J.Mycopathol.Res. 64(2) : 453-461, 2026, ISSN : 0971-3719 (Print), 2583-6315 (Online)
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University of Calcutta, Kolkata 700 019, India

doi.10.57023/JMycR.64.2.2026.453

Enzyme production, plant growth promotion, and antifungal activity of endophytic fungi isolated fromthe medicinal plant *Eclipta prostrata* from Manipur

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Received : 01.05.2026 Accepted : 30.05.2026 Published : 29.06.2026

Endophytic fungi from medicinal plants are a potential source of bioactive compounds with various agricultural and industrial applications. In this study, five different species of endophytic fungi, viz., *Aspergillus* sp. *Colletotrichum* sp., *Curvularia* sp., *Mucor* sp., and *Penicillium* sp. were isolated from the stem segments of the ethnomedicinal plant *Eclipta prostrata* and evaluated for their characteristics in plant growth promotion activities, enzyme production, and antifungal properties. All the isolates producedammonia, lipase, protease, and cellulase, while*Aspergillus* sp. and *Penicillium* sp. were shown to solubilise phosphate. Hydrogen cyanide was produced by *Aspergillus* sp., *Colletotrichum* sp., and *Mucor* sp. The production of laccase was noted in *Colletotrichum* sp., *Curvularia* sp. and *Penicillium* sp. The antifungal activity of the isolated endophytic fungi was assessed using the petriplate dual culture method against economically important phytopathogens. *Mucor* sp. has shown the highest inhibition against *N. oryzae* (93.59%). The findings show that the endophytic fungi from *E. prostrata* have biotechnological potential.

Keywords : Antifungal, *E. prostrata*, endophytic fungi, ethnomedicine, extracellular enzymes,

INTRODUCTION

Endophytic fungi are microfungi that inhabit the internal tissue of living plants without causing any noticeable disease symptoms. They help protect their host from pathogenic microorganisms by competing for habitat and food supplies. Endophytic fungi can protect their host plants by producing toxic compounds that make the host unpalatable to them.A large number of endophytic fungi with important biological applications are associated with ethnomedicinal plants (Hashem *et al.* 2023).

Eclipta prostrata (L.) L. of the Asteraceae family has been used in traditional medicinal practices since ancient times, especially by Ayurveda, Chinese medicine, Siddha and Unani, to treat a range of ailments (Timalsina and Devkota, 2021). Numerous investigations have exhibited the ability of endophytic fungi to synthesise compounds that promote plant growth and wellness, similar to those generated by their host plants (Wijesekara and Xu, 2023). Studies reveal that the production of phytohormones has been recorded in endophytic fungi, such as indole-3-acetic acid, indole-3-acetonitrile, cytokinins and gibberellins which could stimulate crop growth and ameliorate the harmful impact of abiotic stress (Younas and Younas, 2025).

Endophytic fungi have been shown to produce a wide variety of extracellular enzymes.These fungi are able to penetrate their hosts with the aid of hydrolysing enzymes such as amylase, pectinase, and others. The detoxification and remediation of industrial and agricultural waste are gaining steady interest through the bioremediation process involving the enzymatic systems of endophytic fungi. They are also employed in food manufacturing and beverage

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industries extensively to prolong the shelf-life and preserve them without having an impact on nutrition (Kaur and Gill, 2019). Besides, they are also used in leather, paper, textiles, and other industries (Naik *et al.* 2019). Fungal enzymes can also be used as a powerful antimicrobial agent (Kango *et al.* 2019). Natural compounds obtained from endophytic fungi interfere with or destroy a wide array of harmful microorganisms, including bacteria, fungi, viruses, and protozoa by disrupting cellular activities. Due to these characteristics, they are good candidates for biofungicides, biopesticides, and antibiotics. In the last few decades, it has been observed that the global market of microbial inoculants, which can serve as biocontrol agents, has expanded.Various researchers have isolated compounds possessing effective antifungal properties from endophytic fungi of different host plants, including pentaketides, xylarosides, trichothecenes, cytosporone B and C, cryptocin, and ambuic acid (Adeleke and Babalola, 2021; Saxena *et al.* 2024). In the present study, endophytic fungi were isolated from *E. prostrata* stems and evaluated for their ability to promote plant growth, enzyme production, and their antifungal properties.

MATERIALS AND METHODS

Collection of Plant Samples

E. prostrata plants were collected from Yairipok, Imphal East district, Manipur. Sterile polyethylene bags were employed for the transportation of the samples to the laboratory. To prevent contamination the samples were processed within 12 hours.

