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Antifungal and Organic Matter Degradation Activities of Rhizobacteria Associated with *Pseuderanthemum palatiferum* (Nees) Radlk in Tay Ninh Province, Vietnam

Thi Ngoc Thanh Dang, Thi Thu Ly Pham and Minh Tam Hoang *

Faculty of Natural Science Pedagogy, Saigon University, 273 an Duong Vuong Street, Cho Quan Ward, Ho Chi Minh City, Vietnam.

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Abstract

Pseuderanthemum palatiferum (Nees) Radlk is an indigenous Vietnamese medicinal plant cultivated extensively in Tay Ninh province for the production of health-supplement. Building upon a previous discovery of beneficial rhizosphere bacteria, this study evaluated 27 plant growth-promoting rhizobacteria (PGPR) strains for their organic matter degradation and antifungal capabilities. Organic matter decomposition was assessed using the agar well diffusion method. Among the 27 isolates, 13 degraded protein, 16 degraded starch, 20 degraded chitin, and 19 degraded cellulose, with maximum hydrolysis zone diameters reaching 22 mm, 35 mm, 19 mm, and 18 mm, respectively. Antifungal activity against two phytopathogens, *Colletotrichum* sp. and *Fusarium* sp., was evaluated via parallel streak co-culture assays. Only two strains, HNR10 and HNR13, exhibited antifungal activity. Strain HNR10 demonstrated superior efficacy, achieving 7-day inhibition rates of 50.00% against *Colletotrichum* sp. and 55.80% against *Fusarium* sp. Based on MALDI-TOF MS analysis, the prominent isolates HNR10, HNR13, and the high-performing degrader HNR27 were identified as *Lysinibacillus sphaericus*, *Alcaligenes* sp., and *Enterobacter bugandensis*, respectively. These findings highlight the potential applications of *P. palatiferum*-associated PGPR in sustainable agriculture.

Keywords: Biodegradation; fungal inhibition; MALDI-TOF MS; Plant Growth-Promoting Rhizobacteria; *Pseuderanthemum palatiferum* (Nees) Radlk

1. Introduction

Pseuderanthemum palatiferum (Nees) Radlk (locally known in Vietnam as Hoan-Ngoc or Xuan-Hoa), a member of the Acanthaceae family, was first discovered in northern Vietnam in 1990 [1]. It is an easily cultivated perennial shrub that reaches a height of 1–2 meters, characterized by extensive branching, simple opposite lance-shaped leaves, white flower clusters in the leaf axils or branch tips, and a capsule fruit containing four seeds [2]. In traditional Vietnamese and Thai ethnomedicine, the leaves and roots are widely used. The leaves are specifically recommended for treating wounds, colitis, gastric pain, physical injuries, hypertension, nephritis, and diarrhea. Crucially, toxicological studies indicate that the leaves exhibit no acute or subacute toxicity, validating their safety profile [1-4].

* Corresponding author: Minh Tam Hoang

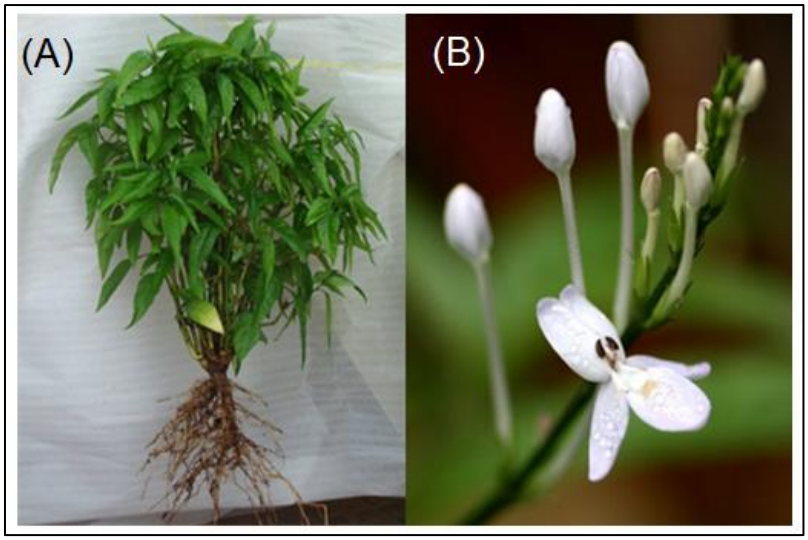


Figure 1 Morphology of the Hoan-Ngoc plant (A) and inflorescence (B) [5, 6]

Although scattered across domestic home gardens throughout Vietnam, the largest concentrated cultivation area of *P. palatiferum* spans more than 80 hectares in Tay Ninh province. More than 85% of this region's natural soil is classified as acrisol-a nutrient-deficient soil characterized by poor water retention. To process this medicinal plant into commercial health products like instant teas and tea bags, local enterprises must adhere to strict governmental cultivation guidelines governing soil management, fertilization, crop care, harvesting, and processing. Consequently, organic fertilizers are heavily favored to mitigate the ecological drawbacks of synthetic chemical inputs [7-10].

Currently, plant-growth-promoting rhizobacteria (PGPR) are recognized as essential components of sustainable agricultural development. According to the theory of multiple mechanisms, a single bacterial strain can directly stimulate plant growth via biological nitrogen fixation, phosphate solubilization, and phytohormone production, while simultaneously deploying indirect mechanisms such as hydrogen cyanide production, siderophore secretion, and hydrolytic enzyme synthesis. These indirect properties drive antagonistic activities that suppress crop diseases, particularly through the inhibition of fungal pathogens. This biocontrol action is primarily mediated by siderophore production—which starves pathogenic fungi of essential iron—and enzymatic pathways that degrade fungal cell walls. Furthermore, by secreting extracellular enzymes such as chitinase, protease/elastase, and β-1,3-glucanase, rhizobacteria decompose complex organic matter into simpler, plant-absorbable nutrients. Consequently, enzyme activity within the rhizosphere plays a more critical role in breaking down carbon compounds and N-, P-, and S-containing organic substances than enzymes found in the bulk soil mass [11].

