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Potassium-mobilizing bacterial isolates: A sustainable approach to enhance growth parameters and yield of *Bt* cotton

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Abstract

The field experiments were conducted for two consequent years 2022 and 2023 at same place at Research farm, All India Network Project on Soil Biodiversity-Biofertilizers, Vasantao Naik Krishi Vidyapeeth, Parbhani, to study the potassium-mobilizing bacterial isolates: a sustainable approach to enhance growth parameters and yield of *Bt* cotton. The experiment was laid out in randomized block design with ten treatments and three replications. Different bacterial isolates with recommended dose of fertilizer were used in experiment. This study explores the role of potassium-mobilizing bacterial isolates (KMBIs) as sustainable bioinoculants to enhance growth parameters and yield in *Bt* cotton. These rhizospheric microbes solubilize insoluble potassium minerals, improving potassium availability in soil through mechanisms such as acid production and chelation. Field experiments demonstrated that the inoculation of potassium mobilizing bacteria with recommended dose of fertilizer significantly improved growth attributes, including plant height, number of leaves, number of branches, root development, chlorophyll content, and yield attributes of *Bt* cotton. Among the different treatments T₉ RDF + *Frateruria aurantia* and T₁₀ RDF + *Pseudomonas striata* was recorded significantly highest growth and yield attributes of *Bt* cotton, followed by KSB -M-1 -*Pseudomonas spp.*, KSB -M-2- *Pseudomonas spp* and KSB -W-1- *Bacillus spp*. Whereas, lowest values recorded in uninoculated treatment i.e. T₁ absolute control and T₂ RDF only. Findings revealed that microbial interventions with recommended dose of fertilizer enhance the growth and yield of *Bt* cotton grown in Vertisol.

Keywords: Potassium-mobilizing bacteria (KMBs), sustainable agriculture, *Bt* cotton

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important commercial cash crop and important fiber crop of global significance cultivated in more than seventy countries. It is an important raw material of economy in terms of both employment generation, foreign exchange and hence it is popularly known as “White gold or friendly fiber”. The cotton plant belongs to the genus *Gossypium* of the family *Malvaceae*. It is grown for fiber and seed. Cotton is a multipurpose crop that supplies five basic products such as lint, oil, meal, seed and hulls and is popularly known as “King of Fiber”. Cotton is one of the principal crops of India and plays a vital role in the country’s economic growth by providing substantial employment and making significant contributions to export earnings. Globally, cotton is cultivated on approximately 33.5 million hectares, with an estimated production of 24.5 million metric tons in 2024. Leading producers include India, China, the United States, Brazil, and Pakistan, which together account for over 75% of global cotton production. India leads in cultivation area, while the United States and Brazil have higher productivity per hectare. In India Maharashtra is the leading cotton-producing state, accounting for over 25% of the national production, followed by Gujarat and Telangana (USDA Foreign Agricultural Service 2024) ^[22].

Sustainable agricultural practices are essential to meet the dual challenges of increasing crop productivity and maintaining environmental health. *Bt* cotton (*Gossypium hirsutum*), a genetically modified crop with inherent pest resistance, has become a cornerstone of cotton farming globally due to its ability to minimize losses caused by bollworms and other pests. However, the realization of optimal growth and yield in *Bt* cotton depends significantly on

