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PROSPECTIVE SOIL MICROBES COLONIZING THE RHIZOSPHERE MICROBIOME OF TEZPUR LITCHI

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ABSTRACT

Tezpur litchi (*Litchi chinensis* Sonn.), known for its unique flavour, is grown in different parts of Assam, but the same quality and taste is not assured in all places. This may be attributed to various biotic and abiotic factors, including the abundance of below ground microbial diversity. In the present research, native plant growth promoting rhizobacteria (PGPR) and bacterial endophytes from rhizosphere microbiome of Tezpur litchi grown in five different locations of Assam were characterized and screened for their plant growth promoting (PGP) traits. From the five locations, a total of seventy-four putative bacterial isolates comprising of sixteen aerobic nitrogen fixing bacteria (ANF), nineteen microaerophilic nitrogen fixing bacteria (MNF), nutrient solubilizers like six phosphate solubilizing bacteria (PSB) and five potassium solubilizing bacteria (KSB); and twenty-eight endophytic bacteria were isolated in their specific medium. All the isolates exhibited PGP traits such as nitrogen fixation, indole acetic acid (IAA) and gibberellic acid (GA) production. Nine isolates showed positive results for siderophore production, however, hydrocyanic acid production was exhibited by 6.75% of the isolates. Among the isolates, 60.81% exhibited halo zone in modified Pikovskaya's media indicating zinc solubilization, while 56.75% of the isolates could solubilize tricalcium phosphate in Pikovskaya's media indicating phosphorus solubilization. The intrinsic antibiotic resistance (IAR) profile of the isolates showed varied resistance to common antibiotics. Twelve PGPR isolates were selected for various biochemical tests based on their potentiality, and the multifarious results exhibited by the PGPR isolates indicated their presence and adaptability in wide ecosystem. Among the selected isolates, five isolates from Tezpur were screened, with enhanced PGP traits, thus indicating that these isolates may play pivotal role in modulating the rhizosphere environment of Tezpur litchi. The soil chemical analysis across all the locations revealed low to medium range of available N (112.90 to 288.51 kg ha⁻¹) and available P₂O₅ (15.26 to 38.47 kg ha⁻¹), while available K₂O was found to be in medium range (136.42 to 233.86 kg ha⁻¹). An acidic range of pH (4.5 to 5.7) was recorded in all the locations, with medium to high organic carbon content (0.62% to 1.17%). Soil biological properties like microbial biomass carbon and soil enzymes (fluorescein di-acetate and phosphomonoesterase) were also estimated in all the areas which indicated high microbial activity across all sites.

Key words : Plant growth promoting rhizobacteria, Soil enzymes, Tezpur litchi.

Introduction

Tezpur litchi is a special type of litchi grown in 'Litchupukhuri' and 'Porowa' village of Sonitpur district, Assam which is known for its excellent quality, pleasant flavour, juice content, tight pulp and attractive red colour (Gogoi *et al.*, 2020). The common varieties grown in these litchi growing areas of Tezpur include Bombaya, Bilati,

Shahi, Elaichi, Piyaji and Haldia (Datta *et al.*, 2020). The Tezpur litchi has received geographical indication (GI) tag in 2013 through North Eastern Regional Agricultural Marketing Corporation Ltd. (NERAMAC) (Sharma, 2025). In Tezpur litchi, the same fruit quality cannot be retrieved even when grown under similar set of conditions in different locations of Assam or similar soil-edaphic

and climatic conditions. This may be attributed to various biotic and abiotic factors, including the below ground microbial diversity (Gogoi *et al.*, 2020). The wide array of microbial diversity in the rhizosphere microbiome of Tezpur litchi, more specifically the plant growth promoting rhizobacteria (PGPR) play significant role in modulating the host environment and also confer requisite taste and quality to the fruit.

Additionally, the recruitment of PGPR in the litchi rhizosphere is affected by several factors such as soil properties, plant genotype, plant nutritional status, climatic conditions *etc.* (Pii *et al.*, 2016), therefore study of the litchi growing soils is also of utmost importance. The hovering of PGPR near plant roots provides the plant with targeted benefits such as acquisition of nutrients like nitrogen, solubilization of phosphorus, potassium, zinc, secretion of phytohormones such as indole acetic acid (IAA), production of siderophore, ammonia (NH₃), hydrocyanic acid (HCN) and other secondary metabolites which act as antagonistic against pathogenic microbes (Compant *et al.*, 2019 and Gayan *et al.*, 2023).

