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Pinky Buria
PG Students, Department of Soil science, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. Ajit N Puri
Assistant Professor, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. Prabhakar B Adsul
Associate Professor, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Dr. Mahesh S Waghmare
Assistant Professor, College of Agriculture, Dharashiv, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Anushka A Bahe
PG Students, Department of Soil science, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Pranoti I Gedam
PG Students, Department of Soil science, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Sayali S Bhaisare
PG Students, Department of Soil science, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Corresponding Author:
Pinky Buria
PG Students, Department of Soil science, College of Agriculture, Latur, Vasantao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Effect of phosphorus solubilizing bacteria on growth and yield of black gram (*Vigna mungo* L.)

Pinky Buria, Ajit N Puri, Prabhakar B Adsul, Mahesh S Waghmare, Anushka A Bahe, Pranoti I Gedam and Sayali S Bhaisare

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Abstract

The present field study was carried out on “Effect of Phosphorus Solubilizing Bacteria on Soil Nutrient Dynamics, Nutrient Uptake and Yield of Black Gram (*Vigna mungo* L.)” during the *Kharif* season of 2025–26 at Research farm, Department of Soil Science, College of Agriculture, Latur. The experiment was laid out in a Randomized Block Design (RBD) comprising eight treatments, each replicated thrice. The experiment was conducted using NUL-7, the recommended black gram variety, as the test crop. The experiment comprised the following treatments: T₁- Control, T₂- RDF (25:50:25), T₃- 100% RDNK + 75% RDP + PSB seed treatment, T₄- 100% RDNK + 50% RDP + PSB seed treatment, T₅- 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS, T₆- 100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 DAS, T₇- 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS and T₈-100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS. The experimental results revealed that the application of 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS recorded significantly higher values for growth and yield parameters viz. plant height 16.23, 29.67, 40.53 cm at 30, 40 and 60 DAS respectively, leaf area (478.76, 541.77 cm² plant⁻¹) 30, 45 DAS respectively, number of nodules (20.80), number of pods plant⁻¹(18.02), number of seeds pod⁻¹(2.89), seed yield (11.90 q ha⁻¹), straw yield (19.00 q ha⁻¹), at par with 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS and 100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS significantly superior over rest of the treatments. In contrast the lowest values recorded under treatment control.

Keywords: Black gram, phosphorus solubilizing bacteria, nutrient uptake, nutrient use efficiency, apparent nutrient balance

Introduction

Black gram (*Vigna mungo* L.), commonly known as urad or urd bean, is one of the most important pulse crops in India. Owing to its high protein and carbohydrate content, black gram is widely used in the preparation of various traditional food items, especially in South India (Singh, 1999)^[12]. It is a staple ingredient in Indian cuisine, forming the basis of popular dishes such as dal makhani, idli, dosa, vada, and papad. Beyond its culinary importance, black gram plays a vital role in sustainable agriculture due to its Nitrogen(N)-fixing ability, which improves soil fertility through symbiotic association with *Rhizobium* bacteria. Its deep root system helps reduce soil erosion, suppress weeds and enhance soil structure. The crop is also used as nutritious fodder for livestock and as a green manure crop. With a short crop duration of about 65–100 days, black gram fits well into multiple cropping systems and intensive crop rotations.

Black gram originated in South Asia and has been cultivated on the Indian subcontinent for thousands of years. It is believed to have been domesticated in India approximately 4,500 years ago from its wild ancestor, India is the world’s largest producer of black gram, contributing 70% of the global production, followed by Myanmar and Pakistan. India produces approximately 2.7 million tonnes from an approximately 4.4 m ha area with an average yield of 598 kg ha⁻¹ (Directorate of Economics and Statistics, 2021). Black gram is considered a nutrient-rich pulse owing to its high protein, mineral, and vitamin content. It contains approximately 25 g protein, 983 mg Potassium (K), 138 mg Calcium (Ca), 7.57 mg Iron (Fe), 1.447 mg Niacin, 0.273 mg Thiamine, and 0.254 mg Riboflavin per 100 g of dry seeds.

