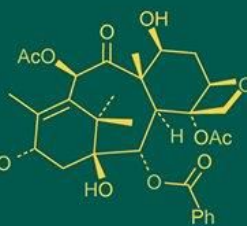
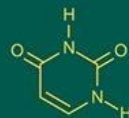


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Isolation and functional screening of native mineral solubilizing bacteria from rice fields of Kalyana Karnataka region

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Abstract

Rice (*Oryza sativa* L.) is a principal staple crop sustaining more than half of the world's population, and improving nutrient availability through beneficial microorganisms is essential for sustainable production. The present investigation (2023-2025) was conducted to isolate and screen efficient phosphate, potassium, zinc and silicate solubilizing bacteria from paddy-growing areas of Kalyana Karnataka. A total of 33 phosphate solubilizing bacteria (PSB), 29 potassium solubilizing bacteria (KSB), 21 zinc solubilizing bacteria (ZSB) and 29 silicate solubilizing bacteria (SSB) were isolated and evaluated under *in vitro* conditions using Pikovskaya's, Aleksandrov, TRIS minimal and silicate solubilizing media, respectively, by measuring halo zone formation after four days of incubation at 28±2 °C. The solubilization efficiency among PSB ranged from 109.47 to 398.29 percent, with SPSB 19 (16.33 mm zone) showing maximum efficiency; potassium solubilization ranged from 111.40 to 456.10 percent, with MKSB 13 (21.30 mm zone) being superior; zinc solubilization ranged from 107.52 to 355.90 percent, with RZSB 6 (19.29 mm zone) recording the highest efficiency; and silicate solubilization ranged from 130.99 to 370.73 percent, with MSSB 23 (15.20 mm zone) exhibiting maximum activity. Significant differences among isolates were observed at one percent level of significance. The study revealed considerable variability among native bacterial isolates, and the superior strains identified hold promise for developing efficient microbial consortia to enhance nutrient availability, reduce dependence on chemical fertilizers and promote sustainable rice cultivation in the Kalyana Karnataka region.

Keywords: Rice, phosphate solubilizing bacteria, potassium solubilizing bacteria, zinc solubilizing bacteria, silicate solubilizing bacteria, microbial consortia, nutrient solubilization, sustainable agriculture

1. Introduction

Rice stands as the principal staple food crop, serving as a major dietary source for nearly two-thirds of the global population. Among Indian states, Karnataka has emerged as a prominent rice-producing region, benefiting from favourable climatic conditions suitable for its cultivation. Around 75% of the world's rice is cultivated in flooded, puddled fields, with approximately 92% of this production concentrated in Asia, primarily for domestic consumption. Rice (*Oryza sativa* L.) is one of the most significant food crops globally and serves as the staple diet for more than half of the world's population. Rice plays an indispensable role in nutrition and food security, being rich in carbohydrates, moderate quantities of protein, essential fatty acids, and vital micronutrients. For more than 3 billion people in Asia, it provides between 30% and 75% of their total calorie intake (Khush, 2014) [8].

Traditionally, rice in the country is grown using the transplanted puddled method, where seedlings are raised in a nursery and transplanted into waterlogged fields. Although effective, this system demands significant water and labour resources, both of which are increasingly scarce and costly. Furthermore, puddling damages the soil structure, leading to compaction, which adversely affects the next non-rice crop. To restore the soil to a granular condition suitable for the succeeding crop, intensive tillage operations are required, increasing labour,

fuel use, and costs, and frequently causing delays in sowing subsequent crops like wheat or maize. In contrast, direct seeding eliminates intensive puddling and preserves an aerobic soil condition, allowing timely establishment of the next crop (Bhushan *et al.*, 2007) ^[1].

