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SS Mali

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

SV Kolase

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

SB Latake

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

DH Sarnobat

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

AR Joshi

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

Corresponding Author:

SS Mali

Department of plant pathology and microbiology, Post Graduate Institute, MPKV, Rahuri, Ahilyanagar, Maharashtra, India

Isolation and characterization of nitrogen-fixing, phosphate- and potash-solubilizing bacteria from rhizosphere and their inoculation effect on growth and yield of okra (*Abelmoschus esculentus* L.)

SS Mali¹, SV Kolase², SB Latake³, DH Sarnobat⁴, AR Joshi⁵

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ABSTRACT

A field and laboratory investigation was conducted during summer 2026 at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, to isolate and characterize nitrogen-fixing, phosphate-solubilizing and potash-solubilizing bacteria from the rhizosphere of okra and to evaluate their influence on crop growth and yield. Rhizospheric soil samples were subjected to serial dilution and spread plate techniques using Ashby's, Pikovskaya's and Aleksandrov's media. Six nitrogen-fixing, four phosphate-solubilizing and three potash-solubilizing isolates were obtained. Based on functional efficiency, ORN-3, ORP-2 and ORK-2 were selected and tentatively identified as *Azotobacter* spp., *Bacillus* spp. and *Pseudomonas* spp., respectively. The selected isolates were evaluated under field conditions in a randomized block design comprising seven treatments with three replications. Seed inoculation with the bacterial consortium at 25 ml kg⁻¹ seed along with 100% RDF recorded the highest germination (92.57%), plant height at harvest (114.87 cm), fruit length (15.11 cm), fruit girth (5.77 cm) and fruit yield (183.60 q ha⁻¹). The treatment receiving 75% RDF with the bacterial consortium was statistically at par with 100% RDF plus inoculation for several major parameters and produced 180.84 q ha⁻¹. The same treatment combination also recorded higher rhizospheric microbial populations and post-harvest available N, P and K. The findings demonstrate the potential of indigenous functional bacterial isolates as bioinoculants for improving nutrient availability, crop growth and productivity of okra.

Keywords: Azotobacter, Phosphate-solubilizing bacteria, Potassium-solubilizing bacteria, PGPR, Biofertilizer, Okra, Nutrient mobilization, Seed inoculation

Introduction

Okra (*Abelmoschus esculentus* L.) is an important vegetable crop cultivated for its tender green fruits and is valued for its nutritional and economic importance. Successful production of okra depends on adequate and balanced availability of essential plant nutrients. Conventional fertilizer use supplies nutrients rapidly, but crop response is also influenced by nutrient transformation, microbial activity and the availability of nutrient fractions in the soil. Plant growth-promoting rhizobacteria constitute a diverse group of microorganisms associated with plant roots. Among the agriculturally useful functional groups, free-living nitrogen-fixing bacteria can contribute biologically fixed nitrogen, phosphate-solubilizing bacteria can increase the availability of insoluble phosphate compounds, and potassium-solubilizing bacteria can mobilize potassium from mineral sources. Aasfar *et al.* (2021) [1] highlighted the potential of *Azotobacter* species for improving crop nutrition and yield stability, whereas Richardson (2001) [2] emphasized the role of soil microorganisms in improving phosphorus acquisition by plants.

The rhizosphere provides a nutrient-rich microenvironment influenced by root exudates and plant growth. Ocampo *et al.* (1975) [3] reported that establishment of *Azotobacter* in the rhizosphere is influenced by soil fertility, manuring practices and interactions with phosphate-solubilizing microorganisms. Similarly, Monib *et al.* (1979) described the association of *Azotobacter* with higher plants through utilization of root-derived substrates. Isolation of functional bacteria from crop rhizospheres is therefore useful for identifying native strains that can subsequently be evaluated under field conditions.