Available literature suggests that the diversity of beneficial microbes in the Tezpur litchi microbiome is still not well known and may be habitat specific. Recently, India has exported its first consignment of Tezpur litchi from Assam to Dubai, marking a milestone in efforts to expand overseas markets for agricultural products from the Northeast, according to the commerce ministry, GoI. The one metric tonne consignment, exported on June 7, 2026 was facilitated by the Agricultural and Processed Food Products Export Development Authority (APEDA) (Times of India, 2026). In view of vast ecological significance in terms of capacity of PGPR from the rhizosphere microbiome, the present research aims to study the PGPR and bacterial endophytes from rhizosphere microbiome of Tezpur litchi growing areas of Assam, with the objective of isolation of PGPR and bacterial endophytes from rhizosphere microbiome of Tezpur litchi grown in different areas of Assam and elucidation of mechanisms involved in plant growth promotion by the selected isolates.

Materials and Methods

Study area

Twenty-nine georeferenced rhizospheric soil samples were collected at 0-20cm depth along with their root samples from five different Tezpur litchi growing areas of Assam, viz., Tezpur litchi orchard, Porowa, Napaam, Tezpur; Aujari progeny orchard and seed farm (APOSF), Morigaon; Farmer's training centre (FTC), department of Horticulture and food processing, Byrnihat; Rangolu

nursery, Nagaon and Tingrai, Dibrugarh and Krishi Vigyan Kendra (KVK), Dibrugarh. As the taste and fruit quality of litchi is exclusive in Tezpur litchi orchard, Napaam maximum samples (ten) were collected from that particular orchard.

Isolation of plant growth promoting rhizobacteria from rhizosphere microbiome of Tezpur litchi

The PGPR were isolated in their specific media *i.e.*, the aerobic nitrogen fixers were isolated in Burk's media (Wilson and Knight, 1952), microaerophilic nitrogen fixers in N-free bromothymol blue (NFB) media (Dobereiner, 1980), phosphate solubilizing bacteria (PSB) in Pikovskaya's media (Pikovskaya, 1948) and potassium solubilizing bacteria (KSB) in Aleksandrov's agar media.

The bacterial endophytes were isolated in Tryptic Soy Agar (TSA) (Leavitt *et al.*, 1955). Prior to serial dilution, surface sterilization procedure was carried out as described by Schluz *et al.* (1993). The morphological characterization of the isolates was carried out using the Bergey's Manual of Systematic Bacteriology.

Mechanism of action of plant growth promoting rhizobacteria in Tezpur litchi microbiome

Phytohormone production by the isolates

Indole acetic acid production

For estimation of IAA colorimetric assay was performed using Salkowski method (Tang and Bonner, 1948). Specific broth was inoculated with the isolates and incubated at 28±2°C for 5 days at 150 rpm in environmental shaker (Seigenics Biotech ORBITEK), followed by centrifugation of the broth culture at 7000 rpm for 3 min. Salkowski reagent (1 mL 0.5 M FeCl₃ in 50 mL of 35% HClO₄) and culture supernatant were mixed in 1:1 ratio. After incubation for half an hour in dark, absorbance at 530 nm was measured and IAA production in cultures was estimated according to the standard curve (Gordon and Weber, 1951).

Gibberellic acid production

The quantitative gibberellic acid (GA) estimation was carried out following the protocol by Holbrook *et al.* (1961) with slight modifications. To 15 mL of the bacterial broth supernatant, 2 mL of zinc acetate reagent (21.9 g of zinc acetate with 1 mL of glacial acetic acid and volume made up to 100 mL with distilled water) was added. Again, after about 2 minutes, 2 mL of potassium ferrocyanide (10.6% of potassium ferrocyanide in distilled water) was added. The samples were then centrifuged at low speed (2000 rpm) for 15 minutes. Thereafter, 5 mL supernatant was drawn and 5 mL of 30% HCl was added. The mixture was then incubated at 20°C for 75 minutes. The solution

was filtered and absorbance was read at 254 nm. The quantities of GA produced was calculated using the calibration curve obtained with standards containing 0, 100, 200, 300, 400, 500 and 600 mgL⁻¹ of GA.