Microbes living in the endorhizosphere of several plants and having several positive effects on the host plant through various mechanisms are usually termed plant growth-promoting rhizobacteria (PGPR). In the rhizosphere, plant roots secrete a number of exudates that act as attractants for microbes, which eventually improve the physicochemical properties of the surrounding soil. On the other hand, these exudates maintain the function and structure of microbial communities near plant roots. Plants and bacteria form symbiotic associations to alleviate abiotic stresses (Raza *et al.*, 2016) ^[12].

PGPR can assist plants in their growth by fixation of atmospheric nitrogen, producing siderophores, generating phytohormones (auxins, gibberellins and cytokinins), solubilizing phosphorus (P), or synthesizing stress-relieving enzymes. Moreover, certain bacteria improve the accessibility of essential nutrients, improve root progression and lessen stress-induced damage by modifying plant defense systems.

With this backdrop, the present paper aims to study on screening of Phosphate, Potassium, Zinc, and Silicate Solubilizing Bacteria in the study area of kalia Karnataka region for the academic year 2023-25.

2. Methodology

The present investigation on development of microbial consortia and their formulation studies on growth and yield of paddy was carried out during 2023-2025. The laboratory and pot experiments were carried out in the department of Agricultural Microbiology, College of Agriculture, Raichur while field experiment was carried out at ARS, Dhadesugur situated in the North eastern dry zone (Zone-2) of Karnataka (at 16° 12' N latitude, 77° 21' E longitudes and an altitude of 389.37 m above MSL). Further, the isolated phosphate solubilizing, potassium solubilizing, zinc solubilizing and silicate solubilizing isolates were spot inoculated on to the Pikovskaya, Aleksandrov, TRIS minimal and silicate solubilizing agar plates, respectively and incubated at 30 °C for 4 days. After 4 days, the solubilization efficiency was measured by using following formula.

$$\text{Solubilization efficiency} = \frac{\text{Solubilization diameter}}{\text{Diameter of colony growth}} \times 100$$

3. Results & Discussion

3.1 *in vitro* screening of phosphate solubilizing bacteria on Pikovskaya medium by plate assay method

The bacterial isolates were primarily screened for their ability to form solubilizing zone on media by plate assay technique. To determine solubilizing activity, 24-48 hrs old test organism was spot inoculated at the center of the Pikovskaya's media plate and incubated at room temperature for 4 days. The mineral solubilizing activity was indicated by a clear zone around the colony and width of the clear zone was measured to find out the solubilization efficiency (%). The isolate produced highest solubilization zone around the colony was selected as an efficient one.

Table 1: Screening of phosphate solubilizing bacteria on Pikovskaya's medium by the plate assay method

Sl. No.	Sample code	Isolate	Phosphate solubilization		Solubilization efficiency (%)
			Solubilization zone (mm)	Culture diameter (mm)	
1	KDR1	SPSB 1	7.27	6.00	121.17
2	KGR1	SPSB 2	15.13	5.13	294.93
3	KSR1	SPSB 3	16.33	4.19	389.74
4	KKR1	SPSB 4	13.40	4.10	326.83
5	YBR1	SPSB 5	10.47	5.17	202.51
6	YWR1	SPSB 6	7.20	5.25	137.14
7	YSR1	SPSB 7	6.10	5.16	118.22
8	YSR2	SPSB 8	7.27	4.56	159.43
9	YKR1	SPSB 9	7.30	4.86	150.21
10	YHR1	SPSB 10	5.70	4.42	128.96
11	BSR1	SPSB 11	6.71	6.13	109.47
12	BKR1	SPSB 12	11.43	5.96	191.78
13	BSR2	SPSB 13	13.00	5.40	240.74
14	BMR1	SPSB 14	10.61	4.94	214.97
15	BBR1	SPSB 15	6.72	3.74	179.68
16	BCR1	SPSB 16	8.28	5.70	145.26
17	BBR2	SPSB 17	10.01	5.66	176.93
18	BCR2	SPSB 18	15.06	6.10	246.07
19	BJR1	SPSB 19	16.33	4.10	398.29
20	RMR1	SPSB 20	13.50	5.06	266.60
21	RYR1	SPSB 21	9.70	5.00	194.00
22	RMR2	SPSB 22	13.23	5.72	231.15
23	RMR3	SPSB 23	7.90	5.43	145.49
24	RKR1	SPSB 24	10.96	5.900	185.76
25	RSR1	SPSB 25	13.20	4.82	273.65
26	RKR1	SPSB 26	10.90	4.73	230.45
27	RKR2	SPSB 27	7.63	5.133	148.61
28	RKR3	SPSB 28	12.20	5.400	225.93
29	RNR1	SPSB 29	10.13	5.73	176.72
30	RGR1	SPSB 30	7.03	5.00	140.60
31	RHR1	SPSB 31	6.60	4.10	161.04
32	RTR1	SPSB 32	6.26	5.55	112.79
33	RST1	SPSB 33	4.86	3.28	148.17
S. Em (±)			0.23	0.24	
S.Ed			0.32	0.33	
C.D. 1%			0.85	0.89	