Phosphate solubilization is commonly screened on Pikovskaya's medium through the formation of clear or halo zones around growing colonies. Pikovskaya (1948) [4] established the classical basis for assessing microbial mobilization of insoluble phosphate, and subsequent studies have used solubilization index, halo-zone diameter and quantitative phosphorus release to compare isolates. Baliah *et al.* (2016) [5] reported phosphate-solubilizing bacteria from several crop rhizospheres, including okra, and identified members of *Bacillus* and *Pseudomonas*. More recently, Bashir *et al.* (2023) [6] characterized PGPR from okra rhizo

sphere and highlighted their potential as biofertilizer resources. [Rahim et al. \(2024\)](#) [7] further reported improved growth, yield and phosphorus uptake in okra following the use of phosphate-solubilizing bacteria with rock phosphate and organic manures.

Potassium is another major nutrient required for plant growth, enzyme activation, water relations and overall physiological functioning. [Saravanan et al. \(2011\)](#) [8] documented the ecological occurrence and agricultural role of potassium-solubilizing bacteria, while [Sindhu et al. \(2016\)](#) [9] and [Parmar et al. \(2016\)](#) [10] described the isolation and characterization of potassium-solubilizing bacteria from rhizospheric soils.

Integrated use of microbial inoculants with mineral fertilizers is particularly relevant because microbial nutrient mobilization and fertilizer-derived nutrient supply may complement each other. [Rana et al. \(2015\)](#) [11] reported synergistic effects of beneficial bacteria on nutrient availability and yield of okra. [Kumar et al. \(2015\)](#) [12] observed beneficial effects of integrated nutrient management involving The present study was designed with three objectives: (i) isolation of nitrogen-fixing, phosphate-solubilizing and potash-solubilizing bacteria from okra rhizosphere; (ii) characterization of efficient isolates using morphological, physiological and biochemical tests; and (iii) evaluation of the effect of selected isolates on growth, yield, rhizospheric microbial population and soil available N, P and K status of okra. The work combined laboratory screening with a field experiment to assess whether native isolates could function as useful microbial inputs in an integrated nutrient management programme.

2. Materials and methods

2.1 Experimental site and planting material

The investigation was conducted at the Department of Plant Pathology and Microbiology, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri, District Ahilyanagar, Maharashtra, during the summer season of 2026. Seeds of okra cv. Phule Vimukta were obtained from the Zonal Agriculture Research Station, Ganeshkhind, Pune. The field experiment was laid out in a randomized block design with seven treatments and three replications. The crop was sown on 10 January 2026 at 30 × 15 cm spacing and final harvesting was completed on 25 April 2026. The gross plot size was 4.00 × 3.00 m and the net plot size was 3.40 × 2.25 m.

2.2 Collection of rhizospheric soil and isolation

Rhizospheric soil samples were collected from healthy okra plants grown at the AICRP on Vegetable Crops, IFD-IWM Project, Organic Farming Project and PGI Farm of MPKV, Rahuri. Samples were collected in sterile polythene bags, labelled and transported to the laboratory. For serial dilution, 1 g of composite rhizospheric soil was suspended in 9 ml sterile water to obtain a 10^{-1} dilution, followed by serial dilution up to 10^{-6} . Aliquots of 0.1 ml from 10^{-4} , 10^{-5} and 10^{-6} dilutions were inoculated on selective media. Ashby's medium was used for nitrogen-fixing bacteria, Pikovskaya's medium for phosphate-solubilizing bacteria and Aleksandrov's agar medium for potash-solubilizing bacteria. Thiram was incorporated in the respective media as described in the thesis procedure to suppress fungal growth. Plates were incubated and distinct bacterial colonies were purified and maintained on the respective media.

2.3 Screening for functional efficiency

Nitrogen-fixing isolates were screened quantitatively using the Micro-Kjeldahl method and nitrogen fixation was expressed as mg N g⁻¹ sucrose utilized. Phosphate-solubilizing isolates were evaluated on

Pikovskaya's medium supplemented with tricalcium phosphate. Clearance zone and colony diameters were recorded, and phosphate-solubilizing efficiency (PSE) and phosphate-solubilization index (PSI) were calculated. Potash-solubilizing isolates were screened on Aleksandrov's medium supplemented with phenol red, and the solubilization ratio was calculated as the diameter of the zone of clearance divided by the colony diameter. The most efficient isolate from each functional group was selected for further characterization and field evaluation.