Total nitrogen content of the isolates

The total nitrogen (TN) content of the bacterial isolates was tested by Micro Kjeldahl method (Jackson, 1973) in N free media. A loopful of the bacterial inoculum (of each isolate separately) was inoculated into an Erlenmeyer flask containing 25 mL of sterilized N free medium. Uninoculated medium served as control. All the culture flasks (3 replicates for each isolate) including the controls were incubated at 30±2°C. Triplicate samples were analyzed for total nitrogen by Kjeldahl method after 10 days of incubation. The amount of total nitrogen content in the isolates by was expressed as mg N g⁻¹ of sucrose used after deducting the amount of nitrogen in control samples.

Nutrient solubilization by the isolates

Phosphate solubilization

Solubilization of soluble mineral phosphates was observed by growing the PGPR isolates on Pikovskaya's agar medium followed by incubation at 30°C. Clear zones around the colony indicated positive solubilization of mineral phosphate.

Zinc solubilization

Zinc (Zn) solubilization of the PGPR isolates was detected by inoculating log phase strains of bacteria on modified Pikovskaya's media plates having 0.1% insoluble ZnO as a source of insoluble inorganic Zn. The inoculated plates were incubated at 28±1°C for 3 days and observed for the clear zone around the colonies due to solubilization of Zn by bacteria (Fasim *et al.*, 2002).

Siderophore production by the isolates

The production of siderophore was assayed by Chrome azurol S (CAS) plate assay method (Schwyn and Neilands, 1987) with several modifications. The assay was performed by using CAS agar medium containing the complex CAS/ Fe³⁺/ hexa-decyl-trimethyl-ammonium bromide as an indicator. For the production of siderophore, PGPR isolates were grown on succinic medium as described by Meyer and Abdallah (1978). The inoculum was placed at the centre of the solid medium. The plates were then incubated in the dark at 30°C for 24-48 hours. The change of colour from blue to yellow/ orange or dark purplish red surrounding the colonies was regarded as positive for siderophore production.

Hydrocyanic acid production by the isolates

HCN production by the isolates were assessed in

specific media with modifications. Glycine at 0.44% was added in the agar media. 20µL of inoculum were transferred in four spots over the modified agar plates and incubated for 48h. Whatman no.1 filter paper disc, soaked in 2% Na₂CO₃ (in 0.5% picric acid) solution was placed on top of each spotted bacterial growth, following which the petri plates were sealed and incubated for 4 days at 30°C. The development of orange to red colour indicated HCN production (Ahmad *et al.*, 2008).

Biochemical characterization of the plant growth promoting rhizobacteria retrieved from Tezpur litchi microbiome

Based on the morphological characterization, the PGPR isolates were assessed for the various biochemical tests such as oxidase test, catalase test, casein hydrolysis, starch hydrolysis and nitrate reduction test. The carbon sources utilization was carried out using rapid biochemical test kit KB002 (HiMedia, Mumbai). The kit contained glucose, adonitol, lactose, arabinose and sorbitol as the carbon sources.

Antibiotic resistance profile of the isolates

Antibiotic resistance profile of the putative PGPR isolates was tested (Doern, 1995) against ampicillin (10 µgdisc⁻¹), chloramphenicol (30 µgdisc⁻¹), penicillin (10 µgdisc⁻¹), streptomycin (10 µgdisc⁻¹), rifampicin (5µgdisc⁻¹), gentamycin (10 µgdisc⁻¹) and tetracycline (10 µgdisc⁻¹).

Soil chemical properties of the Tezpur litchi rhizosphere

The soil samples were analyzed for pH, organic carbon (OC), available N, P₂O₅ and K₂O. Rapid titration procedure of Walkley and Black (1934) was followed for the determination of OC content of the soil. The available N of the soil samples were determined by alkaline potassium permanganate method as described by Subbiah and Asija (1956). The available P₂O₅ of the soil samples were estimated using Bray's-I method meant for acidic soils (Bray and Kurtz, 1945; Jackson, 1973). Available K₂O content of the soil samples were determined using neutral normal ammonium acetate method (Jackson, 1973) and was measured with the help of flame photometer.

