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Original Research Paper

Synergistic effect of endophytic bacteria and potassium solubilizing bacteria on plant growth and flowering of *Jasminum sambac* (L.) Ait.

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ABSTRACT

Sustainable cultivation of *Jasminum sambac* (L.) Ait. requires eco-friendly alternatives to reduce excessive dependence on synthetic fertilizers. This study reports the isolation, characterization, and evaluation of indigenous endophytic bacteria from high-yielding cv. Ramanathapuram Gundumalli and their synergistic interaction with potassium-solubilizing bacteria (KSB) for improving plant growth and flowering. Fifteen bacterial isolates were obtained and screened for plant growth-promoting (PGP) traits, including indole-3-acetic acid (IAA), siderophore, and hydrogen cyanide (HCN) production. Based on PGP potential, five efficient isolates were identified through 16S rRNA gene sequencing as *Methylobacterium radiotolerans* JSM15, *Stenotrophomonas maltophilia* JSM2, *Bacillus velezensis* JSM8, *Bacillus subtilis* JSM4, and *Bacillus altitudinis* JSM3. Field evaluation revealed that *M. radiotolerans* JSM15 combined with KSB significantly enhanced plant height (25.6%), primary branches (36.9%), secondary branches (24.7%), leaf area (53.4%), chlorophyll content (42.5%), buds per cyme (32.0%), and flower yield (33.9%) over the control. Peak-season flower yield increased from 173.20 g plant^{-1} in the control to 231.84 g plant^{-1} with the JSM15 + KSB treatment. The treatment also improved soil available potassium (45.8%), leaf potassium content (44.0%), dehydrogenase activity (39.4%), and phosphatase activity (38.4%). Combining indigenous endophytic bacteria and KSB sustainably boosts jasmine growth, flowering, nutrient uptake, soil health, and yield, producing high-quality flowers for domestic and export markets.

Keywords: Endophytic bacteria, *Jasminum sambac*, potassium solubilizing bacteria, plant growth promotion, flower yield

INTRODUCTION

Jasminum sambac (L.) Ait., commonly known as Arabian jasmine, is an important floricultural crop valued for its fragrant flowers and essential oil production (Bera et al., 2015). Tamil Nadu leads jasmine production in India with an annual yield of 77,247 t from 9,360 ha, and flowers are exported to Sri Lanka, Singapore, Malaysia, Middle Eastern countries, and the USA (Rani & Murugan, 2020). Among the cultivated varieties, Ramanathapuram Gundumalli is highly preferred for its superior flower quality and yield potential (Patel et al., 2020; Sadasivam et al., 2020).

Despite its economic importance, jasmine cultivation relies heavily on synthetic fertilizers and pesticides, leading to nutrient imbalance, reduced soil microbial diversity, declining plant health, and lower productivity (Tripathi et al., 2020). Intensive cultivation in tropical regions accelerates soil organic matter decomposition, reducing soil organic carbon and nitrogen levels (Purwanto & Alam, 2019). Inadequate nutrient management and improper irrigation during flowering further increase plant susceptibility to pests, diseases, and abiotic stresses.

Beneficial microorganisms such as endophytic bacteria and potassium-solubilizing bacteria (KSB) offer sustainable alternatives for improving crop productivity and soil health. Potassium is essential for flower bud formation, flowering intensity, flower quality, water-use efficiency, drought tolerance, and stress resistance. KSB enhance potassium availability by solubilizing insoluble potassium minerals in soil (Naorem et al., 2021). Endophytic bacteria colonize internal plant tissues without causing harm and promote growth through phytohormone production, siderophore synthesis, and other bioactive compounds (Santoyo et al., 2016; Wahla & Shukla, 2017; Liu et al., 2024). Genera such as *Bacillus* and *Methylobacterium* exhibit significant plant growth-promoting

potential (Zhang et al., 2021). Pink-pigmented facultative methylotrophs (PPFMs) enhance plant growth and stress tolerance through cytokinin and auxin production (Nysanth et al., 2023).

However, endophytic bacterial diversity in *J. sambac* from the Sathyamangalam region remains unexplored. Therefore, this study aimed to isolate, identify and characterize endophytic bacteria from high-yielding Ramanathapuram Gundumalli plants and evaluate their synergistic interaction with KSB for improving jasmine growth and flowering.

MATERIALS AND METHODS

Isolation of endophytic bacteria

Healthy leaf samples of *Jasminum sambac* (Ramanathapuram Gundumalli variety) were collected from the six farmers field in Sathyamangalam (11° 30′ 34.1″ N 77° 08′ 55.5″ E), Tamil Nadu, India. Endophytic bacteria were isolated using established microbiological protocols. Pink-pigmented facultative methylotrophs (PPFMs) were obtained through leaf imprinting method as described by Mitra et al. (2012), using ammonium mineral salts (AMS) medium.

For isolation of additional endophytes, stringent surface sterilization protocol was employed, involving sequential immersion in 70% ethanol for 1 minute, followed by 2% sodium hypochlorite for 3 minutes, and subsequently rinsed six times with sterile distilled water to remove epiphytic microorganisms. Sterilized leaf tissues were macerated in sterile phosphate buffer, and homogenate was plated onto nutrient agar (NA) (Hi-Media, Mumbai) as the isolation medium for non-methylobacterial endophytes for bacterial isolation. All isolates were incubated on nutrient agar plates at 28±2°C and also maintained on glycerol stock at -80°C.