2.4 Morphological, physiological and biochemical characterization

Selected isolates were examined for colony size, pigmentation, margin, elevation, opacity, texture, motility, cell shape and Gram reaction after incubation. Physiological characterization included growth at different NaCl concentrations (1 to 5%) and at temperatures of 30, 40 and 50 °C. Biochemical tests included catalase, starch hydrolysis, methyl red, Voges–Proskauer, gelatin hydrolysis, amylase production, indole production, hydrogen sulphide production, nitrate reduction, citrate utilization and urease reactions. Genus-level identification was made by comparison of observed cultural, morphological, physiological and biochemical characteristics with descriptions in Bergey's Manual; molecular identification was not undertaken.

2.5 Field treatments and crop management

The recommended dose of fertilizer (RDF) was 100:50:50 kg N:P₂O₅:K₂O ha⁻¹. Farmyard manure was applied at 8 t ha⁻¹ before sowing. The selected efficient bacterial isolates were combined and applied as a composite culture through seed treatment at 25 ml kg⁻¹ seed. The seven treatments were: T1, 100% RDF + Azotobacter + PSB + KSB; T2, 75% RDF + Azotobacter + PSB + KSB; T3, 50% RDF + Azotobacter + PSB + KSB; T4, 25% RDF + Azotobacter + PSB + KSB; T5, 100% RDF alone; T6, 100% RDF + MPKV Bioconsortium; and T7, untreated control. Seeds under the MPKV Bioconsortium treatment received 10 ml kg⁻¹ seed. Treated seeds were shade-dried before sowing. Irrigation, hand weeding and recommended plant protection measures were carried out as required.

2.6 Observations and soil analysis

Five randomly selected plants from each treatment were used for recording observations. Germination percentage was calculated from the number of germinated seeds relative to the total number of seeds sown. Plant height was measured at flowering and harvesting stages. Days to 50% flowering, fruit length, fruit girth and fruit yield were recorded. Tender fruits harvested from the net plot were weighed and yield was expressed as q ha⁻¹. Rhizospheric soil samples were analyzed for final populations of Azotobacter, PSB and KSB by serial dilution and pour-plate procedures on Ashby's, Pikovskaya's and Aleksandrov's media, respectively. Available soil nitrogen was determined by the alkaline potassium permanganate method, phosphorus by Olsen's sodium bicarbonate extraction method and potassium by neutral normal ammonium acetate extraction followed by flame photometry.

2.7 Statistical analysis

The observations from the field experiment were subjected to analysis of variance appropriate for randomized block design following [Panse et al. \(1967\)](#) [13]. Treatment means were compared using critical difference (CD) at the 5% level of significance. Standard error of mean (S.E.m.) and CD values are presented with the respective observations.

Table 1. Distribution of functional bacterial isolates recovered from okra rhizosphere

Source of rhizospheric soil	Nitrogen-fixing isolates	Phosphate-solubilizing isolates	Potash-solubilizing isolates
AICRP on Vegetable Crops	2 (ORN-1, ORN-2)	1 (ORP-1)	—
IFD-IWM Farm	1 (ORN-3)	1 (ORP-2)	1 (ORK-1)

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Source of rhizospheric soil	Nitrogen-fixing isolates	Phosphate-solubilizing isolates	Potash-solubilizing isolates
Organic Farming Project	2 (ORN-4, ORN-5)	2 (ORP-3, ORP-4)	2 (ORK-2, ORK-3)
PGI Farm	1 (ORN-6)	—	—
Total	6	4	3

The table summarizes the isolates obtained from the four rhizospheric sampling locations used in the investigation.

3. Results and discussion

3.1 Isolation of functional bacterial groups

The rhizospheric soil of healthy okra plants yielded three functionally distinct groups of bacteria. Six nitrogen-fixing isolates were obtained on Ashby's medium and designated ORN-1 to ORN-6. Four phosphate-solubilizing isolates, ORP-1 to ORP-4, were recovered on Pikovskaya's medium based on clear halo formation. Three potash-solubilizing isolates, ORK-1 to ORK-3, were recovered on Aleksandrov's medium. The distribution of isolates among the four sampling locations indicates that the IFD-IWM and Organic Farming Project sites contributed isolates belonging to more than one functional group. Recovery of multiple functional groups from the same rhizospheric environment supports the usefulness of rhizosphere-based screening for obtaining native microbial resources.

