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Influence of Different Levels of Phosphorus and Phosphate-Solubilizing Bacteria on Growth, Yield, Nutrient Content and Quality Attributes of Soybean (*Glycine max* L.)

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ABSTRACT

Background: This study evaluated the effects of phosphorus (P) fertilisation and phosphate-solubilising bacteria (PSB) on soybean performance.

Methods: The study was conducted during the *Kharif* season of 2024-25 in the Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab, to determine the growth, yield and quality parameters of Soybean (*Glycine max*) crop. The impact of different phosphorus levels (0%, 50%, 75%, 100% and 125% of the recommended dose) in seven treatment combinations involving PSB-inoculated and uninoculated treatments on morphophysiological growth parameters (plant height and dry matter accumulation, Chlorophyll content) and yield attributes (number of pods per plant, seed yield and harvest index) was investigated in a field experiment. A randomised block design with seven treatments and three replications was used.

Result: In the soil-plant system, PSB inoculation significantly increased phosphorus availability and utilization efficiency. In comparison to treatments without PSB or with lower Phosphorus levels, the results showed that the combined application of 75% or 100% of the recommended phosphorus dose with PSB significantly improved plant growth, nutrient uptake and seed yield and quality. According to the study's findings, using PSB and phosphorus fertilizer together maximizes soybean productivity and promotes sustainable nutrient management, making it a practical approach to improving crop quality and soil fertility in soybean-based cropping systems.

Key words: Biofertilizer, Growth and yield, Phosphorus-solubilizing bacteria, Soybean, Sustainable crop production.

INTRODUCTION

Soybeans (*Glycine max* L.) are essential to India's agriculture and economy and their production has increased dramatically. Beginning in the middle of the 20th century, soybean growing in India has expanded to several regions, including Madhya Pradesh, Maharashtra, Rajasthan and Karnataka. Because of its high protein content and numerous applications in food products, animal feed and industrial settings, soybeans are important. The development of high-yielding cultivars suited to local needs, advancements in agricultural practices and advantageous agroclimatic conditions are all contributing factors to the success of soybean cultivation in India. For plants to grow and develop, phosphorus is a crucial and necessary macronutrient. In terms of abundance, it ranks eighth in the crust of the planet. It's also known as the "key of life". The generation of roots, flowering, seed formation, photosynthesis, maturation and other biochemical and genetic activities of plants all depend on it for their growth. For optimal growth and reproduction, a sufficient supply of P is necessary, as no other nutrient can fulfil its duties. Insufficient phosphorus from the soil or from the right amounts of fertilizers might restrict normal plant growth. Nevertheless, it is estimated that crops only use 15-20% of the phosphorus that is supplied successfully, with the remainder being stored in forms that are difficult for plants to absorb. The organic acids secreted by PSB (Pseudomonas and Bacillus species) lower pH and dissociate phosphorus, which is fixed as calcium phosphate, increasing the amount of P available in the soil. Compared to other legume crops, soybeans have a greater need for phosphorus. By solubilizing the native phosphorus, PSB may lower the phosphorus dosage. Soybeans are a key source of high-quality forage protein for animal feed worldwide, in addition to offering people high-quality edible oil and proteins. Feed is an essential part of the productivity-raising process for cattle. High-quality feed is the most important factor in increasing animal productivity. A sustainable agricultural system is the only option to boost food crop production in a way that doesn't jeopardize human and environmental health. Legumes that fix nitrogen, like soybeans, should be a feasible crop in all kinds of cropping systems since they can efficiently

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consume atmospheric nitrogen through the process of BNF.

Grain legumes provide a high-protein dietary source that is essential to the diets of people living in tropical areas. Legumes are both protective and productive agricultural food crops that keep and replenish soil fertility because they physiologically fix a large quantity of atmospheric nitrogen (N). One of the most important grain, legume and oilseed crops in the world is soybean, or (*Glycine max* L.).

