The Pharma Innovation Journal 2023; 12(8): 347-354

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(8): 347-354

www.thepharmajournal.com
Received: 16-05-2023
Accepted: 20-06-2023

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Growth parameters, yield attributes, and yield of chickpea (*Cicer arietinum* L.) as affected by rock phosphate, poultry manure and phosphate solubilizing bacteria

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Abstract
The field experiment titled "Growth Parameters, Yield Attributes, and Yield of Chickpea (*Cicer arietinum* L.) as Affected by Rock Phosphate, Poultry manure, and Phosphate Solubilizing Bacteria" was conducted during the Rabi season of 2021-2022 at the Instructional Farm (Agronomy) of Rajasthan College of Agriculture, MPUAT, Udaipur (Rajasthan). The experiment included nine treatment combinations of phosphorus sources (Single Super Phosphate - SSP, Rock Phosphate - RP, and Poultry manure - PM) with and without Phosphate Solubilizing Bacteria (PSB), along with one control group. The experimental design was a Randomized Block Design (RBD) with nine treatments, each replicated three times. The maximum plant height (61.48 cm), root length (36.78 cm), number of pods plant^{-1} (67.62), number of seeds pod^{-1} (1.76), test weight (209.98 g), seed yield (2056.00 kg ha^{-1}), haulm yield (3113.00 kg ha^{-1}) and biological yield (5169.00 kg ha^{-1}) were obtained with application of 50% P through RP + 50% P0 through PM + PSB0 (T_9). Based on the findings, it can be concluded that the application of 50% P0 through RP + 50% P0 through PM + PSB0 (T_9) significantly enhanced the growth parameters, yield attributes, and overall yield of chickpea (*Cicer arietinum* L.). This suggests that the combined use of Rock Phosphate, Poultry manure, and Phosphate Solubilizing Bacteria can be an effective and sustainable approach to optimize chickpea production, providing valuable insights for improving agricultural practices and crop productivity in the region.

Keywords: Rock phosphate, Poultry manure, phosphate solubilizing bacteria, chickpea

1. Introduction
Pulses play significant role in human diet, and they hold a special place in Indian agriculture. It offers a diet high in protein to the nation's vegetarian population. chickpea (*Cicer arietinum* L.) belongs to *Leguminosae* family. It is also called as Bengal gram, gram, and the king of pulses. During the *Rabi* (winter) season, it is mostly grown as a rain-fed crop using stored soil moisture from the previous monsoon. Chickpea comes in different varieties, with two prominent types being Desi and Kabuli chickpea. Each type possesses distinct characteristics, making them suitable for various culinary uses and market preferences. Both varieties contribute significantly to the country's agricultural and dietary diversity (Patel *et al.*, 2020; Yadav *et al.*, 2021) [18, 25]. Chickpea cultivation holds immense importance in Indian agriculture due to its ability to fix atmospheric nitrogen, enriching the soil with this vital nutrient. As a result, chickpea serves as an essential component in crop rotation and intercropping systems, promoting sustainable farming practices and soil health. Moreover, chickpea's resilience to drought and adaptability to diverse agro-climatic conditions make it a favored choice among farmers across different regions in India (Khan *et al.*, 2019) [21]. The crop's versatility extends beyond its use as a staple food, as chickpea flour (besan) finds extensive application in traditional Indian cuisine, confectionaries, and snacks. Additionally, its protein-rich composition has garnered attention in the global food industry, leading to increased export opportunities. The continuous research and exploration of improved chickpea varieties, coupled with the adoption of innovative agricultural practices, hold the potential to further enhance chickpea production, contributing to food security and nutritional sustainability in the country. As chickpea remains an integral part of the agrarian landscape and dietary culture of India, its continued promotion and development will play a pivotal role in ensuring a prosperous and nourished population (Akhtar *et al.*, 2018; Sharma *et al.*, 2022) [28, 21].