Screening for plant growth-promoting traits

Indole-3-acetic acid (IAA) production

Bacterial isolates were inoculated into nutrient broth supplemented with 0.5% L-tryptophan and incubated at 28±2°C for 48 hours on rotary shaker at 120 rpm. After incubation, cultures were centrifuged at 10,000 rpm for 10 minutes. One mL of supernatant was mixed with 2 mL of Salkowski's reagent, comprising 35% perchloric acid and 1 mL of 0.5 M $FeCl_3$. Mixture was incubated in darkness for 20 minutes. IAA production was quantified spectrophotometrically by measuring absorbance at 530 nm using standard curve prepared with pure IAA solutions ranging from 0 to 100 µg/mL (Shokri & Emtiazi, 2010).

Siderophore production

Siderophore production was assessed using Chrome Azurol S (CAS) agar plate method as described by Raval & Desai (2015). CAS reagent was prepared by dissolving 60.5 mg Chrome Azurol S in 50 mL distilled water, followed by addition of iron (III) solution containing 1 mM $FeCl_3 \cdot 6H_2O$ in 10 mM HCl. This solution was mixed with 72.9 mg hexadecyltrimethylammonium bromide (HDTMA) dissolved in 40 mL distilled water. Resulting CAS reagent was autoclaved and incorporated into King's B agar medium in 1:15 (v/v) ratio. Four µL aliquot of each 24-hour bacterial culture was spotted onto CAS agar plates, incubated at 30°C for 48 hours. Appearance of yellow or pink halos surrounding bacterial colonies indicated positive siderophore production (Himpsl & Mobley, 2019).

HCN production

Hydrogen cyanide production was assessed using method described by Lorck (1948). Bacterial cultures were streaked onto nutrient agar supplemented with 4.4 g/L glycine. Whatman No. 1 filter paper strip, pre-soaked in solution containing 2% sodium carbonate and 0.5% picric acid, was affixed to inner surface of Petri dish lid. Plates were sealed and incubated at 28 ± 2°C for 48 hours. Development of orange to red coloration on filter paper indicated positive HCN production (Fotoohiyan et al., 2024)

Molecular identification of selected isolates

Genomic DNA from five selected bacterial isolates (JSM15, JSM2, JSM3, JSM4 and JSM8) was extracted following protocol described by Kalman et al. (1993). Fresh bacterial cultures were grown in nutrient broth for 24 hours at 28±2°C and harvested by centrifugation at 10,000 rpm for 10 minutes.

16S rRNA gene was amplified using universal bacterial primers: 27F (5′-AGAGTTTGATCCTGG CTCAG-3′) and 1492R (5′-ACGGCTACCTTGTT ACGACTT-3′). PCR was conducted in 25 µL reaction volume containing 50 ng genomic DNA, 1× PCR buffer, 1.5 mM $MgCl_2$, 0.2 mM each dNTP, 0.5 µM each primer and 1 U Taq DNA polymerase. Thermal cycling conditions were: initial denaturation at 94°C for 5 minutes; 35 cycles of denaturation at 94°C for

Table 1 : NCBI accession number for effective five isolates

Strain No.	Strain name	Accession number
JSM 2	*Stenotrophomonas maltophilia*	PV961432
JSM 4	*Bacillus subtilis*	PV956140
JSM 3	*Bacillus altitudinus*	PV956132
JSM 8	*Bacillus velezensis*	PV955941
JSM 15	*Methylobacterium radiotolerans*	PV955758

30 seconds, annealing at 55°C for 30 seconds and extension at 72°C for 90 seconds; followed by final extension at 72°C for 7 minutes.

PCR products were visualized by resolving on 1.2% agarose gel and purified using commercial gel extraction kit. Sequencing was performed using both forward and reverse primers. The sequences were submitted on NCBI and their accession numbers are given in Table 1.

Taxonomic identification was carried out through BLAST analysis against NCBI GenBank database. Phylogenetic analysis was conducted using MEGA X software with Maximum Likelihood method based on Tamura-Nei model with 1000 bootstrap replicates (Kumar et al., 2018).

Potassium solubilizing bacteria

Commercial KSB formulation was obtained from Department of Agricultural Microbiology, Tamil Nadu Agricultural University (TNAU), Coimbatore. The KSB strain used was *Frateuria aurantia* (TNAU commercial formulation, 10x CFU/mL). The rationale for combining endophytic isolates with KSB lies in their complementary modes of action: endophytic bacteria enhance plant growth through phytohormone and siderophore production, while KSB solubilizes insoluble potassium minerals, together creating a synergistic multi-mechanistic growth promotion system for jasmine.

Field experiments were conducted in randomized complete block design with three replications on 3-year-old crop plants. Each treatment was applied to 10 plants per replication, totalling 30 plants per treatment across all replications. Field experiment was conducted at Sathyamangalam (1° 30′ 34.1″ 77° 08′ 55.5″ E), Tamil Nadu, India in a lean season: July–October 2024; peak season: February–June 2025 at crop spacing of 1.25 m × 1.25 m. Recommended doses of FYM 10 kg/plant, NPK 60:120:120 g/plant/year applied. Irrigation was carried out at weekly interval and weeding at fortnightly. Plant protection measures were followed as per standard schedule. Initial soil parameters were, pH 7.2, organic carbon 0.68%, available K 149.90 kg/ha. Tretaments include $T_{1:}$ Control (conventional production techniques), T_2: *M. radiotolerans* JSM15 + KSB, T_3: *S. maltophilia* JSM2 + KSB, T_4: *B. velezensis* JSM8 + KSB, T_5: *B. subtilis* JSM4 + KSB, T_6: *B. altitudinus* JSM3 + KSB.