Grain legumes provide a high-protein dietary source that is essential to the diets of people living in tropical areas. Legumes are both protective and productive agricultural food crops that keep and replenish soil fertility because they physiologically fix a large quantity of atmospheric nitrogen (N). One of the most important grain, legume and oilseed crops in the world is soybean (*Glycine max* L.). In today's world of growing populations, increasing crop yield and offering high-quality nutritional supplements are vitally important. Thus, soybeans can be a nutrient-dense meal choice.

MATERIALS AND METHODS

At Lovely Professional University's Department of Agronomy farm in Phagwara, Kapurthala district, the impact of applying varying levels of phosphorus and PSB treatment on the growth, yield and quality attributes of soybean production was investigated. The field experiment was carried out in a region with a subtropical climate during the 2024-2025 kharif season. A randomised block design with seven treatments and three replications was used. The experiment was carried out in a plot that was 315 m^2 overall, with individual plots of 15 m^2 (3 m × 5 m). The farm was located at 31.243° N latitude and 75.697° E longitude, 20 kilometres from Jalandhar. The soybean variety known as SL 958 features black hilum and bright, pale yellow grains. 20.2% of its grains are oil and 41.7% are protein. It matures in roughly 142 days. On average, it produces 7.3 quintals of seed per acre. The seeds were treated with PSB for a minimum of six hours prior to planting. At 15 and 45 days after sowing , various phosphorus dosages were given. Absolute Control is at T1, 100% Phosphorus is at T2, Phosphate-solubilizing bacteria (PSB) is at T3, 50% Phosphorus + PSB is at T4, 75% Phosphorus + PSB is at T6, 100% Phosphorus + PSB is at T6 and 125% Phosphorus + PSB is at T7. Observations were recorded at 30, 60 and 90 days after sowing (DAS) and harvest-related parameters were also recorded. Five plants were chosen at random and tagged in each plot . The height of the tagged plants was measured at 30, 60 and 90 DAS using a measuring scale. At 30, 60 and 90 DAS, we measured plant height, number of branches per plant, number of nodules per plant, chlorophyll content, dry weight and yield and yield-related components. The software programs OPSTAT and SPSS were used to compute and analyze the mean values for these five plants.

RESULTS AND DISCUSSION

Growth parameters

Plant height

One important morphological trait that needs to be measured is plant height. In the current study, plant height was recorded at harvest and at 30-, 60- and 90-day intervals. Diverse treatments produced diverse results at different stages. Treatment T5 (75% P+ PSB) generated the tallest plants at 30DAS, measuring 38.78 cm, while treatment T1 (absolute control) produced the smallest plants, measuring 30.40 cm. Nonetheless, it was discovered that Treatment T5 and Treatments T4 and T6 were statistically equivalent. When 75% P and phosphorous-solubilizing bacteria were administered in treatment T5, the maximum plant height was recorded at 60 DAS. At T5, the plant measured 60.66 cm in height. In the absence of fertilizer and biofertilizers, the lowest plant height recorded was 44.71 cm (T1). Treatments T3, T4, T6 and T7 were statistically similar to treatment T5. At 90 DAS, the tallest plant (101.20 cm) was produced by treatment T6 (100% P+ PSB). At 82.60 cm, the lowest plant height was recorded with treatment T1 (absolute control) At 82.60 cm, the lowest plant height was recorded with treatment T1 (absolute control). However, T6 was found to be statistically comparable to T3, T4, T5 and T7 (Table 1). The increased plant height is due to the inoculation of

Table1: Effect of different levels of phosphorus and phosphorus-solubilizing bacteria on plant height at 30, 60 and 90 DAS.