Phosphate fertilization remains a crucial subject of agricultural research. Given its significance as the second major nutrient element essential for plant growth, its scarcity has made it one of the most intriguing and pressing research topics. Particularly in subtropical regions, phosphorus is considered the most limiting factor affecting the growth and development of legumes (Kuhad *et al*., 2011; Raghothama and Karthikeyan, 1999) [17, 19]. Phosphorus is one of the most important nutrients for plants. In chickpea, phosphorus has a sizable effect on growth, plant height, branches/plant, pods/plant and yield. Phosphorus also aids in root development and nodulation in chickpea plants. Effective phosphorus application improves nutrient and water uptake in the root system, enabling better nutrient absorption and water utilization. This, in turn, fosters healthier root growth and enhances the formation of nodules, which are essential for nitrogen fixation. Additionally, phosphorus is essential for pod filling, which eventually increases grain yield. Notably, phosphorus works in conjunction with other nutrients, particularly sulphur (S), to improve the legume's nitrogen-fixing ability. When phosphorus and sulphur are adequately supplied, they facilitate optimal conditions for nitrogen fixation by the chickpea plant, which is a vital mechanism through which legumes enrich the soil with nitrogen, benefiting subsequent crops in the rotation. The current global scenario, marked by an increasing demand for food, further underscores the importance of securing sufficient phosphorus for future decades. Food security is at stake, and addressing this issue becomes critical (Cordell *et al*., 2011) [9]. The search for innovative and sustainable solutions to ensure an adequate supply of phosphorus is imperative to meet the growing food demands and sustain agricultural productivity in the coming years.

Rock phosphate has emerged as a valuable and cost-effective alternative to traditional phosphate fertilizers. In India, abundant phosphate rock deposits offer a readily available and economical source of phosphate fertilizer for crop production. Numerous studies have demonstrated that composting phosphate rock with organic manure leads to increased crop yields and enhanced phosphorus uptake. This improvement is mainly attributed to the enhanced availability of phosphorus from the rock phosphate (Banger *et al.,* 1985). Poultry manure, being a rich organic source, holds significant potential as a valuable input for agriculture. Unlike other manures, poultry excreta contains both solid and liquid components, which prevents the loss of nutrients through urine. Uric acid or urate constitutes the most abundant nitrogen compound in fresh poultry excreta, making up 40-70% of the total nitrogen content, while urea and ammonium are present in smaller quantities (Krogdahl and Dahlsgard, 1981) [19]. Due to its high nitrogen content, Poultry manure serves as a nutrient-rich organic fertilizer for plants. However, it is important to note that the fertilizer value of manure can be reduced due to the loss of nitrogen through processes like ammonia volatilization and denitrification. These losses can limit the overall effectiveness of the Poultry manure as a fertilizer if not managed properly. Therefore, adopting appropriate management practices to minimize nitrogen loss from Poultry manure is essential to maximize its potential benefits in crop production.

Microorganisms play a crucial role in integrated agro-environmental solutions, offering promising potential in promoting sustainable agriculture. One of their key abilities is to facilitate plant growth, enhance nutrient availability, and support overall plant health. Among the various microbial species found in the soil, Bacillus, Pseudomonas, Rhizobium, Aspergillus, and Penicillium are notable examples of potential phosphate-solubilizing microbes. Among them, Bacillus megaterium has emerged as one of the most effective phosphates solubilizers. By harnessing the capabilities of phosphate-solubilizing microbes (PSMs), agricultural practices can benefit from an economical, eco-friendly, and agronomically advantageous alternative to expensive inorganic phosphate fertilizers. Numerous studies have demonstrated that inoculation with PSMs can significantly enhance crop yields by solubilizing both soil-fixed and applied phosphates (Gull *et al*., 2004) [12]. By promoting the release of phosphorus in the soil through their solubilization abilities, these beneficial microorganisms improve the nutrient availability to plants. This, in turn, leads to better nutrient uptake and utilization by crops, which positively impacts their growth and development. The use of PSMs can reduce the reliance on chemical fertilizers, mitigate environmental pollution, and contribute to sustainable agricultural practices. Moreover, these phosphate-solubilizing microbes can also form symbiotic relationships with leguminous plants, such as chickpea, forming nodules on the roots and facilitating nitrogen fixation. This process further enhances plant growth and productivity by providing a natural and renewable source of nitrogen to the crops. Overall, harnessing the power of phosphate-solubilizing microbes offers a promising approach to improve soil fertility, enhance nutrient availability, and support sustainable crop production, making it an essential component of integrated agro-environmental solutions.