Fungal pathogens belonging to the genera *Colletotrichum* and *Fusarium* frequently cause devastating anthracnose, wilt, and root rot across diverse crops. While various multi-trait PGPR have been cataloged for disease management, *Bacillus* and *Pseudomonas* species remain the most prominent biocontrol agents validated against *Fusarium* and *Colletotrichum* in pot and field trials [12]. Beyond *Bacillus* spp. and *Pseudomonas* spp., *Alcaligenes faecalis* has also demonstrated multifunctional plant growth-promoting traits, including robust pathogen resistance and enzyme production [11, 13, 14]. Meanwhile, *Lysinibacillus* spp. play a documented role in promoting plant growth alongside the bioremediation of heavy metals and organic pollutants [15]. Similarly, specific strains of *Enterobacter* display dual-functioning, multiple growth-promoting characteristics that protect hosts from pathogen attack while offering bioremediation potential; however, the capacity of certain species within this genus to act as opportunistic human and plant pathogens must be carefully evaluated before agricultural application [16, 17].

This study aimed to evaluate the indirect plant growth-promoting potential—specifically through enzyme production and antifungal activity—of bacterial strains isolated from the rhizosphere of the Hoan-Ngoc plant (*P. palatiferum* (Nees) Radlk), supporting the development of biological products for clean medicinal crop cultivation.

2. Material and methods

2.1. Materials

Twenty-seven PGPR strains used in this study were originally isolated from the rhizosphere of Hoan-Ngoc plants cultivated in Duong Minh Chau Commune, Tay Ninh Province, Vietnam. The two fungal pathogens, *Colletotrichum* sp. and *Fusarium* sp. were provided by Ho Chi Minh City University of Medicine and Pharmacy.

2.2. Activation of bacteria and preparation of bacterial suspensions

Following storage, the 27 bacterial strains were reactivated and assessed for purity by streaking onto solid Luria-Bertani (LB) agar medium (10 g tryptone, 5 g yeast extract, 10 g NaCl, 18 g agar per liter, pH 7.0). For each purified strain, a single loop of biomass was collected using an inoculation loop and thoroughly suspended in a test tube containing 5 mL of liquid LB broth. The tubes were incubated on an incubator shaker at 120 rpm and 30°C for 48 hours. Post-incubation, the optical density of each culture was measured via spectrophotometry at a wavelength of 600 nm (OD_{600}) and adjusted to match a 0.5 McFarland standard, which corresponds to an approximate cell density of 1.5 x 10^8 CFU/mL. This standardized bacterial density was uniformly applied across all subsequent experiments [11].

2.3. Investigation of protein, starch, chitin and cellulose decomposition

2.3.1. Formulas of indicator media

The specific compositions and concentrations per liter of the culture media used to evaluate the decomposition of protein, starch, chitin, and cellulose are detailed in Table 1. All media components were dissolved in distilled water, adjusted to the required pH, and solidified by adding 18 g of agar. The media were then sterilized via autoclaving (moist heat) and aseptically poured into sterile Petri dishes.

Table 1 Formulas of culture media and experimental purposes

Media	Experimental purposes	Formulas	References
Skim milk	Decomposition of protein	5 g peptone; 3 g meat extract; 1 g yeast extract; 300 mL skim milk; pH 6.5	[18]
Mt1	Decomposition of starch	3 g meat extract; 5 g peptone; 2 g soluble starch; pH 7.0	[19]
Colloidal chitin	Decomposition of chitin	0.7 g K_2HPO_4; 0.3 g KH_2PO_4; 0.5 g $MgSO_4$. $5H_2O$; 0.01 g $FeSO_4.7H_2O$; 1 mg $ZnSO_4$; 0.1 mg $MnCl_2$; 0.5 g colloidal chitin; pH 6-7	[20]
CMC (Carboxymethyl cellulose)	Decomposition of cellulose	1 g $(NH_4)2SO_4$; 1g K_2HPO_4; 0.5 g $MgSO_4$; 9 mg NaCl; 10 g CMC; pH 6.8	[21]

2.3.2. Agar well diffusion method, color indicator reagent and assessment of substrate decomposition

The agar well diffusion method was employed to evaluate the enzymatic substrate decomposition. Wells were punched into the agar plates using a sterile 6 mm diameter cork borer. A 50 µL aliquot of the supernatant—obtained after centrifugation at 12,000 rpm for 5 minutes—was inoculated into each well. This fraction contained extracellular enzymes produced by bacteria adapted for 48 hours in a liquid medium containing the corresponding substrate. Following a 48-hour incubation period, the formation of a distinct zone of clearance (halo) served as an indicator of substrate degradation. For proteolysis, a transparent halo developed naturally against the opaque white background of the medium without requiring external dyes. Conversely, to visualize clearing zones for starch decomposition, plates were stained with Lugol's iodine solution containing 150 mg/mL of iodine (prepared by dissolving 5 g of iodine and 10 g of potassium iodide in 100 mL of distilled water). For chitin and cellulose decomposition assays, plates were flooded with a 0.1% Congo Red solution for 15 minutes, followed by washing with a 1 M NaCl solution. Substrate degradability was quantitatively determined by subtracting either the well diameter or the colony diameter from the total halo diameter [11].

