

PHARMACEUTICAL AND NUTRACEUTICAL POTENTIAL OF BACTERIAL ENDOPHYTES ISOLATED FROM THE INDIGENOUS YONGCHAK (TREE BEAN) LEGUME *PARKIA TIMORIANA* OF MANIPUR

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ABSTRACT

The Yongchak, also known as *Parkia timoriana* or Tree bean, is a native legume found in Northeast India. It's known for its nutritional, antioxidant, and antibacterial properties. But what's interesting is that the bacteria that live inside this plant, called endophytes, might be contributing to these beneficial properties. Our goal was to isolate these bacterial endophytes and see if they have any potential as pharmaceuticals or in promoting plant growth. We took eight different types of bacteria from the Yongchak and tested them against various other bacteria and fungi that can harm plants. We also looked at how well they could scavenge free radicals, produce plant growth hormones, and solubilize phosphates. Two of these bacteria, STY4 and STY6, stood out and were tested further in a controlled environment with a local rice variety called Thoibi. STY6 was particularly effective against several types of bacteria, including *Staphylococcus aureus* and *Micrococcus luteus*. It also showed strong activity against *Escherichia coli* and *Pseudomonas aeruginosa*. Additionally, it was able to inhibit the growth of two types of fungi that can harm plants, *Fusarium oxysporum* and *Curvularia oryzae*. STY6 also had the lowest IC₅₀ values, which means it was very effective at scavenging free radicals. When we combined STY4 and STY6, we saw a significant increase in rice growth, including longer shoots and more biomass. This suggests that these bacterial endophytes could be useful in agriculture. To our knowledge, this is the first time anyone has isolated and studied the bacterial endophytes from the Yongchak. Our results suggest that these endophytes could be a source of new pharmaceuticals or agricultural biotechnology products. While we can't say for sure whether the beneficial properties of the Yongchak are due to these endophytes, our findings support the idea that they might be contributing to the plant's bioactive chemical pool. Further research, including identifying the bacteria using 16S rRNA, sequencing their genomes, and studying their metabolites, is needed to fully understand their potential.

Keywords: *Parkia timoriana*; Yongchak; Tree bean; legume; bacterial endophytes; antimicrobial; antioxidant; pharmaceutical natural products; secondary metabolites; genome mining; Thoibi rice.

How to cite this article: Shantirani Thokchom¹ Saikat Mukherjee^{2*}. ORIGINAL RESEARCH ARTICLE. Int J Drug Deliv Technol. 2026;16(84s):352-357. DOI: 10.25258/ijddt.16.84s.40.

INTRODUCTION

Endophytic bacteria can be defined as bacteria those inhabit plant tissues without producing overt disease. They are gradually getting recognized for production of secondary metabolites which are chemically diverse. These molecules can be antifungal, antibacterial, antioxidants, anti-inflammatory and cytotoxic compounds. Therefore, bacterial endophytes are attractive sources for natural products and can lead to drug discovery programmes.¹⁻³

Bacterial endophytes also helps in plant performance by production of phytohormones such as auxins, siderophore mediated iron acquisition, nutrient mobilization and other mechanisms.⁴

In North East India, specially Manipur, an indigenous tree legume, *Parkia timoriana* (DC.) Merr., locally known as Yongchak (commonly known as Tree Bean) is an important food resource. In addition, food processing is being attempted for value addition and year round utilization.⁵

As reported through GC-MS and Molecular Docking Analyses, various phenolics, flavonoids and compounds showing antibacterial and antifungal activities are reported.⁶

In addition, recent study have documented antioxidant and nutritional properties in pod anatomical fractions of the Yongchak.⁷

These researches suggest that although bioactive properties in plant tissues are generally attributed to plant metabolites, however, bacterial endophytes can produce their own specialized secondary metabolites and also influence host metabolism.^{2,3}

Endophytes of Yongchak can, therefore, be worth studying to describe such uncharacterized bioactive components which can have pharmaceutical and nutraceutical potential.

Therefore our research objectives were to isolate such culturable endophytic bacteria from Yongchak, and assess their antifungal, antibacterial and antioxidant activities. In addition, we also tested their PGP properties and growth promoting activities on local rice cultivar Thoibi, thereby, establishing its role in both therapeutic and nutraceutical potential.