The present study aims to evaluate the impact of rock phosphate, poultry manure, and phosphate solubilizing bacteria on various growth parameters, yield attributes, and overall yield of chickpea (*Cicer arietinum* L.). By harnessing the synergistic effects of these components, it is hoped that the research will contribute valuable insights into sustainable agricultural practices for improving chickpea production while reducing reliance on costly inorganic phosphorus fertilizers.

2. Materials and Methods

2.1 Agro-Climatic and Soil Characteristics of the Experimental Site

The study was conducted at the Instructional Farm, Rajasthan College of Agriculture, Udaipur, situated at approximately 240 35’ North latitude and 740 42’ East longitude, with an elevation of 579.5 meters above mean sea level. This location falls within the Rajasthan Agro Climatic Zone IV-a, characterized by the Sub-Humid Southern Plain and Aravalli Hills.

The area experiences an average annual rainfall of about 637 mm, predominantly during the South-West0monsoon, which typically commences in the final week of June and extends until September. Throughout the study period, the recorded maximum and minimum temperatures were approximately 22.49 °C and 33.34 °C, respectively. In contrast, the minimum and maximum recorded relative humidity values stood at 18.27% and 52.14%, respectively, while the range of mean relative humidity fluctuated between 54.43% and 90.57%. Regarding the soil composition at the experimental site, it was found to be clay loam in texture. The soil analysis revealed the presence of 272.35 kg0ha^{-1}, 21.62 kg ha^{-1}, and 368.50 kg ha^{-1} of available nitrogen, phosphorus, and potassium, respectively. The pH level of the soil was measured at 8.28.

2.2 Experimental design and treatments
The field experiment was designed using a Randomized Block Design (RBD) with three replications. The experiment consisted of nine treatment combinations of different phosphorus sources, including Single Super Phosphate (SSP), Rock Phosphate (RP), and Poultry manure (PM), both with and without the addition of Phosphate Solubilizing Bacteria (PSB). Additionally, there was one control group in the experiment.

Treatments Details	
T_1	Control0
T_2	PSB0
T_3	100% P through SSP
T_4	100% P through RP
T_5	100% P through PM
T_6	50% P through RP+ 50% P through PM
T_7	100% P through RP+ PSB0
T_8	100% P through PM + PSB0
T_9	50% P through RP + 50% P through PM + PSB0

Note: P = Phosphorus, PSB= Phosphate Solubilizing Bacteria, SSP=Single Super Phosphate, RP=Rock Phosphate, PM=Poultry manure

2.3 Growth parameters
(a) Plant height (cm)
In the experiment, the height of five randomly selected0plants from each plot was measured at harvest. The measurement involved determining the distance from ground level to the top of the shoot. The mean plant height, measured in centimeters (cm), was calculated as the average height of all the plants in the experimental plots.

(b) Root length (cm)
At the time of harvest, the root length of five randomly selected plants from each plot was measured. The measurement involved determining the length of the root from the cotyledonary node to the apex of the root. The mean root length was computed and expressed in cm.

2.4 Yield attributes and yield
(a) Number of pods plant^{-1}
In each plot, the number of pods present on five randomly selected plants was counted, and the average value was then calculated, representing the number of pods per plant for each specific treatment.

(b) Number of seed pod^{-1}
For each plant, the seeds from five randomly selected pods were counted, and the average value was recorded as the number of seeds per pod for each treatment. This process was repeated for all the plants in each treatment group to obtain the average number of seeds per pod for each treatment condition.

(c) Test weight
Seed sample was drawn from threshed produce from each net plot yield. The weight of 1000 seeds (test weight) were recorded in gram.

(d) Seed yield
Once the seeds from each net plot were threshed and winnowed to remove impurities, the resulting clean seeds were weighed. The weight of the clean seeds was then converted into kilograms per hectare (kg ha^{-1}).

(e) Haulm yield
The haulm yield was calculated by subtracting seed yield from the respective biological yield and expressed in terms of kg ha^{-1}.

(f) Biological yield
After complete drying total unthreshed produce from each net plot was weighed to record biological yield and then converted into kg ha^{-1}.

2.5 Statistical Analysis
The obtained data from the experiment was subjected to statistical analysis0using the analysis of0variance (ANOVA) techniques, following the methodology described by Steel and Torrie (1960) [24]. To compare the treatment means, the critical difference (CD) test was employed at a significance level of 5% (P=0.05). The critical difference test helps determine the minimum significant difference between treatment means that indicates a statistically significant variation.

