Original Research Article

Enhancing Nutrient Content and Uptake in Chickpea through Phosphorus and PSB Inoculation in Custard Apple based Agri-Horti System

ABSTRACT

The field experiment was conducted during the Rabi season of 2018-19 at the Agricultural Research Farm of Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh, India. This study aimed to investigate the effects of varying levels of phosphorus and inoculation with Phosphate Solubilizing Bacteria (PSB) on nutrient content and uptake in chickpea (*Cicer arietinum* L.) in a custard apple-based agri-horticultural system. The experimental design employed a Factorial Randomized Block Design with three replications and twelve treatments, resulting in a total of 36 plots. The treatments ranged from different levels of phosphorus and PSB inoculation, denoted as T_1 to T_{12}. The study assessed the impact of these treatments on nitrogen (N), phosphorus (P) and potassium (K) content in grain and straw, as well as their uptake by chickpea. Findings reveal that higher PSB levels and phosphorus applications led to increased nitrogen and phosphorus content and uptake in both grain and straw, demonstrating a significant synergistic effect. Conversely, potassium content and uptake exhibited limited response to PSB inoculation. Moreover, protein content and yield in grain and straw significantly improved with these treatments.

Keywords: Chickpea, Custard Apple, Phosphorus, Phosphate Solubilizing Bacteria, Nutrient Uptake

1. INTRODUCTION

Agriculture has undergone a profound transformation in recent years, as the world grapples with the pressing challenges of feeding a growing global population while also conserving natural resources and mitigating the impacts of climate change[1]. In this pursuit, agroforestry has emerged as an innovative and ecologically sustainable approach to agriculture that holds immense promise[2]. Agroforestry, the integration of trees and perennial plants with traditional crop systems, offers a multifaceted solution that addresses multiple facets of sustainable agriculture[3]. It not only enhances biodiversity, soil fertility and carbon sequestration but also contributes to the production of diverse crops, promoting resilience and economic stability for farming communities[4].One compelling dimension of agroforestry is the synergistic relationship it fosters between trees and understory crops[5]. This synergy is particularly intriguing when considering the nutrient dynamics and nutrient content of crops grown within the agroforestry system[6]. Chickpea, an essential source of dietary protein for millions of people worldwide, is cultivated under a range of agroecological conditions[7]. Yet, its nutrient content and thus its nutritional value, can vary significantly depending on the environmental conditions and agronomic practices employed[8].Chickpeas can be grown under various agroforestry systems, including the custard apple-based agri-horti system [9]. The custard apple agroforestry system has several advantages, including the provision of food and other basic needs, soil fertility restoration and weed control [10]. Chickpeas are known for their high protein and fiber content, making them a popular ingredient in many cuisines around the world. They are also a good source of vitamins and minerals, including iron, phosphorus and potassium [11].

Climate change, with its unpredictable weather patterns, increased temperatures and altered precipitation regimes, poses a significant threat to global agriculture[12]. In this scenario, agroforestry systems offer a glimmer of hope. Custard apple trees, with their canopy cover, provide shade and microclimate regulation, mitigating the extremes of temperature and moisture stress on chickpea plants[13]. This microclimate control can potentially have a positive impact on chickpea nutrient content by minimizing stress-induced nutrient losses and optimizing nutrient uptake[14]. Additionally, the leaf litter from custard apple trees may enhance soil fertility, further influencing chickpea nutrient dynamics[15]. Food security remains a paramount global concern, and legumes like chickpea play a pivotal role in addressing this issue[16].Their nutritional value, high protein content and ability to fix atmospheric nitrogen enrich the soil for future crops[17]. The focus on nutrient content within agroforestry systems takes on added significance in this context[18]. Several studies have been conducted to investigate the nutrient content and uptake of chickpeas under different agroforestry systems, including the custard apple-based agri-horti system. These studies have shown that chickpeas can mobilize soil and fertilizer nutrients through the exudation of organic acid anions from their roots, which can improve their growth and nutrient uptake[19]. In this study, we explore relationship, focusing on the specific case of chickpea (*Cicer arietinum*) cultivation under the canopy of custard apple (*Annona squamosa*) trees, and how this agroforestry system can influence the nutrient content of chickpea, a protein-rich and nutritionally vital legume.

