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CROP SCIENCE | ORIGINAL ARTICLE

Improving Crop Productivity, Nutrient Use Efficiency and Economics of Chamomile (*Matricaria chamomilla* L.) Using Phosphate and Potassium Solubilizing Bacteria

KM Prakhyath[1], Priyanka Mehra[1], Charul Khatri[1], T Arul Prakash[1], Dipender Kumar[2,3], RC Padalia[2,3], ND Yogendra[1,3]

[1] Central Institute of Medicinal and Aromatic Plants (CSIR), Research Centre, Bengaluru-560065, India

[2] Central Institute of Medicinal and Aromatic Plants, Research Centre, Dairy Farm, Nagla, Pantnagar-263 149, Uttarakhand, India

[3] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, Uttar Pradesh, India

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Correspondence
N D Yogendra
✉: yogendra.nd@cimap.res.in

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ABSTRACT

Chamomile (*Matricaria chamomilla* L.) is a vital medicinal and aromatic plant, widely recognized for its industrial applications. However, sustainable cultivation of chamomile faces challenges due to the excessive use of chemical fertilizers, which can negatively impact soil health and the environment. There is a growing need to explore alternative agricultural practices that enhance nutrient use efficiency while minimizing environmental harm. Field experiments were conducted from 2022 to 2024 at the CSIR-CIMAP Research Centre in Bengaluru to evaluate the effects of Phosphate Solubilizing Bacteria (PSB) and Potassium Solubilizing Bacteria (KSB) on the performance and nutrient use efficiency of chamomile. Various treatment combinations of Recommended Dose of Fertilizers (RDF: 100 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1}) with PSB and KSB were tested, including co-inoculation and sole applications, to determine their impact on plant growth, yield and economic returns. Co-inoculating PSB and KSB with 100% RDF significantly increased plant height (48.09 cm) and branch count (15.43), outperforming RDF alone and other treatments. Sole applications of PSB or KSB with 100% RDF were comparable to 75% RDF combinations. The highest agronomic use efficiency (27.28%) and microbial response (37.49%) were achieved with 100% RDF+PSB+KSB, leading to a 137.49% yield increase. The highest concentrations of key compounds, α-bisabolol oxide B and α-bisabolol, were observed with 75% RDF+PSB+KSB. α-bisabolol peaked in the RDF-alone treatment. The 100% RDF+PSB+KSB treatment achieved the highest net monetary returns (US$ 5110 ha^{-1}) and a benefit-to-cost ratio of 2.41, similar to 75% RDF+PSB+KSB. Overall, 75% RDF with PSB and KSB significantly enhances chamomile performance, increases soil bacterial populations, boosts nutrient mineralization, reduces chemical fertilizer use, and minimizes environmental impact. This approach offers a promising pathway for sustainable chamomile cultivation, leading to higher yields, improved economic returns, and reduced environmental impact

1. Introduction

Chamomile (*Matricaria chamomilla* L.) is a medicinal and aromatic plant belongs to Asteraceae/Compositae family. Chamomile is renowned for its relaxing, carminative, and spasmolytic properties, making it a staple in many herbal tea blends. Additionally, its anti-inflammatory, antioxidant, and soothing effects on the skin have made it a popular ingredient in topical health and cosmetic products. The plant, widely used in European herbal medicine, is known for making chamomile tea, one of the most popular single-ingredient herbal teas (Kato 2008). The plant contains volatile oil ranging from 0.24% to 1.9%, comprising various types of chemical compounds. Chamomile boasts approximately 120 secondary metabolites, including 28 terpenoids and 36 flavonoids. The essential oil extracted from chamomile flowers primarily consists of α-bisabolol and its oxide azulenes, such as derivatives of chamazulene and acetylene (Srivastava, 2010)

India has historically relied heavily on agriculture, with around 65% of its workforce engaged in this sector. Traditionally, organic manure was the primary source of soil enrichment. However, starting in the 1960s, the adoption of modern irrigation systems and high-yielding crop varieties led to a surge in chemical fertilizer usage,

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causing significant repercussions for soil and human health, as well as the ozone layer (Pathak et al. 2010). To address these concerns and reduce reliance on harmful fertilizers, farmers must explore alternative nutrient sources that are both cost-effective and environmentally sustainable (Husain et al. 2021). Plants require essential macronutrients like nitrogen (N), potassium (K), and phosphorus (P) for their growth and development. In agriculture crop productivity and quality are significantly impacted by these nutrients. Among these, phosphorus (P) and potassium (K) play vital roles in the synthesis of proteins, enzymes, cells, cellulose, carbohydrates, and vitamins necessary for plant health and vitality. Moreover, potassium (K) plays a significant role in enhancing agricultural sustainability by bolstering resilience against both biotic and abiotic stresses, while also facilitating the efficient delivery and uptake of nutrients (Maqsood et al. 2013).

Potassium (K) stands out as one of the most vital macronutrients essential for plant growth. It plays critical roles in various plant metabolic processes, including cell formation, enzyme activities, protein synthesis, and vitamin production. Additionally, K regulates metabolic pathways and enhances plant resilience against both biotic and abiotic stresses (Bakhshandeh et al. 2017). Apart from its role in signal transduction cascades, inorganic phosphate (Pi) serves as a fundamental component in nucleic acids, membrane lipids, energy metabolites, and activated intermediates within the photosynthetic carbon cycle. However, the relatively limited presence of K and P in soils compared to N poses constraints on crop productivity, posing challenges to food security and agricultural sustainability. Enhancing nutrient utilization efficiency in plants represents a potential strategy to mitigate the effects of K and P deficiencies (Wang et al. 2020).

Bio-fertilizers are beneficial microorganisms in agriculture, facilitate the conversion of non-usable materials into usable forms through biological processes. They offer an alternative to chemical fertilizers, enhancing microbial biomass and soil structure, thus promoting sustainable productivity over the long term (Kumar et al. 2001). Biofertilizers such as Azotobacter, Phosphorus Solubilizing Bacteria (PSB) and Potassium Solubilizing Bacteria (KSB) play a vital role in agriculture by releasing growth-promoting compounds, including vitamins, into the soil, which nourishes crops. Azotobacter fixes atmospheric nitrogen in the root zone of plants, while PSB and KSB solubilize fixed phosphates and potassium that would otherwise remain insoluble in the soil (Chandel et al. 2021). Regular and consistent application of fertilizer nutrients to the soil provides valuable insights into the soil's nutrient status during and after cropping cycles. This facilitates the adjustment of soil characteristics to optimize crop yields. Concerns about potential declines in soil fertility over time due to prolonged chemical fertilizer use are often attributed to the uneven distribution of nutrients from inorganic fertilizers to be overcome by PSB and KSB (Mehra et. 2024; Khatri et al. 2024; Dubey et al. 2012).