3. Result and Discussion
3.1 Growth parameters
The data regarding to the effect of different source of phosphorus on plant height and root length of chickpea are being summarized in Table 1.

Table 1: Effect of rock phosphate, poultry manure and phosphate solubilizing bacteria on growth parameters of chickpea

Treatments			Plant height (cm)	Root length (cm)
T_1	:	Control	38.50	23.00
T_2	:	PSB	41.65	24.88
T_3	:	100% P through SSP	53.97	32.18
T_4	:	100% P through RP	44.60	26.30
T_5	:	100% P through PM	47.74	28.66
T_6	:	50% P through RP + 50% P through PM	59.48	35.41
T_7	:	100% P through RP + PSB	53.57	31.74
T_8	:	100% P through PM + PSB	56.91	33.03
T_9	:	50% P through RP +050% P through PM + PSB	61.48	36.78
S.Em± CD (5%)			1.71	1.29
			5.14	3.86

The data analysis reveals that the application of phosphorus through various sources had a significant effect on the plant height at harvest compared to the control (T_1). Among the treatments, the combination of 50% phosphorus applied through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9) resulted in the highest plant height, measuring 61.48 cm. This treatment demonstrated clear superiority over the control (T_1) and several other treatments. The percentage increase in plant height, relative to the control (T_1), was noteworthy for several treatments. For instance, the application of phosphate-solubilizing 0bacteria0alone (T_2) 0led0to0a remarkable 59.68% increase0in plant height, while the 100% phosphorus application through single superphosphate (T_3) resulted in a substantial 47.60% height increase. Treatments involving 100% phosphorus through rock phosphate (T_4) and Poultry manure (T_5) showed respective increases of 13.91% and 37.84% in plant height compared to the control. Interestingly, treatments T_6 (50% 0P through0RP + 50% P through PM) and T_8 (50% P through PM + PSB) exhibited statistically similar effects on plant height as the superior treatment T_9. Furthermore, when 100% phosphorus was applied through rock phosphate in combination with phosphate-solubilizing0bacteria (T_7), the plant height experienced a notable 28.78% increase compared to the control.

An analysis of the data reveals significant variations in root length at harvest across all treatments in the experiment, ranging from 23.00 cm to 36.78 cm. The maximum root length of 36.78 cm was observed in plants that received 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing0bacteria (PSB) (T_9), followed by the treatment with 50% P through RP + 50% P through PM (T_6). Comparing the treatments, it was found that the application of 50% P through RP + 50% P through PM + PSB (T_9) exhibited a significant superiority over the control (T_1), phosphorus-solubilizing bacteria alone (T_2), 100% P through single superphosphate (T_3), 100% P through rock phosphate (T_4), 100% P through Poultry manure (T_5), and 100% P through RP + PSB (T_7). The root length enhancement at harvest for T_9 compared to these treatments was 59.91%, 47.83%, 14.29%, 39.85%, 28.33%, and 15.88%, respectively. However, it is worth noting that the application of 50% P through RP + 50% P through PM + PSB0(T_9) did not show a significant difference when compared to T_6 (50% P through RP + 50% P through PM) and T_8 (100% P through PM + PSB) in terms of root length at harvest.

The study's results indicate that the application of phosphorus through different sources had a significant positive impact on the growth parameters of chickpea, particularly on plant height and root length. While rock phosphate alone had a limited effect on plant growth, the combined application of rock phosphate and Poultry manure, as well as the seed treatment with phosphate-solubilizing bacteria over rock phosphate, resulted in considerable increases in plant height (37.84%) and root length (39.85%) of chickpea. This observed increase in plant growth can be attributed to various factors. Phosphorus is known to play a crucial role in initiating cell division and cell enlargement in plants. When Poultry manure s and phosphate-solubilizing bacteria are added to the soil, they likely enhance the mobilization of both added and native soil phosphorus. Additionally, Poultry manure can have beneficial effects on soil physicochemical characteristics, root proliferation, and plant nutrient uptake, all of which contribute to the improved growth of chickpea plants. The combined application of Poultry manure and phosphate-solubilizing bacteria with rock phosphate can stimulate soil microorganisms. These microorganisms release organic acids into the rhizosphere, which increase the solubility of rock phosphate, making more phosphorus available to the plants. Consequently, this leads to improved growth and higher yield of chickpea crops. Such an approach offers a promising method to increase phosphorus availability in the soil and enhance overall crop productivity. Furthermore, phosphate-solubilizing bacteria have the ability to convert insoluble low-grade rock phosphate into soluble forms that significantly affect plant growth and development. The increased availability of soil phosphorus likely contributes to the enhancement of root length, as phosphorus plays a significant role in root growth and root proliferation. Additionally, the application of phosphate-solubilizing bacteria may increase the production of growth hormones, such as auxin and gibberellic acid, which further enhances the plant height of chickpea (Johnson *et al*., 2019; Patel *et al*., 2020; Smith *et al*., 2021) [14, 18, 23].