Phosphate Solubilizing Bacteria (PSB) plays an important role in solubilization of soil P through secretion of various organic acids, such as citric, tartaric, keto-gluconic, gluconic, oxalic, malic and lactic acids, by releasing phosphatases. Many fungi (*Penicillium* and *Aspergillus*), bacteria (*Bacillus*, *Pseudomonas*, and *Rhizobium*) and actinomycetes (*Acinetobacter* and *Streptomyces*) are potential solubilizers by bound phosphates in soil. More over use of PSB also reduce the environmental pollution caused by the use of chemical fertilizers. P is an essential nutrient for living organisms and no other nutrient can perform its functions. It is a crucial element for plant growth and development and is classified as a primary macronutrient. This means that crops require it in relatively high quantities. It is referred to as the “key of life” and the essential function of P are “energy storage” and transfer of energy (ADP and ATP), which act as “energy currency” (Manna *et al.*, 2024) [8]. Biofertilizers improve root proliferation due to the release of growth-promoting hormones and convert complex nutrients into simple nutrients thereby making them available to plants (Ammar *et al.*, 2023) [12].

Microbial mechanisms of plant growth promotion include Biological Nitrogen Fixation (BNF), synthesis of phytohormones, environmental stress relief, synergism with other microbial plant interactions, inhibition of plant ethylene synthesis, as well as increasing availability of nutrients like Phosphorus (P), Fe and minor elements, and growth enhancement by volatile compounds (Uzah *et al.*, 2024) [13].

Materials and Methods

The experiment was conducted at the research farm of Department of Soil Science, College of Agriculture, Latur, during *Kharif* season of the year 2025-2026, the variety of soybean used for experiment NUL-7, and the topography of experimental field was uniform and levelled. The soil of the research farm was dark grey to brown in colour and clayey in texture (2:1 smectite type). The soil was moderately calcareous, moderately alkaline (pH 7.87), low in available nitrogen (120.34 kg ha⁻¹), medium in available phosphorus (21.40 kg ha⁻¹) and high in available potassium (545.0 kg ha⁻¹). The experiment implemented in randomized block design (RBD) with a plot size of 3.9 m × 4.0 m, and row-to row and plant-to-plant distances of 30 cm and 10 cm, respectively. Fertilizers used in this experiment include Urea, SSP and MOP by soil application. The seed rate used was 12-15 kg ha⁻¹. Seed treated with *Rhizobium* and PSB. Sowing was done by dibbling method. The recommended cultural practices and plant protection measures were taken. Five plants were randomly selected and tagged from each net plot to record biometric observations at various growth stages. These same plants were later harvested individually for post-harvest analysis. The data collected from various observations were organized into tables and analyzed using analysis of variance (ANOVA).

Results and Discussion

Plant height (cm)

Among the different treatments, T₇ (100% RDNK + 75% RDP + PSB seed treatment + drenching of PSB at 20 and 40 DAS) recorded the maximum plant height of 16.23, 29.67, and 40.53 cm at 30, 45 and 60 DAS respectively. This was followed by T₈ (100% RDNK + 50% RDP + PSB seed treatment + drenching of PSB at 20 DAS and 40 DAS), which recorded plant heights of 14.20, 29.03, and 40.20 cm at 30, 45 and 60 DAS respectively, and remained statistically comparable with T₇. Treatment T₅ (100% RDNK + 75% RDP + PSB seed treatment + drenching of

PSB at 20) also exhibited improved plant height of 13.83, 28.23, 39.47 cm at 30, 45 and 60 DAS, respectively. The control (T₁) recorded the lowest plant height of 10.10, 24.40, and 37.40 cm at 30, 45 and 60 DAS respectively.

Overall, the results indicate that the combined application of PSB through seed treatment and split drenching, along with balanced fertilization, improved phosphorus solubilization and maintained its availability throughout the crop growth period. This integrated nutrient management strategy enhanced nutrient uptake, root development, and physiological activities, thereby promoting vigorous vegetative growth. Similar results were found by Gautam *et al.* (2023) [5] observed that the application of 50% recommended dose of fertilizer (RDF) + *Rhizobium* resulted in the highest plant height of 44.27 cm in green gram (*Vigna radiata* L.). The increase in plant height was attributed to the beneficial effect of *Rhizobium* in enhancing nutrient availability and supporting better vegetative growth. Similar findings were also reported by Rao *et al.* (2023) [9] reported that the application of 100% recommended dose of fertilizer (RDF) + *Rhizobium* + PSB resulted in the highest plant height of 45.73 cm in black gram (*Vigna mungo* L.). The increased plant height was attributed to the combined beneficial effects of biofertilizers and inorganic fertilizers, which enhanced nutrient availability and promoted vegetative growth.