Preparation of bacterial inoculants

The five identified endophytic bacterial strains were cultured individually in suitable broth media for 48 hours at 28±2°C on a rotary shaker at 120 rpm. Following incubation, the cultures were centrifuged at 10,000 rpm for 10 minutes, and the resulting bacterial pellets were washed and resuspended in sterile distilled water to obtain a final concentration of 10x CFU/mL and mixed with commercial KSB formulation immediately before application.

Treatment application

M. radiotolerans JSM15 + KSB treatment (T_2) was applied as foliar spray (*M. radiotolerans*) and soil drenching (KSB) at a rate of 2 mL per liter of water, while all other bacterial treatments (T_3-T_6) were applied as soil drenching at a rate of 100 mL per plant around the root zone. Applications were made at 15-day intervals throughout both growing seasons. Data were collected for both lean-season (July, 2024 to October, 2024) and peak season (February, 2025 to June, 2025) to evaluate treatment efficacy under different climatic conditions. The foliar application route for T_2 was selected because *M. radiotolerans* JSM15 is a PPFM that naturally colonizes the phyllosphere; foliar application ensures direct colonization of its primary niche. *Bacillus* and *Stenotrophomonas* spp. (T3-T6) are rhizosphere-competent bacteria best applied via soil drenching. Spray volume for foliar application was approximately

Table 2 : Plant growth-promoting traits of endophytic bacterial isolates from *Jasminum sambac* Var. Ramanathapuram Gundumalli

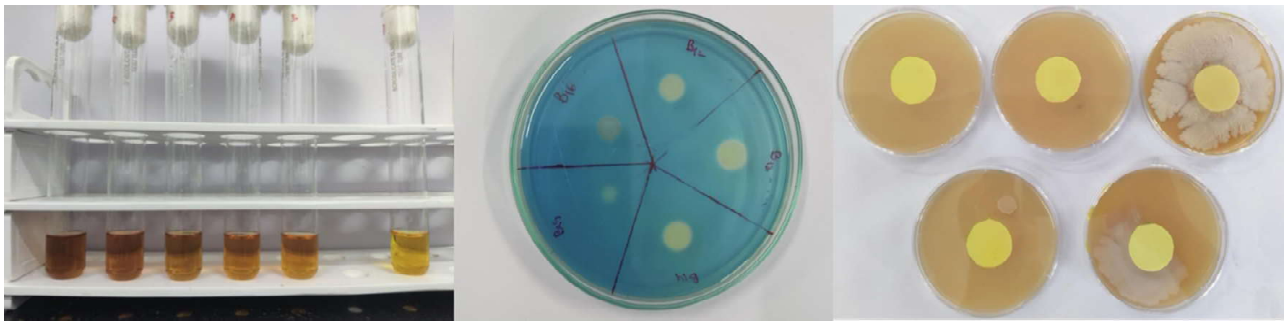
Isolate code	IAA production (µg/mL)	Siderophore production (Halo diameter, mm)	HCN production
JSM1	62.63 ± 3.21	16.42 ± 1.52	-
JSM2	66.32 ± 2.51	18.73 ± 1.12	-
JSM3	75.83 ± 2.72	17.62 ± 1.23	++
JSM4	69.23 ± 2.92	15.83 ± 1.02	++
JSM5	58.42 ± 2.32	14.23 ± 0.92	-
JSM6	45.73 ± 2.12	12.33 ± 0.82	-
JSM7	52.13 ± 2.42	13.53 ± 0.92	-
JSM8	76.83 ± 2.62	15.13 ± 1.02	+
JSM9	41.32 ± 1.92	11.73 ± 0.72	-
JSM10	38.63 ± 1.82	10.93 ± 0.62	-
JSM11	49.23 ± 2.22	12.83 ± 0.82	-
JSM12	35.73 ± 1.62	9.83 ± 0.52	-
JSM13	42.93 ± 2.02	11.43 ± 0.72	-
JSM14	33.23 ± 1.52	8.63 ± 0.42	-
JSM15	94.33 ± 1.22	17.23 ± 0.33	-

Values are means±standard error of three replicates. HCN production: ++ = strong, + = moderate, - = negative

500 mL per plant (applied to run-off). Total bacterial count in each inoculant was 10x CFU/mL.

Data collection and statistical analysis

Plant growth parameters such as plant height, number of primary branches, number of secondary branches, leaf area; physiological parameters *viz*., chlorophyll content; flowering parameters such as number of buds per cyme, 100 bud weight, flower yield; soil available potassium, leaf potassium content, and soil enzyme activities such as dehydrogenase activity and phosphatase activity were recorded at regular intervals. Data were subjected to analysis of variance (ANOVA) and means were compared using Duncan's multiple range test at $p \leq 0.05$ significance level. Statistical analysis was performed using AGRES statistical package (TNAU, Coimbatore, India). Leaf area was calculated as L x B x 0.75 (cm^2/plant). IAA production values represent a 48-hour incubation period. Alkaline phosphatase was estimated using the p-nitrophenol method at pH 11.0 buffer, appropriate for the near-neutral soil (pH 7.2) of the experimental site. Initial soil parameters were pH 7.2, organic carbon 0.68%, available K 149.90 kg/ha. Error df = (t-1)(r-1) = (6-1)(3-1) = 10, consistent with 6 treatments and 3 replications in randomised block design.



a **b** **c**

Fig. 1 : PGP activities of isolated strains, a. IAA production, b. Siderophore production, c. HCN production