efficient nutrient management, particularly potassium (K), a key macronutrient that regulates physiological processes, stress tolerance, and reproductive success in plants (Zorb *et al.* 2014)^[26]. Potassium exists in several forms in the soil, including mineral K, non-exchangeable K, exchangeable K, and dissolved or solution K (K^+ ions). Plants can only directly take up solution K. Among the three major essential nutrients required by plants, one of them is potassium. It is involved in numerous biochemical and physiological processes in plants like stomatal regulation for plants depend upon K to regulate the opening and closing of stomata. The activation of enzymes by potassium and its involvement in adenosine tri phosphate (ATP) production is important in regulating the rate of photosynthesis; sugars produced in photosynthesis must be transported through the phloem to other parts of the plants for utilization and storage. The plants transport system uses energy in the form of ATP if K is inadequate, less ATP is available, transport system breaks down. The enzyme responsible for synthesis of starch is activated by K, hence it plays crucial role in water and nutrient transport (Doman and Geiger, 1979; Pettigrew, 2008)^[5, 15]. The potassium content of Indian soils varies from less than 0.5% to 3.00% (Mengel and Kirkby, 1987)^[12]. In Indian soil the soluble K form are present in approximately 2% and insoluble are present in range of 98% in the form of minerals like biotite, feldspar, mica, muscovite, vermiculite (Goldstein, 1994). Despite its abundance in most agricultural soils, potassium is predominantly found in insoluble forms, limiting its bioavailability to plants (Basak and Biswas, 2009)^[2]. The conventional use of potassium fertilizers has been effective in addressing this issue but raises concerns about environmental sustainability and soil health. Over-reliance on chemical inputs can degrade soil structure, reduce microbial diversity, and lead to nutrient imbalances. These challenges have prompted the exploration of biological alternatives such as potassium-mobilizing bacterial isolates (KMBIs). Many bacteria such as *Acidithiobacillus ferrooxidans*, *Paenibacillus* spp., *Bacillus mucilaginosus*, *B. edaphicus*, and *B. circulans* have capacity to solubilize K minerals (e.g., biotite, feldspar, illite, muscovite, orthoclase, and mica). KSB can dissolve silicate minerals and release K through the production of organic and inorganic acids, acidolysis, polysaccharides, complexolysis, chelation, and exchange reactions. Etesami *et al.* (2017)^[6] In addition to enhancing potassium availability, potassium solubilizing microbes improve soil microbial activity, nutrient cycling, and overall soil fertility, thus benefiting the growth and health of plants. Various microorganisms play a significant role in solubilizing insoluble potassium into forms accessible for plant uptake. These include bacterial species such as *Bacillus mucilaginosus*, *B. edaphicus*, *B. circulans*, *B. cereus*, *B. subtilis*, *B. coagulans*, *B. amyloliquefaciens*, *B. megaterium*, *Enterobacter hormaechei*, *Flectobacillus* spp., *Acidithiobacillus ferrooxidans*, and *Paenibacillus* spp. Additionally, fungal strains like *Aspergillus niger*, *A. fumigatus*, and *A. terreus*, along with yeast species such as *Torulaspora globosa* (Yadav and Sindhu 2016)^[24] Since, potassium is a limiting factor in a crop production and cotton is seen as a potential cash crop for many farmers. Keeping this in the view present study was undertaken for understanding the role of potassium-mobilizing bacterial isolates on growth parameters and yield of Bt cotton” in field condition.

Materials and Methods

In order to evaluate the potassium solubilization potential of different microbial strains *in vitro* condition and in liquid medium, laboratory experiments were carried out using

Aleksandrov media. The experiments were carried out during 2022 in Soil Biodiversity Research Laboratory, Department of Soil Science and Agricultural Chemistry, VNMKV, Parbhani. The observations on colony diameter, halozone diameter, clearing zone on the solid media were recorded systematically. Further, the data on soluble potassium in liquid medium was noted and change in pH of broth was recorded. On the basis of halo zone formation promising microbial strains were selected for further experiment. Thereafter, experiments were conducted to evaluate potassium solubilizing potential of different microbial isolates under field condition. The field trials were conducted during Kharif 2022 and 2023 on Vertisol (Typic Haplustert) at same place at research farm, All India Network Project on Soil Biodiversity and Biofertilizer, Vasant Rao Naik Marathwada Krishi Vidyapeeth, Parbhani. The experiment was laid out in randomized block design with 10 treatments replicated three times. The recommended dose of phosphorus and potassium along with half dose of N were applied at the time of sowing and half dose of N after one month of sowing. The inorganic sources of fertilizers urea, single super phosphate (SSP) and murate of potash (MOP) were used for experiment. The laboratory stock cultures (KSB-W1 (*Bacillus* sp.), KSB-PD-3-A, (*Bacillus* sp.), KSB-NP-3 (*Bacillus* sp.), KSB-M-1 (*Pseudomonas* sp.), KSB-M-2 (*Pseudomonas* sp.), KSB-M-3 (*Sinorhizobium metallidans*)), *Fraturia aurantia*, *Pseudomonas striata*, were selected on the basis of their potash solubilizing ability in laboratory condition. After germinating the cotton seedlings (15 DAS) liquid broth of isolates (10^{-8} CFU ml⁻¹) diluted in water was applied @ 5L ha⁻¹ through drenching. Five plants from each plot were randomly selected were used to collect data for growth and yield attributes. From the net plot cotton yield per hectare was reported. Data were statistically analyzed by the standard procedure of Panse and Sukhatme (1985)^[14].