Our next goal is to create a roadmap that connects phenotypic screening to molecular identification, whole-genome sequencing, biosynthetic gene-cluster mining, metabolite mining, and finally bioactivity-guided purification. So far, this is the first report on isolation and

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characterization of bacterial endophytes from from *P. timoriana*.

MATERIALS AND METHODS

Plant material and isolation of bacterial endophytes

We collected healthy Yongchak, from Manipur, India. We removed the skin from the tree bean, and then sterilized the pods using a special five-step sterilization process. This involved washing them with different chemicals like NaOCl, Na₂S₂O₃, C₂H₅OH, H₂O, and NaHCO₃, one after the other, followed by rinsing them three times with sterile water. After that, we cut the sterile pods into pieces and put them on starch casein nitrate agar, which had some extra ingredients like cycloheximide and nalidixic acid to prevent any fungi or bacteria from growing. We kept these plates at 30°C for 3-4 weeks, until we saw some distinct bacterial colonies growing. Then, we took these colonies and grew them again on fresh plates, twice, at the same temperature, but for a shorter time of 5 days, to make sure we had pure cultures of the bacteria. We ended up with eight different kinds of bacteria, which we labeled as STY1 to STY8. To make sure our sterilization process was working correctly, we also took the final rinse water and plated it to see if any bacteria would grow, as a control.

Antibacterial assay

Antibacterial activity was assessed against three test pathogens such as *Staphylococcus aureus*, *Micrococcu luteus*, *Escherichia coli* and *Pseudomonas aeruginosa* which were procured earlier from IMTECH, Chandigarh using agar diffusion-based screening assay. Inhibition zones were measured in millimeters and the results were expressed as mean $\pm$ SD from three replicates (n=3).

Antifungal assay

Antifungal activity of the endophytic bacterial isolates were tested against four phytopathogenic fungi such as *Fusarium. oxysporum*, *Rhizoctonia solani*, *Curvularia oryzae* and *Bipolaris oryzae* by dual-culture inhibition. Percentage inhibition of radial growth was estimated relative to the uninoculated fungal control. We recorded the results as mean $\pm$ SD (No of replicates =3).

Antioxidant assays

Antioxidant activity of the endophytic bacterial isolates was evaluated by DPPH and ABTS radical-scavenging assays. IC₅₀ values were estimated using nonlinear regression; in principle, lower IC₅₀ values confirm stronger radical-scavenging activity. Our results were recorded as mean $\pm$ SD (No of replicates =3).

Plant growth-promoting traits

We assessed the plant growth promoting traits of the endophytic bacterial isolates. We evaluated IAA production using Salkowski reagent after growth in tryptophan-supplemented medium. Phosphate solubilization was monitored and quantified in phosphate-containing broth. Siderophore production was evaluated using the chrome azurol S assay procedure and results were expressed as percentage siderophore units. Ammonia production was spectrophotometrically

quantified. We recorded our results as mean $\pm$ SD (No of replicates =3).

Rice growth-promotion experiment

STY4 and STY6 were short listed from the functional screen for nethouse trials. Surface-sterilized seeds of the local rice cultivar Thoibi were incubated with endophytic bacterial suspensions in various combinations and maintained under nethouse conditions for 60 days. Following treatments were tested ; T₀, uninoculated control (Nutrient Broth only); T₁, STY4; T₂, STY6; and T₃, STY4+STY6 consortium. We measured the changes in Shoot length, root length, fresh biomass, dry biomass and SPAD chlorophyll values among the treated and untreated samples.

Statistical analysis

We reported our data as mean $\pm$ SD. For the rice experiment. Our experimental dataset includes significance-group letters from one-way ANOVA followed by Tukey's multiple-comparison test at p<0.05.

Ethics statement

The study involved only plant material and bacterial cultures and there was no involvement of human participants or vertebrate animals.

RESULTS

Antibacterial activity

All eight isolates (STY1-STY8) inhibited at least one test pathogenic bacterium (Table 1; Figure 1). STY6 showed the strongest and broadest activity, producing inhibition zones of 21.6 $\pm$ 1.0 mm against *S. aureus*, 22.0 $\pm$ 0.8 mm against *M. luteus*, 19.5 $\pm$ 0.8 mm against *E. coli* and 17.4 $\pm$ 0.6 mm against *P. aeruginosa*. STY4 was ranked next showing inhibition zones ranging from 15.0 $\pm$ 0.8 to 20.0 $\pm$ 0.8 mm.