After 4 days of incubation at 28±2 °C, the plates were observed for clear solubilization zone. The solubilization efficiency ranged from 395.19% to 109.45%. The isolate MPSB 3 showed the maximum solubilization efficiency of 395.19% whereas, MPSB 11 reported minimum efficiency of 109.45%. . The solubilization zone was 16.40 mm and 6.24 mm in MPSB 3 and MPSB 18, respectively. The results pertaining to solubilization zone, culture diameter and solubilization efficiency of all the 33-phosphate solubilizing presented in the Table 1.

Similar work was carried out by Fekadu (2013) ^[5]. Twelve *Pseudomonas* strains from rhizospheric soil of faba bean were isolated and tested for phosphate solubilization. All tested isolates of *Pseudomonas* strains had a potential of phosphate solubilization on

Pikovskaya's media and summarized that all *Pseudomonas* strains can be used as bio-fertilizers for soil fertility improvement.

Similarly, Manouchehr *et al.* (2016) ^[10] studied the phosphate solubilization potential of inhabiting bacteria from rhizosphere of *Avicennia marina* plants. Among 13 isolates screened, four high potential solubilizing bacteria were selected based on the formation and dimension of clear halo zone around the colonies. The isolates were found to be *Bacillus*, *Pseudomonas* and *Acinetobacter* species.

3.2 *in vitro* screening of potassium solubilizing bacteria on Aleksandrov medium by plate assay method

The bacterial isolates were primarily screened for their ability to form solubilizing zone on media by plate assay technique. To determine solubilizing activity, 24-48 hrs old test organism was spot inoculated at the center of the Aleksandrov media plate and incubated at room temperature for 4 days. The mineral solubilizing activity was indicated by a clear zone around the colony and width of the clear zone was measured to find out the solubilization efficiency (%). The isolate producing highest solubilization zone around the colony was selected as an efficient one.

After 4 days of incubation at 28 ± 2 °C, the plates were observed with clear solubilization zone. The solubilization efficiency ranged from .398% to 110.41%. The isolate

MKSB 12 showed the maximum solubilization efficiency of 456.10% and minimum efficiency was reported in MKSB 38 which showed 110.41% solubilization efficiency. The solubilization zone was 21.30 mm and 5.30 mm in MKSB 12 and MKSB 38, respectively. The results pertaining to solubilization zone, culture diameter and solubilization efficiency of all 41-potassium solubilizing bacterial isolates are presented in the Table 2.

Similar results were observed by Duff *et al.* (1963) [4], isolated 2-keto gluconic acid producing *Pseudomonas* strain capable of solubilizing many potassium minerals like quartz, silicates and phlogopite. Hu *et al.* (2006) [20], isolated two phosphate and potassium solubilizing *Bacillus sp.* from the soils, in the modified medium containing phosphate and potassium minerals like kaolinite and potassium feldspar.