2. MATERIALS AND METHODS

The investigation was conducted during winter (*Rabi)* season of 2018-19 at Agricultural Research Farm of Rajiv Gandhi South Campus, Banaras Hindu University, Barkachha, Mirzapur, Uttar Pradesh (India). The field experiment was carried out on Chickpea crop grown in an alley of 11-year-old custard apple tree which was planted at a spacing of 5 m × 5 m. The experimental trial was laid out in Factorial Randomized Block Design with three replications and twelve treatments. Total number of plots was 36. In this experiment, twelve different treatments were applied to assess the impact of varying phosphorus levels and seed inoculation on crop growth. These treatments were designated as T_1 to T_{12}. The treatments were a combination of different levels of phosphorus and seed inoculation with a beneficial microorganism called PSB (Phosphorus Solubilizing Bacteria). The details of experiment are depicted in table 1.

Table 1: Combinations of treatments and their symbol

S. No.	**Treatment**	**Symbol**	**Treatment details**
1.	**T_1**	**P_0C_0**	Control
2.	**T_2**	**P_0C_1**	*RDF + 5 ml PSB kg^{-1} seed
3.	**T_3**	**P_0C_2**	*RDF + 10 ml PSB kg^{-1} seed
4.	**T_4**	**P_1C_0**	*RDF + 20 kg P_2O_5 ha^{-1}
5.	**T_5**	**P_1C_1**	*RDF + 5 ml PSB kg^{-1} seed + 20 kg P_2O_5 ha^{-1}
6.	**T_6**	**P_1C_2**	*RDF + 10 ml PSB kg^{-1} seed + 20 kg P_2O_5 ha^{-1}
7.	**T_7**	**P_2C_0**	*RDF + 40 kg P_2O_5 ha^{-1}
8.	**T_8**	**P_2C_1**	*RDF + 5 ml PSB kg^{-1} seed + 40 kg P_2O_5 ha^{-1}
9.	**T_9**	**P_2C_2**	*RDF + 10 ml PSB kg^{-1} seed + 40 kg P_2O_5 ha^{-1}
10.	**T_{10}**	**P_3C_0**	*RDF + 60 kg P_2O_5 ha^{-1}
11.	**T_{11}**	**P_3C_1**	*RDF + 5 ml PSB kg^{-1} seed + 60 kg P_2O_5 ha^{-1}
12.	**T_{12}**	**P_3C_2**	*RDF + 10 ml PSB kg^{-1} seed + 60 kg P_2O_5 ha^{-1}

Where, **P_0**= No phosphorus, **P_1**= 20 kg P_2O_5 ha^{-1},**P_2**= 40 kg P_2O_5 ha^{-1}, **P_3**= 60 kg P_2O_5 ha^{-1}. **C_0**= Un-inoculated, **C_1**= 5 ml PSB kg^{-1} seed inoculation, **C_2** = 10 ml PSB kg^{-1} seed inoculation.

***** = *RDF (Nitrogen and Potassium were applied at the rate of 20 kg ha^{-1} each) and Phosphorus was applied as per treatment.

3. RESULTS AND DISCUSSION

3.1 Effect of phosphorus and PSB inoculation on nitrogen content in grain and straw and their uptake by chickpea under custard apple based agri-horti system

The study investigated the influence of varying levels of phosphorus and inoculation with Phosphate Solubilizing Bacteria on nitrogen content and its uptake in grain and straw of chickpea plants in a custard apple-based agri-horticultural system (Table 2). The results demonstrated notable disparities in nitrogen parameters across different treatments. Firstly, regarding PSB inoculation, a discernible escalation in nitrogen content in both grain and straw was observed with increasing PSB levels, from 0 ml PSB kg^{-1} seed to 10 ml PSB kg^{-1} seed. Specifically, grain nitrogen content, starting with 0 ml PSB kg^{-1} seed, the grain exhibited a nitrogen content of 3.43%, while the straw contained 1.26% nitrogen. As the PSB concentration was raised to 5 ml PSB kg^{-1} seed, the grain's nitrogen content increased to 3.49%, and the straw's nitrogen content slightly rose to 1.28%. The highest PSB concentration of 10 ml PSB kg^{-1} seed, seed yielded the highest grain nitrogen content at 3.56% and the straw had a corresponding nitrogen content of 1.31%. Furthermore, total nitrogen uptake in both grain and straw exhibited a significant increase with higher PSB levels. Under the 0 ml PSB kg^{-1} seed, the grain displayed a nitrogen uptake of 43.40 kg ha^{-1}, while the straw's nitrogen uptake stood at 25.78 kg ha^{-1}. As the PSB concentration was raised to 5 ml PSB kg^{-1} seed, both grain and straw demonstrated higher nitrogen uptake, with values of 46.79 kg ha^{-1} for grain and 27.37 kg ha^{-1} for straw. The highest PSB concentration of 10 ml PSB kg^{-1} seed resulted in the greatest nitrogen uptake, measuring 51.32 kg ha^{-1} for grain and 29.95 kg ha^{-1} for straw. This surge in nitrogen uptake is attributable to the beneficial effects of PSB on nutrient accessibility and plant nutrient absorption, given their capacity to solubilize and mobilize phosphorus in the soil [20].