Table 1. Antibacterial activities of bacterial endophytes isolated from Yongchak

Name of Bacterial Isolate	<i>S. aureus</i> (mm)	<i>M. luteus</i> (mm)	<i>E. coli</i> (mm)	<i>P. aeruginosa</i> (mm)
STY1	12 $\pm$ 0.4	13 $\pm$ 0.2	10 $\pm$ 0.3	9 $\pm$ 0.2
STY2	15 $\pm$ 0.7	16.2 $\pm$ 0.6	13 $\pm$ 0.6	12 $\pm$ 0.7
STY3	17 $\pm$ 0.9	18 $\pm$ 0.4	15.5 $\pm$ 0.9	14 $\pm$ 0.6
STY4	19.2 $\pm$ 0.7	20 $\pm$ 0.8	17.2 $\pm$ 0.6	15 $\pm$ 0.8
STY5	14.3 $\pm$ 0.4	15 $\pm$ 0.8	12.8 $\pm$ 0.5	11.2 $\pm$ 0.4

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STY6	21.6 ± 1.0	22 ± 0.8	19.5 ± 0.8	17.4 ± 0.6
STY7	16.6 ± 0.6	17.2 ± 0.8	15 ± 0.6	13.4 ± 0.4
STY8	13.5 ± 0.5	14.5 ± 0.5	12 ± 0.4	10 ± 0.3

Values are mean ± SD, n=3.

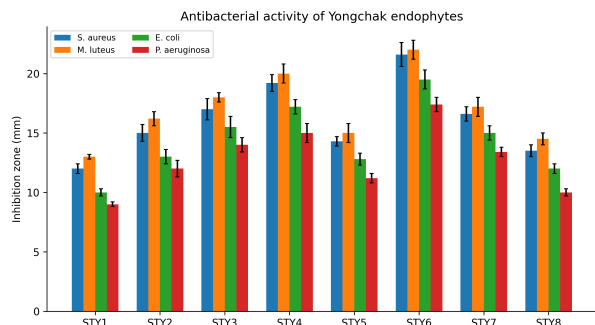


Figure 1. Antibacterial activity of STY1-STY8. Bars show mean ± SD (n=3).

Antifungal activity

In addition, the endophytic bacterial isolates also displayed significant antifungal activity (Table 2; Figure 2). STY6 inhibited *F. oxysporum* by 73.0±2.5%. *C. oryzae* was inhibited by 74.5±2.5% by STY6. STY4 produced the highest inhibition against *R. solani* (69.2±2.2%), while STY6 showed 66.5±2.2% inhibition against *B. oryzae*.

Table 2. Antifungal activity of bacterial endophytes isolated from Yongchak

Name of Bacterial Isolate	<i>F. oxysporum</i> (%)	<i>R. solani</i> (%)	<i>C. oryzae</i> (%)	<i>B. oryzae</i> (%)
STY1	35 ± 1.7	31.2 ± 1.4	38.3 ± 1.5	30.5 ± 1.2
STY2	48 ± 2	44.5 ± 1.6	51 ± 1.8	43.5 ± 1.6
STY3	58.2 ± 2.3	55.5 ± 2	61.5 ± 2.1	52.2 ± 1.8
STY4	67.2 ± 2	69.2 ± 2.2	70.2 ± 2	62 ± 2
STY5	45 ± 1.6	42.2 ± 1.6	49 ± 1.8	40 ± 1.5

STY6	73 ± 2.5	68 ± 2	74.5 ± 2.5	66.5 ± 2.2
STY7	54.5 ± 2	51.5 ± 1.8	58 ± 1.8	50 ± 1.6
STY8	39.5 ± 1.5	36.4 ± 1.4	42.3 ± 1.5	35 ± 1.3

Values are mean ± SD, n=3.