Table 2: Screening of potassium solubilizing bacteria on Aleksandrov medium by plate assay method

Sl. No.	Sample code	Isolate	Potassium solubilization		Solubilization efficiency (%)
			Solubilization zone (mm)	Culture diameter (mm)	
1	KDR1	MKSB 1	12.86	5.07	253.64
2	KGR1	MKSB 2	13.45	5.13	262.18
3	KSR1	MKSB 3	12.11	4.30	281.62
4	KKR1	MKSB 4	11.54	6.047	190.88
5	YBR1	MKSB 5	9.67	5.07	190.72
6	YWR 1	MKSB 6	7.20	5.13	140.35
7	YSR1	MKSB 7	6.71	5.86	114.41
8	YSR 2	MKSB 8	7.66	5.50	139.25
9	YKR 1	MKSB 9	7.30	4.97	146.88
10	YHR 1	MKSB 10	5.72	4.42	129.4
11	BSR 1	MKSB 11	7.2	6.46	111.4
12	BKR 1	MKSB 12	12.30	4.67	156.10
13	BSR 2	MKSB 13	21.30	4.67	456.10
14	BMR 1	MKSB 14	10.61	5.02	211.06
15	BBR 1	MKSB 15	4.43	2.51	176.40
16	BCR 1	MKSB 16	7.87	4.66	168.63
17	BBR 2	MKSB 17	10.01	5.46	183.09
18	BCR 2	MKSB 18	15.06	4.35	346.36
19	BJR 1	MKSB 19	16.10	5.10	315.68
20	RMR 1	MKSB 20	13.50	5.13	263.0
21	RMR 1	MKSB 21	9.70	5.00	194
22	RMR 3	MKSB 22	13.23	5.90	224.28
23	RMR 3	MKSB 23	7.90	5.38	146.64
24	RKR 1	MKSB 24	10.96	4.36	251.13
25	RSR 1	MKSB 25	13.20	4.76	276.90
26	RKR 1	MKSB 26	11.08	5.00	221.66
27	RKR 2	MKSB 27	7.21	4.97	145.21
28	RKR 3	MKSB 28	12.10	5.15	234.81
29	RNR 1	MKSB 29	10.13	5.50	184.23
S. Em (±)			0.34	0.32	
S.Ed			0.48	0.45	
C.D. 1%			1.28	1.20	

3.3. *In vitro* screening of zinc solubilizing bacteria on TRIS minimal medium by plate assay method

The bacterial isolates were primarily screened for their ability to form solubilizing zone on media by plate assay technique. To determine solubilizing activity, 24-48 hrs old test organism was spot inoculated at the center of the TRIS minimal media plate and incubated at room temperature for 4 days. The mineral solubilizing activity was indicated by a clear zone around the colony and width of the clear zone was measured to find out the solubilization efficiency (%). The isolate produced highest solubilization zone around the colony was selected as an efficient one.

After 4 days of incubation at 28 ± 2 °C, the plates were observed with clear solubilization zone. The solubilization efficiency ranged from 355.90% to 107.52%. The isolate

MZSB 6 showed the maximum solubilization efficiency of 355.90% and MZSB 16 showed minimum solubilization efficiency of 107.52%. The solubilization zone was 19.29 mm and 9.00 mm in MZSB 7 and MZSB 10, respectively. The results pertaining to solubilization zone, culture diameter and solubilization efficiency of all 41 zinc solubilizing bacterial isolates are presented in the Table 3. Similarly, Sunitha *et al.* (2016) [21] isolated thirty-five zinc solubilizing bacteria from eight different agricultural fields in and around Coimbatore district of Tamil Nadu.

3.4 *in vitro* screening of silicate solubilizing bacteria on silicate solubilizing medium by plate assay method

The bacterial isolates were primarily screened for their ability to form solubilizing zone on media by plate assay

technique. To determine solubilizing activity, 24-48 hrs old test organism was spot inoculated at the center of the silicate solubilizing media plate and incubated at room temperature for 4 days. The mineral solubilizing activity was indicated

by a clear zone around the colony and width of the clear zone was measured to find out the solubilization efficiency (%). The isolate producing highest solubilization zone around the colony was selected as an efficient one.

