P fixation and solubilizing

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unavailable P, which increased nutrient uptake and yield attributes. Combined inoculation had a synergistic effect, enhancing growth, yield attributes, and ultimately seed yield, similar to reports by Meena *et al*. (2001), Jat and Ahalawat (2004) and Singh *et al*. (2006).

4.2.3 Nutrient Content, Uptake and Quality:

Inoculation with Rhizobium, PSB, and Rhizobium + PSB significantly increased seed and straw N and P content, N and P uptake, and seed protein content over control. Combined inoculation recorded the highest values. Rhizobium fixed more nitrogen, improving absorption of all nutrients, while PSB released native and added phosphorus. Together, they enhanced nutrient availability and protein content. These findings match those of Meena (1997), El Sayed (1999) and Shivakumar *et al*. (2004).

4.2.4 Economics:

Seed inoculation with Rhizobium + PSB gave the highest net returns (₹22,247 ha^{-1}) over control, Rhizobium, and PSB alone. As biofertilizers are low-cost (₹10 per packet) compared with the yield benefit, both individual and combined inoculations were profitable. Dual inoculation recorded the highest B:C ratio (2.98).

Table: 1 Analysis of variance for yield attributes characters of chickpea

Treatments	d. f.	Mean sum of squares		
		Number of pods per plant	Number of seeds per pod	Test weight (g)
Replication (R)	2	3.28	0.01	0.67
Phosphorus (P)	3	189.04**	0.41**	466.94**
Biofertilizer (B)	3	110.06**	0.03	2.58**
P x B	9	0.75	0.0002	0.05
Error	30	9.59	0.03	43.97

*,**Significant at 5 and 1% level of significance, respectively.

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Table: 2 Analysis of variance for seed, straw and biological yield and harvest index of chickpea

Treatments	d. f.	Mean sum of squares			
		Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Replication (R)	2	1059.65	91487.90	73225.69	1.11
Phosphorus (P)	3	303687.85**	677525.91**	1887236.56**	5.89**
Biofertilizer (B)	3	270324.52**	305859.24**	1136565.44**	25.17**
P x B	9	16606.82	25638.48	67800.81	4.10
Error	30	8897.76	33462.56	42484.58	1.93

**Significant at 1% level of significance

Table: 3 Analysis of variance for nitrogen content, uptake in seed and straw and protein content in grain of chickpea

Treatments	d. f.	Mean sum of squares					
		Nitrogen content (%)		Nitrogen uptake (kg ha^{-1})		Total nitrogen uptake (kg ha^{-1})	Protein content in seed (%)
		Seed	Straw	Seed	Straw		

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Replication (R)	2	0.05	0.00022	6.16	6.30	0.93	1.93
Phosphorus (P)	3	0.82**	0.02144**	862.03**	108.50**	1581.14**	32.11**
Bio-fertilizer (B)	3	0.35**	0.00883**	611.79**	48.41**	1001.28**	13.86**
P x B	9	0.00	0.00001	26.38	2.68	41.51	0.00
Error	30	0.04	0.00113	17.95	2.68	23.39	1.65

**Significant at 1% level of significance

Table: 4 Analysis of variance for phosphorus content and uptake in seed and straw of chickpea

Treatments	d. f.	Mean sum of squares				
		Phosphorous content (%)		Phosphorous uptake (kg ha^{-1})		Total Phosphorous uptake (kg ha^{-1})
		Seed	Straw	Seed	Straw	
Replication (R)	2	0.0011	0.0002	0.22	0.38	0.74
Phosphorus (P)	3	0.0115**	0.0059**	13.59**	13.43**	53.94**
Bio-fertilizer (B)	3	0.0066**	0.0032**	10.51**	6.76**	33.71**
P x B	9	0.0001	0.0000	0.47	0.25	1.20
Error	30	0.0005	0.0003	0.27	0.31	0.97

**Significant at 1% level of significance

Table: 5 Analysis of variance for net returns and B: C ratio of chickpea

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Treatments	d. f.	Mean sum of squares	
		Net returns (Rs. ha^{-1})	B:C ratio
Replication (R)	2	87938.15	0.001
Phosphorus (P)	3	150091969.52**	0.85**
Biofertilizer (B)	3	141066816.52**	1.07**
P x B	9	8373734.87	0.06
Error	30	3867721.26	0.03

**Significant at 1% level of significance

5. Conclusion

The experiment revealed that the application of phosphorus up to 30 kg P_2O_5 ha^{-1} and seed inoculation with Rhizobium and PSB, individually and in combination, had a significant positive effect on plant height, number of branches, dry matter accumulation and root nodulation at various growth stages. These treatments also enhanced yield attributes such as pods per plant, seeds per pod, 100-seed weight, seed yield, straw yield and biological yield. Nutrient content and uptake of nitrogen and phosphorus in seed and straw increased notably with phosphorus application and biofertilizer inoculation. Combined inoculation with Rhizobium + PSB consistently recorded the highest nutrient content, uptake and protein content in seed. Economic analysis showed that applying 30 kg P_2O_5 ha^{-1} together with seed inoculation of Rhizobium + PSB gave the maximum net returns and the highest benefit:cost ratio, making it the most profitable treatment combination. the study indicates that for chickpea grown under the humid south-eastern plains of Rajasthan, the integrated application of 30 kg P_2O_5 ha^{-1} along with seed inoculation of Rhizobium + PSB is an effective and economical practice. This combination improves growth, yield, nutrient uptake and profitability of chickpea and can be recommended for similar agro-ecological conditions.

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