Isolation of endophytic fungi

The endophytic fungi were isolated from the stem parts of *E. prostrata* using standard protocol proposed by Chand *et al.* (2020). Surface-sterilising agents were ethanol (70%) and sodium hypochlorite solution (4%), which were allowed to remain in for 3 minutes and 2 minutes, respectively. The surface-sterilized leaf segments (5 mm) were placed on petriplates of potato dextrose agar (PDA)with the broad-spectrum antibiotic streptomycin sulfate (200 mg/L) and were cultured at 28 ± 1^{0}C for 5–7 days. The fungal colonies formed around the leaf segments were then pure cultured.

Identification of endophytic fungi

Conventional identification methods based on morphological features were used which included colony colour, shape, texture, sporulating structures and growth characteristics (Watanabe, 2010). The isolates were deposited at the National Fungal Culture Collection of India (NFCCI), Pune.

Plant growth promotion activities - Qualitative

The endophytic fungal isolates were tested for their phosphate (PO_4) solubilization, ammonia (NH_4) production and hydrogen cyanide (HCN) production ability. Each test was replicated three times.

Phosphate (PO_4) solubilization assay

Inorganic phosphate solubilization was evaluated by Pikovskaya's agar medium which was supplemented with calcium phosphate. The petriplates were inoculated with the fungal endophytes and kept at 27 ± 1 °C for 7 days. The observation of clear zone around the fungal culture suggests PO_4 solubilization (Ripa *et al.* 2019).

Ammonia (NH_4) production assay

Fungal endophytes were tested for their ammonia production in peptone water. Freshly grown fungal cultures were placed in 10mL of peptone water in each tube and these tubes were incubated at 28 ± 1 °C for 72 hours. Then 0.5 mL of Nessler's reagent was pipetted into each tube. The development of a brown to yellow colour indicates the production of NH_4 (Khalil *et al.*2021).

Hydrogen cyanide (HCN) assay

The isolates were transferred to the test tubes containing the Bennett agar supplemented with 4.4 g/L of glycine. A sample of picric acid (0.5%) in sodium carbonate (2%) solution was applied to Whatman filter paper for 1 minute, the length of which was 4 cm each. The filter paper was then inserted into the test tubes and incubated 28 ± 1 °C. Production of HCN was detected when a brown to red colour appeared on the filter paper after 10 days of incubation (Potshangbam *et al.* 2017).

Extracellular enzyme production activities - Qualitative

For the enzyme production assay endophytic fungi were cultured for 5 days at 28 ± 1 °C on appropriate substrate containing culture media for protease, lipase, amylase, cellulase, and laccase (Sunitha *et al.* 2013; Sopalun and Iamtham, 2020). Each experiment was repeated three times.

Protease Activity

Skim milk was added to the glucose yeast peptone (GYPA) medium to determine the production of proteases. The endophytic fungi were cultured and the formation of a clear zone around the colony was recorded.

Lipase Activity

The endophytes were inoculated onto Peptone Agar (PA) medium containing Tween 20. The presence of a clear zone around the colony indicated lipase production.

Amylase Activity

The endophytic fungi was placed on the GYPA medium with 1% soluble starch. After incubation, the culture plate was flooded with 1% iodine solution and a clear zone around the colony was observed.

Cellulase Activity

The isolates were inoculated onto GYPA medium containing carboxymethyl cellulose (CMC). The plates were then stained by Congo Red Solution and de-stained by NaCl (1M) solution for 15 minutes each and then incubated. Secretions of cellulase was confirmed because of the yellow colour zone around the endophyte colony.

Laccase Activity

The production of laccase was tested by inoculating fungal endophytes on GYPA media with 1-naphthol. The activity of laccase was estimated from the colour change of the medium to blue/purple after the incubation period.

Antifungal Activity

The dual culture method as described by Nongthombam *et al.* (2024) was used to test the antifungal activity. The plant pathogens used were *Fusarium oxysporum* (ITCC 4998), *Nigrospora oryzae* (ITCC 7884), and *Colletotrichum capsici* (ITCC 6078). The culture plugs were prepared and cultured for 7 days for endophyte and pathogens separately, then at 6 cm distance between each other on a petri plate and cultured at 28±1 °C. Antagonistic percentage inhibition (I%) was determined after 7th and 10th day of incubation, using the formula $I\%=[(R_1 - R_2)] \times 100$; where R_1 is the growth of pathogens in the control plate and R_2 is the growth in the dual culture plate. Each test was repeated three times.