The current agricultural practices often rely heavily on chemical fertilizers, which can lead to soil degradation, nutrient imbalance, and environmental pollution. In contrast, biofertilizers offer a sustainable alternative by promoting nutrient solubilization and uptake through beneficial microbial interactions. However, there is a significant gap in research focusing on optimizing biofertilizer applications tailored to chamomile's specific nutrient requirements under varying soil conditions. Addressing this gap is essential for developing precise and effective strategies that enhance nutrient availability, improve plant growth, and increase essential oil yield in chamomile cultivation under limited P and K soil under field conditions, an experiment was carried to assess the response of chamomile to phosphate and potassium solubilizing biofertilizers.

2. Materials and Methods

2.1. Experimental details

Field experiments were conducted at the CSIR-Central Institute of Medicinal and Aromatic Plants Research Centre, Bengaluru during the 2022-23 and 2023-24 seasons, consecutively. The experiment site was situated in the southern plateau, characterized by a subtropical climate. The soil of the experiment site was neutral in reaction with a medium in major and micronutrient status. The experimental layout followed a Random Block Design (RBD), with eight treatments in triplicates. The treatments comprised: T1: Control, T2: Recommended Dose of Fertilizer (RDF), T3: 100% RDF+KSB, T4: 75% RDF+KSB, T5: 100% RDF+PSB, T6: 75% RDF+PSB, T7: 100% RDF+PSB+KSB, and T8: 75% RDF+PSB+KSB.

2.2. Crop husbandry

Seeds of chamomile var. CIM-Sammohak were sown in a nursery and 30- 35 days old seedlings were subsequently transplanted to the pre-ploughed main field, adopting a planting spacing of 30x30 cm. The recommended dose of fertilizers (RDF) was administered at a rate of 100 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1}. At the time of sowing, 50% of the nitrogen and the entire amounts of phosphorus and potassium were applied as a basal dose, while the remaining nitrogen was distributed evenly in two split doses. Prior to transplantation, Phosphate Solubilizing Bacteria (*Bacillus megaterium*) and Potassium Solubilizing Bacteria (*Frateuria aurantia*) were inoculated to the treatment plots at a rate of 10 kg ha^{-1}. The crop was irrigated to maintain soil moisture condition at field capacity. Weed management within each plot was achieved through regular manual weeding. During crop growth red mite infestation was noticed and was controlled using Quinalphos 25 EC at a concentration of 1 mL^{-1}. The crop was harvested at its maturity stage, followed by shade drying of the flowers at room temperature to bring down the moisture to 10-12% for further analysis. Moisture loss was calculated by the following formula;

$$\text{Moisture loss }\% = \frac{\text{Wi} - \text{Wf}}{\text{Wi}}\ x\ 100$$

Where, W_i - Initial weight of the sample, W_f – Final weight of the sample.

2.3. Extraction and analysis of essential oil

The harvested biomass was dried in the shade followed by hydro-distillation using Clevenger apparatus (Soxhlet extraction unit by Super Scientific Company Bengaluru) for 5 hours and essential oil was collected over anhydrous sodium sulphate to remove the moisture content of the oil and preserved in a cool and dark environment until chemical analysis was performed. The chemical constituents of the essential oils were determined through gas chromatographic analysis using the Thermo Fischer Trace GC-1300, as well as Gas Chromatography-Mass Spectrometry utilizing a PerkinElmer Clarus 680 GC coupled with an SQ 8C MS (Adams 2007).

2.4. Colony Forming Unit (CFU)

The serially diluted rhizosphere soil of chamomile and surface-sterilized roots, stems, and leaves of chamomile were inoculated onto nutrient agar media and incubated at 30°C for 24 hours. Microbial growth was recorded by counting Colony Forming Units (CFUs) (Sieuwerts et al. 2008). Each colony that appeared on the plate was considered one CFU. Plates were sub-cultured to gain pure culture isolate and to revive bacteria. The different colonies according to color, shape, and size were further subjected to the identification of genera using staining techniques and biochemical analysis. (Duhan et al. 2020).

$$\text{CFU} = \frac{\text{Number of colonies x Dilution factor}}{\text{Volume of the sample}}$$

2.5. Phosphate Solubilization Index (PSI)

1 g of soil from chamomile rhizosphere was collected and serially diluted and poured on Pikovskaya medium agar (Himedia M520-100G), and incubated at 30˚C until halo zone appeared. Halo zone appearance indicates the presence of phosphate solubilization, and it was measured as a Phosphate Solubilization index (SI) (Pande et al. 2017).

$$\text{PSI} = \frac{\text{Colony diameter} + \text{Halozone diameter}}{\text{Colony diameter}}$$

2.6. Agronomic Efficiency (AE)

The agronomic efficiency of biofertilizer is the amount of additional biomass harvested per kilogram of biofertilizer applied. This efficiency was calculated by using the following formula given by Dobermann **(**2005**)**

$$AE = \frac{\text{Yield (Treatment)} - \text{Yield (control)}}{\text{Bio fertilizer applied}}$$

2.7. 2.6 Yield Response Percentage (YR)

The yield response percentage is calculated to assess the relative increase in crop yield attributable to the application of an input (such as a fertilizer) compared to a control where no input was applied (Schütz et al.2018).

$$YR\ (\%) = \frac{Yield\ (innoculated)}{Yiled(non\ innoculated)}\ x\ 100$$

2.8. Microbial Response (MR) %

Percentage increase in essential oil yield in inoculated plants compared to control. This was computed by using the following equations (Gao et al. 2007)

$$\text{MR (\%)} = \frac{\text{EO yield (Innoculated)} - \text{EO yield (control)}}{\text{EO yield (Control)}} \text{x 100}$$

2.9. Data analysis

The data on plant growth and yield parameters was documented at the time of harvest and subjected to statistical analysis using a Random Block Design as specified by Gomez and Gomez (1984). The analysis of variance was executed and the F test was performed at a 5% level of significance. In the tables, values noted with different letters (a, b, c) indicate a significant difference between means, as determined by post-hoc tests.