Table 3: Screening of zinc solubilizing bacteria on TRIS minimal medium using the plate assay method

Sl. No.	Sample code	Isolate	Zinc oxide solubilization		Solubilization efficiency (%)
			Solubilization zone (mm)	Culture diameter (mm)	
1	KDR1	RZSB 1	13.02	7.25	179.58
2	KGR1	RZSB 2	11.20	6.53	171.51
3	KSR1	RZSB 3	12.31	5.91	208.29
4	KKR1	RZSB 4	16.35	6.42	254.67
5	YBR1	RZSB 5	10.43	7.52	138.69
6	YWR 1	RZSB 6	10.01	5.46	183.09
7	YSR1	RZSB 7	19.29	5.42	355.90
8	YSR 2	RZSB 8	20.48	7.56	270.68
9	YKR 1	RZSB 9	20.98	8.32	252.16
10	YHR 1	RZSB 10	16.21	5.52	293.65
11	BSR 1	RZSB 11	15.05	5.53	272.13
12	BKR 1	RZSB 12	15.70	11.16	140.65
13	BSR 2	RZSB 13	12.51	9.22	135.71
14	BMR 1	RZSB 14	10.76	9.23	116.53
15	BBR 1	RZSB 15	14.75	6.55	225.13
16	BCR 1	RZSB 16	9.00	8.37	107.52
17	BBR 2	RZSB 17	10.01	5.46	183.09
18	BCR 2	RZSB 18	15.41	10.48	147.10
19	BJR 1	RZSB 19	15.83	8.40	188.48
20	RMR 1	RZSB 20	16.90	6.46	261.32
21	RYR 1	RZSB 21	10.30	7.28	141.34
S. Em. (±)			0.35	0.16	
S. Ed			0.49	0.22	
C.D. (1%)			1.30	0.58	

Table 4: Screening of silicate solubilizing bacteria on silicate solubilizing medium by plate assay method.

Sl. No.	Sample code	Isolate	Silicate solubilization		Solubilization efficiency (%)
			Solubilization zone (mm)	Culture diameter (mm)	
1	KLM 1	MSSB 1	7.32	3.20	228.75
2	SRV 1	MSSB 2	10.20	4.10	270.73
3	KVT 1	MSSB 3	12.88	4.82	267.21
4	KLR 1	MSSB 4	9.17	3.57	256.86
5	KPG 1	MSSB 5	10.85	5.00	217
6	NMV 1	MSSB 6	6.13	4.65	131.8
7	GKL 1	MSSB 7	10.95	6.86	159.6
8	HRV 1	MSSB 8	7.27	4.27	170.42
9	TNP 1	MSSB 9	7.78	4.86	159.99
10	SND 1	MSSB 10	13.89	5.23	265.56
11	SND 2	MSSB 11	7.01	4.30	163.09
12	GVT 1	MSSB 12	12.06	4.53	266.20
13	GVT 2	MSSB 13	19.01	5.81	326.85
14	GVT 3	MSSB 14	10.61	5.20	204.03
15	SDP 1	MSSB 15	6.20	4.73	130.99
16	KTG 1	MSSB 16	7.87	5.86	134.14
17	DNP 1	MSSB 17	8.32	5.60	148.57
18	KHT 1	MSSB 18	13.45	4.03	333.49
19	BNB 1	MSSB 19	8.48	5.95	142.52
20	WDG 1	MSSB 20	13.53	6.00	225.28
21	SHP 1	MSSB 21	9.56	5.42	176.28
22	SGR 1	MSSB 22	11.68	5.22	223.81
23	KNP 1	MSSB 23	15.20	4.10	370.73
24	HLK 1	MSSB 24	12.71	5.90	215.47
25	SRG 1	MSSB 25	13.80	4.82	285.89
26	KKH 1	MSSB 26	10.66	4.50	237.04
27	SVL 1	MSSB 27	7.91	5.03	157.30
28	MKA 1	MSSB 28	11.56	4.86	237.66
29	BNP 1	MSSB 29	9.42	6.00	157.05
S. Em (±)			0.32	0.21	
S. Ed			0.45	0.29	
C.D. 1%			1.20	0.78	