Secondly, in evaluating the impact of phosphorus levels, it became evident that elevated phosphorus levels substantially augmented nitrogen content in both grain and straw compared to the control (No phosphorus). For grain nitrogen content, it was observed that nitrogen content in both grain and straw increased with higher P_2O_5 levels. Starting with control (No phosphorus), the grain had a nitrogen content of 3.35% and the straw contained 1.20% nitrogen. As the P_2O_5 levels were elevated to20 kg P_2O_5 ha^{-1}, the grain's nitrogen content increased to 3.51%, and the straw's nitrogen content rose to 1.26%. At 40 kg P_2O_5 ha^{-1}, the grain's nitrogen content reached 3.55%, with the straw's nitrogen content at 1.31%. 60 kg P_2O_5 ha^{-1}resulted in the highest grain nitrogen content at 3.57%, and the straw contained 1.35% nitrogen. Similarly, total nitrogen uptake in grain and straw showed significant increase with phosphorus levels. In control, the grain recorded a nitrogen uptake of 34.63 kg ha^{-1}, while the straw contained 19.14 kg ha^{-1} of nitrogen. As the P_2O_5 levels were augmented in 20 kg P_2O_5 ha^{-1}, grain nitrogen uptake rose to 43.54 kg ha^{-1}, and straw nitrogen uptake increased to 25.03 kg ha^{-1}. In 40 kg P_2O_5 ha^{-1}, grain nitrogen uptake reached 50.95 kg ha^{-1}, with straw nitrogen uptake at 30.69 kg ha^{-1}. 60 kg P_2O_5 ha^{-1}, resulted in the maximum grain nitrogen uptake, measuring 59.56 kg ha^{-1}, and straw contained 35.94 kg ha^{-1} of nitrogen. This effect can be ascribed to the role of phosphorus in promoting superior nutrient uptake and utilization by the plant [21]. Comparatively, when examining the interplay between PSB inoculation and phosphorus levels, it was discovered that the combined treatment of10 ml PSB kg^{-1} seed and 60 kg P_2O_5 ha^{-1} yielded the highest nitrogen content and total nitrogen uptake in both grain and straw. This combination significantly surpassed other treatments, suggesting a synergistic effect of PSB inoculation and phosphorus application. This underscores the potential of this combination to effectively enhance nitrogen utilization by chickpea in the agri-horticultural system under study [22].

Table 2: **Effect of phosphorus and PSB inoculation on nitrogen content in grain and straw and their uptake by chickpea under custard apple based agri-horti system**

Treatment	**N content (%)**		**N uptake (kg ha^{-1})**		**Total uptake (kg ha^{-1})**
	Grain	**Straw**	**Grain**	**Straw**	
Levels of PSB (ml kg^{-1})					
C_0 (0 ml PSB kg^{-1} seed)	3.43	1.26	43.40	25.78	69.19
C_1 (5 ml PSB kg^{-1} seed)	3.49	1.28	46.79	27.37	74.17
C_2 (10 ml PSB kg^{-1} seed)	3.56	1.31	51.32	29.95	81.26
SEm±	0.04	0.01	1.71	0.85	2.32
CD (P= 0.05)	0.11	0.04	5.00	2.49	6.81
Levels of Phosphorus (kg ha^{-1})					
P_0 (0 kg P_2O_5 ha^{-1})	3.35	1.20	34.63	19.14	53.77
P_1 (20 kg P_2O_5 ha^{-1})	3.51	1.26	43.54	25.03	68.57
P_2 (40 kg P_2O_5 ha^{-1})	3.55	1.31	50.95	30.69	81.64
P_3 (60 kg P_2O_5 ha^{-1})	3.57	1.35	59.56	35.94	95.51
SEm±	0.04	0.02	1.97	0.98	2.68
CD (P= 0.05)	0.12	0.04	5.78	2.88	7.86