3. Results

3.1. Growth attributes of chamomile

The integration of phosphorus and potassium fertilization sources with microbial inoculants apparently influenced the morphological development of chamomile (Table 1). The co-inoculation of PSB and KSB in conjunction with 100% RDF resulted in a statistically significant enhancement in both plant height and the proliferation of branches, registering 48.09 cm in height and 15.43 in branch count, respectively, surpassing the outcomes observed with RDF alone and all other experimental conditions. This was succeeded by the application of 75% RDF along with PSB and KSB (46.62 cm and 15.43, respectively). Moreover, the administration of 100% RDF in combination with either PSB or KSB independently also yielded a notable enhancement in both plant height and branch count, outperforming RDF and control treatment. Intriguingly, the growth parameters from separate applications of PSB or KSB with RDF demonstrated comparably equivalent outcomes. The minimal growth metrics were observed in the control group devoid of any treatment (34.59 cm and 8.50, respectively). This growth pattern was consistently observed in the years 2023 and 2024, reflecting a steady trend in the morphological attributes assessed.

3.2. Flower and essential oil yield

The present investigation substantiates the hypothesis that the synergistic application of inorganic nutrient sources alongside microbial inoculation distinctly enhances the chamomile yield, as evidenced in Table 2. The dry flower yield and essential oil yield recorded in combined inoculation of PSB and KSB with 100% RDF (1.55 t $ha^{-1}$and 10.01 L ha^{-1}) was statistically superior compared to all other treatments. Conversely, yields from the 75% RDF combined with PSB and KSB treatment (1.47 t ha^{-1} and 9.76 L ha^{-1} respectively) were statistically comparable to those from the aforementioned superior treatment. A notable enhancement in the number of flowers per picking was observed in the treatment with 100% RDF+ PSB +KSB (233.11), contributing to the

Table 1. Growth attributes of Chamomile due to the application of biofertilizers

Treatment	Plant height (cm)			Number of branches		
	2023	2024	Pooled	2023	2024	Pooled
Control	33.93	35.25	34.59	8.00	9.00	8.50
RDF	41.03	43.30	42.17	12.00	14.00	13.00
100% RDF+PSB	45.43	46.45	45.94	13.00	13.00	13.00
75% RDF+PSB	46.44	48.00	47.22	11.00	12.00	11.50
100% RDF+KSB	45.16	46.80	45.98	12.00	14.00	13.00
75% RDF+KSB	47.05	47.50	47.28	11.00	13.00	12.00
100% RDF+PSB+KSB	48.73	48.30	48.52	14.00	17.00	15.50
75% RDF+PSB+KSB	49.23	47.97	48.60	13.00	15.00	14.00
SEm±	0.46	0.78	0.47	0.10	0.24	0.12
CD (5%)	1.38	2.36	1.44	0.31	0.74	0.38

Table 2. Yield of Chamomile due to the application of biofertilizers

Treatment	Number of flowers/ pickings			Weight of dry flowers (t/ha)			Oil yield (l/ha)		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Control	98.55	100.86	99.71	0.74	0.76	0.75	4.75	4.78	4.77
RDF	182.88	187.36	185.12	1.09	1.13	1.11	7.29	7.27	7.28
100% RDF+PSB	186.03	188.18	187.11	1.31	1.32	1.32	8.51	8.58	8.55
75% RDF+PSB	177.37	193.14	185.26	1.30	1.34	1.32	8.45	8.71	8.58
100% RDF+KSB	186.70	191.26	188.98	1.27	1.30	1.29	8.25	8.17	8.21
75% RDF+KSB	172.37	178.07	175.22	1.25	1.26	1.26	7.87	8.15	8.01
100% RDF+PSB+KSB	227.03	239.18	233.11	1.54	1.56	1.55	10.14	9.88	10.01
75% RDF+PSB+KSB	218.03	230.23	224.13	1.49	1.47	1.48	10.11	9.53	9.82
SEm	3.59	4.06	2.41	0.02	0.03	0.02	0.16	0.17	0.10
CD	10.88	12.32	7.31	0.07	0.08	0.05	0.49	0.53	0.32

Table 3. Chemical constituents of chamomile essential oil

Sl.No	Compound Name	T1	T2	T3	T4	T5	T6	T7	T8
1	Limonene	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10
2	(E)-β-ocimene	0.20	0.30	0.20	0.10	0.40	0.20	0.20	0.30
3	Artemisia ketone	1.60	1.60	1.10	1.30	2.50	1.80	1.70	2.50
4	Camphor	0.70	0.60	0.40	0.30	0.90	0.50	0.60	0.50
5	Isoborneol	0.60	0.30	0.30	0.30	0.40	0.40	0.30	0.40
6	β-elemene	0.20	0.10	0.30	0.10	0.20	0.10	0.10	0.20
7	β-caryophyllene	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
8	(E)-β-farnesene	4.80	4.40	5.10	3.50	5.70	6.00	5.70	5.60
9	Germacrene-D	0.70	0.50	0.40	0.30	0.40	0.70	0.50	0.40
10	Bicyclogermacrene	0.20	0.10	0.30	0.10	0.10	0.10	0.10	0.10
11	10-epi-Ɣ-eudesmol	0.80	0.90	0.70	1.70	0.90	1.00	1.90	1.10
12	α-bisabolol oxide B	21.50	23.70	24.36	22.50	20.50	21.34	23.45	25.90
13	α-bisabolol	23.64	26.00	22.70	20.60	26.65	22.45	23.80	25.65
14	Chamuzelene	1.40	1.70	3.20	2.80	3.00	3.20	2.10	2.60
15	α-bisabolol oxide A	16.78	15.00	16.80	20.90	18.45	18.65	16.54	18.86
16	(Z)-spiro ether	8.20	10.90	11.80	9.20	8.10	11.70	10.90	5.80
17	(E)-spiro ether	0.30	0.60	0.70	0.10	0.40	0.60	0.60	0.30

(T1: Control, T2: Recommended dose of fertilizer (RDF), T3: 100% RDF+KSB, T4: 75% RDF+KSB, T5: 100% RDF+PSB, T6: 75% RDF+PSB, T7: 100% RDF+PSB+KSB, T8: 75% RDF+PSB+KSB) increased dry flower yield in the same treatment group. Similarly, the independent application of PSB and KSB, in conjunction with 100% RDF, significantly elevated the flower count and, consequently, increased both the dry flower and oil yields in comparison to the RDF alone (185.12, 1.11 t ha^{-1} and 7.28 L ha^{-1} respectively) and control treatments ((99.71, 0.75 t ha^{-1} and 4.77 L ha^{-1} respectively), followed by the treatments involving 75% RDF with PSB or KSB. Although a consistent pattern in treatment efficacy was observed across both seasons, a marginal increase in dry flower yield was recorded in 2024 relative to 2023, whereas the essential oil yield exhibited an inverse trend. Variations in essential oil content attributable to different treatment applications were insignificant in both years, ranging from 0.63% to 0.67%, with 2024 witnessing slightly higher recovery rates.