Treatments	30 DAS	60 DAS	90 DAS
T_1	30.40^{c}±0.83	44.71^{c}±6.37	82.60^{c}±4.00
T_2	31.75^{cd}±1.79	53.27^{b}±2.34	92.80^{b}±2.80
T_3	32.14^{cd}±3.43	56.25^{ab}±3.18	96.60^{ab}±5.38
T_4	38.36^{ab}±1.69	56.67^{ab}±2.54	97.73^{ab}±3.93
T_5	38.78^{a}±1.98	60.66^{a}±1.13	98.00^{ab}±1.11
T_6	36.40^{abc}±4.44	59.12^{ab}±1.51	101.20^{a}±2.84
T_7	32.79^{bcds}±5.05	56.33^{ab}±4.77	97.13^{ab}±6.03
CD	3.16	5.82	7.31
SE(m)	1.01	1.86	2.34
CV	5.12	5.85	4.27

microorganisms, specifically Phosphorous solubilizing bacteria, which convert fixed phosphorous to soluble phosphorous, increasing P availability. The administration of phosphorus and bacteria that solubilize it may have increased plant height by improving root access to nutrients such as N, P and K, all of which are necessary for plant growth These findings were found similar with the results of Taliman *et al.* (2019); Bulgarelli *et al.* (2020). The increased plant height in treatments with PSB and phosphorus is attributed to enhanced nutrient availability, particularly phosphorus, which supports cell division and elongation. This aligns with Taliman *et al.* (2019), who reported improved growth with phosphorus supplementation. Bulgarelli *et al.* (2020) noted that PSB enhances phosphorus uptake, promoting vigorous growth. Similarly, Withers *et al.* (2005) found that integrated nutrient management with biofertilizers significantly boosts plant height by improving nutrient assimilation in soybeans.

Chlorophyll content

Throughout the experiment, measurements of chlorophyll levels were made at regular intervals of 30, 60 and 90 DAS. The chlorophyll content was shown to rise sharply from the days of sowing to the mature stage before thereafter falling. Treatment T5 had the highest concentration of chlorophyll at 30 DAS (37.33), while treatment T1 had the lowest (27.81). Statistics showed that the T4, T5 and T6 treatments were comparable. The maximum chlorophyll content at 60DAS was found in treatment T6 (35.70), while the lowest was found in treatment T1 (no fertilizers or biofertilizers applied) (28.52). It was found that treatments T4, T5 and T7 were similar to treatment T6. Treatment T1, which acted as the absolute control, had the lowest chlorophyll content (28.48), whereas treatment T6 had the highest at 90 DAS (38.01). Statistics showed that Treatments T5 and T6 were similar (Table 2). In nature, photosynthesis is the most significant chemical process. The findings of Shome *et al.* (2022) and Jakhar *et al.* (2023) support this, showing that adding phosphorus to PSB increases the amount of chlorophyll in leaves. Similar results were obtained by Jaga *et al.* (2015). The higher chlorophyll content in treatments T5 and T6 reflects improved photosynthetic capacity due to increased phosphorus availability facilitated by PSB. Shome *et al.* (2022) reported similar increases in chlorophyll with PSB application.

Number of branches per plant

At various points during the plant's growth, the number of branches per plant was recorded 30, 60 and 90 days following sowing. The treatment with the most branches per plant at 30 DAS was T5, which had 9.53, whereas the treatment with the fewest branches per plant was T1, which had 6.33. At 60 days, treatment T1 (total control) had the fewest branches (12.47), while treatment T6 (100 per cent P_2O_5+ PSB) had the most (17.60). At 90DAS, the highest number of branches was 29.87, while the lowest number of branches was produced by treatment T1 (absolute control), which yielded 23.13 (Table 3). The increased branching in treatments with PSB and phosphorus is due to enhanced nutrient uptake, which supports lateral growth. Kumar *et al.* (2020) observed similar branching improvements with biofertilizers. Shome *et al.* (2022) noted that PSB enhances nutrient availability, promoting branching.