3.2 Functional screening and selection of efficient isolates

Nitrogen fixation differed appreciably among the six isolates. ORN-3 recorded the highest activity at 12.44 mg N g⁻¹ sucrose utilized, followed by ORN-2 at 10.18 mg N g⁻¹, whereas ORN-5 recorded the lowest value of 6.28 mg N g⁻¹. The variation is consistent with differences in functional capacity among bacterial strains. Upadhyay *et al.* (2015) [14] reported nitrogen fixation values ranging from 6.04 to 18.88 mg N g⁻¹ sucrose among *Azotobacter* strains, placing the selected ORN-3 within the range reported for efficient isolates. Kaviyaran *et al.* (2020) likewise observed considerable variability in nitrogen-fixing ability among *Azotobacter* isolates.

3.3 Phosphate and potassium solubilization

The PSB isolates differed in halo-zone development and calculated solubilization efficiency. ORP-2 recorded a clear zone diameter of 15 mm, colony diameter of 3 mm, phosphate-solubilizing efficiency of 400% and phosphate-solubilization index of 5.00, making it the most efficient PSB isolate. ORP-1, ORP-3 and ORP-4 recorded PSE values of 225, 200 and 233%, respectively. The high PSI of ORP-2 indicates strong in vitro phosphate-mobilizing potential under the screening conditions. Baliah *et al.* (2016) [5] and Sajeesh *et al.* (2019) [15] similarly demonstrated that rhizospheric PSB can be selected us-

ing solubilization traits and subsequently evaluated for agricultural application.

3.4 Potash-solubilizing ability

Among the KSB isolates, ORK-2 produced the largest solubilization zone of 15 mm and the highest zone-to-colony ratio of 3.75. ORK-1 and ORK-3 recorded ratios of 2.40 and 3.33, respectively. The selection of ORK-2 was therefore based on its superior in vitro solubilization ratio. The result is consistent with the concept that rhizospheric microorganisms can differ substantially in their ability to mobilize mineral potassium. Studies cited in the thesis, including Sindhu *et al.* (2016) [9] and Parmar *et al.* (2016) [10], have similarly used cultural and solubilization characteristics to identify promising KSB.

3.5 Morphological and genus-level characterization

ORN-3 produced transparent white to creamy-white colonies with smooth entire margins, raised convex elevation, translucent appearance and mucoid consistency. The cells were circular, motile and Gram-negative. ORP-2 produced creamy-white colonies with wavy margins, flat elevation, opaque appearance and slime production; cells were rod-shaped and Gram-positive. ORK-2 produced whitish-creamy, smooth, convex and translucent mucoid colonies; cells were rod-shaped, motile and Gram-negative. On the basis of these traits, together with physiological and biochemical characteristics and comparison with Bergey's Manual, ORN-3, ORP-2 and ORK-2 were tentatively identified at genus level as *Azotobacter* spp., *Bacillus* spp. and *Pseudomonas* spp., respectively. Because the study did not use molecular identification, these assignments should be interpreted as genus-level phenotypic identifications rather than sequence-confirmed species identifications.

3.6 Physiological characteristics

The selected isolates showed their strongest growth at 30 °C and moderate growth at 40 °C, indicating mesophilic growth characteristics under the conditions tested. ORN-3 and ORK-2 showed full growth up to 3% NaCl, moderate growth at 4% and weak growth at 5%. ORP-2 showed full growth at 1% NaCl, moderate growth at 2%, poor growth at 3% and no growth at 4 and 5%. The differential salt tolerance indicates that the selected strains possess distinct physiological responses. The observed tolerance also provides useful preliminary information for subsequent formulation and field testing, although laboratory salt tolerance alone should not be taken as proof of field performance under saline soils.