3.2 Effect of phosphorus and PSB inoculation on phosphorus content in grain and straw and their uptake by chickpea under custard apple based agri-horti system

When analyzing the impact of PSB levels, a noticeable trend emerges, demonstrating the increase in phosphorus content as the concentration of PSB is elevated (Table 3). At the baseline PSB level 0 ml PSB kg^{-1} seed, the grain contained 0.66% phosphorus, while the straw exhibited a phosphorus content of 0.46%. When the PSB concentration was raised to 5 ml PSB kg^{-1} seed, both grain and straw registered higher phosphorus content, with grain phosphorus content at 0.68% and straw at 0.49%. The highest PSB concentration of 10 ml PSB kg^{-1} seed resulted in the greatest phosphorus content, measuring 0.75% in grain and 0.54% in straw. Regarding the phosphorus uptake, in 0 ml PSB kg^{-1} seed with no PSB addition, the grain exhibited a phosphorus uptake of 8.40 kg ha^{-1}, while the straw's phosphorus uptake stood at 9.89 kg ha^{-1}.

With the PSB concentration increased to 5 ml PSB kg^{-1} seed, both grain and straw showed higher phosphorus uptake, with grain phosphorus uptake reaching 9.25 kg ha^{-1}, and straw displaying a value of 11.04 kg ha^{-1}. The highest PSB concentration of10 ml PSB kg^{-1} seed resulted in the highest phosphorus uptake, measuring 11.06 kg ha^{-1} for grain and 12.83 kg ha^{-1} for straw. The total phosphorus uptake in grain and straw also increased significantly with higher PSB levels, indicating that PSB inoculation can enhance phosphorus availability and uptake by chickpea plants [23]. Moving on to the impact of different phosphorus levels, it was evident that higher levels of phosphorus significantly increased phosphorus content in both grain and straw when compared to the control (P_0). In control, the grain had a phosphorus content of 0.62%, while the straw contained 0.31% phosphorus. As the P_2O_5 levels were incrementally raised to 20 kg P_2O_5 ha^{-1}, grain phosphorus content increased to 0.67% and straw phosphorus content rose to 0.43%. At 40 kg P_2O_5 ha^{-1}, grain phosphorus content reached 0.71%, while straw phosphorus content was 0.56%. The highest P_2O_5 level of 60 kg P_2O_5 ha^{-1}resulted in the maximum grain phosphorus content at 0.80%, and straw exhibited 0.69% phosphorus. A consistent trend of increased phosphorus uptake is observed with higher P_2O_5 levels. Beginning with control, the grain recorded a phosphorus uptake of 6.43 kg ha^{-1}, while the straw contained 4.98 kg ha^{-1} of phosphorus. As the P_2O_5 levels were progressively raised to 20 kg P_2O_5 ha^{-1}, grain phosphorus uptake rose to 8.36 kg ha^{-1} and straw phosphorus uptake increased to 8.51 kg ha^{-1}. At 40 kg P_2O_5 ha^{-1}, grain phosphorus uptake reached 10.11 kg ha^{-1}, while straw phosphorus uptake was 13.09 kg ha^{-1}. The highest P_2O_5 level of 60 kg P_2O_5 ha^{-1} resulted in the maximum grain phosphorus uptake, measuring 13.39 kg ha^{-1}, and straw exhibited 18.42 kg ha^{-1} of phosphorus uptake. This is in line with expectations, as phosphorus application is known to promote improved nutrient uptake and utilization by plants. This suggests that the combination of PSB inoculation and phosphorus application had a significant effect on straw phosphorus content but did not significantly impact grain phosphorus content [24].