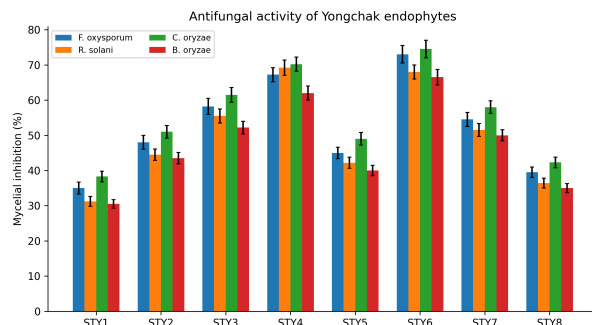


Figure 2. Percentage mycelial inhibition by STY1-STY8. Bars show mean ± SD (n=3).

Antioxidant activity

STY6 showed the strongest antioxidant profile, with DPPH and ABTS IC₅₀ values of 42.6±1.8 and 39.1±1.6 µg/mL, respectively (Table 3; Figure 3). STY4 was the second strongest endophytic bacterial isolate in antioxidant assay (49.8±2.1 and 45.3±1.9 µg/mL). These activities have significance in pharmaceutical screening as oxidative-stress-modulating natural products will guide for further pharmacological investigation, inspite the fact that radical-scavenging assays alone do not confirm therapeutic efficacy.

Table 3. Antioxidant activity of bacterial endophytes isolated from Yongchak

Name of Bacterial Isolate	DPPH IC ₅₀ (µg/mL)	ABTS IC ₅₀ (µg/mL)
STY1	96.4 ± 3.8	88.6 ± 3.1
STY2	78.3 ± 3	70.5 ± 2.8
STY3	61.7 ± 2.6	57.4 ± 2.3
STY4	49.8 ± 2.1	45.3 ± 1.9
STY5	82.5 ± 3.2	74.8 ± 2.9
STY6	42.6 ± 1.8	39.1 ± 1.6
STY7	65.4 ± 2.7	59.8 ± 2.5
STY8	89.7 ± 3.5	80.6 ± 3

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Values are mean $\pm$ SD, $n=3$. Lower IC_{50} indicates stronger radical-scavenging activity.

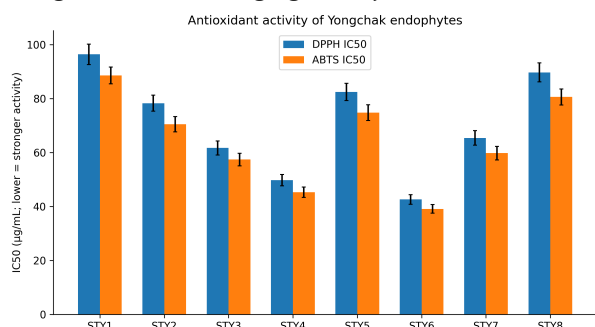


Figure 3. DPPH and ABTS IC_{50} values of STY1-STY8. Bars show mean $\pm$ SD ($n=3$).

Plant growth-promoting traits

In evaluation of plant growth promoting traits, STY6 showed the highest values for all four PGP parameters: IAA 61.4 ± 1.4 $\mu g/mL$, phosphate solubilization 58.0 ± 1.2 $\mu g/mL$, siderophore production $62.1 \pm 1.5\%$ and ammonia 49.2 ± 1.2 $\mu g/mL$ (Table 4; Figure 4). STY4 was the next strongest endophytic bacterial isolate for PGP traits. STY4 and STY6 was further shortlisted for the rice experiment in nethouse condition.

Table 4. Plant growth-promoting traits of of bacterial endophytes isolated from Yongchak

Name of Bacterial Isolate	IAA ($\mu g/mL$)	Phosphate ($\mu g/mL$)	Siderophore (%)	Ammonia ($\mu g/mL$)
STY1	21 ± 0.75	25.7 ± 0.7	26.5 ± 1.2	18.6 ± 0.8
STY2	32.7 ± 1.2	34.6 ± 0.9	35.7 ± 1.3	26.4 ± 0.9
STY3	45.6 ± 1	42.9 ± 1.1	47.6 ± 1.5	35.8 ± 1
STY4	55 ± 1.2	51.7 ± 1.2	55.2 ± 1.7	43.6 ± 1.2
STY5	37.3 ± 1.3	38 ± 1.3	40 ± 1.2	30.3 ± 0.6
STY6	61.4 ± 1.4	58 ± 1.2	62.1 ± 1.5	49.2 ± 1.2

STY7	48.5 ± 1.3	45.5 ± 1	50 ± 1.4	38 ± 1
STY8	30 ± 0.1	29 ± 0.6	31.2 ± 1.1	22.2 ± 0.6

Values are mean $\pm$ SD, $n=3$.