RESULTS AND DISCUSSION

Identification of endophytic fungi

Five endophytic fungi were isolated from the stem segments of *E. prostrata*. Morphologically, they were identified as *Aspergillus* sp., *Colletotrichum* sp., *Curvularia* sp., *Mucor* sp., and *Penicillium* sp. (Fig.1). These endophyte isolates belong to the phylum Ascomycota, indicating that the *E. prostrata* stem is rich in ascomycetous fungi.

Aspergillus spp. and *Penicillium* spp. are common endophytes that are found throughout a variety of agro-ecosystems and in different parts of the plant, such as leaves, stems, and petioles (Chauhan *et al.* 2019; Majhi *et al.* 2025). This prevalence highlights their importance in the ecology as plant symbionts, where *Aspergillus* species make up a significant percentage of isolated endophytes. *Aspergillus* spp., and in particular *Aspergillus niger*, have also been found as the dominant species in other studies of endophytic fungi from plants in dry environments (Mohamed *et al.* 2021). Other common genera are also often found as endophytes, such as *Alternaria*, *Fusarium*, and *Phoma*. In addition, Ascomycota is abundant in the endosphere of plants, accounting for more than 95% of all the recorded population (Rungjindamai and Jones,

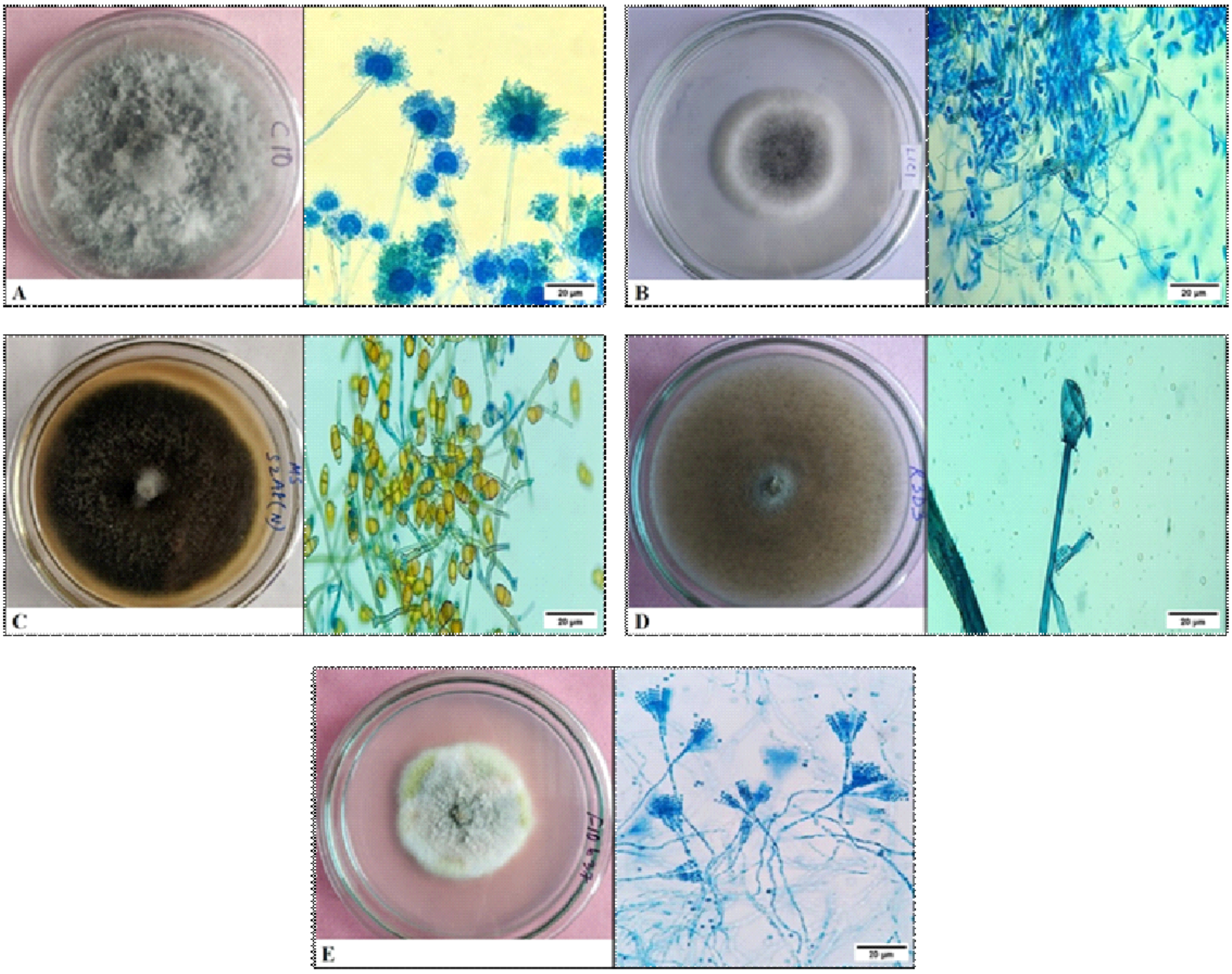


Fig 1 : Morphological identification of endophytic fungi isolated from E. prostrata (A) *Aspergillus* sp., (B) *Colletotrichumn* sp., (C) *Curvularia* sp., (D) *Mucor* sp., and (E) *Penicillium* sp.

2024; Yao *et al.* 2026). The ability to produce resilient ascospores is thought to be the reason for this dominance, as it enables them to survive the antagonistic microbial activity in fluctuating environments. Furthermore, genera like *Colletotrichum*, *Fusarium*, and *Cladosporium* are commonly isolated from the different tissues of a wide range of host plants, indicating their ubiquitous colonisation of different host tissues, and supporting the idea that these are highly adaptable and versatile fungi (Shetty *et al.* 2016). In addition to their taxonomic diversity, these fungal endophytes are becoming a major source of bioactive secondary metabolites that have great pharmaceutical potential.