Results and Discussion

Growth parameters

1. Plant height

The effect of inoculation of potassium solubilizing microbial inoculants with recommended dose of fertilizers on plant height was recorded at critical growth stages of Bt cotton and data is presented in Table 1. The data shows that plant height was significantly influenced by inoculation of different bacterial isolates. Increase in plant height from flowering till to harvest due to inoculation of different potassium solubilizing microbial inoculants the significantly highest plant height of cotton in pooled analysis, was recorded in treatment T₉ RDF + *Fraturia aurantia* (84.28, 108.35, 113.47 and 118.63 cm) at respective critical growth stages which was found at par with T₃, T₄, T₅, T₆, T₇ and T₁₀ at flowering and boll development stage, at boll bursting; T₃, T₇ and T₁₀, at harvest T₃, T₆, T₇ and T₁₀ respectively. The lowest values were obtained (44.79, 61.14, 63.26 and 67.71 cm) with treatment T₁ which is absolute control (71.92, 95.76, 100.64 and 105.54 cm) followed by treatment T₂ (only RDF) at respective critical growth stages of cotton. The treatment results reveal that inoculation with specific potassium-solubilizing bacteria (KSB) significantly enhanced plant height compared to both the absolute control (T₁) and the sole RDF treatment (T₂). Overall, the data suggest that potassium-mobilizing bacteria, particularly *Fraturia aurantia*, *Pseudomonas striata*, and *Bacillus* spp., significantly enhance the plant height of Bt cotton by improving potassium solubilization, nutrient uptake, and the provision of growth-promoting compounds. Our findings supported by Hamed *et al.* (2019)^[8].

Table 1: Effect of potassium mobilizing bacterial isolates on plant height of *Bt* cotton

Treatments	Plant height (cm)			
	Flow	BD	BB	AH
T ₁ : Absolute control	44.79	61.14	63.26	67.71
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	71.92	95.76	100.64	105.54
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	79.21	104.09	106.77	113.63
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	78.31	102.19	105.03	111.45
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	77.77	100.97	104.89	110.99
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	77.70	104.47	106.45	113.89
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	78.38	103.77	106.93	112.11
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	75.79	96.13	102.12	107.69
T ₉ : RDF + <i>Fratureia aurantia</i>	84.28	108.35	113.47	118.63
T ₁₀ : RDF + <i>Pseudomonas striata</i>	82.45	106.66	109.44	115.83
SE ₊	2.48	2.73	2.27	2.27
C.D. at 5%	7.37	8.12	6.74	6.76

*(Flow- flowering, BD-Boll development, BB- Boll brusting and AH- at harvest)

2. Number of leaves

Data on mean number of leaves as influenced by the application of different potassium solubilizing microbial inoculants are presented in Table 2. Inoculation of potassium solubilizing bacteria i.e. *Fratureia aurantia* along with RDF (T₉) and *Pseudomonas striata* along with RDF (T₁₀) recorded significantly maximum number of leaves of cotton. In the pooled analysis, the highest number of leaves in *Bt* cotton was recorded in treatment T₉ (94.90, 136.15, 145.12, and 148.36) with RDF + *Fratureia aurantia* at the respective critical growth stages (flowering, boll development, boll bursting, and harvest). This treatment was found at par with T₆ (87.32, 123.33, 136.04, and 133.64), and T₁₀ (90.42, 127.95, 140.84, and 142.29) and T₃ (84.78, 120.19, 132.69, and 134.05), across most growth stages.

At flowering, it was also at par with T₄ (75.84, 115.07, 125.91, and 133.33) and T₇ (83.80, 117.48, 132.15, and 134.02). The lowest number of leaves was observed in T₁ (absolute control) with values of 36.43, 58.29, 57.59, and 62.70 at flowering, boll development, boll bursting, and harvest stages, respectively, followed by T₂ (only RDF) with values of 72.35, 107.60, 120.25, and 119.24 at the corresponding stages. (Hamed *et al.* 2019) [8]. Results showed that *Bacillus circulance* (BC) and *Bacillus megatherium* (BM) strains in combination with chemical fertilizers had an effective synergistic impact on plant growth traits and yield parameters of cotton. Similarly, (Prajapati and Modi 2012) [18] reported that use of KSB having multi-faceted beneficial traits would be highly effective for improving growth.