3.3. Essential oil composition

The analysis of chamomile essential oil composition, as shown in Table 3 indicates a notable recovery of essential oil across all treatments, although the differences in composition among treatments were not significant. The highest concentrations of key marker compounds such as α-bisabolol oxide B, and α-bisabolol, were observed in the combined application of 75% RDF+PSB+KSB, while α-bisabolol peaked in the treatment with RDF alone. Chamuzelene, which imparts the blue color, reached its peak level with the sole application of PSB, followed by the combined application of solubilizers (Figure 1). However, other constituents including (Z)-spiro ether, (E)-β-farnesene, Artemisia ketone, 10-epi-Ɣ-eudesmol, and Isoborneol showed no significant variations among the treatments.

3.4. Efficacy of different biofertilizers

The integration of biofertilizers significantly enhanced the efficiency of both applied and indigenous nutrient utilization in chamomile cultivation (Figure 2). Applying 100% RDF combined with PSB and KSB resulted in the highest AUE of 27.28%. This was closely followed by the treatment involving 75% RDF combined with PSB and KSB, exhibiting an efficacy of 24.81%. however, the AUE of individual application of PSB and KSB with RDF was remarkable and did not reach the levels achieved by their combined application.

Nutrient use efficiency significantly improved with reduced phosphorus and potassium fertilizer applications (Figures 3 and 4). Despite comparable outcomes, treatments involving 75% RDF with either PSB or KSB, as well as their combined application, significantly enhanced phosphorus and potassium use efficiency than 100% treatment combinations. The highest efficiency rates were observed in the treatment combining 75% RDF with PSB and KSB, recording 9.68% and 14.52% for phosphorus and potassium, respectively.

3.5. Effect of PSB and KSB on the soil microbial population

The utilization of various solubilizers exerted a notable influence on the rhizosphere bacterial population dynamics (Figure 5). The initial bacterial count, quantified at 9×10^4 colony forming units per gram (Cfu g^{-1}), exhibited a substantial escalation, reaching 59×10^4 Cfu $g^{-1}$with the application of 100% RDF+PSB+KSB followed by 75% RDF combined with PSB and KSB yielded a population count of 55×10^4 Cfu g^{-1}. Interestingly, the exclusive application of PSB and KSB with 75% RDF resulted in a higher bacterial population count compared to the corresponding combinations with 100% RDF. Conversely, the lowest bacterial population counts were observed in the RDF-alone (12×10^4 Cfu g^{-1}) and control treatments (11×10^4 Cfu g^{-1}).

3.6. Solubility index

A varied assortment of bacterial populations in both endophytes and soil was identified. Gram-positive bacteria constituted 58.33% of soil, with gram-negative bacteria accounting for 41.67%. There 4 isolates of PSB were examined for their solubility index. The isolates obtained from PSB-treated plots recorded a higher solubility index, which ranged from 2.41 to 2.88 indicating the greater the ability of the Phosphate Solubilizing Bacteria to convert insoluble phosphate into a soluble form.

3.7. Microbial and yield response to application of biofertilizers

The application of 100% RDF with PSB and KSB has resulted in a maximum microbial response of 37.49%, which subsequently translated into a yield response of 137.49% compared to other treatment modalities (Figures 6 and 7). However, the results of microbial response and yield response obtained in 75% RDF with PSB and KSB inoculation were comparable to those achieved with 100% RDF +PSB+KSB. Moreover, when PSB and KSB were applied individually, PSB demonstrated higher microbial and yield responses in both 100% RDF (17.43% and 117.43%, respectively) and 75% RDF (17.93% and 117.93%, respectively) combinations compared to KSB with 100% RDF (12.77% and 112.77%, respectively) and 75% RDF (10.06% and 110.06%, respectively).

3.8. Economics

Data on the economics of chamomile, as influenced by the application of PSB and KSB solubilizing bacteria on growth and yield, was presented in Figure 8. The higher net returns of 5110.52 US$ ha^{-1} was noticed with T_7 followed by T_8 (4990.56 US$ ha^{-1}). The higher B:C ratio was noticed with the application of 100% RDF+PSB+KSB (2.41) followed by 75% RDF+PSB+KSB (2.37). The highest cost of cultivation was incurred by the 100% RDF+PSB+KSB treatment, amounting to 2121.42 US$ ha^{-1}, followed by the 75% RDF+PSB+KSB treatment, which amounted to 2104.51 US$ ha^{-1}. The cost of cultivation for the sole application of solubilizers is nearly comparable to that of the combined applications. Although the control treatment had the lowest cultivation cost (2027.27 US$ ha^{-1}), its reduced yield led to comparatively lower returns.