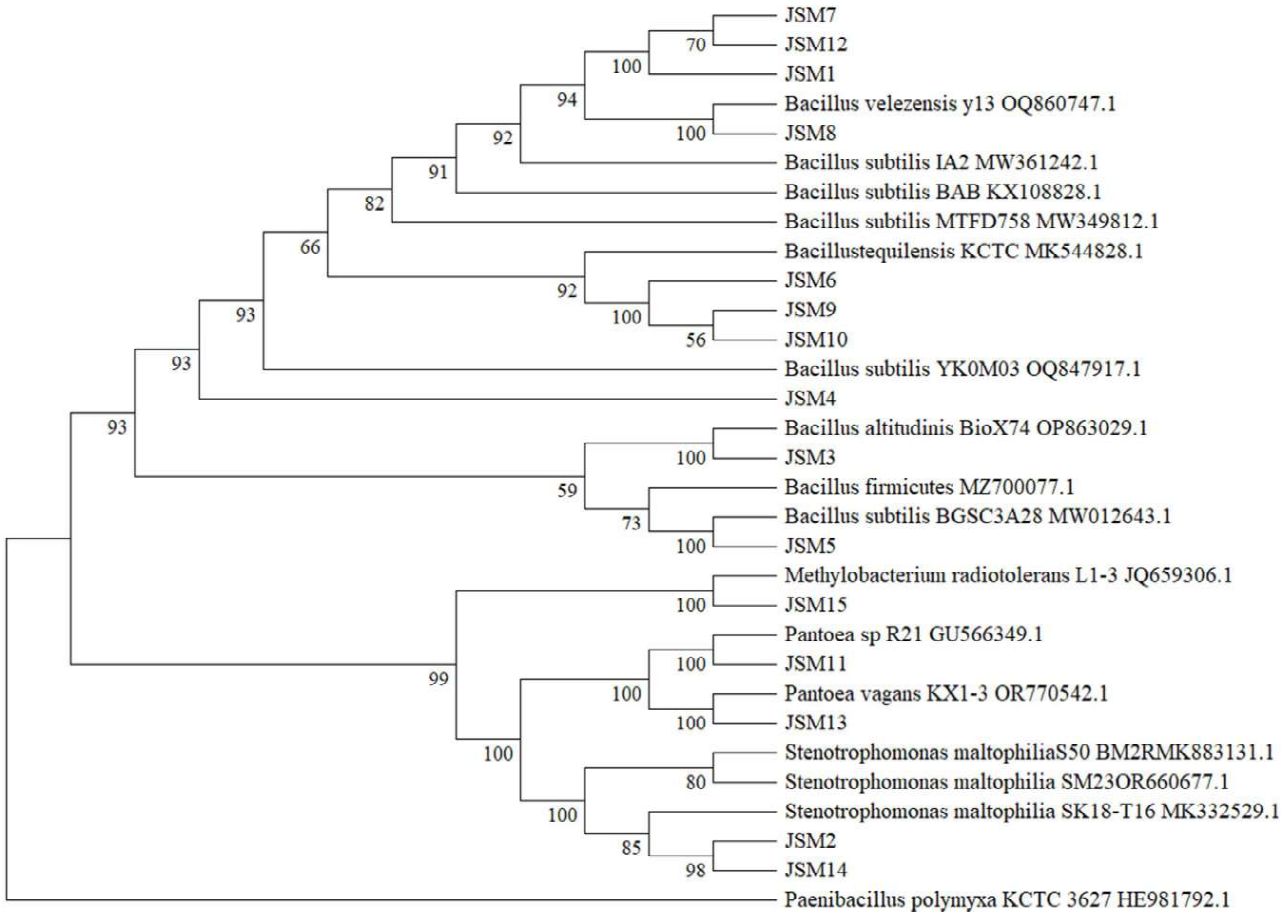


Fig. 2 : Phylogenetic tree for the isolated endophytic bacterial strains from *J. sambac* Var. Ramanathapuram Gundumalli

RESULTS AND DISCUSSION

Plant growth-promoting properties of bacterial isolates

Fifteen bacterial isolates exhibiting plant growth-promoting traits were isolated from *J. sambac* leaf samples collected from high-yielding commercial fields in Sathyamangalam. IAA production ranged from 33.23 to 94.33 µg/mL, with *M. radiotolerans* JSM15 exhibiting the highest production (94.33±1.22 µg/mL), followed by *B. velezensis* JSM8 (76.83±2.62 µg/mL) and JSM3 (75.83±2.72 µg/mL) (Table 2).

Siderophore production, measured by halo diameter formation on CAS agar, ranged from 8.63 to 18.73 mm. JSM2 showed the highest siderophore production (18.73±1.12 mm), followed by JSM3 (17.62±1.23 mm) and JSM15 (17.23±0.33 mm). HCN production was primarily observed in *Bacillus* species, with JSM3 and JSM4 exhibiting strong production (++), JSM8 showing moderate production (+) and other isolates displaying no production (–).

These findings align with previous research reporting strong IAA biosynthesis by phyllosphere *Methylobacterium* species, which enhances lateral root formation and stimulates auxin-responsive pathways in *Arabidopsis thaliana* (Grossi et al., 2024). The significant siderophore production by these isolates corresponds with studies identifying siderophores as essential for growth under iron-limited conditions, a critical trait for phyllosphere-dwelling bacteria (Juma et al., 2022).

Molecular identification and phylogenetic analysis

Based on 16S rRNA gene sequencing and phylogenetic analysis, five effective isolates were identified as *Methylobacterium radiotolerans* JSM15, *Stenotrophomonas maltophilia* JSM2, *Bacillus velezensis* JSM8, *Bacillus subtilis* JSM4 and *Bacillus altitudinus* JSM3. Phylogenetic analysis revealed distinct taxonomic affiliations with strong bootstrap support, confirming their identities and evolutionary relationships.