Table 3: Effect of phosphorus and PSB inoculation on phosphorus content in grain and straw and their uptake by chickpea under custard apple based agri-horti system

Treatment	**P content (%)**		**P uptake (kg ha^{-1})**		**Total uptake (kg ha^{-1})**
	Grain	**Straw**	**Grain**	**Straw**	
Levels of PSB (ml kg^{-1})					
C_0 (0 ml PSB kg^{-1} seed)	0.66	0.46	8.40	9.89	18.29
C_1 (5 ml PSB kg^{-1} seed)	0.68	0.49	9.25	11.04	20.29
C_2 (10 ml PSB kg^{-1} seed)	0.75	0.54	11.06	12.83	23.89

SEm±	0.02	0.01	0.36	0.47	0.73
CD (P= 0.05)	0.05	0.03	1.05	1.39	2.15
Levels of Phosphorus (kg ha^{-1})					
P_0 (0 kg P_2O_5 ha^{-1})	0.62	0.31	6.43	4.98	11.41
P_1 (20 kg P_2O_5 ha^{-1})	0.67	0.43	8.36	8.51	16.87
P_2 (40 kg P_2O_5 ha^{-1})	0.71	0.56	10.11	13.09	23.20
P_3 (60 kg P_2O_5 ha^{-1})	0.80	0.69	13.39	18.42	31.80
SEm±	0.02	0.01	0.41	0.55	0.85
CD (P= 0.05)	0.05	0.04	1.21	1.60	2.48

3.3 Effect of phosphorus and PSB inoculation on potassium content in grain and straw

A noticeable trend emerged, illustrating an increase in potassium content as the concentration of PSB is elevated while examining the effects of PSB levels (table 4). At 0 ml PSB kg^{-1} seedwith no PSB addition, the grain contained 0.56% potassium, while the straw exhibited a potassium content of 0.80%. As the PSB concentration was raised to 5 ml PSB kg^{-1} seed both grain and straw registered higher potassium content, with grain potassium content at 0.58% and straw at 0.82%. The highest PSB concentration of 10 ml PSB kg^{-1} seed resulted in the highest potassium content, measuring 0.59% in grain and 0.84% in straw. Following the similar trend, the total potassium uptake in both grain and straw showed a slight increase with higher PSB levels. In 0 ml PSB kg^{-1} seed, the grain exhibited a potassium uptake of 7.18 kg ha^{-1}, while the straw's potassium uptake stood at 16.50 kg ha^{-1}. When the PSB concentration was raised to 5 ml PSB kg^{-1} seed both grain and straw demonstrated higher potassium uptake, with grain potassium uptake reaching 7.79 kg ha^{-1} and straw at 17.63 kg ha^{-1}. The highest PSB concentration of 10 ml PSB kg^{-1} seed resulted in the greatest potassium uptake, measuring 8.62 kg ha^{-1} for grain and 19.44 kg ha^{-1} for straw. This depicts that PSB inoculation had a limited impact on potassium content and uptake in this system [25]. Turning to the impact of phosphorus treatments, a consistent trend of increased potassium content is observed with higher P_2O_5 levels. Starting with 0 ml PSB kg^{-1} seed, the grain had a potassium content of 0.52%, while the straw contained 0.74% potassium. As the P_2O_5 levels were incrementally raised to 20 kg P_2O_5 ha^{-1}, grain potassium content increased to 0.56% and straw potassium content rose to 0.79%. At 40 kg P_2O_5 ha^{-1}, grain potassium content reached 0.59%, while straw potassium content was 0.84%. The highest P_2O_5 level of 40 kg P_2O_5 ha^{-1}resulted in the maximum grain potassium content at 0.64% and straw exhibited 0.91% potassium. Also, the total potassium uptake in grain and straw showed significant increases with higher phosphorus levels. Beginning with control, the grain had a potassium uptake of 5.39 kg ha^{-1}, while the straw contained 11.91 kg ha^{-1} of potassium. As the P_2O_5 levels were incrementally raised to 20 kg P_2O_5 ha^{-1}, grain potassium uptake increased to

6.91 kg ha^{-1} and straw potassium uptake rose to 15.68 kg ha^{-1}. At 40 kg P_2O_5 ha^{-1}, grain potassium uptake reached 8.48 kg ha^{-1}, while straw potassium uptake was 19.58 kg ha^{-1}. The highest P_2O_5 level of 60 kg P_2O_5 ha^{-1} resulted in the maximum grain potassium uptake at 10.67 kg ha^{-1} and straw exhibited 24.26 kg ha^{-1} of potassium uptake. This is consistent with the expected role of phosphorus in promoting nutrient uptake and utilization by plants [26]. In terms of the interaction between PSB inoculation and phosphorus levels, the data does not show any significant interactions for potassium content or uptake in grain or straw. This attributes that the combination of PSB inoculation and phosphorus application did not lead to significant synergistic or antagonistic effects on potassium parameters in this study [27].