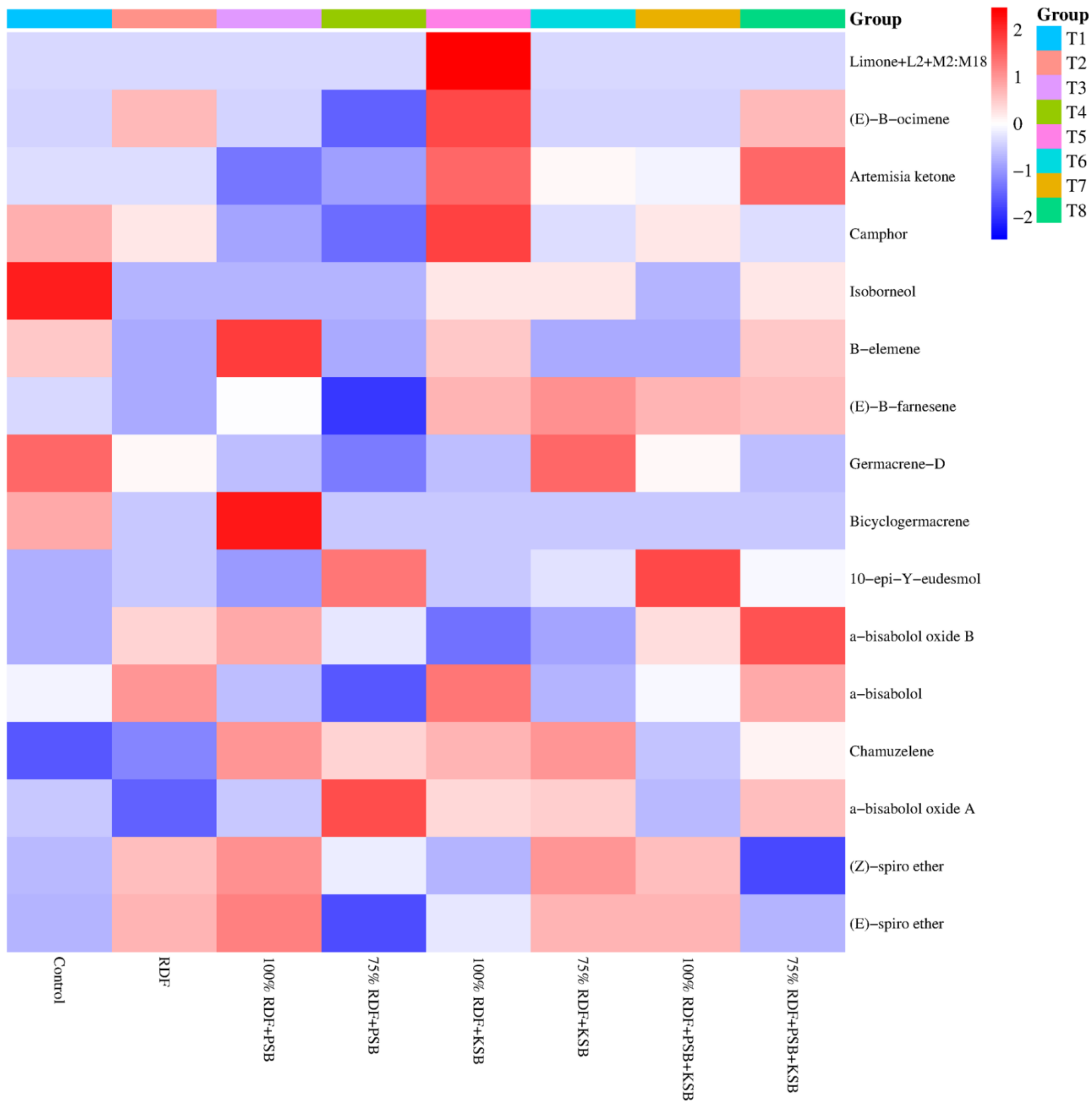

Figure 1. Heatmap showing variation of chemical composition of chamomile essential of different treatments