Soil biological parameters of the Tezpur litchi rhizosphere

Estimation of key soil enzymes, fluorescein diacetate (FDA) hydrolysis activity was carried out following the method described by Adam and Duncan (2001), while phosphomonoesterase (PMEase) activity was estimated following the method of Tabatabai and Bremner (1969).

Microbial biomass carbon (MBC) was determined by chloroform fumigation- extraction technique following the method of Vance *et al.* (1987).

Results and Discussion

Isolation of plant growth promoting rhizobacteria from rhizosphere microbiome of Tezpur litchi

A total of seventy-four putative PGPR isolates were retrieved in specific media from the rhizosphere microbiome of Tezpur litchi and maximum number of isolates (thirty-two) were retrieved from Tezpur litchi orchard, Porowa. Out of the seventy-four isolates, sixteen were identified as aerobic nitrogen fixers (ANF), nineteen as microaerophilic nitrogen fixers (MNF), six as PSB, five as KSB and twenty-eight as endophytic bacteria (ENDO). All the isolates were morphologically characterized on the basis of shape, elevation, margin *etc.* on their specific media. In line with this research work, Kumari and Khare (2020) screened rhizobacteria with phosphate solubilizing potential from litchi orchards of East and West Champaran district of Bihar. Earlier, Priya *et al.* (2018) isolated actinomycetes from litchi orchards of Muzaffarpur, Bihar and studied various plant growth promoting traits.

Mechanism of action of plant growth promoting rhizobacteria in Tezpur litchi microbiome

Phytohormone production by the isolates

Indole acetic acid production

PGPR are well known for their ability to produce auxins which result in pronounced effects on plant growth. The amount of IAA produced by the isolates in absence of tryptophan ranged from 3.36 to 42.36 $\mu\text{g mL}^{-1}$ culture filtrate. In the isolates from Tezpur litchi orchard, Napaam IAA production ranged between 3.45 to 41.4 $\mu\text{g mL}^{-1}$ culture filtrate. In KSB isolates, Raji and Thangavelu (2021) recorded IAA production in the range between 0.78 $\mu\text{g mL}^{-1}$ (*Burkholderia cenocepacia*) to 13.45 $\mu\text{g mL}^{-1}$ (*Bacillus licheniformis*) in the absence of tryptophan.

Gibberellic acid production

GA production was found to range between 4.57 to 32.14 $\mu\text{g mL}^{-1}$ culture filtrate. In the isolates retrieved from Tezpur litchi orchard, Napaam, GA production ranged between 4.57 to 32.14 $\mu\text{g mL}^{-1}$ culture filtrate. Borah *et al.* (2018) observed the GA production in twenty-four endophytic bacteria to range between 7.94 to 67.23 $\mu\text{g mL}^{-1}$.

Total nitrogen content of the isolates

All the isolates showed presence of nitrogen in N

free culture media, ranging between 4.90 to 12.61 mg g^{-1} sucrose consumed. Among the isolates of Tezpur litchi orchard, Napaam the TN content, was observed to range between 4.90 to 12.04 mg g^{-1} sucrose consumed. Bag *et al.* (2017), observed the TN content of the *Azotobacter* isolates to range between 3.16 to 12.66 mg g^{-1} sucrose consumed. Tanvir *et al.* (2017) reported that *Azospirillum* isolates exhibited higher N fixing abilities than *Azotobacter*.

Nutrient solubilization by the isolates

Phosphate solubilization

Nutrient solubilization is one of the important direct mechanisms performed by many PGPR. Seventeen out of the thirty-two isolates (53.12%) retrieved from Tezpur litchi orchard, Napaam, could solubilize insoluble phosphorus. A total of thirty bacterial isolates were screened for phosphate solubilization, out of which twelve isolates showed the development of sharp phosphate solubilization zones, ranging from 4 to 22 mm (Sundaram and Murali, 2018). In another study by Nath *et al.* (2010) the frequency of well recognized PSB colonies that produced clear zones in Pikovskaya's solid media ranged from 3.0 to 10.33×10^6 cfu g^{-1} in rhizosphere of four different crops across the selected sites of Assam.

Zinc solubilization

The results exhibited that 59.37% of the isolates from Tezpur litchi orchard, Napaam, were able to solubilize Zn. Verma and Pal (2019), observed the Zn solubilizing ability of the rhizobacterial isolates by spot inoculation on Tris-minimal medium plates.