After 4 days of incubation at 28 ± 2 °C, the plates were observed with clear solubilization zone. The solubilization efficiency ranged from 370.73% to 130.99%. The isolate MSSB 2 showed the maximum solubilization efficiency of 370.73% and minimum was observed in MSSB 15 which showed 130.99% solubilization efficiency.

The solubilization zone was 15.20 mm and 6.20 mm in MSSB 2 and MSSB 15, respectively. The results pertaining to solubilization zone, culture diameter and solubilization efficiency of all 29-silicate solubilizing bacterial isolates are presented in the Table 4.

Similar results were obtained by Chandrakala *et al.* (2019) [2] isolated silicate solubilizing bacterial isolate IIRR-1 from

rhizosphere soil of rice was characterized for its potential to release soluble silica from insoluble inorganic (Ca, Al, K and Mg) silicates and biogenic materials like diatomaceous earth, siliceous earth, rice husk and rice straw. Incubation studies revealed the ability of the isolate to colonise and grow on all insoluble silicates leading to increased release of silica (12.45-60.15% over control) into culture media by the process of acidolytic (pH 4.5) dissolution of silicates. The results were supported by Gopal *et al.* (2005) [6], Sheng *et al.* (2008) [14] and Vijayapriya and Muthukkaruppan (2010) [17].

