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Effect of Potassium Mobilizing Bacteria on Growth, Yield, Nutrient Uptake, and Nutrient Use Efficiency of Chickpea (*Cicer arietinum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Aims: The present investigation was undertaken to evaluate the influence of potassium mobilizing bacteria (KMB) on growth, yield, nutrient uptake and nutrient use efficiency of chickpea (*Cicer arietinum* L.).
Study Design: The experiment was conducted in a Randomised Block Design comprising eight treatments with three replications.
Place and Duration of Study: The experiment was conducted at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur, Maharashtra, India, during the *Rabi* season of 2025–26.
Methodology: Eight nutrient management treatments involving recommended fertiliser doses, reduced potassium levels, KMB seed treatment and KMB drenching were evaluated. Observations on growth, yield attributes, seed and straw yields, nutrient

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content, nutrient uptake and nutrient use efficiency were recorded using standard analytical procedures. The experimental data were subjected to analysis of variance, and treatment means were compared at the 5% level of significance.
Results: Significant differences among treatments were observed for most of the studied parameters. Treatment T_7, comprising 100% recommended nitrogen and phosphorus, 75% recommended potassium, KMB seed treatment and KMB drenching at 20 and 40 days after sowing, recorded the highest numerical values for plant height (48.24 cm), leaf area (375.36 cm^2 $plant^{-1}$), number of pods $plant^{-1}$ (71.27), seed yield (23.15 q ha^{-1}) and straw yield (45.50 q ha^{-1}). T_7 also recorded the highest numerical values for total uptake of nitrogen (177.31 kg ha^{-1}), phosphorus (34.44 kg ha^{-1}) and potassium (139.85 kg ha^{-1}). For nutrient use efficiency, T_7 recorded 54.42% nitrogen use efficiency, 27.21% phosphorus use efficiency and 54.42% potassium use efficiency.
Conclusion: Under the conditions of the present investigation, integration of KMB with 75% of the recommended potassium dose showed potential to improve nutrient utilisation and crop performance while reducing potassium fertiliser input by 25%. Further evaluation across multiple seasons, locations and contrasting soil potassium levels is required to establish the wider applicability of this nutrient management strategy.

Keywords: Chickpea; integrated nutrient management; potassium mobilizing bacteria; potassium nutrition; nutrient uptake; nutrient use efficiency.

1. Introduction

Chickpea (*Cicer arietinum* L.) is the second most widely cultivated grain legume after dry beans and is an important source of dietary protein, carbohydrates, vitamins, minerals, and dietary fibre, particularly in developing countries (Jukanti et al., 2012). Besides its nutritional value, chickpea contributes to sustainable agriculture through biological nitrogen fixation, which improves soil fertility and reduces the dependence on synthetic nitrogen fertilisers. However, productivity in many chickpea-growing regions remains below its potential due to poor soil fertility, imbalanced nutrient management, and declining nutrient use efficiency (Ali & Kumar, 2005). Improving nutrient management practices is therefore essential to sustain chickpea productivity while maintaining soil health.

Potassium is an essential macronutrient involved in enzyme activation, photosynthesis, osmotic regulation, carbohydrate translocation, protein synthesis, and stress tolerance (Zörb et al., 2014). In legumes, adequate potassium nutrition promotes root development, nodulation, and efficient utilisation of other nutrients, ultimately improving seed yield and quality. Although agricultural soils often contain substantial reserves of total potassium, only a small proportion exists in forms readily available for plant uptake. Continuous cropping and inadequate potassium replenishment further reduce the availability of exchangeable potassium, resulting in suboptimal crop performance and declining fertiliser use efficiency.

In recent years, beneficial microorganisms have received increasing attention as environmentally sustainable alternatives for improving nutrient availability and fertiliser use efficiency. Among these, potassium mobilizing bacteria (KMB) convert mineral-bound potassium into plant-available forms through the production of organic acids and other metabolites (Etesami et al., 2017). In addition to enhancing potassium availability, KMB have been reported to stimulate root growth, improve nutrient uptake, increase microbial activity in the rhizosphere, and enhance crop productivity. Consequently, integrating KMB with inorganic fertilizers has emerged as a promising strategy for improving nutrient utilisation while reducing dependence on chemical fertilisers.