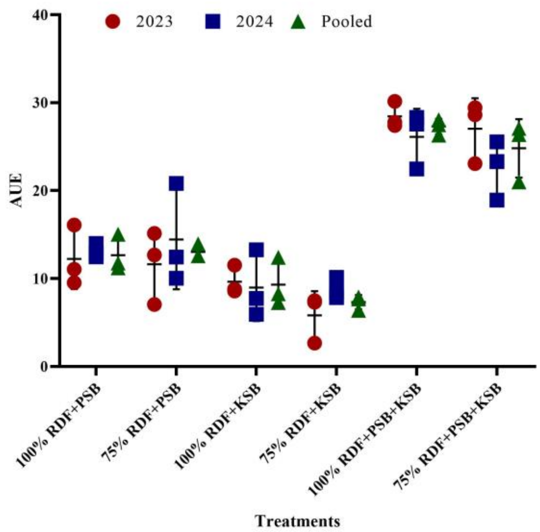

Figure 2. Agronomic use efficiency of biofertilizer

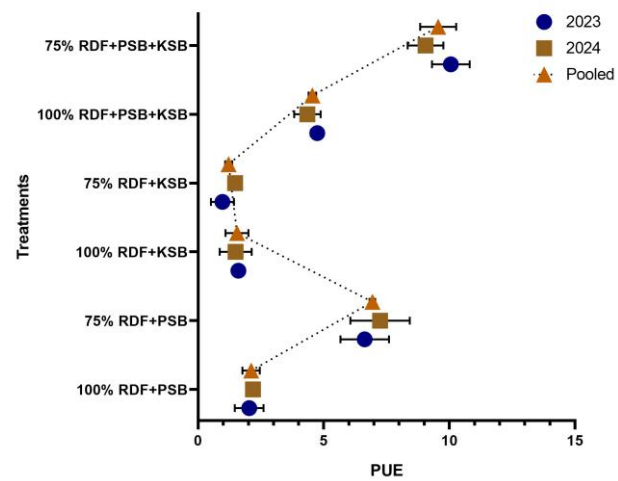

Figure 3. Phosphate use efficiency of PSB and KSB

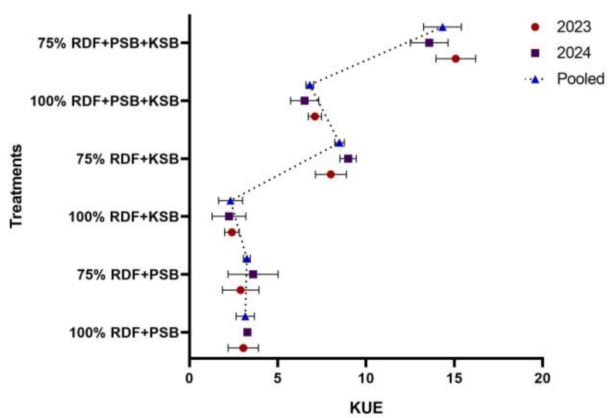

Figure 4. Potassium use efficiency of PSB and KSB

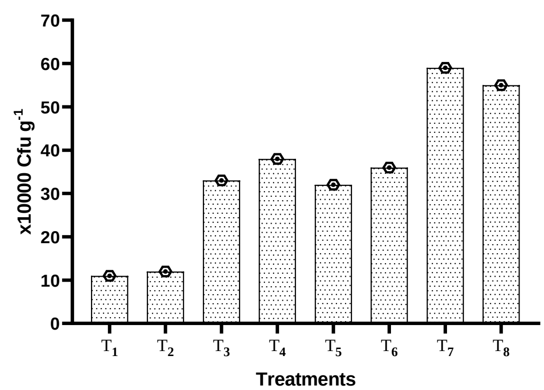

Figure 5. Microbial population in soil inoculated with bio fertilizer

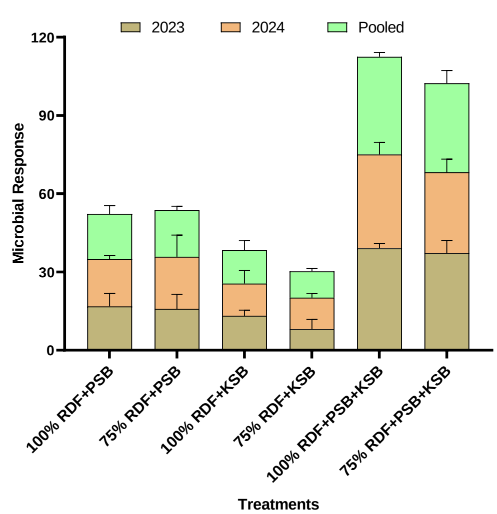

Figure 6. Microbial response of chamomile due to biofertilizer application

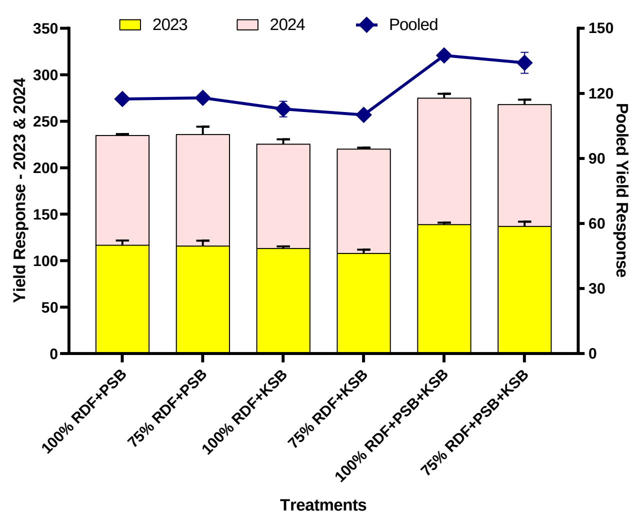

Figure 7. Yield response of chamomile due to application of biofertilizers

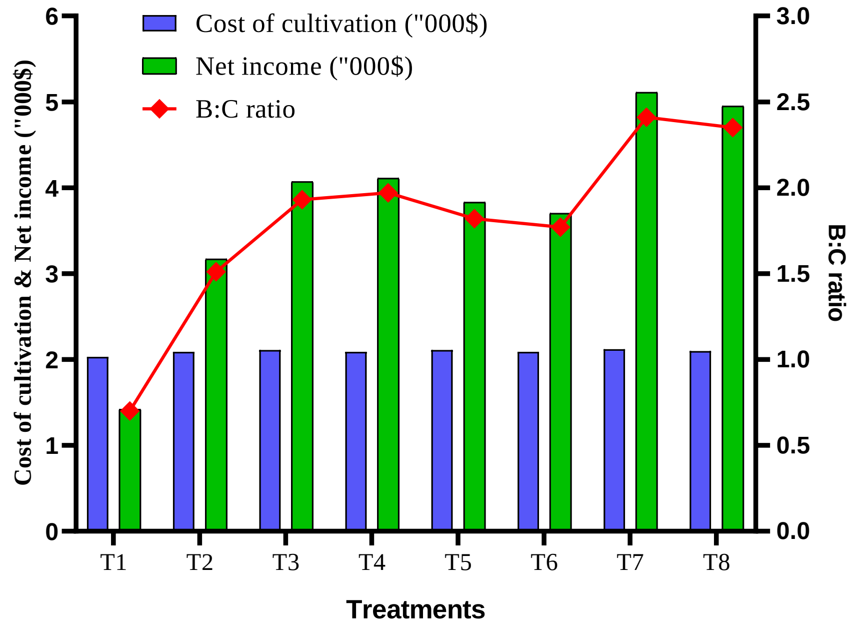

Figure 8. The economic influence of biofertilizers on chamomile. T1 - Control; T2 - RDF; T3 - 100% RDF+PSB; T4 - 75% RDF+PSB; T5 - 100% RDF+KSB; T6 - 75% RDF+KSB; T7 - 100% RDF+PSB+KSB; T8 - 75% RDF+PSB+KSB

4. Discussion

Biofertilizers are the ecofriendly alternative to chemical fertilizers which not only safe for the environment but also help maximize the utilization of unavailable native nutrient pools due to factors such as immobilization, fixation, etc. Phosphorus and potassium are essential macronutrients required for various physiological processes in plants, including cell division, photosynthesis, and energy transfer. However, these nutrients are highly susceptible for fixation by soil lattice. Solubilization of these nutrients by PSB and KSB and making these nutrients readily available for plant uptake (Richardson 2001; Lugtenberg et al. 2016). The application of PSB and KSB had a significant impact in this study, leading to superior growth performance in chamomile when the recommended dose of fertilizer (RDF) was reduced by 25% and co-inoculated with PSB and KSB. The solubilization action by microorganisms, consequently, facilitated improved nutrient uptake by chamomile plants, thereby promoting superior growth. This may also be supported by improved physicochemical properties of soil due to the application of biofertilizers as outlined by El Gendy et al. 2013 in lemongrass. Additionally, our findings align with those of Ordookhani et al. (2011) in *Ocimum basilicum*, and Cheena et al. 2022 in *Aloe barbadensis* regarding the beneficial effects of biofertilizers indicating their potential for enhancing crop growth.

Additionally, the reduced application of chemical fertilizers combined with solubilizers led to a noticeable increase in flower yield and essential oil yield by 33.33% and 34.89%, respectively, compared to RDF alone. It is due to the enhanced soil solubilization of phosphorus and potassium by microorganisms facilitates heightened metabolic activities, thereby augmenting the rate of photosynthesis and promoting optimal translocation of nutrients, (Chauhan and Raghav 2017), which contribute to the manifestation of developmental characteristics critical for yield optimization. Moreover, the comparable yield increments observed in the 75% RDF+PSB+KSB treatment suggest that even at reduced fertilizer doses, the combined application of biofertilizers can effectively supplement nutrient requirements and promote crop growth.