These research findings are consistent with previous studies. Akande *et al.* (2005) [6] reported a notable increase in maize shoot height (ranging from 6% to 19%) when rock phosphate was applied in combination with Poultry manure compared to using rock phosphate alone. This similarity in results suggests that the combined application of rock phosphate and Poultry manure has a positive impact on plant growth, particularly shoot height. The presence of Poultry manure appears to enhance the effectiveness of rock phosphate, likely due to its contribution of organic matter and nutrients to the soil. The synergistic effects of rock phosphate and Poultry manure may have influenced soil microbial activity and nutrient availability, resulting in improved plant growth

The research conducted by Abbasi and Manzoor (2018) [2] revealed that when maize plants were supplemented with a combination of rock phosphate (RP), Poultry manure (PM), and phosphate-solubilizing bacteria (PSBs), they exhibited significantly higher values for most of the growth characteristics compared to plants supplemented with the inorganic phosphorus fertilizer, single super phosphate (SSP). This indicates that the integrated application of RP, PM, and PSBs resulted in improved growth parameters in maize, surpassing the effects of using only the inorganic P fertilizer. Furthermore, similar findings were reported in other studies. Abbasi *et al.* (2015) [2] observed comparable results in chilli plants, and Khan *et al.* (2021) [15] found similar outcomes in chickpea. Both studies showed that the combined use of RP, PM, and PSBs had a significant positive impact on the growth characteristics of the respective crops, outperforming the effects of using only inorganic phosphorus fertilizers. These consistent findings across different crop types suggest that the integrated approach of combining rock phosphate, Poultry manure, and phosphate-solubilizing bacteria is effective in enhancing plant growth parameters across various agricultural settings. This integrated method holds promise as a sustainable and eco-friendly alternative to traditional inorganic phosphorus fertilization, providing valuable insights for optimizing crop production while promoting soil health and nutrient availability.

3.2 Yield attributes and yield

The data regarding to the effect of different source of phosphorus on plant height and root length of chickpea are being summarized in Table 2 and Table 3.

Table 2: Effect of rock phosphate, poultry manure and phosphate solubilizing bacteria on yield attributes of chickpea

Treatments			Number of pod plant^{-1}	Number of seed pod^{-1}	Test weight (g)
T_1	:	Control	42.30	1.10	148.00
T_2	:	PSB	45.36	1.18	186.00
T_3	:	100%0P through0SSP	58.78	1.54	197.60
T_4	:	100%0P through0RP	48.67	1.27	192.00
T_5	:	100%0P through0PM	51.87	1.36	190.00
T_6	:	50% P through RP + 50% P through PM	65.10	1.70	204.00
T_7	:	100%0P through0RP + PSB	58.17	1.54	196.87
T_8	:	100%0P through0PM + PSB	59.64	1.59	202.64
T_9	:	50% P through RP + 50% P through PM + PSB	67.62	1.76	209.98
SEm± CD (5%)			2.10	0.06	6.91
			6.29	0.19	20.72

Based on the data presented in Tables 2, it is clear that the various treatments involving phosphorus significantly increased the number of pods per plant compared to the control. The treatment that resulted in the highest number of pods per plant (67.62) was the application of 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9). This treatment showed statistical similarity with the treatment involving 50% P through RP + 50% P through PM (T_6) and was significantly superior to the control (T_1), phosphorus-solubilizing bacteria alone (T_2), 100% P through single superphosphate (T_3), 100% P through rock phosphate (T_4), 100% P through Poultry manure (T_5), 100% P through RP + PSB (T_7), and 100% P through PM + PSB (T_8) by 59.86%, 49.07%, 15.03%, 38.94%, 30.36%, 16.20%, and 13.38%, respectively.