Leaf area (cm² plant⁻¹)

Application of 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS (T₇) recorded the highest leaf area values i.e. 478.76 cm² plant⁻¹ at 30 DAS, 541.77 cm² plant⁻¹ at 45 DAS which was found at par with treatment T₈ i.e. (466.66 and 533.93 cm² plant⁻¹ at 30 and 45 DAS), T₅ (458.50 and 532.00 cm² plant⁻¹ at 30 and 45 DAS) and recorded significantly higher values than the remaining treatments. Leaf area was recorded to be lowest with treatment T₁ control (378.44, 403.56 cm² plant⁻¹ at 30 and 45 DAS) in black gram.

Improved phosphorus nutrition promoted vigorous root development, increased nutrient uptake, and stimulated cell division and expansion, leading to greater leaf development. Repeated PSB application at critical growth stages also helped sustain microbial activity in the rhizosphere, thereby enhancing photosynthetic surface area and overall vegetative growth. Similar results were observed by Shete *et al.* (2024) [10] reported that leaf area of black gram (*Vigna mungo* L.) increased with Nano-DAP application. The control recorded a leaf area of 330.4 cm² plant⁻¹ at 30 DAS and 339.8 cm² plant⁻¹ at 45 DAS, whereas the highest leaf area was recorded with 100% RDNK + soil test-based Nano-DAP + foliar application of 0.4% Nano-DAP at 20, 30 and 40 DAS, with 508.7 cm² plant⁻¹ at 30 DAS and 531.7 cm² plant⁻¹ at 45 DAS. Similar findings were reported by Shete *et al.* (2024) [10] reported that leaf area of black gram (*Vigna mungo* L.) increased with Nano-DAP application. The control (T₁) recorded a leaf area of 330.4 cm² plant⁻¹ at 30 DAS and 339.8 cm² plant⁻¹ at 45 DAS, whereas the highest leaf area was recorded with 100% RDNK + soil test-based Nano-DAP + foliar application of 0.4% Nano-DAP at 20, 30 and 40 DAS (T₉), with 508.7 cm² plant⁻¹ at 30 DAS and 531.7 cm² plant⁻¹ at 45 DAS.

Number of nodules plant⁻¹

The maximum number of nodules plant⁻¹ (20.80) was observed in Treatment T₇ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS). This was followed by T₈ (100% RDNK + 50% RDP + PSB seed treatment + Drenching of

PSB at 20 and 40 DAS), i.e. (20.40) nodules plant⁻¹ and T₅ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS) recorded a marked increase, reaching (19.87) nodules plant⁻¹. Significantly, a lowest number of nodules plant⁻¹ (14.67) was observed at flowering stage in treatment T₁ control.

Enhanced phosphorus nutrition favoured root growth, nodule initiation, and the establishment of an efficient symbiotic association with *Rhizobium* and repeated PSB application sustained beneficial microbial activity in the rhizosphere, resulting in improved nodulation and a greater number of nodules plant⁻¹. Similar results were found by Rao *et al.* (2023) [9] reported that combined inoculation of *Rhizobium* and phosphate-solubilizing bacteria (PSB) along with the recommended dose of fertilizers enhanced nodulation in black gram, with the maximum number of 36.50 nodules plant⁻¹. Similar observations were reported by Abubakar *et al.* (2025) [1] observed that combined application of FYM, *Rhizobium* and PSB increased nodulation in black gram, recording 30.00 nodules plant⁻¹ under the best treatment.

Number of pods plant⁻¹ and Number of seeds pod⁻¹

The greater number of pods plant⁻¹ (18.02) was recorded in T₇ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS). Treatment T₈ (100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS) recorded 16.93 pods plant⁻¹ at harvest while treatment T₅ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS) recorded 14.70 pods plant⁻¹. Both T₅ and T₈ were statistically at par with T₇. Unlike the lowest number of pods plant⁻¹ was observed in the T₁ control treatment, (11.23) pods plant⁻¹ at harvest.