Table 3 : Effect of treatments on plant growth, & flower parameters

Treatment	Plant height (cm)	Primary branches	Secondary branches	Leaf area (cm²)	Buds/ cyme
T_1: Control	101.21	10.92	51.61	18.54	6.31
T_2: *M. radiotolerans* + KSB	127.10	14.95	64.36	28.43	8.33
T_3: *S. maltophilia* + KSB	106.15	11.70	54.25	20.36	6.72
T_4: *B. velezensis* + KSB	116.25	13.32	59.35	24.35	7.53
T_5: *B. subtilis* + KSB	121.33	14.12	61.80	26.41	7.94
T_6: *B. altitudinus* + KSB	111.18	12.51	56.72	22.21	7.11
SEd	2.0439	0.3300	0.9828	0.8010	0.1565
CD (p=0.05)	4.5540	0.7354	2.1898	1.7847	0.3488

Data represent mean values from peak flowering season (Feb–Jun, 2025), except primary branches and secondary branches; KSB: potassium-solubilizing bacteria

The phylogenetic analysis of 16S rRNA gene sequences from the isolated endophytic bacterial strains (designated as JSM1 to JSM15) revealed distinct clustering patterns, indicating their taxonomic affiliations and potential functional roles as plant growth-promoting bacteria (PGPB) (Fig. 2). Notably, JSM15 clustered closely with *Methylobacterium radiotolerans* L1-3 (GenBank accession no. JQ659306.1), suggesting a strong phylogenetic relationship within the *Methylobacterium* genus. The clustering patterns observed in the phylogenetic tree underscore the evolutionary relationships among the isolates and their potential functional similarities in promoting plant growth.

To root the phylogenetic tree and establish evolutionary directionality, an appropriate outgroup was selected. The outgroup should be a taxon that is closely related to the ingroup but not part of it, ensuring that it shares a common ancestor with the ingroup while remaining distinct. In this study, *Paenibacillus polymyxa* (GenBank accession no. HE981792.1) was chosen as the outgroup. This selection is based on its phylogenetic position, which is sufficiently related to allow for meaningful comparisons yet distinct enough to serve as a reference point for rooting the tree. The inclusion of this outgroup enables the determination of ancestral and derived traits within the ingroup, facilitating a more accurate interpretation of evolutionary relationships among the isolated strains. Careful selection of an appropriate outgroup is crucial, as it influences the topology of the phylogenetic tree and the inferred evolutionary pathway

Effect on plant growth parameters

All bacterial treatments significantly enhanced plant growth parameters compared to control, with T_2 (*M. radiotolerans* JSM15 + KSB) exhibiting superior performance across all measured parameters (Table 3). At 240 days after treatment application, T_2 recorded the highest plant height (127.10 cm), representing a 25.6% increase over control (101.21 cm), followed by T_5 (*B. subtilis* JSM4 + KSB) with 121.33 cm. Primary branches per plant showed remarkable enhancement with T_2 recording 14.95 branches (36.9% increase over control), while secondary branches increased by 24.7% (64.36 vs 51.61 in control) and leaf area expanded by 53.4% (28.43 cm² vs 18.54 cm²). The exceptional growth promotion by *M. radiotolerans* JSM15 can be attributed to its highest IAA production (94.33 µg/mL), which stimulates cell elongation through auxin-responsive gene expression and promotes apical dominance release, leading to enhanced lateral branching. IAA activates expansin proteins that loosen cell walls, facilitating cell expansion and ultimately increasing plant height and biomass accumulation (Grossi et al., 2024).

The synergistic combination with KSB amplifies growth enhancement through improved root architecture and nutrient acquisition efficiency. The substantial siderophore production by *M. radiotolerans* JSM15 (17.23 mm halo diameter) enhances iron chelation and uptake, supporting optimal functioning of iron-dependent enzymes involved in cellular respiration and photosynthesis, which provide energy for growth processes. Enhanced potassium availability (45.8% increase in soil K) from KSB

activity improves osmotic regulation, enzyme activation and protein synthesis, directly contributing to increased cell division and elongation rates. The improved leaf area development reflects enhanced photosynthetic capacity and carbon assimilation, creating a positive feedback loop where increased photosynthesis supports further vegetative growth. These morphological improvements are consistent with studies by Boruah et al. (2010) and Zhang et al. (2021), demonstrating that *Methylobacterium*-mediated phytohormone production and enhanced mineral nutrition synergistically promote comprehensive plant growth enhancement in various crop species.

Effect on physiological parameters

Chlorophyll content was significantly enhanced across all bacterial treatments, with T_2 (*M. radiotolerans* JSM15 + KSB) recording the highest chlorophyll content (56.60 SPAD units), representing a 42.5% increase over control (39.73 SPAD units) (Fig. 3). The superior chlorophyll enhancement with *M. radiotolerans* JSM15 can be attributed to its exceptional capacity for cytokinin and auxin production, which regulate chloroplast biogenesis and chlorophyll biosynthetic gene expression. Cytokinins, particularly zeatin derivatives synthesized by *Methylobacterium* species, enhance the expression of key enzymes including δ-aminolevulinic acid synthase and protochlorophyllide oxidoreductase in the chlorophyll biosynthetic pathway (Palberg et al., 2022). Additionally, the high IAA production (94.33 µg/mL) promotes vascular development and nutrient transport efficiency, facilitating better delivery of essential minerals like magnesium and iron to developing chloroplasts.