Table 2. In vitro functional screening of bacterial isolates

Isolate	Functional group	Key screening result	Selection
ORN-1	Nitrogen fixer	9.04 mg N g ⁻¹ sucrose	—
ORN-2	Nitrogen fixer	10.18 mg N g ⁻¹ sucrose	—
ORN-3	Nitrogen fixer	12.44 mg N g ⁻¹ sucrose	Selected
ORN-4	Nitrogen fixer	7.12 mg N g ⁻¹ sucrose	—
ORN-5	Nitrogen fixer	6.28 mg N g ⁻¹ sucrose	—
ORN-6	Nitrogen fixer	8.54 mg N g ⁻¹ sucrose	—
ORP-1	PSB	PSE 225%; PSI 3.00	—
ORP-2	PSB	PSE 400%; PSI 5.00	Selected
ORP-3	PSB	PSE 200%; PSI 3.00	—
ORP-4	PSB	PSE 233%; PSI 3.33	—
ORK-1	KSB	Solubilization ratio 2.40	—
ORK-2	KSB	Solubilization ratio 3.75	Selected

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Isolate	Functional group	Key screening result	Selection
ORK-3	KSB	Solubilization ratio 3.33	—

3.7 Effect on germination and plant height

Field inoculation produced clear differences in crop establishment. Germination ranged from 74.73% in the untreated control to 92.57% in T1. T2 recorded 91.42% and was statistically at par with T1. T5, representing 100% RDF without the selected consortium, recorded 84.12%, while T6 with MPKV Bioconsortium recorded 86.92%. The results indicate that the selected consortium, when combined with adequate mineral nutrition, was associated with improved crop establishment. Chauhan *et al.* (2023) [16] reported enhanced germination and seedling vigour following biofertilizer application in okra, while Phua *et al.* (2013) [17] observed beneficial effects of seed treatment with PSB on okra establishment.

3.8 Plant height and flowering

At flowering, T1 recorded the highest plant height (62.42 cm), followed by T2 (61.51 cm), whereas T7 recorded the lowest value (42.07 cm). At harvest, T1 recorded 114.87 cm, closely followed by T2 at 113.53 cm; T7 recorded 84.27 cm. T5 recorded 102.43 cm and T6 recorded 109.83 cm. The higher vegetative growth in inoculated treatments may reflect improved nutrient acquisition and the combined contribution of nitrogen fixation and nutrient mobilization. The number of days to 50% flowering was lowest in T1 (45.52 days) and highest in T7 (55.76 days), with T2 at 46.48 days. Earlier flowering under inoculated treatments was also reported in studies of integrated nutrient management in okra, including Kumar *et al.* (2015) [12] and Ram *et al.* (2007) [18].

3.9 Fruit characteristics and yield

T1 recorded the highest fruit length (15.11 cm) and fruit girth (5.77 cm), followed by T2 with 14.42 cm and 5.58 cm, respectively. The untreated control recorded the lowest fruit length (9.43 cm) and girth (4.01 cm). Fruit yield followed a similar pattern. T1 produced 183.60 q ha⁻¹, while T2 produced 180.84 q ha⁻¹ and was statistically at par with T1. T6 produced 177.46 q ha⁻¹ and T5 produced 172.91 q ha⁻¹, whereas T7 produced only 114.72 q ha⁻¹. The yield response indicates that the selected bacterial consortium complemented mineral fertilizer supply. Rana *et al.* (2015) [11] reported enhanced nutrient uptake and fruit yield of okra following beneficial bacterial inoculation. Dutta *et al.* (2020) [19], Choudhary *et al.* (2025) [20] and Kujur *et al.* (2020) [21] also reported improvements in okra yield attributes under nutrient management programmes incorporating biofertilizers.

3.10 Rhizospheric microbial population

At harvest, T1 recorded the highest populations of Azotobacter (42.58 × 10⁶ CFU), PSB (31.59 × 10⁶ CFU) and KSB (28.42 × 10⁶ CFU). T2 followed with 40.97, 30.34 and 27.49 × 10⁶ CFU, respectively. The untreated control had the lowest populations at 20.95, 13.71 and 11.06 × 10⁶ CFU. The increase in the targeted microbial groups in inoculated plots is consistent with successful introduction and/or enhancement of the corresponding functional populations in the rhizosphere. Anisa *et al.* (2016) [22] reported increased beneficial microbial populations in okra rhizosphere under integrated nutrient management, supporting the present trend.