Table 2: Effect of potassium mobilizing bacterial isolates on number of leaves of *Bt* cotton

Treatments	Number of leaves			
	Flow	BD	BB	AH
T ₁ : Absolute control	36.43	58.29	57.59	62.70
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	72.35	107.60	120.25	119.24
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	84.78	120.19	132.69	134.05
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	75.84	115.07	125.91	133.33
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	71.95	112.90	127.12	129.49
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	87.32	123.33	136.04	133.64
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	83.80	117.48	132.15	134.02
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	76.92	112.33	126.67	126.54
T ₉ : RDF + <i>Fratureia aurantia</i>	94.90	136.15	145.12	148.36
T ₁₀ : RDF + <i>Pseudomonas striata</i>	90.42	127.95	140.84	142.29
SE ₊	2.71	3.37	2.74	3.73
C.D. at 5%	8.07	10.00	8.13	11.08

*(Flow- flowering, BD-Boll development, BB- Boll brusting and AH- at harvest)

3. Number of branches

It is evidenced from the data presented in Table 3 that the potassium solubilizing microbial inoculants have significant impact on the number of branches at different growth stages of cotton during both years. Number of branches were increased from flowering stage till to the harvest stage of crop. In the pooled analysis, significantly the highest number of branches in *Bt* cotton was observed in treatment T₉ (15.07, 20.10, 22.67, and 26.20) with RDF + *Fratureia aurantia* at the critical growth stages of flowering, boll development, boll bursting, and harvest, respectively. This treatment was found statistically at par with T₁₀ (14.30, 19.33, 21.23, and 25.00) at all stages and with T₆ (13.62, 18.73, 19.47, and 22.73) and T₇ (13.28, 18.50, 19.47, and 22.70) at flowering, boll development, and boll bursting. Treatments T₃ (13.27, 18.43, 19.57, and 23.12) respectively. The lowest number of branches was recorded in T₁

(absolute control) with values of 8.70, 11.05, 13.67, and 15.27, followed by T₂ (only RDF) with values of 10.47, 16.23, 18.30, and 19.90 across the respective growth stages. These results highlight the limitations of non-inoculated treatments (T₁) and sole RDF application (T₂) in promoting branch development. Potassium is essential for cellular functions, including cell division and elongation, which contribute to branch formation and development. The increased branch numbers in treatments with *Fratureia aurantia* may also be due to this bacterium's ability to produce plant growth-promoting substances, such as indole-3-acetic acid (IAA) and gibberellins, which further stimulate growth and branching. The efficient K-solubilizing microbes (KSM) should be applied for solubilization of a fixed form of K to an available form of K in the soils. This available K can be easily taken up by the plant for growth and development (Verma *et al.* 2017) [23].

Table 3: Effect of potassium mobilizing bacterial isolates on number of branches of *Bt* cotton

Treatments	Number of branches			
	Flow	BD	BB	AH
T ₁ : Absolute control	Flow	BD	BB	AH
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	8.70	11.05	13.67	15.27
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	10.47	16.23	18.30	19.90
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	13.27	18.43	19.57	23.12
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	12.28	17.53	19.17	21.30
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	12.30	17.43	19.13	21.73
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	13.62	18.73	19.47	22.73
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	13.28	18.50	19.47	22.70
T ₉ : RDF + <i>Frateruria aurantia</i>	12.27	17.80	19.12	21.77
T ₁₀ : RDF + <i>Pseudomonas striata</i>	15.07	20.10	22.67	26.20
SE ₊	14.30	19.33	21.23	25.00
C.D. at 5%	0.50	0.74	0.70	0.77

*(Flow- flowering, BD-Boll development, BB- Boll brusting and AH- at harvest)