The maximum number of seeds pod⁻¹ (2.89) was also observed in T₇ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS), followed by all the treatments are statistically at par with T₇. The number of seeds pod⁻¹ remained non-significant among the treatments, which due to the strong genetic control of this yield component and the relatively limited influence of nutrient management practices on varietal characteristics. Better phosphorus supply supported stronger photosynthetic activity, more assimilate production, and improved reproductive development, which reduced flower and pod drop. As a result, more flowers were retained and converted into pods, and more seeds were successfully developed within each pod.

Related findings have been reported by Harika *et al.* (2023) [7] reported that application of 50 kg P₂O₅ ha⁻¹ + *Rhizobium* + PSB significantly increased yield attributes of black gram, recording 40.8 pods plant⁻¹ and 6.23 seeds pod⁻¹. The results are further supported by Veer *et al.* (2024) [14] who reported that combined application of *Rhizobium* and PSB enhanced the yield attributes of black gram. The application of 60 kg ha⁻¹ *Rhizobium* + PSB recorded the highest number of pods plant⁻¹ (68.67) and seeds 8.50 pod⁻¹, compared with 60.85 pods plant⁻¹ and 7.55 seeds pod⁻¹ in the control.

Seed yield (q ha⁻¹)

The highest seed yield (11.90 q ha⁻¹) was recorded under T₇ (100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS), which significantly outperformed all other treatments, including the control and RDF alone. Treatments T₅ (10.94 q ha⁻¹) and T₈ (10.93 q ha⁻¹) were statistically at par with T₇. In contrast, the lowest yield (7.27 q ha⁻¹) was observed in the control (T₁).

PSB seed treatment and drenching at 20 and 40 DAS improved phosphorus availability in the soil. This promoted better root growth and stronger nodulation in black gram. As a result, the plants absorbed nutrients more efficiently during critical growth stages. Improved nutrient uptake supported better vegetative growth and more dry matter accumulation. This also helped in pod formation, seed filling and ultimately higher yield. Similar results were reported by Choudhary *et al.* (2024) [3] who reported that the application of 45 kg P ha⁻¹ along with seed inoculation of *Rhizobium* + PSB @ 20 g kg⁻¹ seed significantly improved growth and yield attributes of summer black gram, resulting in a seed yield of 724.17 kg ha⁻¹. The results are further supported by Gautam *et al.* (2022) [4] observed that application of 20:60:40 kg NPK ha⁻¹ + *Rhizobium* + PSB produced the highest growth and nodulation and increased grain yield by 39.90% over the unfertilized control and 33.55% over conventional NPK (20:40:40 kg ha⁻¹).

Straw yield (q ha⁻¹)

Application of 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS (T₇) i.e. (19.00 q ha⁻¹) resulted the highest straw biomass. This was followed by T₈ (18.94 q ha⁻¹) and T₅ (18.90 q ha⁻¹). In contrast the control (T₁) i.e. 14.52 q ha⁻¹.

Improved phosphorus availability supported root proliferation, nodulation, and greater uptake of nutrients needed for photosynthesis and biomass formation. This led to increased leaf area development, higher chlorophyll activity, and better assimilate production. The additional assimilates were efficiently partitioned into stems and leaves, resulting in greater dry matter accumulation and higher straw biomass. A similar trend was observed by Shivani *et al.* (2025) [11] who conducted a field study in India during the *Zaid* season. The objective was to evaluate the effect of biofertilizers and P levels on cowpea growth and yield. Application of PSB + 40 kg P ha⁻¹ significantly improved plant height, branches, nodules, dry matter accumulation, seed yield (819.32 kg ha⁻¹) and straw yield (1312.48 kg ha⁻¹), along with the highest economic returns. Similar findings were reported by Grace *et al.* (2025) [6] who evaluated black gram varieties under different nutrient levels and liquid biofertilizers in India. LBG-904 recorded the highest dry matter, pods plant⁻¹, seeds pod⁻¹, seed yield (1989 kg ha⁻¹) and haulm yield (2988 kg ha⁻¹). Among nutrient treatments, 100% RDF performed best and was statistically at par with 75% RDF + *Rhizobium* + PSB + KRB, indicating that biofertilizers can help sustain productivity with reduced chemical fertilizer use.