Recent crop studies further support the relevance of integrating mineral fertilization with nutrient-solubilizing bacteria. In cowpea, combined application of phosphorus and potassium fertilizers with phosphorus- and potassium-solubilizing bacterial inoculation was associated with improved growth and nodulation (Lone et al., 2023). In brinjal assays, selected potassium-solubilizing *Bacillus* isolates showed potassium-mobilizing and plant growth-promoting activity (Parmar et al., 2024). In chickpea, nutrient-solubilizing bacterial inoculants improved nutrient acquisition and crop performance under water-stress conditions (Das et al., 2024). A recent multi-environment meta-analysis further indicated that the response to potassium-solubilizing microorganisms varies with microbial group, soil, crop, management, and environmental context (Fan et al., 2025). Controlled studies in maize have also reported improved potassium and phosphorus uptake following inoculation with selected potassium-solubilizing bacteria (Saxena et al., 2026).

Several studies have demonstrated the beneficial effects of potassium-solubilizing microorganisms on crop growth, nutrient uptake, yield, and soil fertility under different agro-ecological conditions. Nevertheless, their performance varies with soil characteristics, crop species, climatic conditions, and fertilizer management practices. Information on the combined use of KMB with reduced potassium fertilizer levels in chickpea under the conditions of the Deccan Plateau of Maharashtra remains limited. Generating such information is essential for developing efficient and location-specific nutrient management strategies for chickpea cultivation.

Therefore, the present investigation was undertaken to evaluate the effect of potassium mobilizing bacteria applied through seed treatment and drenching in combination with different potassium fertilizer levels on the growth, yield, nutrient uptake, and nutrient use efficiency of chickpea under field conditions.

2. Materials and Methods

2.1 Experimental Site and Soil

A field experiment was conducted during the rabi season of 2025–26 at the research farm, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur, Maharashtra, India, using chickpea variety BDNG-797 (Aakash). The soil was clayey, calcareous and moderately alkaline (pH 8.50), with low available nitrogen (222.89 kg ha^{-1}), medium available phosphorus (26.24 kg ha^{-1}) and high available potassium (628.06 kg ha^{-1}).

2.2 Experimental Design and Treatments

The experiment was laid out in a Randomised Block Design with eight treatments and three replications. The recommended dose of fertiliser (RDF) was 25:50:25 kg NPK ha^{-1}. Treatments included control (T_1), 100% RDF (T_2), and 100% recommended N and P with either 75 or 50% recommended K combined with KMB seed treatment and KMB drenching at 20 and/or 40 days after sowing (T_3–T_8). Urea, SSP and MOP were used as sources of N, P and K, respectively. Approximately 10 t FYM ha^{-1} was applied before sowing.
The crop was sown on 22 November 2025 at 30 × 10 cm spacing with a seed rate of 50 kg ha^{-1} in plots measuring 3.6 × 3.0 m and harvested at physiological maturity on 5 March 2026.

2.3 Observations and Nutrient Analysis

Plant height, leaf area, nodulation and pods $plant^{-1}$ were recorded using five representative plants from each plot. Seed and straw yields were recorded at harvest and expressed as kg ha^{-1}. Soil samples collected before sowing were analysed for pH, electrical conductivity, organic carbon and available N, P and K using standard procedures. Plant samples were digested using a H_2SO_4 (5:1) di-acid mixture. Nitrogen, phosphorus and potassium contents were determined by the micro-Kjeldahl, vanado-molybdate phosphoric acid and flame photometric methods, respectively.

Nutrient uptake was calculated as:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = [\text{Nutrient content (\%)} \times \text{total dry matter yield (kg ha}^{-1}\text{)}] / 100.$$

Nutrient use efficiency was calculated as the product of physiological efficiency and apparent recovery efficiency:

$$\text{NUE} = \text{Physiological efficiency} \times \text{Apparent recovery efficiency}$$

where physiological efficiency was calculated as:

PE = (Dry matter yield of fertilized crop − Dry matter yield of unfertilized crop) / (Nutrient uptake by fertilized crop − Nutrient uptake by unfertilized crop)

and apparent recovery efficiency as:

$$\text{ARE} = (\text{Nutrient uptake by fertilized crop} - \text{Nutrient uptake by unfertilized crop}) / \text{Quantity of fertilizer applied.}$$

2.4 Statistical Analysis

The data were subjected to analysis of variance appropriate for a Randomised Block Design following Panse and Sukhatme (1967). Standard error and critical difference (CD) at the 5% level of significance were calculated for comparison of treatment means wherever applicable.

3. Results and Discussion

3.1 Effect of Potassium Mobilizing Bacteria on Growth Parameters

Application of potassium mobilizing bacteria (KMB) influenced the vegetative growth of chickpea. T_7 recorded the numerically highest plant height (48.24 cm at 60 DAS) and leaf area (375.36 cm^2 $plant^{-1}$ at 45 DAS), whereas the control recorded the lowest values. However, T_7 and T_8 were statistically at par for both plant height and leaf area, as the differences between their means were smaller than the respective critical differences. The highest number of nodules (24.53 $plant^{-1}$) was also recorded under T_7, although nodulation did not differ significantly among treatments.