Siderophore production by the isolates

A total of nine isolates showed positive results for siderophore production as indicated by formation of a yellow halo around the colonies, while the rest isolates showed negative results. Siderophore production was exhibited by 9.37% of the PGPR isolates from Tezpur litchi orchard, Napaam. Pereira *et al.* (2012), observed fourteen out of the ninety-two endophytic bacterial isolates to produce siderophore in CAS agar media.

Hydrocyanic acid production by the isolates

PGPR are known to produce certain metabolites such as HCN, which inhibit phytopathogens in soil. Results indicated that only five isolates out of seventy-four isolates tested positive for HCN. However, 6.25% of the isolates from Tezpur litchi orchard, Napaam, exhibited HCN production. Afzal *et al.* (2017), observed thirteen out of the fifteen endophytic bacterial isolates to produce HCN.

Table 1 : Carbon sources utilization, oxidase activity, catalase activity, casein hydrolysis, starch hydrolysis and nitrate reduction by the selected isolates.

S. no.	Isolate Code	Carbon Sources					Oxidase Activity	Catalase Activity	Casein Hydrolysis	Starch Hydrolysis	Nitrate Reduction
		Glucose	Adonitol	Lactose	Arabinose	Sorbitol					
1.	T/ANF-7	+	+	-	+	+	+	+	-	-	+
2.	T/ANF-8	+	-	+	-	+	+	+	-	+	+
3.	D/ANF-2	+	+	+	+	+	-	-	-	-	+
4.	T/MNF-4	+	-	+	+	+	+	+	-	+	+
5.	M/MNF-1	+	+	+	+	-	+	+	-	+	+
6.	B/MNF-1	+	+	+	+	+	+	+	-	+	-
7.	N/MNF-1	+	+	+	+	+	+	+	-	+	+
8.	T/NSP-1	+	+	-	+	+	+	+	+	-	+
9.	M/NSK-1	+	+	+	+	+	-	+	-	-	+
10.	T/ENDO-10	+	-	-	+	+	-	-	-	+	-
11.	M/ENDO-3	+	-	-	-	-	-	-	-	+	+
12.	B/ENDO-2	+	-	+	-	+	-	-	+	+	+

‘+’ indicates presence, ‘-’ indicates absence.

Biochemical characterization of the plant growth promoting rhizobacteria retrieved from Tezpur litchi microbiome

A total of twelve PGPR isolates were selected for further biochemical characterization. Three ANF (T/ANF-7, T/ANF-8 and D/ANF-2) and four MNF (B/MNF-1, M/MNF-1, T/MNF-4 and N/MNF-1) were selected on the basis of total nitrogen content. One PSB (T/NSP-1) and one KSB (M/NSK-1) were selected on the basis of Khandeparkar's ratio. Three endophytic bacteria (T/ENDO-10, B/ENDO-2 and M/ENDO-3) which showed resistance to two and more than two antibiotics were selected. Among the selected isolates, five isolates (T/ANF-7, T/ANF-8, T/MNF-4, T/NSP-1 and T/ENDO-10) from Tezpur litchi orchard, Napaam were screened. The results of the biochemical tests are indicated in Table 1. The *Azotobacter* isolates retrieved from different crop rhizospheres of Assam showed decarboxylase activity and could ferment citrate as sole carbon source, and therefore were highly prolific in the rhizosphere (Gayan *et al.*, 2020).

Antibiotic resistance profile of the isolates

The selected isolates exhibited varied responses to the intrinsic antibiotic resistance (IAR) profile of the tested antibiotics (ampicillin, chloramphenicol, penicillin, streptomycin, rifampicin, gentamycin and tetracycline). Several PGPR have the intrinsic ability to tolerate or inhibit antibiotics, which is important for the suppression of pathogens in soils (Raaijmakers and Mazzola, 2012).

Gayan *et al.* (2020) assessed the prospective *Azotobacter* from different crop rhizospheres of Assam. It was observed that the isolates exhibited characteristic IAR, against streptomycin, chloramphenicol, ampicillin, kanamycin and rifampicin in between 50-650 µg mL⁻¹.