2.4. Investigation of antifungal ability

The two indicator fungal strains, *Colletotrichum* sp. and *Fusarium* sp., were cultured on Potato Dextrose Agar (PDA) for 5 days to prepare fungal mycelial plugs (5 mm diameter). A single fungal plug was placed at the center of a fresh PDA plate, and two bacterial streaks were inoculated parallel to each other on opposite sides of the plug (Figure 2). The co-cultured plates were incubated at room temperature for 3 to 7 days to monitor the formation of zones of inhibition. The percentage of fungal growth inhibition (I) was calculated using the following formula [22]:

$$I(\%) = \frac{R - r}{R} \, x \, 100$$

where R represents the mycelial growth radius of the fungal colony in the negative control treatment (inoculated with the fungal plug alone), and r represents the fungal colony radius on the plate co-cultured with the bacterial strain [22].

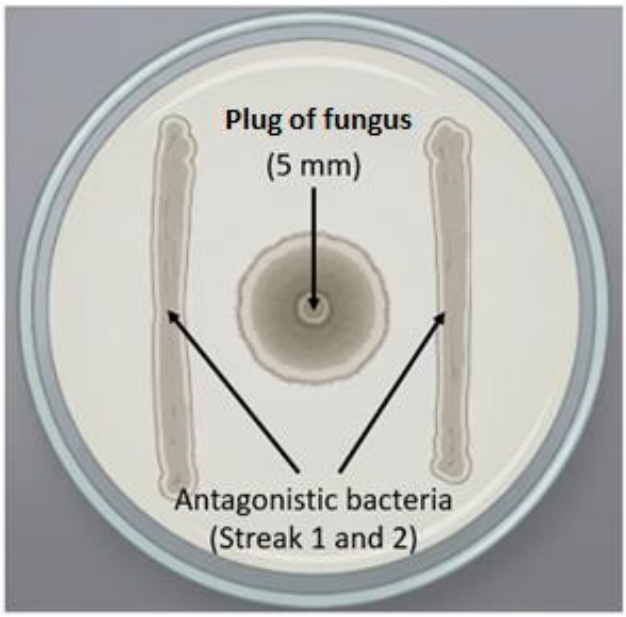


Figure 2 Parallel streak method in fungal and bacterial co-culture

2.5. Identification of selected bacterial strains

Taxonomic identification was restricted to the bacterial strains that exhibited the highest performance in the growth-promotion and antifungal assays. Species classification was performed via Matrix-Assisted Laser Desorption/Ionization-Time of Flight Mass Spectrometry (MALDI-TOF MS) at the Center for Science and Technology Bio-Trends, Faculty of Biology and Biotechnology, VNU-HCM University of Science.

2.6. Experimental design and data analysis

All quantitative experiments were arranged in a completely randomized design (CRD) with three independent replications. Statistical analyses, including one-way analysis of variance (ANOVA) and Duncan's multiple range test (alpha = 0.05), were performed using IBM SPSS Statistics software (version 20.0).

3. Results and discussion

3.1. Ability of PGPR strains isolated from Hoan-Ngoc plants to degrade protein, starch, chitin, and cellulose

In addition to the Hoan-Ngoc plant (*P. palatiferum*), numerous species within the Acanthaceae family—such as *Andrographis paniculata, Barleria lupulina, Barleria prionitis*, and *Hygrophila auriculata*—are widely utilized as medicinal herbs. Although the ecological significance of interactions between medicinal hosts and plant-associated bacteria in synthesizing bioactive molecules is increasingly recognized [23], most contemporary research prioritizes phytochemical profiling and pharmacological activities. Consequently, studies focusing on the rhizosphere microbiota of these specific medicinal species remain scarce, limiting available comparative data.

In this study, the enzymatic capacity of the isolated strains to decompose organic matter was qualitatively evaluated by the formation of a clear halo surrounding the colony or well. Table 2 and Fig. 3 present the net halo diameters, calculated by subtracting the well or colony diameter, which serve as an index of substrate degradation efficiency.

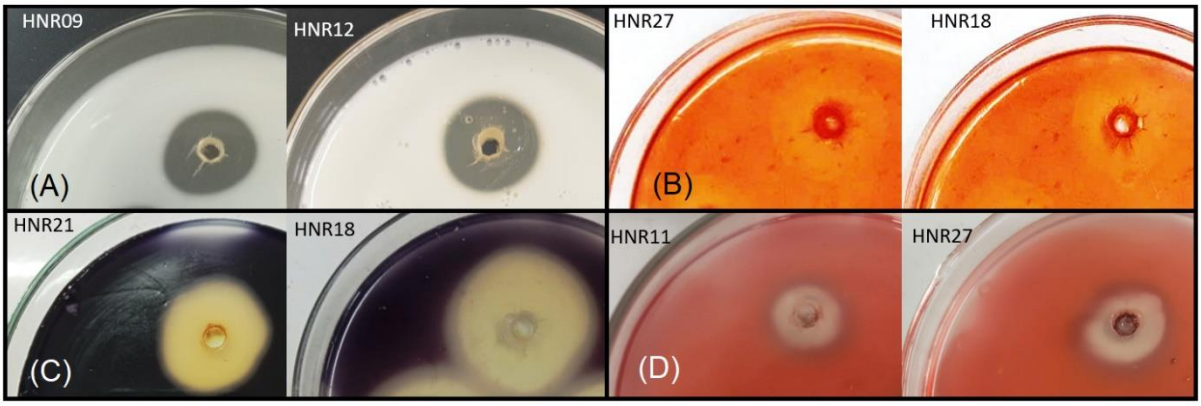
Table 2 Ability to decompose organic compounds of 27 PGPR strains isolated from Hoan-Ngoc plants