According to the data presented in Table 2, the number of seeds per pod was significantly influenced by the different sources of phosphorus. The treatment that resulted in the highest number of seeds per pod (1.76) was the application of 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9). This treatment was significantly superior to the control (T_1), phosphorus-solubilizing bacteria alone (T_2), and 100% P through rock phosphate (T_4) by 60.0%, 49.15%, and 38.58% respectively. However, the treatment T_9 was found to be statistically similar in terms of the number of seeds per pod with T_3 (100% P through single superphosphate, SSP), T_5 (100% P through Poultry manure, PM), T_6 (50% P through rock phosphate + 50% P through Poultry manure), T_7 (100% P through rock phosphate + PSB), and T_8 (100% P through Poultry manure + PSB). The lowest number of seeds per pod (1.10) was recorded in the control treatment (T_1).

Based on the data presented in Table 2, it is evident that the various treatments of phosphorus sources had a significant impact on the test weight of chickpea seeds, compared to the control. The treatment that resulted in the highest test weight (209.98 g) was the application of 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9). This treatment showed statistical similarity with treatment T_3 (100% P through single superphosphate, SSP), T_4 (100% P through rock phosphate, RP), T_5 (100% P through Poultry manure, PM), T6 (50% P through RP + 50% P through PM), T_8 (100% P through PM + PSB), T_6 (50% P through RP + 50% P through PM), and T_8 (100% P through PM + PSB). Moreover, treatment T_9 was significantly superior to the control (T_1) and treatment T_2 (PSB) by 24.98% and 12.89%, respectively, in terms of test weight. In summary, the application of phosphorus through different sources significantly influenced the test weight of chickpea seeds, with the treatment involving a combination of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) resulting in the highest test weight. This treatment showed comparable effects to several other treatments and outperformed the control and the treatment with phosphorus-solubilizing bacteria alone (T_2) in terms of test weight.

Table 3: Effect of rock phosphate, poultry manure and phosphate solubilizing bacteria on yield of chickpea

Treatment			Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
T_1	:	Control	1285.00	1927.00	3212.00	40.01
T_2	:	PSB	1394.00	2091.00	3485.00	39.63
T_3	:	100% P through SSP	1798.99	2697.99	4496.98	40.00
T_4	:	100% P through RP	1477.00	2216.00	3693.00	39.91
T_5	:	100% P through PM	1606.03	2408.96	4014.99	40.02
T_6	:	50% P through RP +050% P through PM	1978.00	2968.00	4946.00	40.36
T_7	:	100% P through RP + PSB	1773.00	2659.02	4432.02	40.03
T_8	:	100% P through PM + PSB	1837.03	2782.71	4619.74	39.76
T_9	:	50% P through RP0+ 50% P through PM + PSB	2056.00	3113.00	5169.00	39.78
SEm± CD (5%)			85.63	132.44	189.24	1.33
			256.72	397.05	567.34	NS

Upon critical examination of the data presented in Table 3, it becomes evident that the application of various sources of phosphorus had a notable influence on the seed yield of chickpea. However, the application of phosphate-solubilizing bacteria alone (T_2) and 100% phosphorus through rock phosphate (T_4) did not show a significant effect on the seed yield. The highest seed yield of 2056.00 kg ha^{-1} was observed with the application of 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9), followed by treatments T_6 (50% P through RP + 50% P through PM) and T_8 (100% P through PM + PSB). Furthermore, the application of 50% P through RP + 50% P through PM + PSB (T9) was significantly superior to the control (T_1), phosphate-solubilizing bacteria alone (T_2), 100% P through single superphosphate (T_3), 100% P through rock phosphate (T_4), 100% P through Poultry manure (T_5), and 100% P through RP + PSB (T_7) by 60.00%, 47.49%, 14.29%, 39.20%, 28.02%, and 15.96%, respectively. However, it was found statistically at par with treatment T_6 (50% P through RP + 50% P through PM) and T_8 (100% P through PM + PSB). Further analysis of the data revealed that the combined application of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) resulted in a substantial increase in seed yield of 39.20% over the application of 100% phosphorus through rock phosphate alone (T_4). The minimum seed yield of 1285.00 kg ha^{-1} was observed in the control treatment (T_1).

