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PERFORMANCE OF BIOFERTILIZERS AND PHOSPHORUS LEVELS ON YIELD ATTRIBUTES AND YIELD OF LENTIL (*Lens culinaris* Medik.)

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ABSTRACT

A field experiment was conducted during the *Rabi* season of 2025-26 at the Crop Research Centre-I, School of Agriculture, ITM University, Gwalior, Madhya Pradesh, to evaluate the effects of biofertilizers and phosphorus levels on lentil (*Lens culinaris* Medik.). Ten treatments comprising three biofertilizer inoculations (Rhizobium, PSB, and Rhizobium + PSB) combined with three phosphorus levels (20, 40, and 60 kg P_2O_5 ha^{-1}) along with a control were evaluated in a Randomized Block Design with three replications. The application of 60 kg P_2O_5 ha^{-1} significantly enhanced yield attributes, recording the higher number of pods $plant^{-1}$ (79.13), pod length (1.75 cm), and seeds pod^{-1} (1.54). Similarly, inoculation of Rhizobium + PSB resulted in higher yield attributes, with the maximum number of pods $plant^{-1}$ (80.51), pod length (1.77 cm), and seeds pod^{-1} (1.55). The same treatment also produced the highest grain yield (1298 kg ha^{-1}), stover yield (1888 kg ha^{-1}), and biological yield (3187 kg ha^{-1}). The enhanced productivity was attributed to improved phosphorus availability, biological nitrogen fixation, nutrient uptake, and efficient translocation of assimilates. The study indicates that integrated application of Rhizobium + PSB along with 60 kg P_2O_5 ha^{-1} is an effective nutrient management strategy for improving yield attributes and productivity of lentil under the agro-climatic conditions of Gwalior, Madhya Pradesh, India.

***Keywords*:** Lentil, Rhizobium, PSB, phosphorus, yield attributes, grain yield, biological yield, biofertilizers.

Introduction

Lentil (*Lens culinaris* Medik.) is one of the most important cool-season grain legumes cultivated worldwide and serves as a major source of protein, minerals, vitamins, and dietary fibre. In India, lentil occupies a prominent position among pulse crops due to its adaptability to diverse agro-climatic conditions and its ability to improve soil fertility through biological nitrogen fixation. However, the productivity of lentil remains relatively low compared to its potential, primarily due to nutrient deficiencies and poor nutrient-use efficiency.

Phosphorus (P) is an essential macronutrient that plays a vital role in root development, energy transfer, nodulation, flowering, and seed formation in legumes. Adequate phosphorus availability enhances root growth and stimulates symbiotic nitrogen fixation, leading to improved crop growth and productivity. However, a large proportion of applied phosphorus becomes fixed in the soil, thereby reducing its availability to plants (Dhingra *et al.*, 2009). Consequently, improving phosphorus-use efficiency remains a key challenge in lentil production.

Biofertilizers such as *Rhizobium* and phosphate-solubilizing bacteria (PSB) have gained considerable attention as sustainable nutrient management tools. *Rhizobium* forms a symbiotic association with lentil roots and fixes atmospheric nitrogen, whereas PSB enhances phosphorus availability by solubilizing insoluble phosphate compounds in the soil. The combined application of *Rhizobium* and PSB has been reported to improve nodulation, nutrient uptake, growth, yield attributes, and grain yield of lentil

(Khanna and Sharma 2011; Biswas *et al.*, 2015). Integrated use of phosphorus and beneficial microorganisms can also reduce fertilizer requirements while maintaining crop productivity and profitability (Singh *et al.*, 2018).

Several studies have demonstrated that co-inoculation of biofertilizers with phosphorus fertilization significantly improves nutrient uptake, biological nitrogen fixation, and economic returns in lentil cultivation (Singh *et al.*, 2017; Dwivedi *et al.*, 2019). Nevertheless, information regarding the combined effects of phosphorus levels and biofertilizer inoculation under the agro-climatic conditions of central India is limited. Therefore, the present investigation was undertaken to evaluate the effect of different phosphorus levels and biofertilizer inoculations on growth, yield attributes, yield, and economics of lentil under the conditions of Gwalior, Madhya Pradesh.