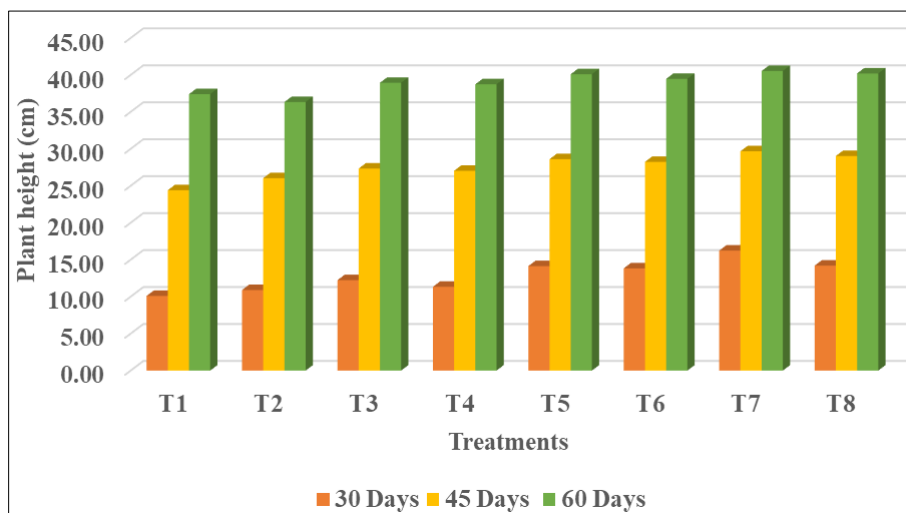


Fig 1: Effect of PSB on plant height (cm) of black gram at 30, 45 and 60 DAS

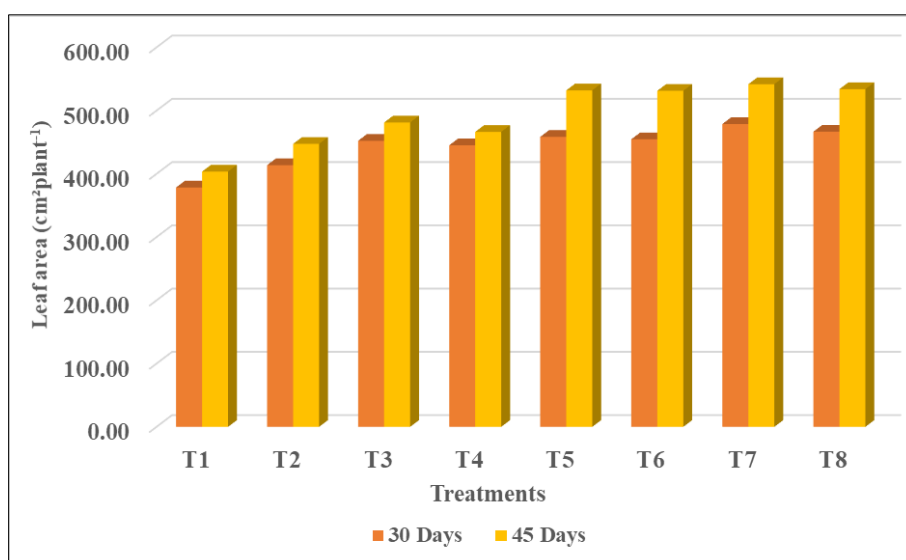


Fig 2: Effect of PSB on leaf area ($\text{cm}^2 \text{plant}^{-1}$) of black gram at 30 and 45 DAS