Treatments (Strains)	**Substrate decomposition ability (mm)**			
	Protein	Starch	Chitin	Cellulose
HNR01	0.00 ^{h} ± 0.00	4.67 ^{fg} ± 1.15	3.33 ^{cd} ± 1.15	11.33 ^{d} ± 2.31
HNR02	0.00 ^{h} ± 0.00	8.00 ^{ef} ± 2.00	4.00 ^{cd} ± 0.00	9.33 ^{e} ± 1.15
HNR03	9.33 ^{ef} ± 1.15	4.67 ^{fg} ± 1.15	4.67 ^{c} ± 1.15	6.00 ^{f} ± 2.00
HNR04	0.00 ^{h} ± 0.00	5.33 ^{fg} ± 2.31	2.00 ^{de} ± 0.00	13.05 ^{cd} ± 2.15
HNR05	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	0.00 ^{e} ± 0.00	2.00 $^{h-k}$ ± 0.00
HNR06	9.67 ^{def} ± 2.08	11.33 ^{de} ± 1.15	0.00 ^{e} ± 0.00	4.00 ^{fgh} ± 0.00
HNR07	8.67 ^{f} ± 1.15	0.00 ^{h} ± 0.00	0.00 ^{e} ± 0.00	0.00 ^{k} ± 0.00
HNR08	14.67 ^{c} ± 1.15	3.33 ^{gh} ± 1.15	0.00 ^{e} ± 0.00	0.00 ^{k} ± 0.00
HNR09	19.17 ^{b} ± 0.83	6.67 ^{fg} ± 1.15	2.67 ^{cd} ± 1.15	3.33 ^{gh} ± 1.15
HNR10	18.11 ^{b} ± 0.61	31.87 ^{a} ± 6.82	2.00 ^{de} ± 0.00	2.67 ^{h} ± 1.15
HNR11	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	4.00 ^{cd} ± 0.00	15.15 ^{b} ± 1.95
HNR12	22.07 ^{a} ± 1.19	10.67 ^{de} ± 4.62	2.67 ^{cd} ± 1.15	3.33 ^{gh} ± 1.15
HNR13	12.00 ^{d} ± 3.46	16.33 ^{c} ± 1.53	4.00 ^{cd} ± 0.00	5.33 ^{fg} ± 2.31
HNR14	10.67 ^{def} ± 2.89	0.00 ^{h} ± 0.00	12.55 ^{b} ± 1.12	2.00 $^{h-k}$ ± 0.00
HNR15	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	2.00 ^{de} ± 0.00	2.67 ^{h} ± 1.15
HNR16	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	4.00 ^{cd} ± 0.00	0.00 ^{k} ± 0.00
HNR17	8.67 ^{f} ± 3.06	19.33 ^{c} ± 4.16	2.67 ^{cd} ± 1.15	0.00 ^{k} ± 0.00
HNR18	11.67 ^{de} ± 2.89	34.64 ^{a} ± 1.30	14.37 ^{b} ± 3.73	2.67 ^{h} ± 1.15
HNR19	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	2.00 ^{de} ± 0.00	14.75 ^{bc} ± 0.46
HNR20	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	2.67 ^{cd} ± 1.15	0.00 ^{k} ± 0.00
HNR21	0.00 ^{h} ± 0.00	26.08 ^{b} ± 1.65	0.00 ^{e} ± 0.00	0.00 ^{k} ± 0.00
HNR22	0.00 ^{h} ± 0.00	8.00 ^{ef} ± 2.00	2.00 ^{de} ± 0.00	3.33 ^{gh} ± 1.15
HNR23	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	2.00 ^{de} ± 0.00	0.00 ^{k} ± 0.00
HNR24	9.67 ^{def} ± 0.58	23.01 ^{b} ± 0.91	0.00 ^{e} ± 0.00	0.00 ^{k} ± 0.00
HNR25	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	0.00 ^{e} ± 0.00	2.67 ^{h} ± 1.15
HNR26	4.67 ^{g} ± 1.15	0.00 ^{h} ± 0.00	3.33 ^{cd} ± 2.31	3.33 ^{gh} ± 1.15
HNR27	0.00 ^{h} ± 0.00	12.67 ^{d} ± 1.15	19.13 ^{a} ± 2.49	18.42 ^{a} ± 2.46
Control	0.00 ^{h} ± 0.00	0.00 ^{h} ± 0.00	0.00 ^{e} ± 0.00	0.00 ^{k} ± 0.00

Means within a column followed by the same letters were not significantly different at α =0.05 using Duncan test.

Among the 27 PGPR strains surveyed, the numbers of isolates capable of degrading protein, starch, chitin, and cellulose were 13 (48.1%), 16 (59.3%), 20 (74.1%), and 19 (70.3%), respectively. The proportion of substrate-degrading bacteria varies considerably among studies due to differences in host plants, environmental conditions, and isolation sources. Nevertheless, the frequencies of chitin- and cellulose-degrading strains observed in this study were generally higher

than those previously reported, where chitin degradation ranged from 13–29% [24-26] and cellulose degradation ranged from 60–64% [27, 28].