The improved growth under KMB application may be attributed to enhanced potassium availability in the rhizosphere. Potassium plays an important role in photosynthesis, enzyme activation and assimilate translocation, while KMB can enhance nutrient availability through potassium solubilization and production of plant growth-promoting metabolites. These effects may have contributed to improved vegetative growth.

The present findings are in agreement with Mustafa and Khudhur (2020), who reported increased shoot height in chickpea following potassium-mobilizing bacterial inoculation. Bhat et al. (2022) also observed improved plant height in lentil with integrated application of potassium fertilizer and potassium-solubilizing bacteria. Bakhshandeh et al. (2017) reported increased leaf area following inoculation with potassium-solubilizing bacteria, while Alladi et al. (2014) and Prakhyath et al. (2024) observed improved vegetative growth under integrated nutrient management involving beneficial microorganisms. Siddiqui et al. (2021) further reported multiple plant growth-promoting traits in potassium-solubilizing rhizobacteria associated with chickpea.

Table 1. Effect of potassium mobilizing bacteria on growth parameters

Treatments	Plant Height (60 DAS)	Leaf Area (45 DAS)	Nodules plants^{-1} (45 DAS)
T1: Control	35.38	281.69	18.9
T2: 100% RDF	37.73	298.25	20.1
T3: 100% RDNP + 75% RDK + KMB Seed treatment.	40.41	320.22	22.8
T4: 100% RDNP + 50% RDK + KMB Seed treatment.	39.64	305.52	22.43
T5: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	45.92	354.08	23.67
T6: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	42.78	335.97	23.07
T7: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	48.24	375.36	24.53
T8: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	46.63	364.9	24.13
SE±	1.66	11.88	0.82
CD at 5%	5.05	36.02	NS

3.2 Effect of Potassium Mobilizing Bacteria on Yield Attributes and Yield

KMB application improved yield attributes and yield of chickpea. T_7 recorded the numerically highest number of pods plant^{-1} (71.27), seed yield (23.15 q ha^{-1}) and straw yield (45.50 q ha^{-1}), whereas the control recorded the lowest values. However, the differences between T_7 and T_8 were not significant for pods plant^{-1}, seed yield and straw yield, indicating that the two treatments were statistically at par for these parameters.

The higher productivity under KMB application may be associated with improved potassium availability and nutrient acquisition, which support photosynthetic activity, assimilate translocation and reproductive development. Repeated KMB application through drenching at 20 and 40 DAS may have maintained microbial activity and nutrient availability during crop growth, contributing to greater biomass and yield.

The present results are consistent with Bhat et al. (2022), who reported increased pod production in lentil following integrated application of potassium fertilizer and potassium-solubilizing bacteria. Mustafa and Khudhur (2020) also observed improved chickpea productivity following microbial inoculation. Similar improvements in yield and biomass under integrated potassium fertilization and potassium-solubilizing bacterial application have been reported by Goswami and Maurya (2020), Priyavardhini et al. (2021), and Bakhshandeh et al. (2017).

Table 2. Effect of potassium mobilizing bacteria on yield attributes and yield

Treatments	Seed Yield (q ha^{-1})	Straw Yield (q ha^{-1})	No. of Pods plants^{-1}
T1: Control	18.44	36.60	59.13
T2: 100% RDF	20.22	38.29	60.83
T3: 100% RDNP + 75% RDK + KMB Seed treatment.	21.45	40.77	63.40
T4: 100% RDNP + 50% RDK + KMB Seed treatment.	21.14	39.95	61.53
T5: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	22.32	43.09	66.97
T6: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	21.90	41.93	64.37
T7: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	23.15	45.50	71.27
T8: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	22.78	44.33	67.97
SE±	0.39	0.81	2.20
CD at 5%	1.20	2.47	6.63

3.3 Effect of Potassium Mobilizing Bacteria on Nutrient Uptake

Application of KMB improved the uptake of nitrogen, phosphorus and potassium by chickpea. T_7 recorded the numerically highest total uptake of nitrogen (177.31 kg ha^{-1}), phosphorus (34.44 kg ha^{-1}) and potassium (139.85 kg ha^{-1}), whereas the control recorded the lowest values. However, T_7 and T_8 were statistically at par for all three nutrients, as the differences between their means were lower than the respective critical differences.

The greater nutrient uptake under integrated KMB and potassium fertilization may be attributed to improved nutrient availability in the rhizosphere and enhanced root activity. Adequate potassium availability also supports nutrient transport, enzyme activation and metabolic processes, thereby contributing to efficient nutrient acquisition and crop growth.