3.11 Available N, P and K in soil after harvest

Initial available N, P and K in the experimental soil were 145.34, 14.46 and 312.86 kg ha⁻¹, respectively. The highest post-harvest values were recorded in T1, with 173.84 kg N, 18.88 kg P and 364.38 kg K ha⁻¹. T2 was close to T1 with 172.87, 18.24 and 362.18 kg ha⁻¹, respectively. T6 recorded 168.73, 16.77 and 351.66 kg ha⁻¹, while T5 recorded 165.10, 14.78 and 344.62 kg ha⁻¹. The untreated control had 146.17 kg N, 10.22 kg P and 325.07 kg K ha⁻¹. The higher nutrient availability in inoculated treatments is consistent with the functional roles of the selected bacteria in nitrogen fixation and nutrient mobilization. Akhila *et al.* (2019) [23] and Sharma and Chadak (2022) similarly reported improved post-harvest soil nutrient status under integrated use of organic inputs and biofertilizers.

3.12 Integrated interpretation

Across the laboratory and field phases, the same three isolates selected for functional efficiency were associated with improved crop performance when applied together with mineral fertilizer. The laboratory screening identified distinct functional strengths, while field observations showed improvements in germination, vegetative growth, flowering, fruit characteristics, yield, targeted microbial populations and post-harvest nutrient status. T1 recorded the highest numerical values for most major traits. Importantly, T2, which used 75% RDF with the selected consortium, remained statistically at par with T1 for several key observations, including major growth and yield measures reported in the thesis. This indicates the practical interest of testing reduced fertilizer levels with microbial inoculation. However, the present conclusion is based on one summer season at one location and should therefore be validated under additional seasons, locations and soil conditions before broad agronomic recommendations are made.

Table 3. Effect of bacterial inoculation and fertilizer levels on growth, flowering, fruit traits and yield of okra

Tr.	Treatment	Germination (%)	Plant height at harvest (cm)	50% flowering (days)	Fruit length (cm)	Fruit girth (cm)	Yield (q ha ⁻¹)
T1	100% RDF + Azotobacter + PSB + KSB @ 25 ml kg ⁻¹ seed	92.57	114.87	45.52	15.11	5.77	183.60
T2	75% RDF + Azotobacter + PSB + KSB @ 25 ml kg ⁻¹ seed	91.42	113.53	46.48	14.42	5.58	180.84
T3	50% RDF + Azotobacter + PSB + KSB @ 25 ml kg ⁻¹ seed	80.72	96.80	52.08	11.23	4.30	162.67

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Tr.	Treatment	Germination (%)	Plant height at harvest (cm)	50% flowering (days)	Fruit length (cm)	Fruit girth (cm)	Yield (q ha ⁻¹)
T4	25% RDF + Azotobacter + PSB + KSB @ 25 ml kg ⁻¹ seed	79.31	92.37	54.11	10.63	4.12	152.43
T5	100% RDF alone	84.12	102.43	49.67	12.49	4.56	172.91
T6	100% RDF + MPKV Bioconsortium	86.92	109.83	48.08	13.63	5.00	177.46
T7	Untreated control	74.73	84.27	55.76	9.43	4.01	114.72
S.Em. ±	—	0.40	0.50	0.37	0.29	0.06	1.25
CD at 5%	—	1.25	1.56	1.14	0.90	0.19	3.86

Table 4. Rhizospheric population of targeted functional bacteria at harvest

Tr.	Azotobacter (CFU × 10 ⁶)	PSB (CFU × 10 ⁶)	KSB (CFU × 10 ⁶)
T1	42.58	31.59	28.42
T2	40.97	30.34	27.49
T3	36.26	24.67	20.70
T4	33.56	21.19	18.61
T5	29.26	17.98	15.95
T6	38.65	28.85	24.70
T7	20.95	13.71	11.06
S.Em. ±	0.63	0.42	0.32
CD at 5%	1.95	1.29	1.00

Table 5. Available N, P and K status of soil at harvest

Tr.	Available N (kg ha ⁻¹)	Available P (kg ha ⁻¹)	Available K (kg ha ⁻¹)
Initial soil	145.34	14.46	312.86
T1	173.84	18.88	364.38
T2	172.87	18.24	362.18
T3	162.57	13.78	338.11
T4	155.57	12.13	331.58
T5	165.10	14.78	344.62
T6	168.73	16.77	351.66
T7	146.17	10.22	325.07
S.Em. ±	0.40	0.28	0.81
CD at 5%	1.25	0.89	2.49