Materials and Methods

Experimental site

A field experiment was conducted during the Rabi season of 2025-26 at the Crop Research Centre-I, School of Agriculture, ITM University, Gwalior, Madhya Pradesh, India. Geographically, Gwalior is situated at 26°13′ N latitude and 78°14′ E longitude with an altitude of approximately 211 m above mean sea level. The region experiences a subtropical climate characterized by hot summers and cool winters.

Soil characteristics

Before sowing, representative soil samples were collected from the experimental field (0-15 cm depth) and analyzed using standard laboratory procedures. The soil was sandy loam in texture with pH 7.45, electrical conductivity (EC) 0.28 dS m^{-1}, organic carbon 0.41%, available nitrogen 167.2 kg ha^{-1}, available phosphorus 16.2 kg ha^{-1}, and available potassium 372 kg ha^{-1}.

Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) comprising ten treatments with three replications. The treatments consisted of three phosphorus levels i.e. 20, 40 and 60 kg/ha and three biofertilizer inoculations i.e. Rhizobium, PSB, Rhizobium + PSB along with an absolute control.

Crop management

Certified seeds of lentil variety IPL-81 were inoculated with the respective biofertilizer cultures prior to sowing. Recommended agronomic practices were followed throughout the crop growth period. Phosphorus was applied as basal dose through an appropriate phosphorus fertilizer source at the time of sowing. All other cultural operations, including irrigation, weed management, and plant protection measures, were carried out uniformly in all plots.

Observations recorded

Five representative plants were randomly selected from each plot for recording growth and yield attributes. Growth parameters included plant height at harvest, dry matter accumulation, number of nodules $plant^{-1}$, and nodule dry weight. Yield attributes such as number of pods $plant^{-1}$, pod length, number of seeds pod^{-1}, and test weight were recorded at maturity. Grain yield and stover yield were recorded from the net plot area and converted to kg ha^{-1}. Biological yield and harvest index were calculated using standard procedures.

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for Randomized Block Design as described by Gomez and Gomez (1984). Treatment means were compared using the least significant difference (LSD) test at the 5% level of significance ($P \leq 0.05$). The statistical analysis was using agrianalyze.com.

Results and Discussion

Number of pods $plant^{-1}$

The number of pods $plant^{-1}$ increased significantly with increasing phosphorus levels, with the highest value recorded under 60 kg P_2O_5 ha^{-1} (79.13). Phosphorus plays a crucial role in energy transfer, root proliferation, flowering, and reproductive development, which ultimately enhances pod formation. Similar findings were reported by Waroda *et al.* (2024). Among biofertilizer treatments, Rhizobium + PSB inoculation produced the highest number of pods $plant^{-1}$ (80.51). The synergistic effect of biological nitrogen fixation by Rhizobium and phosphorus solubilization by PSB improves nutrient availability and plant Vigor, resulting in greater reproductive growth. Similar results were reported by Khanna and Sharma (2011).

The interaction effect was significant, and higher number of pods $plant^{-1}$ (99.73) recorded under the combined application of 60 kg P_2O_5 ha^{-1} + Rhizobium + PSB may be attributed to improved phosphorus availability, enhanced biological nitrogen fixation, better root development, and increased nutrient uptake. These factors promoted greater flowering, pod setting, and retention, resulting in higher pod production.

Similar findings were reported by Singh *et al.* (2023) and Kumar and Singh (2023).

Pod length (cm)

Pod length increased significantly with increasing phosphorus levels and biofertilizer inoculation. The maximum pod length was recorded under 60 kg P_2O_5 ha^{-1} (1.75 cm) and Rhizobium + PSB inoculation (1.77 cm). The increase in pod length may be attributed to enhanced cell division and cell elongation resulting from improved phosphorus nutrition. Phosphorus plays a vital role in ATP synthesis and metabolic activities, which promote rapid tissue development and elongation of reproductive structures. In addition, inoculation with Rhizobium and PSB improved nutrient acquisition and physiological efficiency, leading to greater accumulation and translocation of photosynthates to developing pods, thereby increasing pod size. Similar findings were reported by Sharma *et al.* (2022) and Nare *et al.* (2022).