(A): Protein; (B): Chitin; (C): Starch; (D): Cellulose

Figure 3 Halo rings of some PGPR strains in organic matter decomposition experiments

Of the Hoan-Ngoc rhizobacteria evaluated, strains HNR18 and HNR10 exhibited the highest amylolytic activity, generating clear zones of 34.64 mm and 31.87 mm, respectively. Cellulolytic efficiency was most prominent in strain HNR27, which produced a hydrolysis halo of 18.42 mm. For the remaining traits, strain HNR12 demonstrated the strongest proteolytic capacity with a clearing zone of 22.07 mm, while strain HNR27 topped the chitinolytic profiles with a halo diameter of 19.13 mm. When contextualized with existing literature, several Hoan-Ngoc-associated isolates demonstrated superior hydrolytic potential. The maximum clearing zones observed for starch and cellulose degradation in this study substantially exceeded the benchmarks of 5 mm [29] and 9 mm [30] reported previously. Similarly, the proteolytic performance of strain HNR12 surpassed the typical range of 2–16 mm documented in prior PGPR investigations [30]. Meanwhile, the chitinolytic activity of strain HNR27 fell well within the established literature range of 17–31 mm [31]. Because starch and cellulose constitute the primary structural elements of plant residues in soil, the capacity of these isolates to aggressively hydrolyze such substrates highlights their proficiency in driving rhizosphere nutrient cycling and organic matter turnover. Furthermore, the robust, multi-enzymatic degradation profiles—spanning protein, starch, cellulose, and chitin—underscore the dual-functional potential of these elite isolates to simultaneously mobilize locked nutrients and suppress fungal pathogens via cell-wall degradation.

3.2. Antifungal ability of PGPRs of Hoan-Ngoc plants

Out of the 27 surveyed isolates, only two strains (7.4%) showed clear activity against the tested fungal pathogens. The in vitro biocontrol effects recorded after 7 days of co-cultivation are summarized in Table 3 and Fig. 4. The two strains showed similar data against *Fusarium* sp., with strain HNR10 achieving 55.83 % and strain HNR13 achieving 55.00 %. Conversely, their performance against *Colletotrichum* sp. was noticeably different; strain HNR10 achieved a significantly higher inhibition rate (50.00%) than strain HNR13 (39.47%). Both isolates successfully reduced fungal growth compared to the untreated control group.

Table 3 Inhibition rate of two strains HNR10 and HNR13 against *Colletotrichum* sp. and *Fusarium* sp.

Strains	**Inhibition rate (%) against *Colletotrichum* sp.**	**Inhibition rate (%) against *Fusarium* sp.**
HNR10	50.00 ^{a} ± 2.63	55.83 ^{a} ± 1.44
HNR13	39.47 ^{b} ± 0.00	55.00 ^{a} ± 2.50
Control	0.00 ^{c} ± 0.00	0.00 ^{b} ± 0.00

Means within a column followed by the same letters were not significantly different at α =0.05 using Duncan test.

When compared to existing literature, the baseline inhibition percentages recorded in this study were lower than those of certain highly specialized biocontrol agents. For instance, *Bacillus subtilis* strain gt11 and *Enterobacter soli* strain TH8 achieved inhibition rates of 73.57% [32] and 70.7% [33] against *Fusarium oxysporum*, respectively. Similarly, twelve distinct strains of *B. subtilis* exhibited inhibitory rates against *F. oxysporum* sp. *niveum* spanning 50.4% to 67.0%, though

isolates capable of exceeding a 50% inhibition threshold generally accounted for only 26.7% to 40.0% of the total screened populations [22, 32, 33].

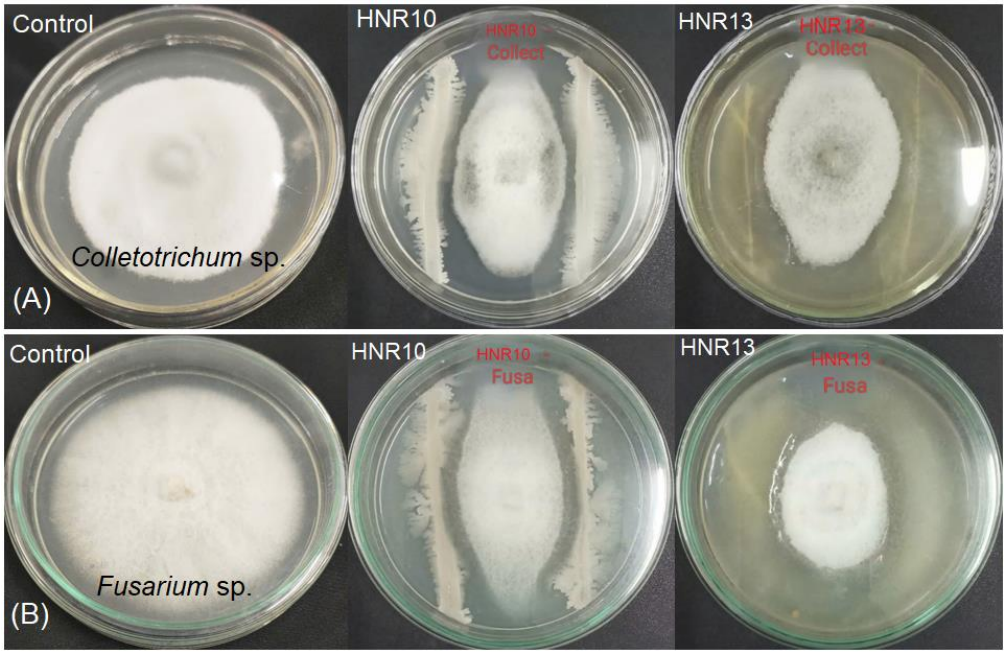


Figure 4 Ability to inhibit *Colletotrichum* sp. (A) and Fusarium sp. (B) of two strains HNR10 and HNR13

Regarding *Colletotrichum* suppression, *Bacillus siamensis* strain GP-P8 demonstrated robust inhibition rates against *C. acutatum* (78.5%), *C. dematium* (71.0%), and *C. coccodes* (82.0%) [34]. In another broad screening of 125 PGPR strains, only seven isolates (5.6%) exhibited resistance toward *C. acutatum*, led by strain AB15 (identified as *Paenibacillus polymyxa*) with a peak inhibition rate of 69.2% [35].