4. Chlorophyll content

The chlorophyll a and b are virtually essential pigments for the conversion of light energy to stored chemical energy. The amount of solar radiation observed by a leaf is a function of the photosynthetic pigment content, thus chlorophyll content can directly determine photosynthetic potential and primary production. In addition, chlorophyll gives an indirect estimation of the nutrient status because much of leaf nitrogen is incorporated in chlorophyll. Thus, according to necessity, chlorophyll content in fresh leaves of cotton were estimated at flowering stage of crop and data is presented in Table 4. The table illustrates the effect of potassium-mobilizing bacterial (KSB) isolates on chlorophyll content (Chl-a, Chl-b, and total chlorophyll) of *Bt* cotton. Among the treatments, T₉: RDF + *Frateruria aurantia* showed the significantly highest values for Chl-a (1.54 mg g⁻¹), Chl-b (0.83 mg g⁻¹), and total chlorophyll (2.37 mg g⁻¹), indicating its superior ability to enhance photosynthetic pigment content. This was closely followed by T₁₀: RDF + *Pseudomonas striata*, which was at par with T₉ for

Chl-b (0.80 mg g⁻¹) and total chlorophyll (2.19 mg g⁻¹). Other notable treatments include T₆: RDF + KSB - M - 1 (*Pseudomonas* spp.), which recorded 1.37 mg g⁻¹ Chl-a, 0.78 mg g⁻¹ Chl-b, and 2.15 mg g⁻¹ total chlorophyll, as well as T₇: RDF + KSB - M - 2 (*Pseudomonas* spp.) and T₈: RDF + KSB - M - 3 (*Sinorhizobium metallidans*), both with similar total chlorophyll values (2.13 mg g⁻¹). In contrast, the lowest chlorophyll content was observed in T₁: absolute control, with Chl-a (1.12 mg g⁻¹), Chl-b (0.55 mg g⁻¹), and total chlorophyll (1.67 mg g⁻¹), reflecting the lack of nutrient enhancement in the absence of fertilizers or bioinoculants. Our results corroborate with the conclusions of Sheng and He (2006) [20] revealed that bacterial inoculation significantly increased chlorophyll content and potassium uptake. Imran *et al.* (2022) [11] concluded that K enriched compost with efficient KSB inoculant can be used to enhance maize growth and productivity in semi-arid agroecosystems. Increased chlorophyll content in levels and photosynthetic efficiency, which ultimately contributed to higher crop productivity.

Table 4: Effect of potassium mobilizing bacterial isolates on chlorophyll content at flowering stage of *Bt* cotton

Treatments	Chlorophyll content		
	Chl-a	Chl- b	Total chlorophyll
T ₁ : Absolute control	1.12	0.55	1.67
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	1.19	0.70	1.89
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	1.28	0.72	2.01
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	1.24	0.77	2.01
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	1.38	0.67	2.05
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	1.37	0.78	2.15
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	1.34	0.78	2.13
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	1.35	0.78	2.13
T ₉ : RDF + <i>Frateruria aurantia</i>	1.54	0.83	2.37
T ₁₀ : RDF + <i>Pseudomonas striata</i>	1.39	0.80	2.19
SE ₊	0.04	0.03	0.05
C.D. at 5%	0.11	0.10	0.16

5. Root parameters

The table no.5 presents the effect of potassium-mobilizing bacterial (KSB) isolates on root parameters of *Bt* cotton, including oven dry weight of shoot and root, root volume, root-shoot ratio, and root density. Among the treatments, T₉: RDF + *Frateruria aurantia* exhibited the best performance, with the highest values for oven dry weight of shoot (45.83 g), root (2.43 g), root volume (16.25 cc), and root-shoot ratio (18.88). The treatment T₁₀: RDF + *Pseudomonas striata* was statistically at par with T₉ for oven dry weight of root (2.38 g), root volume (15.46 cc), root-shoot ratio (17.54). Conversely, the lowest

values across all parameters were recorded in T₁: absolute control, with oven dry weight of shoot (14.17 g), root (1.43 g), root volume (5.91 cc), root-shoot ratio (9.90). Highest root density of cotton was noticed in treatment T₁ (0.229, 0.253, and 0.240. g/cc) treatment strictly control no RDF no KSB inoculant. Followed by treatment T₂ (0.156, 0.155 and 0.160 g/cc) with only RDF in pooled data. Whereas, lowest root density among all treatment recorded in treatment T₉ ((RDF + *Frateruria aurantia*) followed by T₁₀ (RDF + *Pseudomonas striata*) and T₃ (RDF + KSB W1-*Bacillus* spp.) as pooled data.