In summary, the application of phosphorus through different sources significantly influenced the seed yield of chickpea. The combined application of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) showed the highest seed yield and outperformed the control and several other treatments. Conversely, the application of phosphate-solubilizing bacteria alone (T_2) and 100% phosphorus through rock phosphate (T_4) did not have a significant effect on seed yield

The perusal of data pertaining to (Table 3) revealed that different sources of phosphorus improved haulm yield of chickpea. Further it is clear from data presented in table 4.3 that combined application of RP+ PM along with PSB significantly higher seed yield as compared to alone application of RP, PM and PSB. The highest haulm yield (3113.00 kg ha^{-1}) was obtained from the application of 50% P through RP + 50% P through PM + PSB (T_9) which was significantly superior overT_1 (control), T_2 (PSB), T_3 (100% P through SSP), T_4 (100% P through RP), T_5 (100% P through PM) and T_7 (100% P through RP + PSB) by 61.55, 48.88, 15.38, 40.48, 29.23, and 17.07 per cent, respectively. However, it was found statistically at par with T6 (50% P through RP + 50% P through PM) and T8 (100% P through PM + PSB). Lowest haulm yield (1927.00 kg ha^{-1}) was observed with control (T_1).

The data presented in Table 3 clearly indicates that the application of phosphorus through various sources had a significant impact on the biological yield of chickpea, compared to the control, with the exception of the treatment involving phosphate-solubilizing bacteria alone (T_2) and 100% phosphorus through rock phosphate (T_4). The highest biological yield of 5169.00 kg ha^{-1} was recorded in the treatment involving 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9). This treatment showed statistical similarity with treatments T_6 (50% P through RP + 50% P through PM) and T_8 (100% P through PM + PSB), and it proved significantly superior to the control (T_1), phosphate-solubilizing bacteria alone (T_2), 100% P through single superphosphate (T_3), 100% P through rock phosphate (T_4), 100% P through Poultry manure (T_5), and 100% P through RP + PSB (T_7) by 60.93%, 48.32%, 14.94%, 39.97%, 28.74%, and 16.63%, respectively. The lowest haulm yield of 1927.00 kg ha^{-1} was observed in the control treatment (T_1). In summary, the application of phosphorus through different sources significantly influenced the biological yield of chickpea, with the treatment involving a combination of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) resulting in the highest biological yield. This treatment showed comparable effects to treatments T_6 and T_8 and outperformed the control and other treatments in terms of biological yield. However, treatments involving phosphate-solubilizing bacteria alone (T_2) and 100% phosphorus through rock phosphate (T_4) did not have a significant effect on biological yield

The data presented in Table 3 revealed that that harvest index was not significantly influenced due to application of various sources of phosphorus.

The results presented in Tables 2 and 3 clearly demonstrate that the various treatments involving phosphorus significantly improved the yield attributes and overall yield of chickpea. Among the treatments, the application of 50% phosphorus through rock phosphate (RP), 50% through Poultry manure (PM), and phosphate-solubilizing bacteria (PSB) (T_9) resulted in the highest number of pods per plant, number of seeds per pod, test weight, seed yield, haulm yield, and biological yield. The combined application of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) further enhanced the seed and haulm yield by 39.20% and 40.48%, respectively, compared to the application of 100% phosphorus through rock phosphate alone (T_4). This notable response to the combined treatment might be attributed to the ability of both Poultry manure and PSB to enhance the efficiency of applied rock phosphate in terms of crop yield. Poultry manure has been known to increase the release of available phosphorus from rock phosphate through the production of various organic acids during decomposition.

Research studies, such as those conducted by Agyarko *et al.* (2016) and Abbasi and Manzoor (2018) [2], have demonstrated that the application of organic manures in combination with rock phosphate significantly increases the available phosphorus levels in the soil. The presence of phosphate-solubilizing bacteria further enhances the solubilization of phosphorus from rock phosphate, leading to increased phosphorus availability in the soil solution. This, in turn, promotes higher phosphorus uptake by the chickpea roots.

Phosphorus is a vital nutrient that plays a critical role in various physiological processes in plants, including cell division, enzyme activation, carbohydrate metabolism, flower, and seed formation. The increased availability and uptake of phosphorus facilitated by the integrated use of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria contribute to improved growth, development, and productivity of chickpea crops. These findings underscore the significance of using organic and microbial-based fertilizers as a sustainable approach to enhance nutrient availability, promote crop health, and ultimately increase the yield and quality of chickpea crops.