Number of nodules per plant

Nodules are an essential component of leguminous plants that fix nitrogen from the atmosphere. PSB had a major effect on the number of root nodules on the plants. According to the findings, the root nodules started at 30 DAS, became apparent at 60 DAS, grew until 90 DAS, then declined and went dormant from maturity till harvest. The quantity of nodules caused by PSB and different phosphorus levels was recorded at 30, 60 and 90 DAS. Treatment T6 produced the highest number of nodules (19.33 per plant) at 90 DAS. The treatment T1, sometimes referred to as the absolute control, which did not employ any fertilizers or biofertilizers, had the fewest nodules (9.67). Treatment T5 and Treatment T6 were determined to be comparable after comparison (Table 4). Nitrogenase activity, metabolic processes and the development of root nodules can all be regulated with the right phosphorus fertiliser application. Rather than promoting the growth of

Table 2: Effect of different levels of phosphorus and phosphorus-solubilizing bacteria on chlorophyll content at 30, 60 and 90 DAS.

Treatments	30 DAS	60 DAS	90 DAS
T_1	27.81^{b}±3.02	28.52^{d}±0.58	28.48^{d}±0.80
T_2	28.10^{b}±2.10	32.78^{c}±0.50	33.15^{c}±1.42
T_3	34.87^{a}±0.57	33.96^{b}±0.31	33.69^{bc}±1.64
T_4	36.12^{a}±3.40	35.40^{a}±0.18	35.29^{bc}±2.18
T_5	37.33^{a}±1.50	35.47^{a}±0.50	36.01^{ab}±1.35
T_6	37.01^{a}±2.72	35.70^{a}±0.71	38.01^{a}±0.86
T_7	34.41^{a}±1.26	35.36^{a}±0.27	35.19^{bc}±0.22
CD	4.35	0.60	2.43
SE(m)	1.39	0.19	0.78
CV	7.19	0.98	3.94

rhizobia or the formation of soy nodules, phosphorus promotes growth by increasing the growth of the host plant. The phosphorus solubility and biological nitrogen fixation have been improved by the use of fertilisers in conjunction with biofertilizer, such as PSB. This increases the plants' access to nutrients, allowing them to colonize and form high-quality nodules. These findings were found to be similar with results of Bulgarelli *et al.* (2020).

Dry weight

The plants' dry weight was recorded 30, 60 and 90 days interval. Variations in dry weight were seen across all treatments. With 75% P_2O_5 of the suggested phosphorous and PSB administered, treatment T5 had the maximum dry weight at 30 DAS, 10.00 gm/plant. At 2.27 grams per plant, treatment T1, which did not apply any fertiliser or biofertilizer, had the lowest dry weight. At 60 DAS, Treatment T6 (15.50 g/plant), which received 100% P of the suggested phosphorus and PSB, had the maximum dry weight, while Treatment T1 (Absolute Control) had the lowest dry weight (5.09 g/plant). At 90 DAS, Treatment T6 (21.20 g/plant), which received 100% P of the suggested phosphorus and PSB, had the maximum dry weight, while Treatment T1 (Absolute Control) had the lowest dry weight (8.64 g/plant) (Table 5). Bulgarelli *et al.* (2020) noted that PSB enhances phosphorus uptake, promoting vigorous growth.

Number of pods per plant

One important yield factor that affects the yield is the number of pods per plant. Out of all the treatments,

Table 3: Effect of different Levels of Phosphorus and Phosphorus-Solubilizing Bacteria on branches/plant at 30, 60 and 90 DAS.

Treatments	30 DAS	60 DAS	90 DAS
T_1	$6.33^{c}\pm0.12$	$12.47^{c}\pm0.31$	$23.13^{c}\pm0.23$
T_2	$6.60^{c}\pm0.40$	$12.80^{c}\pm0.40$	$24.27^{c}\pm0.95$
T_3	$6.80^{c}\pm0.53$	$13.00^{c}\pm0.87$	$24.73^{bc}\pm0.50$
T_4	$8.20^{b}\pm0.20$	$15.07^{b}\pm1.03$	$27.33^{ab}\pm1.14$
T_5	$9.53^{a}\pm1.45$	$15.40^{b}\pm0.72$	$27.53^{a}\pm0.46$
T_6	$8.13^{b}\pm0.12$	$17.60^{a}\pm2.65$	$29.87^{a}\pm3.14$
T_7	$8.20^{b}\pm0.72$	$15.20^{b}\pm0.40$	$27.27^{ab}\pm1.36$
CD	1.19	2.17	2.69
SE(m)	0.38	0.69	0.86
CV	8.65	8.34	5.68

Table 4: Effect of different levels of phosphorus and phosphorus-solubilizing bacteria on no. of nodules.