Table 5: Effect of potassium mobilizing bacterial isolates on root parameters of *Bt* cotton

Treatments	Root parameters				
	Oven dry weight Shoot (g)	Oven dry weight root (g)	Root volume (cc)	Root-shoot ratio	Root density (g/cc)
T ₁ : Absolute control	14.17	1.43	5.91	9.90	0.24
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	25.17	2.01	13.02	12.53	0.16
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	35.50	2.33	15.44	15.24	0.15
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	28.00	2.16	13.84	13.00	0.16
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	30.83	2.30	14.91	13.43	0.15
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	34.00	2.25	14.19	15.14	0.16
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	35.83	2.22	14.75	16.19	0.15
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	28.83	2.09	13.52	13.89	0.16
T ₉ : RDF + <i>Frateuria aurantia</i>	45.83	2.43	16.25	18.88	0.15
T ₁₀ : RDF + <i>Pseudomonas striata</i>	41.67	2.38	15.46	17.54	0.16
SE+	1.03	0.04	0.57	0.53	0.01
C.D. at 5%	3.05	0.12	1.68	1.58	0.02

The application of KSB isolates, particularly *Frateuria aurantia* and *Pseudomonas striata*, significantly improved root parameters compared to the control and RDF-only treatments. These enhancements likely contribute to better nutrient acquisition and crop performance. Findings supported by (Prajapati and Modi 2016) [16] The inoculated cucumber plants vine length and root length were more than controls, where root elongation is associated with the production of IAA in early stages. The IAA content was increased in inoculated plants as compared to control and so increased root length, shoot length due to bacterial phytohormones, and the lack of essential nutrient cause the elongation of roots to obtain nutrient (Hamid, 2008 and Hassan *et al.* 2009) [9, 10].

Work done by P.P. Nihala Jabin and Syed Ismail (2017) [13] inoculation of KSB strains which can synergistically solubilized rock K that were added into soil and make them much more available for uptake by plant root and leading to plant growth. Further, Prajapati (2015) [17] indicated the largest increase in

plant height in soil inoculated with KSB strain compared to the uninoculated soil. Our results are also concurring with the findings of Zhang and Kong (2014) [25] who reported that seedlings inoculated with KSB showed greater height than uninoculated seedlings. Our results are also corroborating with the findings of earlier workers. Chishi, (2010) [4] found that inoculation of KSB showed higher number of leaves as compared with control. Basavesha (2013) [3] also found that the inoculation of potassium solubilizing bacteria increased the number of leaves in plant significantly superior over control. It may be due to inoculation of KSB strains which can synergistically solubilized Rock K that were added into soil and make them much more available for uptake by plant root and leading to plant growth (Sheng, 2005) [21]. The decrease in number of leaves at later stage might be a result of senescence.

Yield and yield attributes

Table 6: Effect of potassium mobilizing bacterial isolates on yield attribute of of *Bt* cotton

Treatments	Yield attribute of of <i>Bt</i> cotton.				
	No. of bolls	Seed cotton yield Kg ha ⁻¹	% increase over RDF	Dry matter yield Kg ha ⁻¹	% increase over RDF
T ₁ : Absolute control	35.97	793	-	1053	-
T ₂ : Only RDF (120: 60: 60 NPK kg ha ⁻¹)	43.44	1495	-	2321	-
T ₃ : RDF + KSB - W1 (<i>Bacillus</i> spp.)	48.63	1595	6.69	2620	13.35
T ₄ : RDF + KSB - PD - 3 - A (<i>Bacillus</i> spp.)	46.00	1523	1.87	2517	8.50
T ₅ : RDF + KSB - NP - 3 (<i>Bacillus</i> spp.)	45.19	1529	2.27	2560	10.09
T ₆ : RDF + KSB - M - 1 (<i>Pseudomonas</i> spp.)	48.00	1563	4.55	2551	10.31
T ₇ : RDF + KSB - M - 2 (<i>Pseudomonas</i> spp.)	47.19	1556	4.08	2565	9.54
T ₈ : RDF + KSB - M - 3 (<i>Sinorhizobium metallidans</i>)	45.01	1543	3.21	2429	5.50
T ₉ : RDF + <i>Frateuria aurantia</i>	57.83	1930	29.10	2892	21.02
T ₁₀ : RDF + <i>Pseudomonas striata</i>	54.87	1880	25.75	2682	14.90
SE+	1.46	32.59	-	67.40	-
C.D. at 5%	4.35	96.84	-	200.26	-