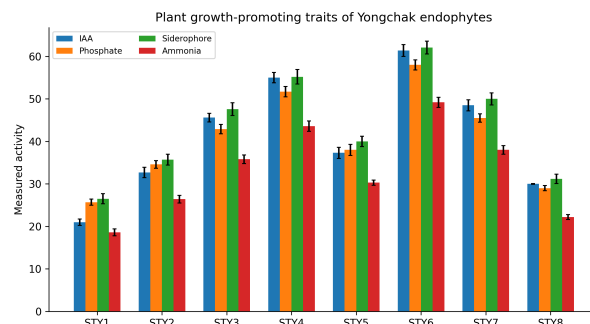


Figure 4. Plant growth-promoting traits of STY1-STY8. Bars show mean $\pm$ SD ($n=3$).

Growth promotion of Thoibi rice

Both the shortlisted endophytic bacterial isolates enhanced the rice growth parameters as compared to the uninoculated control (Table 5; Figure 5). Treatment with STY6 showed shhot length of 58.9 ± 2.6 cm and dry biomass of 1.87 ± 0.11 g/plant. The control treatment (with bacteriological media Nutrient Broth) showed shoot length of 41.8 ± 2.1 and dry biomass of 1.18 ± 0.09 . The consortium produced the greatest shoot length (62.4 ± 2.7 cm), root length (25.1 ± 1.4 cm), fresh biomass (8.86 ± 0.45 g/plant), dry biomass (1.98 ± 0.12 g/plant) and SPAD value (42.5 ± 1.9). Superscript groupings supplied by ANOVA/Tukey testing ($p < 0.05$).

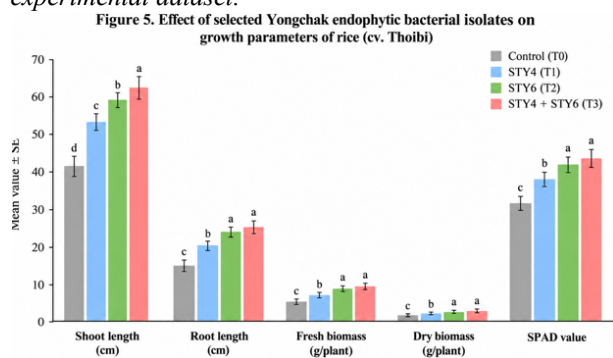
Table 5. Effect of selected bacterial endophytes from Yongchak on local rice cultivar Thoibi

Treatment	Shoot (cm)	Root (cm)	Fresh biomass (g/plant)	Dry biomass (g/plant)	SPAD
Control	41.8 ± 2.1^d	15.2 ± 1^c	5.42 ± 0.31^c	1.18 ± 0.09^c	31.6 ± 1.5^c
STY4	52.7 ± 2.4^c	20.8 ± 1.2^b	7.26 ± 0.38^b	1.61 ± 0.1^b	37.8 ± 1.7^b

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STY6	58.9 ± 2.6 ^b	23. 6 ± 1.3 ^a	8.41 ± 0.42 ^a	1.87 ± 0.11 ^a	41.2 ± 1.8 ^a
STY4+STY6	62.4 ± 2.7 ^a	25. 1 ± 1.4 ^a	8.86 ± 0.45 ^a	1.98 ± 0.12 ^a	42.5 ± 1.9 ^a

Values are mean ± SD. Different letters within a column indicate significant differences by one-way ANOVA followed by Tukey's test ($p < 0.05$), as supplied with the experimental dataset.



Values are mean ± SE (n = 3). Different letters above bars within each parameter indicate significant differences according to one-way ANOVA followed by Tukey's test ($p < 0.05$).

Figure 5. Percentage change in Thoibi rice growth parameters relative to the uninoculated control.