Treatments	30 DAS	60 DAS	90 DAS
T_1	$4.67^{d}\pm2.08$	$7.33^{d}\pm2.52$	$9.67^{d}\pm2.08$
T_2	$5.00^{cd}\pm1.00$	$7.33^{d}\pm0.58$	$10.67^{d}\pm1.15$
T_3	$5.67^{bcd}\pm1.15$	$8.33^{cd}\pm1.53$	$12.33^{cd}\pm2.52$
T_4	$6.67^{abcd}\pm1.53$	$10.00^{bcd}\pm2.65$	$15.00^{bc}\pm2.00$
T_5	$8.33^{ab}\pm1.53$	$12.33^{ab}\pm2.52$	$18.33^{ab}\pm2.52$
T_6	$9.00^{a}\pm2.00$	$14.00^{a}\pm2.00$	$19.33^{a}\pm2.52$
T_7	$7.67^{abc}\pm1.15$	$11.67^{abc}\pm2.08$	$16.33^{abc}\pm2.52$
CD	1.23	1.61	2.93
SE(m)	0.39	0.51	0.94
CV	10.19	8.82	11.22

Table 5: Effect of different levels of phosphorus and phosphorus-solubilizing bacteria on dry weight.

Treatments	30 DAS	60 DAS	90 DAS
T_1	$2.27^{c}\pm0.14$	$5.09^{c}\pm0.27$	$8.64^{c}\pm0.67$
T_2	$4.21^{bc}\pm1.05$	$8.85^{b}\pm1.63$	$14.17^{b}\pm3.38$
T_3	$4.46^{bc}\pm0.75$	$9.05^{b}\pm0.75$	$14.60^{b}\pm0.49$
T_4	$5.38^{bc}\pm0.36$	$10.66^{b}\pm3.10$	$15.77^{b}\pm2.83$
T_5	$10.00^{a}\pm2.49$	$10.80^{b}\pm0.79$	$16.07^{b}\pm1.27$
T_6	$6.43^{b}\pm3.98$	$15.50^{a}\pm1.85$	$21.20^{a}\pm2.10$
T_7	$6.21^{b}\pm0.40$	$9.56^{b}\pm1.06$	$16.58^{b}\pm0.54$
CD	0.84	1.57	1.36
SE(m)	0.27	0.50	0.43
CV	8.47	8.79	4.97

treatment T6 (100% P+ PSB) produced the most pods (42.33/plant), while treatment T1 (absolute control) produced the fewest (29.67/plant). However, it was found that Treatments T5 and T7 were statistically equivalent to Treatment T6 (Table 6). The characteristics of soybean yield were significantly impacted by the fertilizer source that contained phosphorus. Sources of phosphorus fertilizer have been shown to boost soybean yields. The use of biofertilizers has reportedly increased plant yield and growth. Bacteria that solubilize phosphorous can convert insoluble phosphorous into soluble forms, like phosphate, which plants can easily absorb and use to ensure a sufficient supply for growth and reproduction. These findings were found similar to the results of (Gonyane and Sebetha, 2022; Tarekegn and Kibret, 2017; Islam *et al.*, 2017). The higher pod counts in treatment T6 are attributed to improved phosphorus availability, which supports reproductive growth. Gonyane and Sebetha (2022) reported that phosphorus enhances pod formation. Tarekegn and Kibret (2017) noted that PSB increases pod yield by improving nutrient uptake.