The present findings corroborate the results of Maheta et al. (2020), who reported enhanced nitrogen uptake following combined application of potassium fertilizer and potassium-solubilizing bacteria. Han and Lee (2005) observed improved N, P and K uptake with phosphate- and potassium-solubilizing bacteria. Similar improvements in nutrient acquisition following application of potassium-solubilizing microorganisms have been reported by Bagyalakshmi et al. (2012), Savaliya et al. (2018), Patel and Viradiya (2022), and Kammar et al. (2016).

Table 3. Effect of potassium mobilizing bacteria on nutrient uptake

Treatments	Nitrogen Uptake (Kg ha^{-1})	Phosphorus Uptake (Kg ha^{-1})	Potassium Uptake (Kg ha^{-1})
T1: Control	104.75	16.69	71.16
T2: 100% RDF	124.53	20.11	85.87
T3: 100% RDNP + 75% RDK + KMB Seed treatment.	144.40	24.69	102.95
T4: 100% RDNP + 50% RDK + KMB Seed treatment.	137.89	22.41	92.71
T5: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	162.62	29.71	119.42
T6: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	152.82	26.72	108.56
T7: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	177.31	34.44	139.85
T8: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	169.54	32.02	128.24
SE±	6.73	1.73	6.76
CD at 5%	20.41	5.25	20.51

3.4 Effect of Potassium Mobilizing Bacteria on Nutrient Use Efficiency

Application of KMB improved nutrient use efficiency in chickpea. T_7 recorded the highest nutrient use efficiency, with nitrogen use efficiency (NUE) of 54.42%, phosphorus use efficiency (PUE) of 27.21% and potassium use efficiency (KUE) of 54.42%. These values were significantly higher than those recorded under T_8, as the differences between T_7 and T_8 exceeded the respective critical differences.

The improved nutrient use efficiency under T_7 may be attributed to the combined application of 75% of the recommended potassium with KMB through seed treatment and drenching. KMB-mediated potassium mobilization may improve the availability of native and applied potassium, while enhanced root activity and balanced nutrient supply may promote more efficient utilisation of available nutrients for biomass production and seed development.

The present findings are supported by Prakhyath et al. (2024), who reported improved nutrient use efficiency under integrated application of reduced fertilizer doses with phosphate- and potassium-solubilizing bacteria. Singh et al. (2023) also observed improved nutrient use efficiency under integrated nutrient management involving beneficial microorganisms. Similar improvement in nutrient use efficiency following potassium-solubilizing bacterial application has been reported by Kavya et al. (2023).

Table 4. Effect of potassium mobilizing bacteria on nutrient use efficiency

Treatments	NUE (%)	PUE (%)	KUE (%)
T1: Control	-	-	-
T2: 100% RDF	13.87	6.93	13.87
T3: 100% RDNP + 75% RDK + KMB Seed treatment.	28.70	14.36	28.71
T4: 100% RDNP + 50% RDK + KMB Seed treatment.	24.19	12.09	24.19
T5: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	41.45	20.73	41.46
T6: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 DAS.	35.14	17.57	35.15
T7: 100% RDNP + 75% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	54.42	27.21	54.42
T8: 100% RDNP + 50% RDK + KMB Seed treatment + Drenching of KMB at 20 and 40 DAS.	48.25	24.13	48.26
SE±	1.83	0.94	1.96
CD at 5%	5.63	2.89	6.03

4. Conclusion

The study indicates that integrating potassium mobilizing bacteria (KMB) with reduced potassium fertilisation can support chickpea growth, yield, nutrient uptake, and nutrient use efficiency under the experimental conditions. Treatment T_7, consisting of 100% recommended nitrogen and phosphorus, 75% recommended potassium, KMB seed treatment, and KMB drenching at 20 and 40 days after sowing, recorded the highest numerical values for most measured growth and yield parameters. It also recorded the highest numerical uptake of nitrogen, phosphorus, and potassium. For growth, yield, and nutrient uptake, T_7 remained statistically at par with T_8, whereas the reported nutrient-use-efficiency values were higher under T_7. These findings suggest that combining KMB with 75% of the recommended potassium dose has the potential to reduce potassium fertiliser input by 25% while maintaining favourable crop performance in the study environment. However, the result should be interpreted within the conditions of this single-season, single-location experiment. Evaluation across multiple seasons, locations, and soils with contrasting potassium availability is required before wider agronomic application can be established.

5. Limitations of the Study

The experiment was conducted during a single rabi season at one location, where the experimental soil had high available potassium (628.06 kg ha^{-1}). Therefore, the response to KMB and reduced potassium fertilization may vary in soils with different potassium availability and environmental conditions. Multi-season and multi-location evaluation across contrasting soil potassium levels is required to validate the consistency and wider applicability of the findings.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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