Plant growth promotion activities

The endophytic fungal isolates from *E. prostrata* are found to possess potential plant growth-enhancing properties. All five endophytic fungi produce ammonia. Phosphate solubilisation was observed in *Aspergillus* sp. and *Penicillium* sp., and hydrogen cyanide was produced by *Aspergillus* sp., *Colletotrichum* sp., and *Mucor* sp. (Table 1).

The ability to solubilise inorganic phosphate and ammonia production is important for nutrient availability and growth of the plant. One of the ways in which endophytes can release organic phosphates is by producing organic acids such as malic, gluconic, and citric acids (Dezam *et al.* 2017). Moreover, these metabolites enhance the resilience of plants by inhibiting the cellular respiration of pathogens and creating an imbalance in their cytochrome system. These endophytic fungal isolates not only suppress pathogens in direct contact but also help in the vegetative development by mineralising nutrients

Table 1. Qualitative analysis for extracellular enzyme production and plant growth promotion abilities of endophytic fungi from *E. prostrata*.

Endophytic fungi	Enzyme production					Growth promotion		
	Protease	Lipase	Amylase	Cellulase	Laccase	NH_4	PO_4	HCN
Aspergillus sp.	+	+	+	+	-	+	+	+
Colletotrichum sp.	+	+	+	+	+	+	-	+
Curvularia sp.	+	+	+	+	+	+	-	-
Mucor sp.	-	+	+	+	-	+	-	+
Penicillium sp.	+	+	+	+	+	+	+	-

'+' indicates presence; '-' indicates absence

Table 2. Antagonistic inhibition percentage (I%) of endophytic fungi from *E. prostrata* against three phytopathogens.

Endophytic fungi	Growth inhibition percentage (I%)					
	Colletotrichum capsici		*Fusarium oxysporum*		*Nigrospora oryzae*	
	Day 7	Day 10	Day 7	Day 10	Day 7	Day 10
Aspergillus sp.	39.65±0.23	64.31±0.18	33.52±0.72	59.33±0.32	28.11±0.55	67.42±0.38
Colletotrichum sp.	35.33±0.21	61.54±0.08	31.67±0.09	54.37±0.45	52.08±0.18	81.29±0.21
Curvularia sp.	26.71±0.09	48.45±0.16	23.32±0.45	55.12±0.23	21.85±0.08	49.37±0.32
*Muc*or sp.	32.37±0.27	65.61±0.45	38.15±0.21	70.15±0.38	60.55±0.72	93.59±0.38
Penicillium sp.	41.28±0.38	62.42±0.05	23.90±0.16	56.87±0.46	34.05±0.29	49.62±0.45