3.5 Multivariate and Graphical Analysis

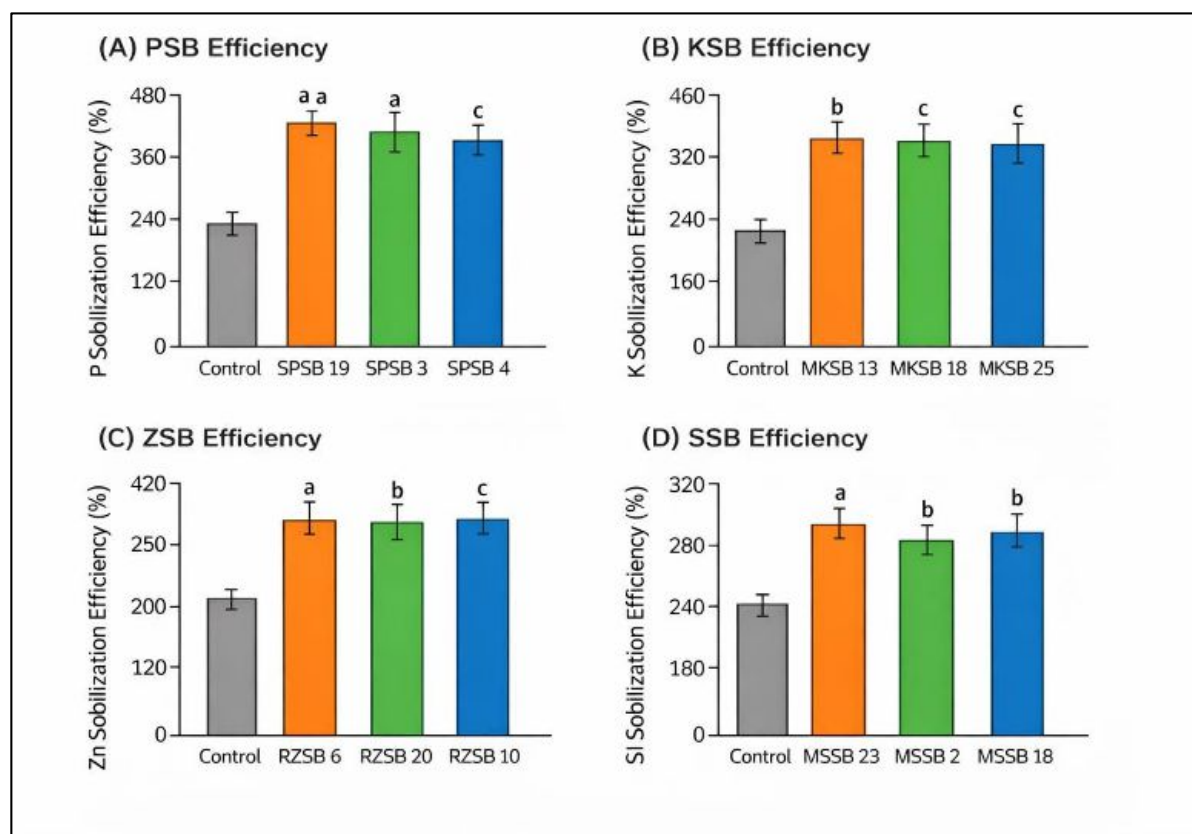


Fig 1: Comparative solubilization efficiency of selected mineral solubilizing bacterial isolates representing phosphate (PSB), potassium (KSB), zinc (ZSB), and silicate (SSB) solubilization under *in vitro* conditions.

Phosphate Solubilization

Among the phosphate solubilizing bacteria, significant variation in solubilization efficiency was observed among the isolates. The efficiency ranged from 109.47% to 398.29%, indicating substantial diversity in phosphate solubilization potential. The isolate SPSB 19 exhibited the highest solubilization efficiency (398.29%) with a prominent halo zone (16.33 mm), followed by SPSB 3 and SPSB 4. The superior performance of these isolates may be attributed to their ability to produce higher amounts of organic acids, leading to effective solubilization of insoluble phosphates. Statistical analysis indicated that the differences among isolates were significant at the 1% level ($p < 0.01$).

Potassium Solubilization

The potassium solubilizing bacterial isolates also demonstrated considerable variability. The solubilization efficiency ranged from 111.40% to 456.10%, with MKSB 13 showing the highest efficiency (456.10%) and a maximum solubilization zone of 21.30 mm. Other isolates

such as MKSB 18 and MKSB 19 also showed notable performance. The enhanced potassium solubilization is likely due to the production of organic acids such as citric and oxalic acids, which facilitate mineral weathering. The differences among isolates were statistically significant ($p < 0.01$), highlighting the presence of highly efficient native K-solubilizers (Figure 1. B).

Zinc Solubilization

Zinc solubilizing bacteria exhibited solubilization efficiencies ranging from 107.52% to 355.90%. The isolate RZSB 6 recorded the highest efficiency (355.90%) with a solubilization zone of 19.29 mm, followed by RZSB 8 and RZSB 10. The ability of these isolates to solubilize zinc compounds may be associated with acidification of the medium and chelation mechanisms. Significant variation among isolates ($p < 0.01$) suggests the presence of efficient zinc solubilizers suitable for biofertilizer development (Figure 1. C).

Silicate Solubilization

In the case of silicate solubilizing bacteria, the efficiency ranged from 130.99% to 370.73%, with MSSB 23 exhibiting the highest solubilization efficiency (370.73%) and a solubilization zone of 15.20 mm. Other isolates such as MSSB 18 and MSSB 13 also showed considerable activity. The solubilization of silicates is primarily attributed to acidolytic reactions and enzymatic activity leading to the release of plant-available silica. The observed differences were statistically significant ($p < 0.01$) (Figure 1. D).

The present investigation revealed considerable variability among native bacterial isolates in their ability to solubilize phosphorus, potassium, zinc and silicate, indicating a diverse and functionally active microbial population in the rice rhizosphere. The superior performance of isolates such as SPSB 19, MKSB 13, RZSB 6 and MSSB 23 suggests their strong potential as efficient bioinoculants for improving nutrient availability. The enhanced solubilization observed may be attributed to multiple mechanisms including the production of organic acids, proton extrusion, chelation and enzymatic activity, which facilitate the conversion of insoluble mineral forms into plant-available nutrients. The significant differences observed among isolates further indicate niche specialization, where individual strains exhibit efficiency for specific nutrients rather than a broad-spectrum capability.