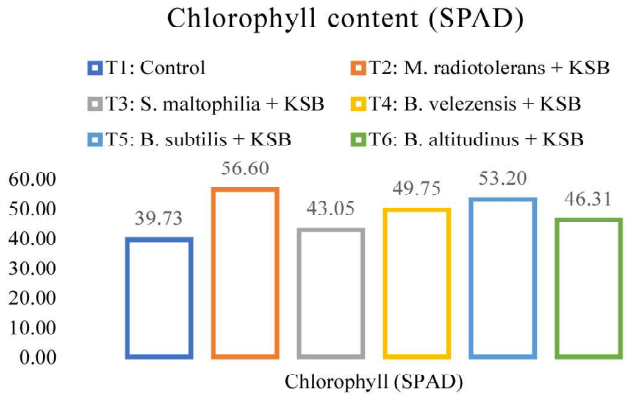


Fig. 3 : Effect of treatments on chlorophyll content (SPAD) in peak season

The synergistic combination with KSB further amplifies chlorophyll synthesis through enhanced iron and potassium availability. The significant siderophore production by *M. radiotolerans* JSM15 (17.23 mm halo diameter) solubilizes iron, which serves as a cofactor for chlorophyll biosynthetic enzymes including δ-aminolevulinic acid dehydratase and ferrochelatase. The 45.8% increase in soil available potassium directly correlates with improved photosynthetic efficiency, as potassium activates essential photosynthetic enzymes like RuBisCO and regulates stomatal function. These physiological improvements translate to enhanced light-harvesting efficiency and photosynthetic carbon fixation rates, providing the energetic foundation for the observed increases in plant growth and flower yield. These findings align with studies by Ryu et al. (2006) in tomato & red pepper and Grossi et al. (2024) in *Arabidopsis thaliana*, demonstrating *Methylobacterium*-mediated enhancement of photosynthetic capacity through phytohormone production and improved mineral nutrition.

Effect on flowering parameters

Significant enhancement in flowering parameters was observed across all treatments (Table 3). T_2 (*M. radiotolerans* JSM15 + KSB) recorded highest number of buds per cyme (8.33), representing 32.0% increase over control (6.31). Similarly, 100 bud weight increased by 33.0% with T_2 treatment (29.80 g) compared to control (22.41 g). Most importantly, flower yield per plant was substantially enhanced, with T_2 recording highest yield (231.84 g/plant), representing 33.9% increase over control (173.20 g/plant) (Fig. 4). Other treatments also showed considerable improvements: T_5 recorded 214.65 g/plant (23.9% increase), T_4 achieved 204.30 g/plant (17.9% increase), T_6 produced 192.85 g/plant

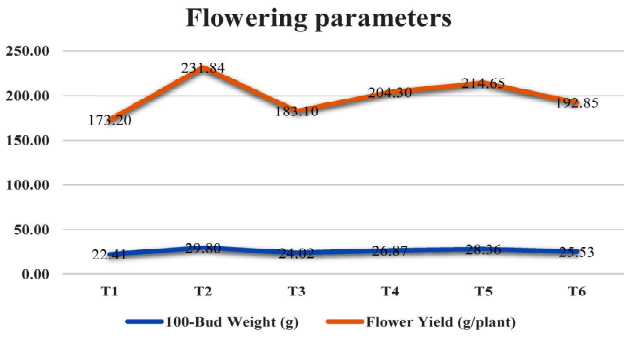


Fig. 4 : Effect of treatments on 100 bud weight (g) & flower yield (g/plant) in peak season

Table 4 : Effect of treatments on soil potassium and enzyme activities

Treatment	Soil available K (kg ha^{-1})	Leaf K Content (%)	Dehydrogenase activity (µg TPF g^{-1} soil day^{-1})	Phosphatase activity (µg pNP g^{-1} soil h^{-1})
T_1: Control	149.90	1.68	21.40	16.71
T_2: *M. radiotolerans* + KSB	218.63	2.42	29.84	23.12
T_3: *S. maltophilia* + KSB	162.80	1.82	23.05	18.03
T_4: *B. velezensis* + KSB	188.71	2.10	26.41	20.61
T_5: *B. subtilis* + KSB	201.22	2.27	28.05	21.85
T_6: *B. altitudinus* + KSB	175.76	1.95	24.76	19.33
SEm±	5.7239	0.0542	0.6638	0.4630
CD (p=0.05)	12.7537	0.1208	1.4789	1.0315

TPF: triphenyl formazan; pNP: p-nitrophenol

(11.3% increase) and T_5 yielded 183.10 g/plant (5.7% increase). This significant enhancement aligns with findings of Madhaiyan et al. (2015) in Jatropha.

Effect on soil and plant potassium status

Application of bacterial inoculants significantly influenced soil available potassium levels (Table 4). At 180 days after treatment, T_2 (*M. radiotolerans* JSM15 + KSB) recorded highest available potassium content (218.63 kg/ha), representing 45.8% increase over control (149.90 kg/ha). Correspondingly, leaf potassium content increased by 44.0% with T_2 (2.42%) compared to control (1.68%).