Although the inhibition rates observed in this study were lower than those reported for some specialized biocontrol strains, HNR10 and HNR13 exhibited a broad antagonistic spectrum against both *Fusarium* sp. and *Colletotrichum* sp.. Therefore, these two isolates, together with the highly chitinolytic and cellulolytic strain HNR27, were selected for taxonomic identification.

3.3. Results of identification of selected strains

Taxonomic identification of the three high-performing isolates (HNR10, HNR13, and HNR27) using the Bruker Daltonik MALDI-TOF mass spectrometry method yielded matches to *Lysinibacillus sphaericus*, *Alcaligenes faecalis*, and *Enterobacter bugandensis*, with score values of 2.00, 1.83, and 2.26, respectively. According to the method criteria, scores ≥ 2.00 provide highly reliable species-level identification, confirming the identities of strains HNR10 (*L. sphaericus*) and HNR27 (*E. bugandensis*). In contrast, strain HNR13 produced a score of 1.83, which supports reliable identification only at the genus level. Therefore, this isolate was assigned to Alcaligenes sp..

Enterobacter bugandensis is recognized for its broad environmental stress tolerance, encompassing drought resilience, halotolerance, and the bioaccumulation of toxic heavy metals like lead (Pb) and cadmium (Cd). For instance, *E. bugandensis* strain WRS7 can withstand severe drought conditions without exhibiting alterations in cellular morphology. Metabolic engineering approaches applied to this strain revealed key mechanisms for coping with oxidative and osmotic stress, providing a foundation for developing bio-inoculants tailored for drought-affected agricultural ecosystems [36]. Similarly, the halotolerance of *E. bugandensis* strain R-18, isolated from saline-alkaline soil, was shown to mitigate NaCl-induced stress in hydroponically grown maize (*Zea mays* L.). Strain R-18 tolerated a wide pH range (8.0–11.0) and survived at NaCl concentrations up to 10.0% while expressing multiple plant growth-promoting (PGP) traits, including nitrogen fixation, phosphate/potassium solubilization, ACC deaminase activity, and indole-3-acetic acid (IAA) biosynthesis. Inoculating maize with strain R-18 significantly enhanced plant height, stem dry weight, and root biomass by improving ionic balance, driving osmotic adjustment, and reducing oxidative stress [37]. Furthermore, *E. bugandensis* strain TJ6 was shown to reduce Cd and Pb accumulation in wheat tissue. This heavy-metal mitigation was achieved through direct bacterial absorption of the metals and the up-regulation of host plant root DNA

repair capacities, antioxidant activities, and endogenous hormone levels, supporting the application of metal-fixing bacteria in safe food production [38]. Despite its promising plant growth-promoting and stress-mitigation traits, *Enterobacter bugandensis* has also been reported as an opportunistic pathogen [17]. Therefore, comprehensive biosafety assessments should be conducted before its large-scale agricultural application.

Similarly, *Lysinibacillus sphaericus* is known for its heavy metal tolerance and biocontrol efficacy against insect larvae, such as mosquitoes. Seven evaluated *L. sphaericus* strains demonstrated nitrogen-fixing, nitrifying, and IAA-producing capabilities; among these, the four most effective strains promoted shoot length, root length, and leaf development in *Canavalia ensiformis* while enhancing root lead bioaccumulation by up to 40% under greenhouse conditions [39]. In another study, strains S2B and S3C, isolated from Sago palm trees, were identified as *L. sphaericus* and *Bacillus thuringiensis*, both exhibiting high IAA production, nitrogen fixation, and pronounced phosphate solubilization [40]. Furthermore, *Lysinibacillus fusiformis*, alongside *Alcaligenes faecalis* and *Bacillus cereus*, was evaluated as a seed inoculant for wheat cultivated under varying salinity levels (4, 6, and 9 dS m^{-1} EC) amended with biogas slurry. Rhizobacterial inoculation increased shoot and root lengths by up to 40% and 34%, respectively, with the combination of biogas slurry and *L. fusiformis* yielding the highest growth and crop yield under salt stress [41]. Because salt stress elevates harmful endogenous ethylene levels that stunt root development, deploying ACC deaminase-producing PGPR like *L. fusiformis*, *B. cereus*, and *A. faecalis* offers an effective strategy to regulate plant ethylene levels and restore growth in saline soils [42].

4. Conclusion

Rhizobacteria associated with *Pseuderanthemum palatiferum* (Nees) Radlk exhibited diverse capacities for organic matter degradation and fungal suppression, highlighting their potential contribution to nutrient cycling and plant health in the rhizosphere. Among the 27 isolates evaluated, HNR10, HNR13, and HNR27 demonstrated the most promising functional traits, combining strong hydrolytic activity and/or antifungal effects. These strains, identified as *Lysinibacillus sphaericus*, *Alcaligenes* sp., and *Enterobacter bugandensis*, respectively, represent potential candidates for the development of microbial inoculants for sustainable medicinal-plant cultivation. Further greenhouse and field evaluations, together with comprehensive biosafety assessments, are needed to verify their efficacy and biosafety under practical cultivation conditions.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

References

[1] Padee P. Current information of medicinal plants: *Pseuderanthemum palatiferum* (Nees) Radlk. Journal of Health Science. 2009; 18(1):131-138.