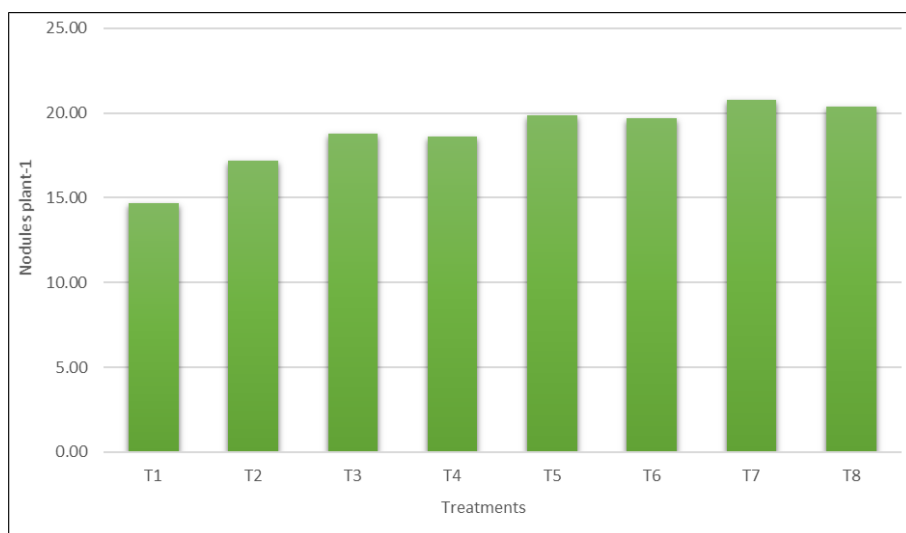


Fig 3: Effect of PSB on nodulation of black gram at flowering stage

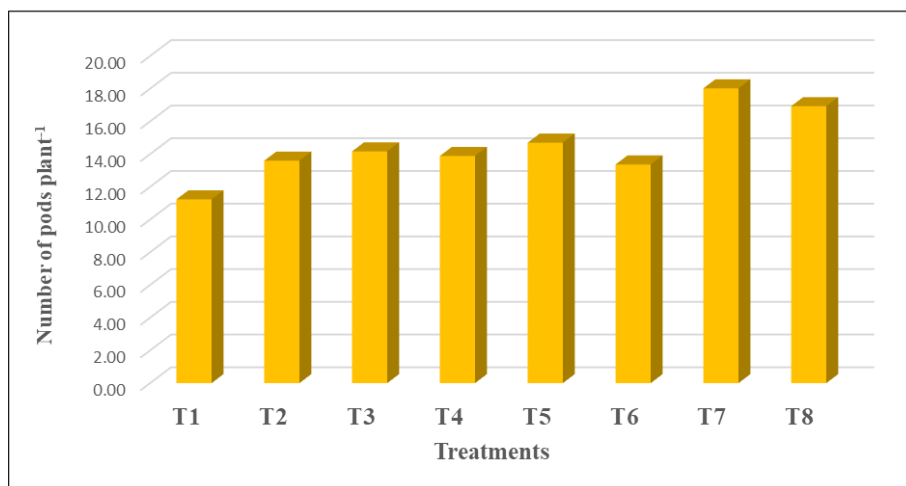


Fig 4: Effect of PSB on number of pods plant⁻¹ at harvest of black gram

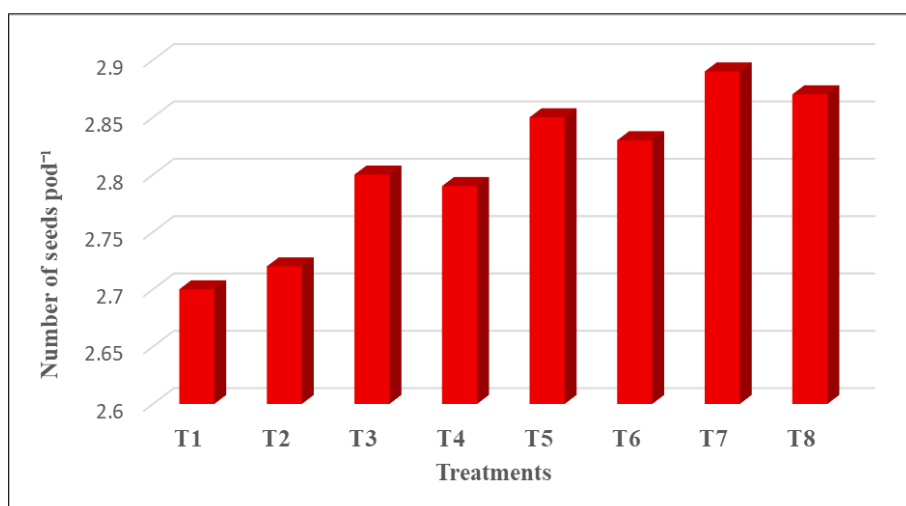


Fig 5: Effect of PSB on number of seeds pod⁻¹ at harvest of black gram

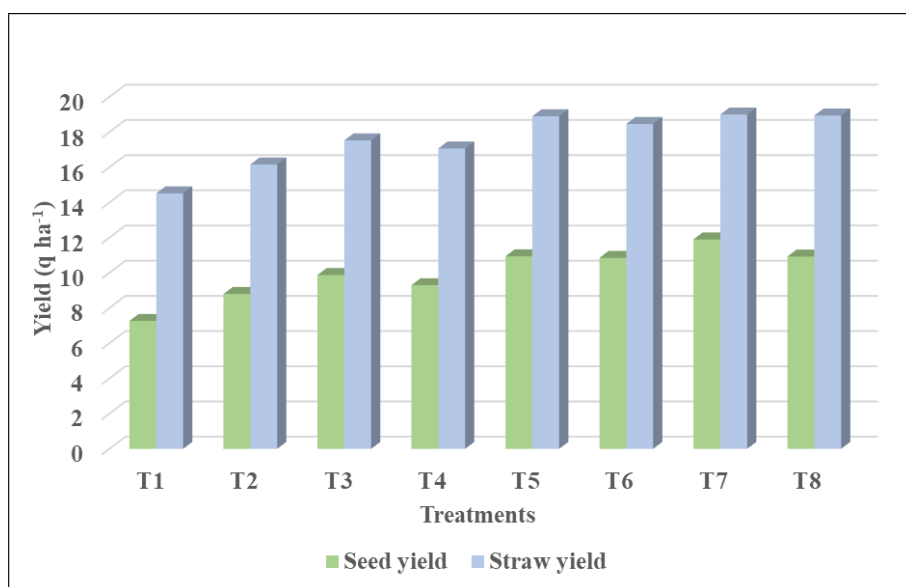


Fig 6: Effect of PSB on seed and straw yield (q ha⁻¹) of black gram crop

Table 1: Mean of growth and yield parameters of black gram as influenced by various treatments.

Treatments	Plant height (cm)			Leaf area (cm ² plant ⁻¹)		No. of nodules plant ⁻¹	No. of pods plant ⁻¹	No. of seeds pod ⁻¹	Seed yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)
	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS					
T ₁ - Control	10.10	24.40	37.40	378.44	403.56	14.67	11.23	2.70	7.27	14.52
T ₂ - 100% RDF	10.90	26.03	36.33	413.77	447.40	17.20	13.60	2.72	8.80	16.16
T ₃ - 100% RDNK + 75% RDP + PSB seed treatment.	12.23	27.33	38.93	452.34	481.23	18.80	14.17	2.80	9.88	17.53
T ₄ - 100% RDNK + 50% RDP + PSB seed treatment.	11.33	27.03	38.73	445.16	466.33	18.60	13.89	2.79	9.30	17.07