Number of seeds pod^{-1}

The number of seeds pod^{-1} increased significantly with increasing phosphorus levels and biofertilizer inoculation. The highest number of seeds pod^{-1} was recorded with 60 kg P_2O_5 ha^{-1} (1.54) and Rhizobium + PSB inoculation (1.55). The increase in seeds pod^{-1} may be attributed to improved pollen viability, fertilization efficiency, and nutrient supply during seed development. Adequate phosphorus availability enhances ATP production and carbohydrate metabolism, which support embryo development and seed formation. Furthermore, combined inoculation of Rhizobium and PSB improves nitrogen fixation and phosphorus availability, ensuring a continuous supply of nutrients during the reproductive phase and reducing flower and ovule abortion. This ultimately results in a greater number of seeds per pod. Similar findings were reported by Patel *et al.* (2021) and Kumar and Singh (2020).

Test weight (g)

Although test weight was not significantly affected by phosphorus levels or biofertilizer inoculation, numerically higher values were recorded with 60 kg P_2O_5 ha^{-1} (27.13 g) and Rhizobium + PSB inoculation (27.30 g). The non-significant effect may be due to the greater influence of genetic factors on seed size and weight. Similar observations were reported by Gajera *et al.* (2014), who found that phosphorus and biofertilizer treatments had limited influence on test weight despite significant effects on other yield attributes. Nevertheless, improved nutrient availability may have contributed to better seed filling, resulting in slightly higher test weight values.

Grain yield (kg ha^{-1})

Grain yield was significantly influenced by phosphorus levels and biofertilizer inoculation. Among phosphorus levels, application of 60 kg P_2O_5 ha^{-1} recorded the highest grain yield (1290 kg ha^{-1}), which was significantly superior to 40 kg P_2O_5 ha^{-1} (1231 kg ha^{-1}) and 20 kg P_2O_5 ha^{-1} (1074 kg ha^{-1}). The increase in grain yield may be attributed to improved root growth, enhanced nutrient uptake, greater photosynthetic activity, and efficient translocation of assimilates towards developing seeds. Among the biofertilizer treatments, Rhizobium + PSB recorded the maximum grain yield (1298 kg ha^{-1}), owing to enhanced biological nitrogen fixation and phosphorus solubilization, which improved nutrient availability and crop productivity. Similar findings were reported by Yadav *et al.* (2022) and Nagar *et al.* (2021), who observed significant increases in grain yield of lentil under integrated phosphorus and biofertilizer management.

Table 1 : Performance of biofertilizers along with different phosphorous levels on Yield Attributes of lentil

Treatment		Yield Attributes			
		No. of pods $plant^{-1}$	Pod length (cm)	No. of seeds pod^{-1}	Test weight (g)
Phosphorus Levels (kg $ha^{-1)}$					
P_1	20 kg ha^{-1}	65.12	1.50	1.34	25.95
P_2	40 kg ha^{-1}	73.92	1.66	1.47	26.66
P_3	60 kg ha^{-1}	79.13	1.75	1.54	27.13
SE(m)±		1.42	0.04	0.03	0.59
LSD (P=0.05)		4.23	0.13	0.10	NS
Biofertilizers					
B_1	Rhizobium	70.62	1.60	1.44	26.52
B_2	PSB	67.04	1.54	1.38	25.93
B_3	Rhizobium + PSB	80.51	1.77	1.55	27.30
SE(m)±		1.42	0.04	0.03	0.59
LSD (P=0.05)		4.23	0.13	0.10	NS

Absolute Control	51.89	1.30	1.07	25.30
P x B interaction				
SE(m)±	2.47	0.08	0.06	1.03
LSD (P=0.05)	7.33	NS	NS	NS

Table 2 : Interaction effect of Performance of biofertilizers along with different phosphorous levels on no. of pods per plant of lentil

No. of pods plant^{-1}					
Treatments		**Rhizobium** (B1)	**PSB** (B2)	**Rhizobium + PSB** (B3)	**Mean**
P_1	20 kg ha^{-1}	61.65	60.68	73.03	65.12
P_2	40 kg ha^{-1}	79.93	73.07	68.76	73.92
P_3	60 kg ha^{-1}	70.28	67.37	**99.73**	79.13
Mean		70.62	67.04	80.51	72.72
SE(m)±		2.47			
LSD (P=0.05)		7.33			

Stover yield (kg ha^{-1})