DISCUSSION

Our study identifies a culturable bacterial endophytic community from *P. timoriana* demonstrating antimicrobial, antioxidant and plant growth promoting traits. The most active isolate, STY6, had broad antibacterial activity, strongly inhibiting phytopathogenic fungi, showed the lowest radical-scavenging IC₅₀ values and demonstrated highest PGP activities. These bacterial endophytes from Yongchak therefore possess biosynthetic pathways for production of specialized metabolites with pharmaceutical and agricultural relevance.¹⁻³

If we consider the pharmaceutical perspective, the inhibition of both Gram-positive and Gram-negative bacteria provides a platform for further research of STY6 and STY4 in determining minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC), time-kill and mechanism-oriented assays. Similarly, the antifungal phenotype can be further investigated to minimum fungicidal concentration testing and fractionation of extracellular metabolites.

The antioxidant results also add another pharmacological dimension. *P. timoriana* tissues have already been documented to show phenolic, flavonoid and antioxidant properties.^{6,7} Our reports show that culturable internal bacteria also exhibit radical-scavenging activity. It opens up a new hypothesis: the Yongchak holobiont might possess both plant-derived and microbial sources of bioactive chemistry. Endophytes produce secondary

metabolites and they may modulate host metabolism.^{2,3} Future studies involving testing that proposition will require paired plant-endophyte metabolomics, axenic or endophyte-reduced plant material, isotope tracing and chemical matching of microbial and plant metabolites can establish that the plant's previously reported nutraceutical properties are caused by its endophytes..

Our agricultural data involving the shortlisted bacterial isolates strengthen the biological relevance of the isolates. Endophytic bacteria influence plant growth by assisting in nutrient acquisition as well as developmental modulation.⁴ High IAA, phosphate-solubilizing and siderophore activities of STY6 were accompanied by improved growth of Thoibi rice cultivars, however, the STY4+STY6 consortium produced the greatest overall response. Our study demonstrates a parallel translational opportunity: the same Yongchak microbiome can result in yield of both pharmaceutical lead-producing strains as well as bioinoculant candidates.

Pharmaceutical development and future genome/metabolite mining

Our future work will focus on establishing chemical identity from phenotype. STY4 and STY6 will be first identified through 16S rRNA gene sequencing followed by whole-genome sequencing. Genome mining with antiSMASH will be performed to identify candidate BGCs encoding non-ribosomal peptides, polyketides, terpenes, siderophores, RiPPs, and other specialized metabolites; the computational tool antiSMASH⁷ is instrumental in bBGC detection and improved structural predictions.⁸ The Candidate clusters will then be validated with experimentally characterized BGCs in MIBiG.⁹ Our Genome mining approaches should be integrated with LC-MS/MS- and GC-MS-based metabolite mining, followed by molecular networking, bioactivity-guided fractionation, purification and finally structural elucidation.

A pharmaceutical development pipeline emerging from our research will follow this roadmap: Yongchak endophyte isolation → reproducible bioactivity → molecular identification → whole-genome sequencing → BGC prioritization → fermentation optimization → metabolite extraction → LC-MS/MS profiling → bioactivity-guided purification → structure elucidation → MIC/MBC/MFC and mammalian cytotoxicity → mechanism studies → formulation and delivery studies. Our staged approach will be instrumental for converting endophytic microbial metabolites from crude extracts into lead molecules.^{10,11}

Yongchak value addition and regional bioeconomy

Yongchak is a known economically and culturally important food legume of Manipur, and various food-processing strategies are underway for value addition.⁵ Our work extends this concept from the edible product to associated microbiome. Yongchak-derived strains or metabolites, if properly developed, can initiate new research directions in antioxidant preparations, biocontrol, natural-product pharmaceuticals, and

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microbial bioinoculants.¹² For an economically constrained region, locally sourced microbial bioresources may offer a route to higher-value biotechnology built around indigenous biodiversity. However, commercial claims require strain authentication, biosafety, scalable fermentation, formulation stability, regulatory evaluation, intellectual-property analysis and techno-economic assessment. The significance of this research lies in being the first to isolate and study the bacteria living inside *P. timoriana*, and using this to find new medicines. This approach changes how we think about the value of plants, from just looking at the chemicals they produce, to considering the whole system of the plant and the tiny living things inside it. This could lead to a better understanding of how plants and their microbiomes work together to create new medicines. By looking at the individual contributions of each part of the system, we can learn more about how they interact and how we can use them to improve human health. This new way of thinking could open up new possibilities for finding and developing new medicines from plants.