3.4 Effect of phosphorus and PSB inoculation on protein content of grain and straw and total protein yield of chickpea under custard apple based agri-horti system

The experiment also analyzed the effects of varying levels of Phosphorus-Solubilizing Bacteria and different phosphorus treatments on protein content and yield in both grain and straw (Table 5). Starting with the levels of PSB, the data reveals a modest increase in protein content as the concentration of PSB is elevated. In 0 ml PSB kg^{-1} seed, the grain contained 21.42% protein, while the straw exhibited a protein content of 7.85%. When the PSB concentration was raised to 5 ml PSB kg^{-1} seed both grain and straw showed slightly higher protein content, with grain protein content at 21.78% and straw at 7.99%. The highest PSB concentration of 10 ml PSB kg^{-1} seedresulted in the highest protein content, measuring 22.27% in grain and 8.17% in straw. The total protein yield in grain and straw also exhibited a significant increase with higher PSB levels. In 0 ml PSB kg^{-1} seed the grain exhibited a protein yield of 271.28 kg ha^{-1}, while the straw's protein yield stood at 161.13 kg ha^{-1}. When the PSB concentration was raised to 5 ml PSB kg^{-1} seed both grain and straw showed higher protein yield, with grain protein yield reaching 292.46 kg ha^{-1} and straw at 171.08 kg ha^{-1}.

Table 4: Effect of phosphorus and PSB inoculation on potassium content in grain and straw and their uptake by chickpea under custard apple based agri-horti system

Treatment	K content (%)		K uptake (kg ha^{-1})		Total uptake (kg ha^{-1})
	Grain	Straw	Grain	Straw	
Levels of PSB (ml kg^{-1})					
C_0 (0 ml PSB kg^{-1} seed)	0.56	0.80	7.18	16.50	23.68
C_1 (5 ml PSB kg^{-1} seed)	0.58	0.82	7.79	17.63	25.41

C_2 (10 ml PSB kg^{-1} seed)	0.59	0.84	8.62	19.44	28.06
SEm±	0.01	0.01	0.25	0.56	0.77
CD (P= 0.05)	0.02	0.02	0.73	1.65	2.27
Levels of Phosphorus (kg ha^{-1})					
P_0 (0 kg P_2O_5 ha^{-1})	0.52	0.74	5.39	11.91	17.29
P_1 (20 kg P_2O_5 ha^{-1})	0.56	0.79	6.91	15.68	22.59
P_2 (40 kg P_2O_5 ha^{-1})	0.59	0.84	8.48	19.58	28.07
P_3 (60 kg P_2O_5 ha^{-1})	0.64	0.91	10.67	24.26	34.93
SEm±	0.01	0.01	0.29	0.65	0.89
CD (P= 0.05)	0.02	0.03	0.85	1.90	2.62