The presence of PSB and KSB in the rhizosphere can also stimulate growth-promoting substances, including phytohormones, siderophores, organic acids and extracellular phosphatases (Vessey 2003; Wu et al. 2019), subsequent solubilization of native pool of nutrients leading to enhanced nutrient uptake efficiency, and overall plant vigour, increasing biomass production and yield (Glick 2014). Similar enhancements were also documented by Mali et al. 2023 who stated that maximum foliage yield and oil yield were obtained in the treatment of 100 percent GRDF + PSB 10 g/plant + VAM 20 g/plant + Azotobacter 10 g plant^{-1} (2.98 tonnes ha^{-1} and 76.66 kg ha^{-1} respectively). Similarly, Prasad et al. 2012 stated that co-inoculation of geranium with AM fungi and PSB significantly enhanced the dry matter yield of the shoot (14.35 g plant^{-1}) and essential oil yield (0.125 ml plant^{-1}) compared to the control (10.79 g plant^{-1} and 0.095 ml plant^{-1} respectively). This finding was consistent with previous studies in fenugreek (Sahu et al. 2020) Chrysanthemum (Mishra et al. 2018) and basil (Tarquino et al. 2023). Nevertheless, the application of biofertilizers did not influence the composition of chamomile essential oil.

In the current study, we observed that the highest agronomic efficiency of biofertilizers occurred when Phosphate Solubilizing Bacteria (PSB) and Potassium Solubilizing Bacteria (KSB) were applied together, particularly at 100% Recommended Dose of Fertilizer (RDF) followed by the 75% RDF treatment. Additionally, applying PSB and KSB led to notable improvements in phosphorus and potassium utilization efficiency. This enhancement can be attributed to the timely mineralization of phosphate and potassium by biofertilizers, facilitating their availability to crops and making it more effective utilization (Singh et al. 2019). Similarly, Savaliya et al. (2018) also reported an improvement in nutrient use efficiency. Enhanced efficacy was additionally underscored by the substantial proliferation of beneficial microorganisms observed in the treated plots. Population densities of 59×10^4 Cfu g^{-1} and 55×10^4 Cfu g^{-1} were recorded with the combined application of PSB and KSB at 100% and 75% RDF, respectively. The diminished microbial population density in untreated plots distinctly elucidates the synergistic interplay between PSB, KSB, and indigenous microorganisms. The improved population density of solubilizers, coupled with their synergistic effects, was also evident in the progressive microbial yield response by marked enhancement in microbial response and yield of chamomile due to the combined application of PSB and KSB along with RDF.

The application of 100%RDF+PSB+KSB significantly enhanced both the flower and essential oil yields of chamomile, proving to be economically viable with a high benefit-cost (B:C) ratio of 2.41. Notably, the treatment with 75% RDF + PSB + KSB also demonstrated comparable economic viability, with a B:C ratio of 2.35 considered superior to others due to its reduced chemical fertilizer usage, which offers additional ecological and environmental advantages. The economic advantage observed in our study is consistent with the findings of Mishra et al. 2018 in Chrysanthemum by utilizing biofertilizers.

5. Conclusion

The study shows that using 75% RDF combined with PSB and KSB biofertilizers might result in nearly identical chamomile performance to 100% RDF. This method not only reduces chemical fertilizer use by 25%, but it also improves nutrient mineralization and use efficiency due to the synergistic effects of biofertilizers. Furthermore, this decreased RDF technique produces equivalent economic returns and has a favourable benefit-cost ratio, highlighting the possibility for sustainable and environmentally friendly chamomile growing. Adopting such a strategy can increase soil health, reduce environmental impact, and ensure long-term agricultural productivity.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Adams, R. P. (2007). *Identification of essential oil components by gas chromatography/mass spectrometry*. Allured Publishing Corporation, USA.

Bakhshandeh, E., Pirdashti, H., & Lendeh, K. S. (2017). Phosphate and potassium-solubilizing bacteria effect on the growth of rice. *Ecological Engineering*, 103, 164-169.

Chandel, Y., Singh, B. N., Singh, K. P., Thakur, L., & Bali, B. (2021). Influence of N, P, K and biofertilizers on growth and yield attributes of Cabbage (*Brassica oleracea* var. *capitata* L.). *The Pharma Innovation Journal*, 10(10), 303-305.

Chauhan, S. V. S. & Raghav, B. S. (2017). Effect of phosphorus and phosphate solubilizing bacteria on growth, yield and quality of chickpea (*Cicer arietinum*), *Annuals of Plant and Soil Research,* 19(3), 303-306.

Cheena, J., Veni V. K., & Sreenivas, M. (2022). Effect of different organic manures and biofertilizers on growth and yield of aloe (*Aloe barbadensis*). *The Pharma Innovation Journal,* 11(5), 265-8.

Dobermann, A., & Cassman, K. G. (2005). Cereal area and nitrogen use efficiency are drivers of future nitrogen fertilizer consumption. Science in China Series C: *Life Sciences,* 48, 745-758.

Dubey, V., Singh, D., Shukla, A., Shukla, S., & Singh, N. (2012). Effect of application of different pesticides to leguminous crops on soil microflora of Sidhi district (MP). *International Journal of Engineering Research and Development*, 3(12), 1-3.

Duhan, P., Bansal, P., & Rani, S. (2020). Isolation, identification and characterization of endophytic bacteria from medicinal plant *Tinospora cordifolia*. *South African Journal of Botany*, 134, 43-49.

El Gendy, A. G., Hegazy T. A & El-Sayed S. M. (2013) Effect of Biofertilizers and/or Urea on Growth, Yield, Essential Oil and Chemical Compositions of *Cymbopogon citratus* Plants. *Journal of Applied Sciences Research*, 9(1), 309-320.

Glick, B. R, 2014. Bacteria with ACC deaminase can promote plant growth and help to feed the world. *Microbiological Research*, 169, 30–39.

Gao, R., Mack T. R., & Stock, A. M. (2007). Bacterial response regulators: versatile regulatory strategies from common domains. *Trends in biochemical sciences*, 32(5), 225-234.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research. John Wiley and Sons Inc. London, UK.