4. Conclusion

The study demonstrated that the rhizosphere of okra harbours functionally diverse bacteria capable of nitrogen fixation and phosphate and potassium solubilization. Six nitrogen-fixing, four phosphate-solubilizing and three potash-solubilizing isolates were obtained. ORN-3, ORP-2 and ORK-2 were selected as efficient isolates based on their respective in vitro activities and were tentatively identified as *Azotobacter* spp., *Bacillus* spp. and *Pseudomonas* spp. At field level, seed inoculation with the selected consortium in combination with RDF improved crop establishment, plant growth, flowering, fruit attributes and fruit yield compared with the untreated control. The 100% RDF + consortium treatment recorded the highest fruit yield of 183.60 q ha⁻¹, while 75% RDF + consortium produced 180.84 q ha⁻¹ and was statistically at par with T1 for several major observations. The inoculated treatments also maintained higher populations of the targeted microbial groups and greater available N, P and K after harvest. These findings support further development and testing of native multifunctional bacterial consortia for integrated nutrient management in okra. Since the experiment was conducted during a single

season at a single location, multi-season and multilocation experiments, together with molecular confirmation and formulation studies, are required before wider recommendation.

References

1. Aasfar A, Bargaz A, Yaakoubi K, Hilali A, Bennis I, Zeroual Y, Kadmiri IM. Nitrogen fixing *Azotobacter* species as potential soil biological enhancers for crop nutrition and yield stability. *Frontiers in Microbiology*. 2021;12:628379.
2. Richardson AE. Prospects for using soil microorganisms to improve the acquisition of phosphorus by plants. *Australian Journal of Plant Physiology*. 2001;28:897–906.
3. Ocampo JA, Barea JM, Azcón R. Interactions between *Azotobacter* and phosphobacteria and their establishment in the rhizosphere as affected by soil fertility. *Canadian Journal of Microbiology*. 1975;21:1160–1165.
4. Pikovskaya RI. Mobilization of phosphorus in soil in connection with the vital activity of some microbial species. *Microbiologiya*. 1948;17:362–370.