[2] Bich DH, Chung DQ, Chuong BX, Dong NT, Dam DT, Hien PV, Lo VN, Mai PD, Man PK, Nhu DT, Tap N, Toan T. Medicinal Plants and Medicinal Animals in Vietnam. Vol. 2. Hanoi: Science and Technology Publishing House; 2006.

[3] Dieu HK, Loc CB, Yamasaki S, Hirata Y. The effects of *Pseuderanthemum palatiferum*, a new medicinal plant, on growth performances and diarrhea of piglets. Japan Agricultural Research Quarterly. 2006; 40(1):85-91.

[4] Dieu HK. Study on acute and subacute toxicity of *Pseuderanthemum palatiferum* leaves. Can Tho University Journal of Science. 2009; (11B):173-178.

[5] Nguyen Tri Phuong Hospital. New discoveries in the medicinal compounds of the Hoan Ngoc plant [Internet]. Ho Chi Minh City: Nguyen Tri Phuong Hospital; 2016 [cited 2025 Apr 25]. Available from: https://bvnguyentriphuong.com.vn/y-hoc-co-truyen/phat-hien-moi-trong-duoc-chat-cua-cay-hoan-ngoc

[6] Vietnamese health. Characteristics, uses and 20 medicinal remedies of Hoan-Ngoc plant [Internet]. Hanoi: Suc Khoe Viet Magazine; 2023 Nov 22 [cited 2025 Apr 25]. Available from: https://suckhoeviet.org.vn/dac-diem-cong-dung-va-20-bai-thuoc-tri-benh-cua-cay-hoan-ngoc-9324.html

[7] Nga Tay Ninh. Clean Agriculture [Internet]. [cited 2025 Apr 25]. Available from: https://www.hoanngoc.vn/Nong-nghiep-sach-vnexpress--661.xtml

[8] Economy & Urban. Tam Lan Tea Company develops sustainable agriculture with green tourism [Internet]. [cited 2025 May 25]. Available from: https://kinhtedothi.vn/tra-tam-lan-phat-trien-nong-nghiep-ben-vung-gan-voi-du-lich-xanh.html

[9] Tay Ninh Provincial People's Committee. General information [Internet]. Tay Ninh: Tay Ninh Electronic Information Portal; [cited 2025 May 25]. Available from: https://www.tayninh.gov.vn/vi/page/GIOI-THIEU-CHUNG-53.html

[10] Ba LH, Quan NV. Research and evaluate the degradation of land environmental ecosystems, propose plans for reasonable use, resource recovery and sustainable development. [Internet]. EU-Vietnam Business Network; [cited 2026 Apr 22]. Available from: https://evbn.org/chuong-trinh-de-tai-khoa-hoc-nghien-cuu-danh-gia-su-suy-thoai-he-sinh-1680608009/

[11] Dang TNT, Ha BS, Chau KX. The ability of degrading protein, lipid, starch, chitin, and fungal inhibiting of rhizobacteria isolated from black pepper plants (*Piper nigrum* L.) cultivated in Chon Thanh district, Binh Phuoc province. Can Tho University Journal of Science. 2020;56(1B):95-103.

[12] Wang H, Liu R, You MP, Barbetti MJ, Chen Y. Pathogen biocontrol using plant growth-promoting bacteria (PGPR): Role of bacterial diversity. Microorganisms. 2021; 9(9):1988.

[13] Purnima, Singh P. Study on biocontrol aspect of potential *Alcaligenes faecalis* against *Fusarium* sp.: Concept and approach. Journal of Plant Biota. 2024; 3(1):34-36.

[14] Abdul Salam S, Parthiban VK, Paranidharan V, Johnson I, Karthikeyan M, Kavitha C. *Alcaligenes faecalis* strain SASBG203: A novel biocontrol agent against *Colletotrichum orbiculare*. Annals of Phytomedicine. 2022; 11(1):714-723.

[15] Pantoja-Guerra M, Burkett-Cadena M, Cadena J, Dunlap CA, Ramirez CA. *Lysinibacillus* spp.: An IAA-producing endospore forming-bacteria that promotes plant growth. Antonie van Leeuwenhoek. 2023; 116:615-630.

[16] Jha CK, Aeron A, Patel BV, Maheshwari DK, Saraf M. Enterobacter: Role in plant growth promotion. In: Maheshwari DK, editor. Bacteria in Agrobiology: Plant Growth Responses. Berlin, Heidelberg: Springer; 2011. p. 159-182.

[17] Jordan S, de Maayer P, Smits THM, Coutinho TA. *Enterobacter* species: Opportunistic human and plant pathogens with plant-beneficial traits. Molecular Plant Pathology. 2026; 27(3): e70231.

[18] Sokol PA, Ohman DE, Iglewski BH. A more sensitive plate assay for detection of protease production by *Pseudomonas aeruginosa*. Journal of Clinical Microbiology. 1979; 9 (4):538-540.

[19] Geetha K, Venkatesham E, Hindumathi A, Bhadraiah B. Isolation, screening and characterization of plant growth promoting bacteria and their effect on *Vigna radiata* (L.) R. Wilczek. Int J Curr Microbiol App Sci. 2014;3(6):799-809.

[20] Hsu SC, Lockwood JL. Powdered chitin agar as a selective medium for enumeration of actinomycetes in water and soil. Appl Microbiol. 1975;29(3):422-426.

[21] Teather RM, Wood PJ. Use of Congo red-polysaccharide interactions in enumeration and characterization of cellulolytic bacteria from the bovine rumen. Appl Environ Microbiol. 1982;43(4):777-780.