This functional complementarity is highly advantageous for the development of multi-strain microbial consortia, as it enables simultaneous mobilization of macro- and micronutrients, thereby enhancing nutrient use efficiency and crop productivity. Similar findings have been reported earlier, where plant growth-promoting microorganisms significantly improved nutrient solubilization and soil fertility through biochemical processes (Rodríguez and Fraga, 1999; Meena *et al.*, 2014) [22, 23]. Therefore, the efficient isolates identified in this study can be effectively utilized for developing sustainable biofertilizer formulations for rice cultivation (Figure 1. A).

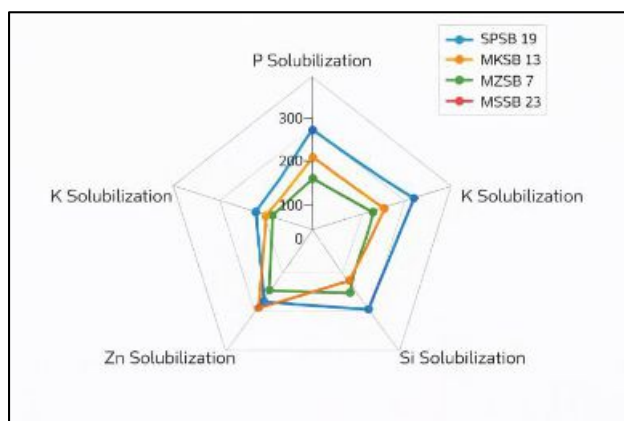


Fig 2: Radar chart depicting multi-nutrient solubilization efficiency (%) of selected bacterial isolates: SPSB 19 (phosphate), MKSB 13 (potassium), MZSB 7 (zinc), and MSSB 23 (silicate).

The selected isolates exhibited complementary functional traits, with SPSB 19, MKSB 13, MZSB 7 and MSSB 23 showing peak efficiency in solubilizing phosphorus, potassium, zinc and silicate, respectively. The radar plot clearly indicates that no single isolate possessed maximum

efficiency across all nutrient parameters, thereby justifying the need for a multi-strain microbial consortium.

The present findings are in agreement with earlier studies that reported the effectiveness of multi-strain bioinoculants over single-strain applications due to their synergistic interactions and broader functional capabilities (Fekadu, 2013; Hu *et al.*, 2006; Sunitha *et al.*, 2016) [5, 20, 21]. The complementary nature of the selected isolates supports their potential use in developing next-generation biofertilizer formulations for sustainable rice cultivation.

Conclusion

The present investigation demonstrated substantial variability among native bacterial isolates collected from paddy-growing soils of the Kalyana Karnataka region. A total of 33 phosphate solubilizing, 29 potassium solubilizing, 21 zinc solubilizing and 29 silicate solubilizing bacterial isolates were evaluated under *in vitro* conditions, revealing significant differences at one percent level of significance. Among the isolates, SPSB 3 (398.29%), MKSB 13 (456.10%), RZSB 7 (355.90%) and MSSB 23 (370.73%) exhibited superior solubilization efficiency for phosphorus, potassium, zinc and silicate, respectively.

The results clearly indicate the presence of efficient indigenous nutrient-solubilizing bacteria capable of enhancing nutrient availability in rice ecosystems. The identification of these high-performing strains provides a strong foundation for developing effective microbial consortia aimed at improving soil fertility and nutrient use efficiency. Adoption of such bio-inoculants may contribute to reducing chemical fertilizer dependency, lowering production costs and promoting environmentally sustainable rice cultivation in the region. Further studies on molecular characterization, compatibility testing and field validation are recommended before large-scale application.

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