This remarkable increase demonstrates synergistic effect between endophytic bacteria and KSB in enhancing potassium availability and uptake. The combination of *M. radiotolerans*, which enhances plant growth and root development through phytohormone production, with KSB, which solubilizes insoluble potassium minerals, creates effective partnership for improving plant nutrition and performance (Berde et al., 2021). The elevated soil available K observed in T2 (foliar treatment) is explained by the presence of *Frateuria aurantia* KSB in the foliar mixture, a portion of which reaches the rhizosphere via spray run-off. Furthermore, phytohormone-mediated improvement in root architecture by *M. radiotolerans* JSM15 increases root exudate quality and quantity, which enhances rhizosphere KSB colonization and potassium solubilization activity (Naorem et al., 2021). This explains why the foliar-applied T2 surpassed soil-drenched treatments in soil K parameters despite the smaller applied volume.

Effect on soil enzyme activities

Bacterial inoculants significantly influenced soil enzyme activities. T_2 (*M. radiotolerans* JSM15 + KSB) exhibited highest dehydrogenase activity (29.84 µg TPF/g soil/day), representing 39.4% increase over control (21.40 µg TPF/g soil/day). Similarly, phosphatase activity increased by 38.4% with T_2 treatment (23.12 µg p-nitrophenol/g soil/hour) compared to control (16.71 µg p-nitrophenol/g soil/ hour).

Enhanced soil enzyme activities indicate improved soil biological activity and nutrient cycling. The relatively low absolute enzyme activity values recorded in this study are attributable to the sandy loam texture and limited organic matter content (organic carbon 0.68%) of the experimental soil, which is characteristic of soils in the Sathyamangalam region (Saliha et al., 2021). Despite the low baseline, the significant percentage increases observed across all bacterial treatments confirm the positive influence of bioinoculants on soil biological activity. These findings corroborate research demonstrating that organic matter application alongside bacterial inoculants significantly increase soil microbial populations and enzyme activities in jasmine cultivation (Saliha et al., 2021).

CONCLUSION

This study demonstrated that the synergistic application of *Methylobacterium radiotolerans* JSM15 and potassium-solubilizing bacteria (KSB) significantly enhanced the growth, flowering, and soil health of *Jasminum sambac* cv. Ramanathapuram Gundumalli. The treatment increased flower yield by 33.9% (231.84 g plant^{-1}) compared to the control (173.20 g plant^{-1}), along with improvements in plant height (25.6%), primary branches (36.9%), chlorophyll content (42.5%), and soil available potassium (45.8%). Enhanced soil biological activity was also observed through increased dehydrogenase (39.4%) and phosphatase (38.4%) activities. The superior performance of *M. radiotolerans* JSM15, attributed to its strong plant growth-promoting traits, highlights its potential in combination with KSB as a sustainable and eco-friendly biofertilizer strategy for improving jasmine productivity and soil health.

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REFERENCES

Berde, C. V., Gawde, S. S., & Berde, V. B. (2021). Potassium solubilization: Mechanism and functional impact on plant growth. In *Soil microbiomes for sustainable agriculture*: *Functional annotation* (pp. 133–148). Springer. https://doi.org/10.1007/978-3-030-73507-4_5

Bera, P., Kotamreddy, J. N., Samanta, T., Maiti, S., & Mitra, A. (2015). Inter-specific variation in headspace scent volatiles composition of four commercially cultivated jasmine flowers. *Natural Product Research*, *29*(14), 1328–1335. doi: 10.1080/14786419.2014.971791

Boruah, H. P. D., Chauhan, P. S., Yim, W. J., Han, G. H., & Sa, T. M. (2010). Comparison of plant growth promoting *Methylobacterium* spp. and exogenous indole-3-acetic acid application on red pepper and tomato seedling development. *Korean Journal of Soil Science and Fertilizer*, *43*(1), 96–104. doi: 10.5338/KJSSF.2010.43.1.096

Fotoohiyan, Z., Samiei, F., Sardoei, A. S., Kashi, F., Ghorbanpour, M., & Kariman, K. (2024). Improved salinity tolerance in cucumber seedlings inoculated with halotolerant bacterial isolates with plant growth-promoting properties. *BMC Plant Biology*, *24*(1), Article 821. https://doi.org/10.1186/s12870-024-05538-y

Grossi, C. E., Tani, A., Mori, I. C., Matsuura, T., & Ulloa, R. M. (2024). Plant growth promoting abilities of *Methylobacterium* sp. 2A involve auxin mediated regulation of the root architecture. *Plant*, *Cell & Environment*, *47*(12), 5343–5357. https://doi.org/10.1111/pce.15116

Himpsl, S. D., & Mobley, H. L. (2019). Siderophore detection using chrome azurol S and cross-feeding assays. In *Proteus mirabilis*: *Methods and protocols* (pp. 97–108). Humana. https://doi.org/10.1007/978-1-4939-9601-8_10

Juma, P. O., Fujitani, Y., Alessa, O., Oyama, T., Yurimoto, H., Sakai, Y., & Tani, A. (2022). Siderophore for lanthanide and iron uptake for methylotrophy and plant growth promotion in *Methylobacterium aquaticum* strain 22A. *Frontiers in Microbiology*, *13*, Article 921635. https://doi.org/10.3389/fmicb.2022.921635

Kalman, S., Kiehne, K. L., Libs, J. L., & Yamamoto, T. (1993). Cloning of a novel cryIC-type gene from a strain of *Bacillus thuringiensis* subsp. *galleriae*. *Applied and Environmental Microbiology*, *59*(4), 1131–1137. doi: 10.1128/aem.59.4.1131-1137.1993

Kumar, S., Stecher, G., Li, M., Knyaz, C., & Tamura, K. (2018). MEGA X: Molecular evolutionary genetics analysis across computing platforms. *Molecular Biology and Evolution*, *35*(6), 1547–1549. doi: 10.1093/molbev/msy096