Number of seeds/pods

Another important yield attributing factor that affects the yield is the number of seeds per pod. Out of all the treatments, treatment T6 (100% P+ PSB) produced the most seeds per pod (4.66 seeds/pod), while treatment T1 (absolute control) produced the fewest (3.00 seeds/pod). However, it was found that Treatment T5 is statistically equivalent to Treatment T6. The results are presented in Table 6. According to reports, the use of biofertilizers has improved plant growth and yield. The increased seed count per pod in treatments T5 and T6 is due to enhanced nutrient availability, particularly phosphorus, which supports seed development. Islam *et al.* (2017) reported that phosphorus improves seed set in soybeans. Gonyane and Sebetha (2022) noted that PSB enhances seed production.

Seed yield

The ultimate economic product of the crop is its seed yield. A higher seed yield is a sign of increased output. Appropriate growth conditions and yield characteristics lead to seed yield. There were notable variations in the seed yield between the various treatment combinations in this investigation. The soybean's seed yield is positively impacted by the fertilizer's incorporation of phosphorous-solubilizing bacteria with phosphorous supplement. At 19.23 q/ha, the treatment T6 (100% P_2O_5+ PSB) produced the highest seed yield (Table 6). The absolute control treatment produced the smallest seed yield, 10.47 q/ha. Treatment T5 (75% P_2O_5 + PSB), with a seed yield of 18.53 q/ha, was reported to be statistically comparable to Treatment T6 (19.23 q/ha). Both macro and micronutrients are released as a result of the microbial breakdown process. In order to minimise the ecological effects of phosphorus and maximise crop yields, phosphorus fertiliser application technology is required. Using SSP + PSB also resulted in the highest grain yield and total phosphorus uptake. Grain and stover yield-attributable characteristics increased in tandem with the amount of phosphorus. These findings were similar to those reported by (Sarkar *et al.*, 2018; Devi *et al.*, 2012; Withers *et al.*, 2005).

Seed index

Treatment T6 (100%P + PSB) yields the highest seed index (18.40 grammes/100 seeds), followed by treatment T5 (17.35 grammes/100 seeds). Treatment T1, an absolute control, yields the lowest seed yield, 13.35 grams/100 seeds. The higher seed index in treatment T6 reflects improved seed quality due to enhanced nutrient uptake Table 6. Devi *et al.* (2012) reported that phosphorus improves seed weight in soybeans. Shome *et al.* (2022) noted that PSB enhances seed quality.

Biological yield

The total amount of biomass that a plant generates is termed as its biological yield. It comprises the yield of both seeds and straw, which contains grain, roots and leaf stems. With the various treatment combinations used in this study, a notable variation in the biological yield was noted. The highest biological yield, 55.64 q/ha, was obtained with treatment T6, which applied 100%P + PSB. Treatment T5 came in second producing 48.52 q/ha, while treatment T1 produced the lowest biological yield, 33.09 q/ha. It was discovered that the T4 and T5 treatments were

Table 6: Effect of different levels of phosphorus and phosphorus-solubilizing bacteria on yield and yield-related components.

Treatments	No. of pods/plant	No. of seeds/pod	Seed yield (q/ha)	Seed index	Biological yield (q/ha)	Harvest index
T_1	29.67^{e}±2.08	3.00^{d}±0.00	10.47^{d}±1.94	13.35^{e}±0.43	33.09^{e}±3.24	31.46^{c}±2.73
T_2	32.00^{de}±3.00	3.33^{cd}±0.57	12.00^{cd}±0.60	14.48^{de}±0.21	36.25^{de}±3.10	33.19^{bc}±1.58
T_3	35.00^{cd}±3.00	3.33^{cd}±0.57	12.67^{cd}±1.90	15.42^{cd}±0.82	38.86^{cde}±2.50	32.50^{c}±3.09
T_4	37.00^{bc}±1.73	3.66^{bcd}±0.57	16.40^{ab}±2.23	16.11^{bc}±0.30	43.68^{ab}±6.01	37.56^{ab}±1.20
T_5	40.67^{ab}±1.53	4.33^{ab}±0.57	18.53^{a}±1.50	17.35^{ab}±1.00	48.52^{b}±1.98	38.16^{a}±1.58
T_6	42.33^{a}±3.06	4.66^{a}±0.57	19.23^{a}±1.82	18.40^{a}±0.98	55.64^{a}±2.67	34.51^{abc}±1.63
T_7	39.33^{ab}±0.58	4.00^{bcd}±0.00	14.67^{bc}±2.60	16.32^{bc}±0.96	41.32^{cd}±3.29	35.31^{abc}±3.53
CD	1.42	0.89	2.52	1.32	4.96	3.77
SE(m)	2.00	0.28	0.80	0.42	1.59	1.21
CV	6.72	13.18	9.43	4.62	6.49	6.05