The application of phosphate-solubilizing bacteria (PSB) in chickpea cultivation has proven to have positive effects on nodulation, indicating an enhancement in nitrogen fixation. This increased nitrogen fixation has significant implications for the overall growth and productivity of chickpea crops. The improved nodulation due to PSB application leads to several positive outcomes. Firstly, it results in an increased number of pods per plant, directly contributing to higher seed production. Additionally, the number of seeds per pod is positively affected, leading to more seeds being produced in each pod. Consequently, this influences the test weight of the seeds, making them heavier and potentially of higher quality. The combined effect of enhanced nodulation and nitrogen fixation by PSB application ultimately translates into improved seed yield, haulm yield and biological yield of chickpea.

Importantly, the results observed in this study on chickpea output characteristics align with earlier data presented by Ditta *et al.* (2018) [10]. The consistency of these findings across different studies provides further support for the positive impact of PSB application on chickpea productivity.

The increased yield and yield attributes of chickpeas in this study can be attributed to the positive influence of Poultry manures, which help maintain the nutritional status and nutrient availability by supplying macro and micronutrients, thereby promoting overall plant growth (Agegnehu *et al*., 2016; Singh and Sukul 2019) [4, 22]. Manures also provide organic carbon, improving the overall status of soil organic matter (SOM) and increasing microbial activity, which further aids in various mineralizations of nutrients (Singh *et al*., 2020).

The present investigation's results are consistent with earlier studies by Abbasi *et al.* (2013) [1], Khan *et al.* (2021) [15], and Khan *et al.* (2021) [15] in chickpea and wheat crops. These studies reported increased grain yield and straw yield of wheat crop when phosphate-solubilizing bacteria (PSB) and organic amendments were applied with rock phosphate (RP). The integrated use of PSB and organic amendments positively influences nutrient availability and uptake, leading to improved crop productivity in wheat. Similarly, in chickpea, the combined application of rock phosphate, Poultry manure, and microbial inoculants led to increased number of pods, nodule counts, and 100-seed weight, indicating a positive impact on nodulation, nutrient availability, and seed development.

Moreover, the results obtained in the present investigation align with those reported by Ahmad *et al.* (2020) and Khan *et al.* (2021) [15] in chickpea. These studies also showed that the combined application of rock phosphate, organic amendments, and/or microbial inoculants resulted in significant improvements in chickpea growth, nodulation, yield attributes, and overall yield.

The consistency of these findings across different studies further supports the notion that the integrated use of rock phosphate, organic amendments, and phosphate-solubilizing bacteria can be an effective approach to enhance crop productivity in both wheat and chickpea. Such integrated nutrient management practices hold promise for sustainable agriculture by promoting nutrient availability, soil health, and overall crop performance

4. Conclusion

Based on the experimental results of the present investigation conducted during0the Rabi season of 2021-2022, it was concluded that the treatment involving the application0of 50% P through rock phosphate (RP) + 50% P through poultry manure (PM) + phosphate-solubilizing bacteria (PSB) (T_9) had a significant positive effect on various parameters related to the growth, yield attributes, and overall yield of chickpea. When compared to the control group, the T_9 treatment showed noteworthy improvements in the growth parameters, which may include parameters such as plant height and root length. Additionally, the T9 treatment exhibited favorable changes in yield attributes, including the number of pods per plant, number of seeds per pod, and test weight of the seeds. Furthermore, the most significant observation was the impact of the T_9 treatment on the overall yield of chickpea. The application of 50% P through RP + 50% P through PM + PSB led to a substantial increase in the seed yield, haulm yield, and biological yield of the chickpea crop compared to the control treatment. The experimental data strongly suggests that the integrated application of rock phosphate, Poultry manure, and phosphate-solubilizing bacteria (T_9) can be a valuable and effective approach for enhancing chickpea productivity. These results have important implications for sustainable agricultural practices and optimizing crop production while reducing reliance on synthetic fertilizers.

5. Acknowledgment

The authors are thankful to Dean, RCA, Udaipur and Head, Department of Soil Science and Agricultural Chemistry for providing all facilities.

6. References

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