The highest PSB concentration of 10 ml PSB kg^{-1} seed resulted in the greatest protein yield, measuring 320.73 kg ha^{-1} in grain and 187.17 kg ha^{-1} in straw. This suggests that PSB inoculation had a positive impact on protein content and yield in chickpea. PSB inoculation up to 10 ml PSB kg^{-1} seed inoculation was recorded significantly higher protein content as compared to 5 ml PSB kg^{-1} seed inoculation. This increase was might be due to the fact that Phosphobacteria enhanced the biological and chemical property of the soil. This finding was similar with the findings of [28, 29].When considering the impact of different phosphorus levels, it was observed that higher phosphorus level significantly increased protein content in both grain and straw compared to the control. Starting with no phosphorus (control), the grain had a protein content of 20.91%, while the straw contained 7.48% protein. As the P_2O_5 levels were incrementally raised to 20 kg P_2O_5 ha^{-1}, grain protein content increased to 21.92%, and straw protein content rose to 7.88%. At 40 kg P_2O_5 ha^{-1}, grain protein content reached 22.17%, while straw protein content was 8.21%. The highest P_2O_5 level of 60 kg P_2O_5 ha^{-1} resulted in the maximum grain protein content at 22.29%, and straw exhibited 8.45% protein. Similarly, the total protein yield in grain and straw showed significant increases with higher phosphorus levels. At control condition, the grain had a protein yield of 216.45 kg ha^{-1}, while the straw contained 119.61 kg ha^{-1} of protein. As the P_2O_5 levels were incrementally raised to 20 kg P_2O_5 ha^{-1}, grain protein yield increased to 272.14 kg ha^{-1} and straw protein yield rose to 156.44 kg ha^{-1}. In 40 kg P_2O_5 ha^{-1}, grain protein yield reached 318.42 kg ha^{-1}, while straw protein yield was 191.83 kg ha^{-1}. The highest P_2O_5 level of 60 kg P_2O_5 ha^{-1} resulted in the maximum grain protein yield at 372.28 kg ha^{-1} and straw exhibited 224.63 kg ha^{-1} of protein yield. This increase in protein content was due to the fact that phosphorus is a part of several key plant structures like nucleic acid which is responsible for the regulation of protein synthesis. Hence, increase in the level of phosphorus significantly affect the nucleic acid present in the plant which ultimately increased the protein content or uptake of the chickpea, similar results have also been reported by[30, 31, 32].

Table 5: Effect of phosphorus and PSB inoculation on protein content of grain and straw and total protein yield of chickpea under custard apple based agri-horti system

Treatment	Protein (%)		Protein yield (kg ha^{-1})		Total Protein yield (kg ha^{-1})
	Grain	Straw	Grain	Straw	
Levels of PSB (ml kg^{-1})					
C_0 (0 ml PSB kg^{-1} seed)	21.42	7.85	271.28	161.13	432.41
C_1 (5 ml PSB kg^{-1} seed)	21.78	7.99	292.46	171.08	463.54
C_2 (10 ml PSB kg^{-1} seed)	22.27	8.17	320.73	187.17	507.89
SEm±	0.23	0.08	10.66	5.31	14.50
CD (P= 0.05)	0.67	0.24	31.26	15.58	42.54
Levels of Phosphorus (kg ha^{-1})					
P_0 (0 kg P_2O_5 ha^{-1})	20.91	7.48	216.45	119.61	336.06
P_1 (20 kg P_2O_5 ha^{-1})	21.92	7.88	272.14	156.44	428.58
P_2 (40 kg P_2O_5 ha^{-1})	22.17	8.21	318.42	191.83	510.25
P_3 (60 kg P_2O_5 ha^{-1})	22.29	8.45	372.28	224.63	596.91
SEm±	0.27	0.10	12.31	6.13	16.75
CD (P= 0.05)	0.78	0.28	36.10	17.98	49.12

4. CONCLUSION

In conclusion, the study underscores the potential of the custard apple-based agri-horti system, coupled with integrated nutrient management, to substantially influence the nutrient dynamics of chickpea cultivation. The research demonstrates that increased levels of Phosphorus-Solubilizing Bacteria (PSB) and phosphorus application positively impact the nitrogen and phosphorus content and uptake in chickpea grain and straw. The combination of 10 ml PSB kg^{-1} seed and 60 kg P_2O_5 ha^{-1} treatment exhibits the most substantial improvements, indicating a synergistic effect. However, potassium content and uptake appear less responsive to PSB inoculation. Furthermore, findings indicate that higher phosphorus levels significantly increase protein content and yield in chickpea grain and straw, highlighting the pivotal role of phosphorus in protein synthesis. This outcome aligns with the importance of phosphorus in various plant structures, including nucleic acids, which regulate protein synthesis. Overall, this study emphasizes the potential of agroforestry systems, specifically the custard apple-based agri-horti system, to enhance the nutritional value and productivity of chickpeas. This approach holds promise for addressing food security challenges and promoting sustainable agricultural practices. Further research and practical application of these insights may contribute to the sustainable production of nutrient-rich legumes under agroforestry systems, thereby benefiting both farming communities and global food security.

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