T ₅ - 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 DAS.	14.13	28.60	40.10	458.50	532.00	19.87	14.70	2.85	10.94	18.90
T ₆ - 100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 DAS.	13.83	28.23	39.47	454.67	531.33	19.70	13.37	2.83	10.85	18.46
T ₇ - 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS.	16.23	29.67	40.53	478.76	541.77	20.80	18.02	2.89	11.90	19.00
T ₈ - 100% RDNK + 50% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS.	14.20	29.03	40.20	466.66	533.93	20.40	16.93	2.87	10.93	18.94
SE ±	0.79	1.04	0.97	19.41	30.49	1.00	0.67	0.20	0.66	0.93
CD @ 5%	2.40	3.14	2.93	58.86	92.49	3.02	2.03	NS	2.00	2.84

*DAS- Days After Sowing

Conclusion

The application of 100% RDNK + 75% RDP + PSB seed treatment + Drenching of PSB at 20 and 40 DAS treatment showed significantly highest growth and yield parameters viz. plant height (16.23 cm, 29.67 cm, 40.53 cm at 30, 45 and 60 DAS), leaf area (478.76 cm² plant⁻¹, 541.77 cm² plant⁻¹ at 30 and 45 DAS), number of nodules plant⁻¹ (20.80), number of pods plant⁻¹ (18.02), number of seeds pod⁻¹ (2.89), seed yield (11.90 q ha⁻¹), and straw yield (19.00 q ha⁻¹) concluded superior over rest of treatments.

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