[22] Zhu J, Tan T, Shen A, Deng X, Ali S, Hafeez R, et al. Biocontrol potential of *Bacillus subtilis* IBFCBF-4 against Fusarium wilt of watermelon. J Plant Pathol. 2020;102(2):433-441. doi: 10.1007/s42161-019-00457-z

[23] Castronovo LM, Vassallo A, Mengoni A, Miceli E, Bogani P, Firenzuoli F, Fani R, Maggini V. Medicinal plants and their bacterial microbiota: A review on antimicrobial compounds production for plant and human health. Pathogens. 2021; 10(2):106.

[24] Bharucha UD, Patel KC, Trivedi UB. In vitro screening of isolates for its plant growth promoting activities from the rhizosphere of Alfalfa (*Medicago sativa*). Journal of Microbiology and Biotechnology Research. 2013; 3(5):79-88.

[25] El-Sayed WS, Akhkha A, El-Naggar MY, Elbadry M. In vitro antagonistic activity, plant growth promoting traits and phylogenetic affiliation of rhizobacteria associated with wild plants grown in arid soil. Frontiers in Microbiology. 2014; 5:651.

[26] Dutta J, Thakur D. Evaluation of multifarious plant growth promoting traits, antagonistic potential and phylogenetic affiliation of rhizobacteria associated with commercial tea plants grown in Darjeeling, India. PLoS One. 2017; 12(8):e0182302.

[27] Fahmy H, Zohri AEA, Mohamed GE, Hafez E. Sugar beet is a suitable source for cellulase-producing bacteria and actinomycetes. Egyptian Sugar Journal. 2022; 18:40-52.

[28] Vo VPQ, Cao ND. Isolation and identification of cellulolytic bacteria. Can Tho University Journal of Science. 2011; 18A:177-184.

[29] Choubane S, Cheba BA, Benourrad A. Screening and phenotypic diversity of amylase producing rhizospheric bacteria from some North African plants. Procedia Technology. 2016; 22:1197-1204.

[30] Azman NA, Sijam K, Hata EM, Othman R, Saud HM. Screening of bacteria as antagonist against *Xanthomonas oryzae* pv. *oryzae*, the causal agent of bacterial leaf blight of paddy and as plant growth promoter. Journal of Experimental Agriculture International. 2017; 16(4):1-15.

[31] Nguyen TL, Nguyen TYN, Tran TXM, Nguyen TP. Isolation and selection of rhizosphere bacteria from chili pepper roots with antagonistic activity against *Colletotrichum* sp. causing anthracnose disease in chili pepper. Can Tho University Journal of Science. 2016; 47B:16-23.

[32] Yao X, Lan X, Jin Y, Li C. Screening, identification, and characterization of plant growth-promoting rhizobacterium strains from alpine grassland as biocontrol agents against *Fusarium oxysporum*. Agronomy. 2024; 14(12):2856.

[33] Do TTT, Dang TNT, Hoang MT. Characterization of phosphate and potassium solubilization, and antifungal activity of bacteria isolated from rhizosphere of *Allium ascalonicum* (L.) grown in Ninh Hai district, Ninh Thuan province, Vietnam. World Journal of Advanced Research and Reviews. 2023; 17(3):18-27.

[34] Woo JM, Kim HS, Lee IK, Byeon EJ, Chang WJ, Lee YS. Potentiality of beneficial microbe *Bacillus siamensis* GP-P8 for the suppression of anthracnose pathogens and pepper plant growth promotion. The Plant Pathology Journal. 2024; 40(4):346-357.

[35] Lamsal K, Kim SW, Kim YS, Lee YS. Application of rhizobacteria for plant growth promotion effect and biocontrol of anthracnose caused by *Colletotrichum acutatum* on pepper. Mycobiology. 2012; 40(4):244-251.

[36] Arora S, Babele PK, Jha PN. Biochemical and metabolic signatures are fundamental to drought adaptation in PGPR *Enterobacter bugandensis* WRS7. Molecular Omics. 2023; 19(8):640-652.

[37] Tian X, Liu Q, Song J, Zhang X, Yang G, Li M, Qu H, Tastanbek A, Tan Y. Effect of *Enterobacter bugandensis* R-18 on maize growth promotion under salt stress. Microorganisms. 2025; 13(8):1796.

[38] Han H, Zhang H, Qin S, Zhang J, Yao L, Chen Z, Yang J. Mechanisms of *Enterobacter bugandensis* TJ6 immobilization of heavy metals and inhibition of Cd and Pb uptake by wheat based on metabolomics and proteomics. Chemosphere. 2021; 276:130157.

[39] Martinez SA, Dussan J. *Lysinibacillus sphaericus* plant growth promoter bacteria and lead phytoremediation enhancer with *Canavalia ensiformis*. Environmental Progress & Sustainable Energy. 2018; 37:276-282.

[40] Lihan S, Benet F, Husaini AASA, Apun K, Roslan HA, Hassan H. Isolation and identification of plant growth promoting rhizobacteria from sago palm (*Metroxylon sagu*, Rottb.). Tropical Life Sciences Research. 2021; 32(3):39-51.

[41] Zafar-Ul-Hye M, Yaseen R, Abid M, Abbas M, Ahmad M, Ahmad Rahi A, Danish S. Rhizobacteria having ACC-deaminase and biogas slurry can mitigate salinity adverse effects in wheat. Pakistan Journal of Botany. 2022; 54(1):297-303.

[42] Zafar-Ul-Hye M, Yaseen R, Akbar MN, Asghar H. Mitigating the effect of salinity stress through integrated application of ACC-deaminase containing rhizobacteria and biogas slurry to improve the productivity of wheat crop. Merit Research Journal of Agricultural Science and Soil Sciences. 2020; 8(5):72-81.