Husain, N., Nair, R., & Bhawana Yadav, R. S. 2021. Crop productivity and nutrient uptake of fenugreek (*Trigonella foenum-graecum* L.) as influenced by inorganic fertilizers and bio-inoculant (Rhizobium, PSB and KSB). *The Pharma Innovation Journal,* 10(9), 2056-2060.

Kato, A., Minoshima, Y., Yamamoto, J., Adachi, I., Watson, A.A., & Nash, R.J. (2008). Protective effects of dietary chamomile tea on diabetic complications. *Journal of Agricultural and Food Chemistry*, 56(17), 8206-8211.

Khatri, C., Mehra, P., Arul Prakash T., Prakhyath, K.M. Yogendra, N.D., Dattesh, B.S., & Pragadheesh, V.S. (2024). Influence of potassium and phosphate solubilizing bacteria on growth and development of davana (*Artemisia pallens* Bees). *Indian Journal of Ecology*, 51(5): 1010-1015. https://doi.org/10.55362/IJE/2024/4343

Kumar, V., Jaiswal, R. C., & Singh, A. P. (2001). Effect of biofertilizers on growth and yield of potato. *Potato Journal*, 28(1), 60-61.

Lugtenberg, B., Kamilova, F., Kamilova, F. (2016). Plant-growth-promoting rhizobacteria. *Annual Review of Microbiology,* 63, 541–556.

Mali, R. B., Narkhede, S. S., Meshram, N.A., Gawali, A. S., & Rane, A. D. (2023). Effect of biofertilizers and inorganic fertilizers on soil fertility and oil yield of patchouli (*Pogostemon cablin* Benth) in Alfisols. *International Journal of Farm Sciences*, 13(1), 32-36. https://doi.org/10.5958/2250-0499.2023.00007.1

Maqsood, M., Shehzad, M. A., Wahid, A., & Butt, A. A. (2013). Improving drought tolerance in Maize (*Zea mays*) with potassium application in furrow irrigation systems. *International Journal of Agriculture and Biology*, 15(6):1193-1198.

Mehra, P., Prakhyath K.M., Khatri, C., Yogendra N.D., Kumar, D., & Padalia R.C. (2024). Influence of phosphate and potassium solubilizing bacteria on performance of crop, endophytic and rhizosphere microbial population in chamomile. *Indian Journal of Horticulture*. 81(3): 294-300. https://doi.org/10.58993/ijh/2024.81.3.12

Mishra, D. K., Jain, R., Shukla, A. K., & Deshwal, A. (2018). Impact of Bio-Fertilizers on the Yield and Economics of Chrysanthemum Under Real Farming Situation. *Current Agriculture Research Journal*, 6(1).

Ordookhani, K., Sharafzadeh, S. H., & Zare, M. (2011). Influence of PGPR on growth, essential oil and nutrients uptake of sweet basil. *Advances in Environmental Biology*, 5(4), 672-677.

Pande, A., Pandey, P., Mehra, S., Singh, M., & Kaushik, S., (2017). Phenotypic and genotypic characterization of phosphate solubilizing bacteria and their efficiency on the growth of maize. *Journal of Genetic Engineering and Biotechnology*, 15(2), 379-391.

Pathak, H., Mohanty, S., Jain, N., & Bhatia, A. (2010). Nitrogen, phosphorus, and potassium budgets in Indian agriculture. *Nutrient Cycling in Agroecosystems*, 86, 287-299. https://doi.org/10.1007/s10705-009-9292-5

Prasad, A., Kumar, S., Pandey, A., & Chand, S. (2012). Microbial and chemical sources of phosphorus supply modulate the yield and chemical composition of essential oil of rose-scented geranium (*Pelargonium* species) in sodic soils. *Biology and Fertility of Soils*, 48, 117-122.

Richardson, A. E. (2001). Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Australian Journal of Plant Physiology*, 28, 897–906.

Sahu, P. K., Naruka, I. S, Haldar, A., Chundawat, R.S., & Kumar, L. (2020). Studies on the effects of integrated nutrient management on fenugreek (*Trigonella foenum-graecum*) L, *International Journal of Chemical Studies*, 8(2), 1082-1089. https://doi.org/10.22271/chemi.2020.v8.i2q.891

Savaliya, N. V., Bhadu, V., Barsiya, R. A., & Vadaliya, B. M. (2018). Promotion of nutrient uptake, nutrient use efficiency and apparent nutrient recovery of wheat (*Triticum aestivum* L.) by application of phosphate and potash solubilizing bacteria, International Journal of *Current Microbiology and Applied Sciences*, 7(7), 2446-2452. https://doi.org/10.20546/ijcmas.2018.707.286

Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., & Mathimaran, N. (2018). Improving crop yield and nutrient use efficiency via biofertilization - A global meta-analysis. *Frontiers in plant science*, 8, 2204.

Sieuwerts, S., De Bok, F. A., Mols, E., De Vos, W. M., & van Hylckama Vlieg, J. E. T. (2008). A simple and fast method for determining colony forming units. *Letters in applied microbiology*, 47(4), 275-278.

Singh, R., Sharma, S. K., & Singh, M. (2019). Role of Biofertilizers in Enhancing Soil Nutrient Availability and Crop Productivity: A Review. *Journal of Soil Science and Plant Nutrition*, 19(4), 897-910. https://doi.org/10.1007/s42729-019-00121-6.

Srivastava, J. K., Shankar, E., & Gupta, S. (2010). Chamomile: A herbal medicine of the past with a bright future. *Molecular medicine reports*, *3*(6), 895-901.

Tarquino, L. E. H., Apaza, E. G., & Viscarra, E. C. (2023). Effects of foliar biofertilization on the Water Use Efficiency in different varieties of basil (*Ocimum basilicum* L.). *Agronomia Mesoamericana,* 34(1), 49302-49302. https://doi.org/10.15517/am.v34i1.49302

Vessey, J. K. (2003). Plant growth promotes rhizobacteria as biofertilizers. *Plant and Soil*, 255, 571–586

Wang, Y., & Lambers, H. (2020). Root-released organic anions in response to low phosphorus availability: recent progress, challenges and future perspectives. *Plant and Soil*, 447, 135-156.

Wu, F., Li, J., Chen, Y., Zhang, L., Zhang, Y., Wang, S., Shi, X., Li, L., & Liang, J. (2019). Effects of phosphate solubilizing bacteria on the growth, photosynthesis, and nutrient uptake of *Camellia oleifera* Abel. *Forests*, 10, 348. https://doi.org/doi:10.3390/f10040348.