The table 7. highlights the effect of potassium-mobilizing bacterial (KSB) isolates on yield attributes of *Bt* cotton, including the number of bolls per plant, seed cotton yield, dry matter yield, and percentage increase over RDF. Among the treatments, T₉: RDF + *Frateuria aurantia* exhibited the highest values across all parameters, with 57.83 bolls per plant, seed cotton yield of 1930 kg ha⁻¹ (29.10% increase over RDF), and dry matter yield of 2892 kg ha⁻¹ (21.02% increase over RDF), making it the most effective treatment. This was closely followed by T₁₀: RDF + *Pseudomonas striata*, which recorded 54.87 bolls per plant, seed cotton yield of 1880 kg ha⁻¹ (25.75% increase), and dry matter yield of 2682 kg ha⁻¹ (14.90%

increase), showing it was at par with T₉ in its performance. Other notable treatments included T₃: RDF + KSB - W1 (*Bacillus* spp.), which produced 48.63 bolls, 1595 kg ha⁻¹ seed cotton yield (6.69% increase), and 2620 kg ha⁻¹ dry matter yield (13.35% increase), and T₆: RDF + KSB - M - 1 (*Pseudomonas* spp.), with 48.00 bolls, seed cotton yield of 1563 kg ha⁻¹ (4.55% increase), and dry matter yield of 2551 kg ha⁻¹ (10.31% increase). In contrast, the lowest values were observed in T₁: Absolute control, with 35.97 bolls per plant, 793 kg ha⁻¹ seed cotton yield, and 1053 kg ha⁻¹ dry matter yield, followed by T₂: Only RDF (120:60:60 NPK kg ha⁻¹), which recorded 43.44 bolls, 1495 kg ha⁻¹ seed cotton yield, and 2321 kg ha⁻¹ dry

matter yield. These findings emphasize the superior role of *Frateuria aurantia* and *Pseudomonas striata* in enhancing yield attributes of Bt cotton compared to the RDF and control treatments. These findings are supported by similar studies. Ahmad *et al.* (2019) demonstrated significant increases in cotton yield with the application of *Bacillus* strains, attributed to enhanced potassium solubilization. Highest increased in number of fruits per plant (23.4), Fruit girth (7.44 cm), Length of the fruit (12.44 cm), Fruit weight (104.94 gm,) and Yield (around 25 tons/ ha) were observed in the treatments were inoculated with the *E. hormaechei* (KSB-8). (Prajapati and Modi 2016) ^[16]. Our findings also supported by (Priyavardhini *et al.* 2022) revealed that application of K₂O 40 gm + KSB 20 ml/ kg Soil (SA) + KSB 30 ml/ kg Seed (SI) was found to be more productive (5.78 t/ha) for receiving of higher yield of Maize.

Conclusion

The application of potassium-mobilizing bacterial (KSB) isolates demonstrates a sustainable and effective strategy for enhancing the growth parameters and yield of Bt cotton. The study revealed significant improvements in growth and yield attributes with potassium mobilizing bacterial strains showcasing their potential to optimize nutrient uptake and plant productivity. Treatment RDF + *Frateuria aurantia* consistently outperformed all others, achieving the highest values for yield including seed cotton yield (1930 kg/ha) and dry matter yield (2892 kg/ha), with an impressive 29.10% and 21.02% increase over RDF, respectively. Additionally, RDF + *Pseudomonas striata* also exhibited strong performance across parameters, proving it to be at par with *Frateuria aurantia* in several aspects and minimum growth and yield improvement observed in uninoculated treatment. These potassium solubilizing (mobilizing) microorganisms can be explored as bio input for improving plant growth and also to improve the potassium availability and reduces the losses of nutrient by making them more available with potassium solubilizing mobilizing bacterial isolates in cotton.

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