Stover yield increased significantly with increasing phosphorus levels. The highest stover yield was recorded under 60 kg P_2O_5 ha^{-1} (1871 kg ha^{-1}), followed by 40 kg P_2O_5 ha^{-1} (1793 kg ha^{-1}) and 20 kg P_2O_5 ha^{-1} (1566 kg ha^{-1}). The increase in stover yield may be attributed to enhanced root growth, greater nutrient uptake, improved photosynthetic activity, and increased dry matter accumulation due to adequate phosphorus supply. Similar findings were reported by Nare *et al.* (2022). Among biofertilizer treatments, Rhizobium + PSB recorded the maximum stover yield (1888 kg ha^{-1}), followed by Rhizobium (1697 kg ha^{-1}) and PSB (1645 kg ha^{-1}). The increase in stover yield under combined inoculation may be due to enhanced biological nitrogen fixation, phosphorus solubilization, and improved nutrient absorption, which promoted vegetative growth and biomass production. Similar results were reported by Gajera *et al.* (2014).

Biological yield (kg ha^{-1})

Biological yield increased significantly with increasing phosphorus levels. The maximum biological yield was recorded under 60 kg P_2O_5 ha^{-1} (3161 kg ha^{-1}), which was significantly higher than 40 kg P_2O_5 ha^{-1} (3024 kg ha^{-1}) and 20 kg P_2O_5 ha^{-1} (2640 kg ha^{-1}). The increase may be attributed to improved crop growth, efficient utilization of nutrients, and enhanced dry matter production throughout the growing period. Adequate phosphorus nutrition improves energy transfer and metabolic activities, resulting in greater biomass accumulation. Among the biofertilizer treatments, Rhizobium + PSB recorded the highest biological yield (3187 kg ha^{-1}). The synergistic effect of Rhizobium and PSB enhanced nitrogen fixation and phosphorus availability, resulting in vigorous plant growth and increased total biomass production. Similar findings were reported by Sharma *et al.* (2022).

Harvest index (%)

Harvest index was not significantly influenced by phosphorus levels. Numerically higher harvest index (40.82%) was recorded under 60 kg P_2O_5 ha^{-1}, the differences among treatments were statistically non-significant. This indicates that phosphorus application increased both grain yield and biological yield proportionately, resulting in little variation in dry matter partitioning towards grain. Similarly, harvest index remained unaffected by biofertilizer inoculation. Numerically higher values were observed under Rhizobium + PSB (40.75%), but the differences were non-significant. The non-significant variation suggests that biofertilizers enhanced both economic yield and biomass production simultaneously without substantially altering the partitioning efficiency of assimilates between grain and vegetative parts. Similar findings were reported by Nath *et al.* (2021) and Kumar *et al.* (2022).

Table 3 : Performance of biofertilizers along with different phosphorous levels on Yield of lentil

Treatment		Yield (kg ha^{-1})			
		Grain	Stover	Biological	Harvest index (%)
Phosphorus Levels (P_2O_5) kg ha^{-1}					
P_1	20 kg ha^{-1}	1074	1566	2640	40.69
P_2	40 kg ha^{-1}	1231	1793	3024	40.71
P_3	60 kg ha^{-1}	1290	1871	3161	40.82
SE(m)±		28.95	42	71	--
LSD (P=0.05)		86.01	125	211	--
Biofertilizers					
B_1	Rhizobium	1166	1697	2863	40.74
B_2	PSB	1130	1645	2776	40.73
B_3	Rhizobium + PSB	1298	1888	3187	40.75
SE(m)±		28.95	42	71	--
LSD (P=0.05)		86.01	125	211	--
Absolute Control		834	1224	2059	40.54
A x B interaction					
SE(m)±		50	73	123	--
LSD (P=0.05)		NS	NS	NS	NS

Conclusion

Based on the findings of the present investigation, it can be concluded that inoculation of Rhizobium + PSB along with the application of 60 kg P_2O_5 recorded the higher yield-attributing characters, *viz.* number of pods plant^{-1} (80.51), pod length (1.77 cm), number of seeds pod^{-1} (1.55), grain yield (1298 kg ha^{-1}), stover yield (1888 kg ha^{-1}), and biological yield (3187 kg ha^{-1}).

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