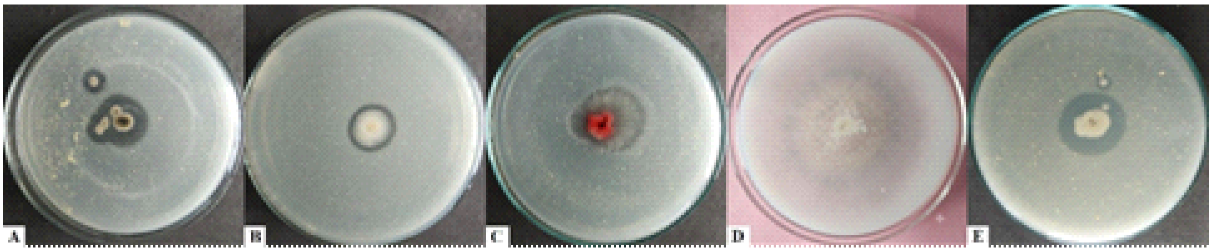
Data are means of inhibition percentage (triplicate) ± standard deviation (SD)

and solubilising insoluble phosphorus in the rhizosphere (Huong *et al.*2022). This metabolic potential disrupts the cytochrome balance and inhibits the cellular respiration of the phytopathogens. This mechanism of action of hydrogen cyanide may be used as a biological control agent, which is an eco-friendly alternative to chemical pesticides for diseases. HCN is a broad-spectrum antimicrobial substance that inhibits the growth of many plant pathogens, most notably *Thielaviopsis basicola*, *Pythium ultimum*, and *Fusarium oxysporum*(Pereg and McMillan, 2015). It disintegrates cellular structures of pathogens, leading to lysis of hyphae and inhibition of spore growth. The synthesis of hydrogen cyanide by fungal endophytes has been linked with systemic resistance induction in the host plant that serves as a multi-pronged defence against other phytopathogens.

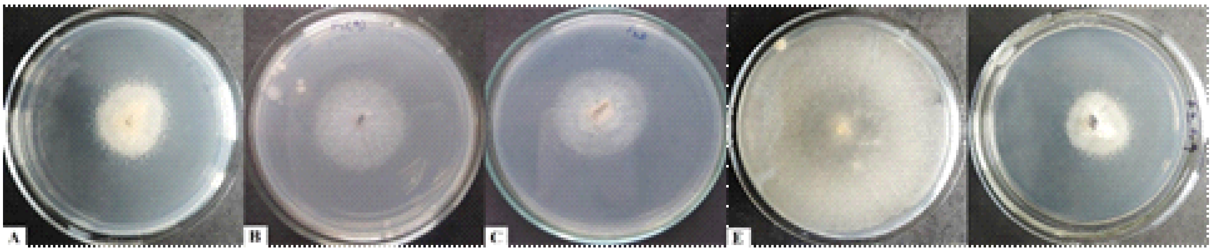
Extracellular enzyme production activities

The endophytic fungi in this study are observed to be good producers of extracellular enzymes.The enzymes, lipase, amylase, and cellulase were produced by all the tested endophytic fungi; protease was produce by *Aspergillus* sp., *Curvularia* sp., and *Penicillium* sp.; laccase was produced by *Colletotrichum* sp., *Curvularia* sp., and *Penicillium* sp. (Table 1, Fig. 2).

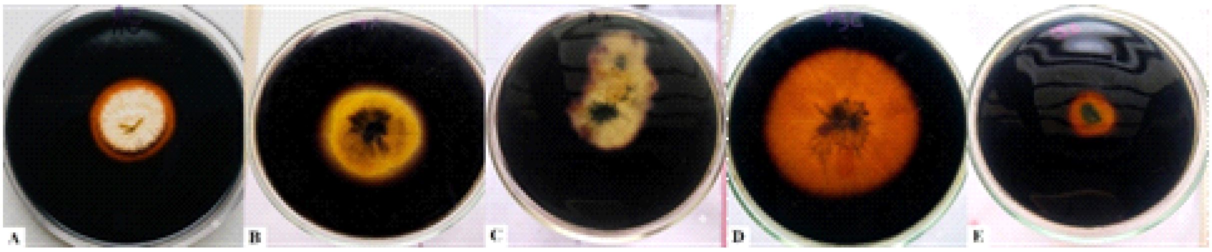
The variability in enzyme activity suggests functional diversity among endophytic fungi and