Liu, Y., Shi, A., Chen, Y., Xu, Z., Liu, Y., Yao, Y., Zhang, W., & Jia, B. (2025). Beneficial microorganisms: Regulating growth and defense for plant welfare. *Plant Biotechnology Journal*, *23*(3), 986–998. doi: 10.1111/pbi.14554

Lorck, H. (1948). Production of hydrocyanic acid by bacteria. *Physiologia Plantarum*, *1*(2), 142. doi: 10.1111/j.1399-3054.1948.tb07118.x

Madhaiyan, M., Alex, T. H. H., Ngoh, S. T., Prithiviraj, B., & Ji, L. (2015). Leaf-residing *Methylobacterium* species fix nitrogen and promote biomass and seed production in *Jatropha curcas*. *Biotechnology for Biofuels*, *8*, Article 1. https://doi.org/10.1186/s13068-015-0404-y

Mitra, B. H. (2012). Standardization of cultivation parameters for the extraction of carotenoid from pink pigmented facultative methylotrophic (PPFM) bacteria. *Asian Journal of Pharmaceutical and Clinical Research*, *5*(2), 52–57.

Naorem, A., Udayana, S. K., & Patel, S. (2021). Potassium solubilizing bacteria: An insight. In J. Malik (Ed.), *Handbook of research on microbial remediation and microbial biotechnology for sustainable soil* (pp. 299–313). IGI Global. https://doi.org/10.4018/978-1-7998-7062-3.ch010

Nysanth, N. S., Anu Rajan, S., Sivapriya, S. L., & Anith, K. N. (2023). Pink pigmented facultative methylotrophs (PPFMs): Potential bioinoculants for sustainable crop production. *Journal of Pure and Applied Microbiology*, *17*(2), 698–711. https://doi.org/10.22207/jpam.17.2.17

Palberg, D., Kisiała, A., Jorge, G. L., & Emery, R. N. (2022). A survey of *Methylobacterium* species and strains reveals widespread production and varying profiles of cytokinin phytohormones. *BMC Microbiology*, *22*(1), Article 49. https://doi.org/10.1186/s12866-022-02454-9

Patel, M., Ganga, M., & Jawaharlal, M. (2018). Assessment of qualitative and quantitative flower quality parameters of certain commercial jasmine varieties during flowering season. *International Journal of Pure & Applied Bioscience*, *6*(1), 1652–1655. doi: 10.18782/2320-7051.5831

Purwanto, B. H., & Alam, S. (2019). Impact of intensive agricultural management on carbon and nitrogen dynamics in the humid tropics. *Soil Science and Plant Nutrition*, *66*(1), 50–59. https://doi.org/10.1080/00380768.2019.1705182

Rani, A. J., & Murugan, P. P. (2020). Yield gap and constraints in jasmine cultivation and suggestions to increase the production in Tamil Nadu India. *International Journal of Current Microbiology and Applied Sciences*, *9*(3), 1373–1381. https://doi.org/10.20546/ijcmas.2020.903.159

Raval, A. A., & Desai, P. B. (2015). Screening and characterization of several siderophore producing bacteria as plant growth-promoters and biocontrolling agents. *International Journal of Pharmacy & Life Sciences*, 6(10/11), 4803.

Ryu, J., Madhaiyan, M., Poonguzhali, S., Yim, W., Indiragandhi, P., Kim, K., & Sa, T. (2006). Plant growth substances produced by *Methylobacterium* spp. and their effect on tomato (*Lycopersicon esculentum* L.) and red pepper (*Capsicum annuum* L.) growth. *Journal of Microbiology and Biotechnology*, *16*(10), 1622–1630.

Sadasivam, S., Jawaharlal, M., Shanmugam, H., Uma, D., & Uthandi, S. (2020). Physiological changes during flower petal developmental stages of *Jasminum sambac* cv. Ramanathapuram Gundumalli. *International Journal of Current Microbiology and Applied Sciences*, *9*(12), 3445-3451.

Saliha, B. B., Banupriya, B., Balasubramaniam, P., & Indirani, R. (2021). Study of soil microbial population and enzyme activities under jasmine cultivation as influenced by nutrient sources. *Current Journal of Applied Science and Technology*, *40*(11), 32–42. https://doi.org/10.9734/cjast/2021/v40i1131368

Santoyo, G., Moreno-Hagelsieb, G., del Carmen Orozco-Mosqueda, M., & Glick, B. R. (2016). Plant growth-promoting bacterial endophytes. *Microbiological Research*, *183*, 92-99. doi: 10.1016/j.micres.2015.11.008

Shokri, D., & Emtiazi, G. (2010). Indole-3-acetic acid (IAA) production in symbiotic and non-symbiotic nitrogen-fixing bacteria and its optimization by Taguchi design. *Current Microbiology*, *61*(3), 217–225. https://doi.org/10.1007/s00284-010-9600-y

Tripathi, S., Srivastava, P., Devi, R. S., & Bhadouria, R. (2020). Influence of synthetic fertilizers and pesticides on soil health and soil microbiology. In *Microclimate & local climate change effects on biochemical cycles in soil matrix* (pp. 25–54). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-103017-2.00002-7

Wahla, V., & Shukla, S. (2017). Plant growth promoting endophytic bacteria: Boon to agriculture. *Environment Conservation Journal*, *18*(3), 107–114

Zhang, C., Wang, M. Y., Khan, N., Tan, L. L., & Yang, S. (2021). Potentials, utilization, and bioengineering of plant growth-promoting *Methylobacterium* for sustainable agriculture. *Sustainability*, *13*(7), Article 3941. https://doi.org/10.3390/su13073941

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