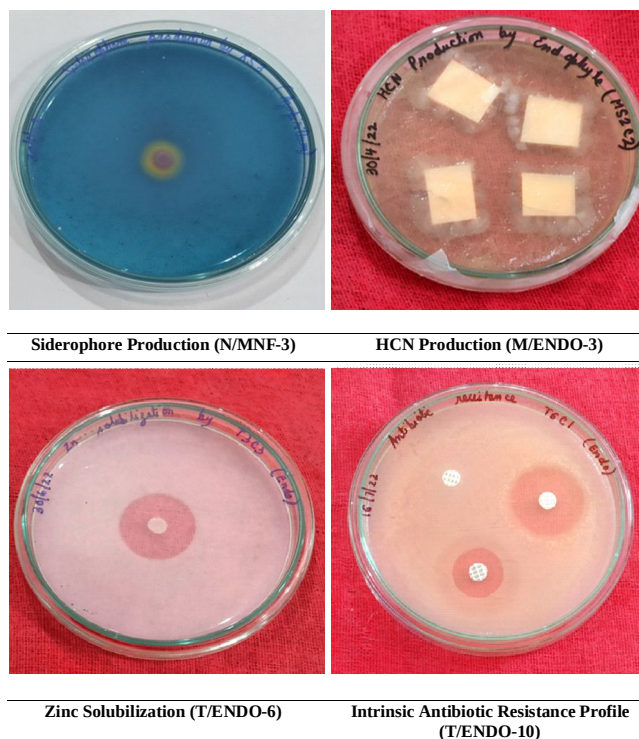
Soil chemical properties of the Tezpur litchi rhizosphere

The pH of the soil samples was recorded to be in the acidic range (4.5 to 5.7) and OC ranged between medium to high (0.62% to 1.17%). The available N (112.90 to 288.51 kg ha⁻¹) and available P₂O₅ (15.26 to 38.47 kg ha⁻¹) of the study areas were found to range between low to medium, while available K₂O was found to be medium (136.42 to 233.86 kg ha⁻¹). An acidic pH range (5.1 to 5.7), medium to high OC (0.74% to 0.98%), low to medium available N (112.90 to 238.34 kg ha⁻¹), P₂O₅ (15.26 to 25.65 kg ha⁻¹) and medium K₂O (136.42 to 193.54 kg ha⁻¹) was observed in Tezpur litchi orchard, Porowa. After analysis of the soil chemical parameters, it was concluded that litchi soils prefer an acidic pH, medium to high OC and low to medium available nutrients. Similar trend of soil chemical parameters was recorded in important litchi growing areas of India and other parts of the world. The available N, P and K in soils ranged between 134.8 to 376.3 kg ha⁻¹, 10.9 to 123.6 kg ha⁻¹ and 34.7 to 285.6 kg ha⁻¹, respectively, in litchi orchards of Dehradun, India (Savita *et al.*, 2015). Soil pH was recorded in acidic range (4.98 to 5.67), mineral nutrients like available N (285.35 to 334.53 kg ha⁻¹), available P (34.03 to 52.58 kg ha⁻¹)

Table 2 : Chemical and biological properties of rhizospheric soil samples of Tezpur litchi growing areas of Assam.