CONCLUSION

Bacteria that live inside plants, called endophytes, have been found in a type of legume called Yongchak. Eight of these bacteria were taken from the plant and tested for their abilities to fight off other bacteria and fungi, as well as to help plants grow. Two of these bacteria, called STY4 and STY6, were particularly good at doing many things, like fighting off other microorganisms and helping plants grow. When used together, STY4 and STY6 helped a type of rice called Thoibi grow the best. This is the first time that bacteria from Yongchak have been studied, and the results are promising. These bacteria could be used to find new medicines or natural products that are good for people. The next steps will be to learn more about what these bacteria are, what genes they have, and what special compounds they make. This could lead to new discoveries about how these bacteria help plants and people, and maybe even to new medicines.

ACKNOWLEDGEMENTS

The authors acknowledge the Department of Biochemistry, School of Life Sciences, Manipur University, for laboratory and academic support.

AUTHOR CONTRIBUTIONS

Shantirani Thokchom: Investigation, methodology, data curation, analysis and manuscript drafting. Saikat Mukherjee: Conceptualization, supervision, methodology, interpretation, manuscript drafting and critical revision. Both authors approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING

Bacteriological media, glasswares and plastic wares were purchased from the Science and Engineering

Research Board (SERB), New Delhi funded Core Research Grant Project.

REFERENCES

1. Strobel G, Daisy B. Bioprospecting for microbial endophytes and their natural products. *Microbiol Mol Biol Rev.* 2003;67(4):491-502. DOI: 10.1128/MMBR.67.4.491-502.2003.
2. Zhang HW, Song YC, Tan RX. Biology and chemistry of endophytes. *Nat Prod Rep.* 2006;23(5):753-771. DOI: 10.1039/B609472B.
3. Zotchev SB. Unlocking the potential of bacterial endophytes from medicinal plants for drug discovery. *Microb Biotechnol.* 2024;17(2):e14382. DOI: 10.1111/1751-7915.14382.
4. Santoyo G, Moreno-Hagelsieb G, Orozco-Mosqueda MDC, Glick BR. Plant growth-promoting bacterial endophytes. *Microbiol Res.* 2016;183:92-99. DOI: 10.1016/j.micres.2015.11.008.
5. Hijam S, Thokchom S, Oinam S. Value Addition of *Parkia timoriana* through Food Processing Methods. *Flora and Fauna.* 2025;31(1):79-85. DOI: 10.33451/florafauna.v31i1pp79-85.
6. Lalrinzuali K, Vabeiryureilai M, Jagetia GC. GC-MS and molecular docking analyses of phytochemicals from the underutilized plant, *Parkia timoriana* revealed candidate anti-cancerous and anti-inflammatory agents. *Sci Rep.* 2022;12:3395. DOI: 10.1038/s41598-022-07320-2.
7. Ruangrak E, et al. Nutritional evaluation and antioxidant activity of the exocarp, mesocarp, and endocarp from *Parkia timoriana* (DC.) Merr. pods for sustainable animal and human nutrition. *Front Sustain Food Syst.* 2025;9:1628357. DOI: 10.3389/fsufs.2025.1628357.
8. Blin K, Shaw S, Augustijn HE, et al. antiSMASH 7.0: new and improved predictions for detection, regulation, chemical structures and visualisation. *Nucleic Acids Res.* 2023;51(W1):W46-W50. DOI: 10.1093/nar/gkad344.
9. Terlouw BR, Blin K, Navarro-Muñoz JC, et al. MIBiG 3.0: a community-driven effort to annotate experimentally validated biosynthetic gene clusters. *Nucleic Acids Res.* 2023;51(D1):D603-D610. DOI: 10.1093/nar/gkac1049.
10. Biju R, Osborne WJ. A comprehensive review on bacterial endophytic secondary metabolites: a road map from crude extract to lead molecule production. *Front Pharmacol.* 2026;17:1837576. DOI: 10.3389/fphar.2026.1837576.
11. Gunatilaka AAL. Natural products from plant-associated microorganisms: distribution, structural diversity, bioactivity, and implications of their occurrence. *Jo Nat Prod.* 2006;69(3):509-526. DOI: 10.1021/np058128n.
12. Schulz B, Boyle C. The endophytic continuum. *Mycol Res.* 2005;109(6):661-686. DOI: 10.1017/S095375620500273X.