5. Baliah NT, Pandiarajan G, Makesh Kumar B. Isolation, identification and characterization of phosphate solubilizing bacteria from different crop rhizosphere soils of Srivilliputtur Taluk, Virudhunagar District, Tamil Nadu. *Tropical Ecology*. 2016;57:465–474.
6. Bashir T, Ahmad S, Hussain A, Iqbal M, Bhat MA, Mir AH, Sheikh TA. Isolation and characterization of plant growth promoting bacteria (PGPR) from rhizosphere of okra. *Journal of Population Therapeutics and Clinical Pharmacology*. 2023;30:1257–1268.
7. Rahim N, Hossain MA, Islam MS, Rahman MM, Uddin MN. Rock phosphate and manures with phosphorus-solubilizing bacteria increase growth, yield and phosphorus uptake of okra (*Abelmoschus esculentus*). *Journal of Applied Research in Plant Sciences*. 2024;5:111–118.
8. Saravanan VS, Madhaiyan M, Thangaraju M, Sa TM. Ecological occurrence of potassium-solubilizing bacteria and their role in agriculture. *Biology and Fertility of Soils*. 2011;47:369–377.
9. Sindhu S, *et al.* Isolation and characterization of potassium-solubilizing bacteria from rhizosphere soils. [Reference as cited in the source thesis]. 2016.
10. Parmar KB, Mehta BP, Kunt MD, Patil DK. Isolation, characterization and identification of potassium solubilizing bacteria from rhizosphere soil of maize. *International Journal of Scientific Environment and Technology*. 2016;5:3030–3037.
11. Rana A, Joshi M, Prasanna R, Shivay YS, Nain L. Beneficial cyanobacteria and eubacteria synergistically enhance bioavailability of soil nutrients and yield of okra (*Abelmoschus esculentus*). *European Journal of Soil Biology*. 2015;71:9–18.
12. Kumar A, Pandita VK. Effect of integrated nutrient management on seed yield and quality in okra (*Abelmoschus esculentus*). *Indian Journal of Agricultural Sciences*. 2015;85:1072–1075.
13. Panse VG, Sukhatme PV. *Statistical Methods for Agricultural Workers* (2nd ed.). Indian Council of Agricultural Research, New Delhi; 1967:97–198.
14. Upadhyay, *et al.* Isolation and characterization of Azotobacter strains and evaluation of nitrogen-fixing ability. *Journal of Applied and Natural Science*. 2015;7:984–990.
15. Sajeesh P, Bini K, Sreelakshmi R, Rajeev P. Evaluation of potential native phosphate-solubilizing bacteria for agricultural practice of okra (*Abelmoschus esculentus*). *International Journal of Engineering and Technology*. 2019;7:40–45.
16. Chauhan K, Kumar A, Singh R, Patel P, Verma S. Effect of biofertilizers PGPB on germination and seedling growth of okra crop. *International Journal of All Research Education and Scientific Methods*. 2023;11.
17. Phua CKH, Halimah M, Zainon H, Sarmani S. Development of seed treatment biofertilizer and nutrient uptake study using tracer technique for okra plants. *Jurnal Sains Nuklear Malaysia*. 2013;25:17–24.
18. Ram RB, Singh JP, Singh BK, Singh R. Effect of bio and chemical fertilizers on growth, flowering, fruiting and yield of okra (*Abelmoschus esculentus* L. Moench). *Progressive Horticulture*. 2007;39:165–170.
19. Dutta S, Teron R, Terangpi R, Engti K. Effect of organic source of nutrients in growth and yield parameters of okra (*Abelmoschus esculentus* L.) in Karbi Anglong district of Assam. *International Journal of Chemical Studies*. 2020;8:1910–1913.
20. Choudhary CS, Yadav RK, Meena P, Kumar R, Sharma D. Response of biofertilizers and organic manure on yield attributes, yield and quality of okra (*Abelmoschus esculentus* L. Moench). *International Journal of Advanced Biochemistry Research*. 2025;9(S):307–311.
21. Kujur E, Toppo S, Lakra R, Minz R. Effect of Azotobacter and phosphorus-solubilizing bacteria on growth and yield of okra. *Indian Journal of Horticulture*. 2020;77:503–508.
22. Anisa NA, Markose BL, Surendra Gopal K. Effect of integrated nutrient management on population of biofertilizers in rhizosphere of okra (*Abelmoschus esculentus* L. Moench). *International Journal of Innovative Research in Science, Engineering and Technology*. 2016;5:5628–5633.
23. Akhila N, Anitha Kumari D, Hanuman Nayak M, Vijaya D. Impact of organic manures and biofertilizers on available NPK in soil and nutrient composition of okra fruit. *International Journal of Current Microbiology and Applied Sciences*. 2019;8:622–631.
24. Aamir M, Rai A, Kashyap SP, Singh SK, Singh UB. Plant microbiome: Diversity, distribution and functional relevance in crop improvement and sustainable agriculture. In *Microbiome Stimulants for Crops: Mechanisms and Applications*. 2021:417–436.
25. Barge MS, Narute TK, Navale AM, Murumkar DR, Durgude AG, Gaikwad PH, Satyam, Shewale SA. Isolation and characterization of Azotobacter from xerophytic plant rhizosphere soils of Maharashtra State, India. *International Journal of Current Microbiology and Applied Sciences*. 2023;12:194–204.
26. Limbachiya TB, Patel BN, Patel PB, Patel MM, Patel AI. Economic performance of different micronutrients and biofertilizers on okra (*Abelmoschus esculentus* L. Moench) cv. GAO-5. *Journal of Pharmacognosy and Phytochemistry*. 2017;6:24–27.
27. Misbahud Din N, Hassan MN, Ahmad W, Hussain A, Ahmad N. Production of nitrogen-fixing Azotobacter SR-4 and phosphorus-solubilizing *Aspergillus niger* and their evaluation on *Lagenaria siceraria* and *Abelmoschus esculentus*. *Biotechnology Reports*. 2019;22:e00323.
28. Shete BT, *et al.* The thesis-reported study on microbial consortium and reduced fertilizer use in green gram. [Reference as cited in the source thesis]. 2019.

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