Location	pH	Organic carbon (%)	Available N (kg ha ⁻¹)	Available P ₂ O ₅ (kg ha ⁻¹)	Available K ₂ O (kg ha ⁻¹)	FDA (µg g ⁻¹ hr ⁻¹)	PMEase (µg g ⁻¹ hr ⁻¹)	MBC (µg g ⁻¹)
Tezpur litchi orchard	Range	5.1-5.7	112.90-238.34	15.26-25.65	136.42-193.54	7.3-11.1	31.59-63.69	87.47-224.27
	Mean	5.3 ^a (±0.20)	175.11 ^{bc} (±36.19)	18.21 ^c (±3.67)	169.48 ^b (±15.86)	9.15 ^a (±1.22)	58.94 ^a (±9.79)	149.70 ^a (±45.48)
APOSE, Morigaon	Range	4.8-5.6	175.62-213.25	30.78-35.91	175.39-213.70	9.87-11.67	47.69-50.84	165.71-388.20
	Mean	5.3 ^a (±0.32)	198.20 ^a (±16.35)	32.83 ^c (±2.14)	188.70 ^b (±16.33)	10.64 ^a (±0.83)	48.79 ^b (±1.33)	258.19 ^a (±88.68)
FTC, Byrnihat	Range	4.5-4.9	137.98-163.07	20.52-25.65	151.87-194.21	9.73-10.85	39.84-41.18	119.72-203.67
	Mean	4.6 ^a (±0.18)	147.40 ^a (±12.01)	23.08 ^b (±2.09)	172.03 ^b (±20.60)	10.25 ^a (±0.51)	40.50 ^a (±0.70)	168.53 ^b (±38.16)
Rangolu Nursery, Nagaon	Range	5.0-5.2	200.70-250.88	35.91-38.47	189.50-233.86	9.20-9.98	17.75-20.48	109.98-131.39
	Mean	5.1 ^{ab} (±0.10)	225.79 ^b (±25.09)	36.76 ^b (±1.48)	216.16 ^a (±23.49)	9.70 ^a (±0.43)	18.70 ^a (±0.39)	121.57 ^b (±10.81)
Tingrai and KVK, Dibrugarh	Range	4.5-5.1	200.70-288.51	25.65-38.47	159.26-187.49	6.66-11.80	15.62-18.52	95.92-277.42
	Mean	4.8 ^{bc} (±0.24)	238.33 ^b (±37.63)	32.61 ^a (±4.60)	169.63 ^b (±11.20)	9.93 ^a (±1.79)	17.36 ^a (±0.98)	174.15 ^{ab} (±65.29)

DMRT: Within columns, values with different letters differ significantly (P<0.05, DMRT) In parenthesis: Standard deviation.

**Plate 1 :** Plant growth promoting attributes of isolates retrieved from Tezpur litchi rhizosphere microbiome.

and available K (131.71 to 163.33 kg ha⁻¹) were observed to be in medium range, while OC ranged between 0.72% to 1.18% in the study sites of Jorhat district, Assam (Gayan *et al.*, 2023).

Soil biological parameters of the Tezpur litchi rhizosphere

Key soil enzymes, FDA activity ranged between 6.66 to 11.80 µg fluorescein g⁻¹ hr⁻¹, while PMEase activity ranged between 15.62 to 63.69 µg p-nitro phenol g⁻¹ hr⁻¹. MBC of the soil samples in Tezpur litchi growing areas ranged from 87.47 to 388.20 µg g⁻¹. In Tezpur litchi orchard, Porowa FDA activity, PMEase activity and MBC were recorded as 7.3 to 11.11 µg fluorescein g⁻¹ hr⁻¹, 31.59 to 63.69 µg p- nitro phenol g⁻¹ hr⁻¹ and 87.47 to 224.27 µg g⁻¹, respectively. The results are depicted in table 2. Generally, soil enzymatic activities are affected by agricultural management practices and temporal changes (Chen *et al.*, 2021 and Gayan *et al.*, 2020). Adak and Pandey (2021) observed wide variability in soil biological analysis across the mango orchards of Lucknow, Uttar Pradesh, with highest FDA activity recorded to be 584.73 µg fluorescein g⁻¹ hr⁻¹ and dehydrogenase (DHA) recorded to be 0.805 µg TPF g⁻¹ hr⁻¹.

Conclusion

A wide array of ANF, MNF, NS and ENDO were isolated from rhizosphere microbiome of Tezpur litchi growing soils of Assam. The selection of maximum

isolates (five) from the Tezpur litchi orchard, Porowa, Napaam and their enhanced PGP traits in terms of nitrogen fixing ability (T/ANF-7: 10.16 mg g⁻¹ sucrose, T/ANF-8: 9.77 mg g⁻¹ sucrose, T/MNF-4: 11.77 mg g⁻¹ sucrose), phosphate solubilization (T/NSP-1: 2.85 Khandeparkar's ratio) and antibiotic resistance (T/ENDO-10: resistant to penicillin, streptomycin, rifampicin and ampicillin) indicated the ecological occurrence of promising PGPR in Tezpur litchi orchard soils. Though, Tezpur litchi is cultivated in various regions of Assam, but the quality and flavour may not be consistent everywhere, which can be ascribed to multiple biotic and abiotic elements, such as the presence of diverse microbial life beneath the soil surface. However, the screened isolates need to be tested for crop performance and their diversity in different locations needs to be evaluated.

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