comparable to the T6 (Table 6). The soybean yield attributes were significantly impacted by the fertilizer source that contained phosphorus in addition to zinc. It is necessary for soybeans to absorb and use in order to properly form nodules, increase crop yield and improve crop quality. Soybean yields have been shown to increase with phosphorus fertilizer sources. In the rhizosphere, PSB biofertilizer will increase the soil's microbial activity, which will promote root growth and penetration, increasing the roots' accessibility to nutrients and water. These findings were found similar to the results of (Gonyane and Sabetha, 2022; Tarekegn and Kibret, 2017; Islam *et al*., 2017). The increased biological yield in treatment T6 is due to enhanced biomass production facilitated by PSB and phosphorus. Tarekegn and Kibret (2017) reported that phosphorus increases total biomass in soybeans. Gonyane and Sebetha (2022) noted that PSB enhances biomass production.

Harvest index

The ability of a plant to convert biomass into a commercially valuable component, like grain or seed, is represented by the term Harvest Index. The current study's different treatments had different harvest indices. The treatment T5, which applied 75% P + PSB, had the highest harvest index (38.16), while the treatment T1, which did not apply fertilizers or biofertilizers, had the lowest harvest index (31.46). However, it was discovered that treatments T4, T6 and T7 were comparable to treatment T5 (Table 6). Phosphate fertilizer has a major impact on soybeans by promoting root growth, which makes the plants more drought-tolerant, speeds up harvest and enhances seed nutrition. It has been shown that phosphorus increases the weight and quantity of root nodules and enhances the seed output of soybeans (Khanam *et al*., 2016; Barman *et al*., 2023). The higher harvest index in treatment T5 reflects efficient biomass partitioning due to improved nutrient availability. Khanam *et al.* (2016) reported that phosphorus enhances harvest index in soybeans. Barman *et al.* (2023) noted that PSB improves seed production efficiency.

CONCLUSION

The present investigation on "Response of different levels of phosphorus and PSB application on growth, yield and quality parameters of soybean" showed that integrated application of phosphorus with phosphate-solubilizing bacteria (PSB) influenced significantly the growth, yield and quality attributes of soybean. Out of the treatment combinations, the application of moderate to high phosphorus with PSB inoculation resulted in consistent improvement in plant height, number of branches, pod formation, seed yield and relevant quality traits, maximize nutrient availability and uptake efficiency, biofertilizers can be integrated with mineral nutrients, as demonstrated by the synergistic effect between chemical phosphorus and PSB. This method lessens reliance on chemical fertilizers, which improves crop productivity while also promoting sustainable soil health management. In conclusion, phosphorus and PSB together provide an agronomically and environmentally better way to increase soybean yields. Future studies should concentrate on long-term field validation and economic viability in various agroclimatic zones to encourage wider adoption of this integrated nutrient management technique.

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Author's contribution

AM carried out research work and LS helped in recording the field and lab observations. HU checked and designed the research work plan and shaped the final manuscript.

Compliance with ethical standards

Ethical issues

None.

Conflict of interest

All authors do not have any conflict of interest to declare.

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