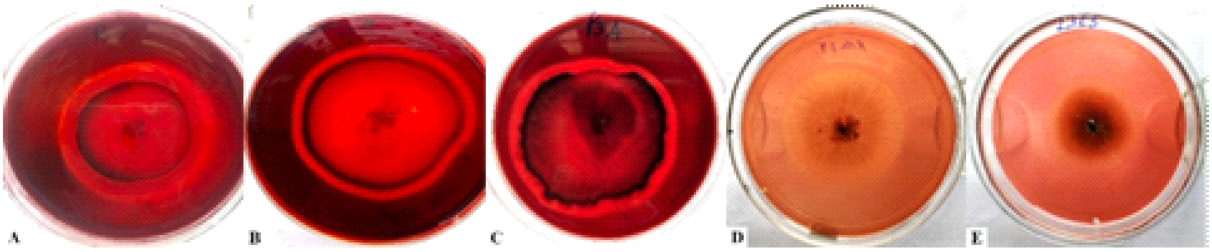
PROTEASE ACTIVITY



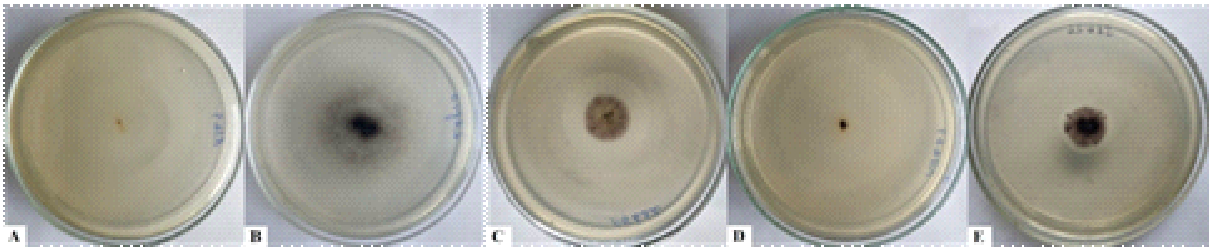
LIPASE ACTIVITY



AMYLASE ACTIVITY



CELLULASE ACTIVITY



LACCASE ACTIVITY

Fig 2 : Extracellular enzyme production activity of endophytic fungi from *E. Prostrata*, (A) *Aspergillus* sp., (B) *Colletotrichum* sp., (C) *Curvularia* sp., (D) *Mucor* sp., and (E) *Penicillium* sp.

indicates different ecological roles and potential industrial applications.The ability of enzymes to break down the polysaccharides of the host enables the endophytes to gain nutrients for their colonisation. In addition, the excretion of hydrolytic enzymes is used as a defence against the pathogen by changing the microenvironment of the host plant. Apart from their ecological role in host-symbiont interaction, owing to the stability and efficacy of these hydrolytic enzymes, they are also of industrial interest in textile, food, and other processes (Darwish *et al.* 2024). Moreover, they produce a variety of enzymes, like amylases, so they can be used to modify starch and agricultural wastes. Mishra *et al.* (2019) demonstrated that *Penicillium* spp. and *Colletotrichum* spp.synthesise protease, lipase, amylase, cellulase and laccase simultaneously. Several studies have identified endophyte genera capable of secreting proteases, for example, *Alternaria* spp., *Cladosporium* spp., *Phoma* spp., *Penicillium* spp., and various isolates from *Nigella sativa* L. exhibit substantial proteolytic activity (Gopane *et al.* 2024). *Fusarium* sp., *Penicillium* sp., *Aspergillus* sp., *Talaromyces* sp., and *Pestalotiopsis* sp. represent some endophytic genera that are high-yield producers of lipases, a crucial property for such applications (Kumar *et al.* 2023). The endophytic fungal genera *Penicillium*, *Aspergillus*, *Fusarium*, *Cochliobolus*, *Diaporthe*, and *Phoma* sp. have proven to be effective agents in producing amylase and show promising amylolytic potential, making them useful for industrial starch modification (Patil *et al.* 2022). Moreover, other studies have reported the ability of some endophytic genera to produce laccases for the breakdown of lignin and other bioremediation for industrial purposes (Mattooand Nonzom, 2022). For instance, *Cladosporium tenuissimum*and *Trichoderma harzianum*are significant laccase producers (Salem *et al.* 2024).These laccases are now used in the treatment of complex industrial wastewater and the clean-up of toxic phenolic wastes (Unuofin *et al.* 2019).

Antifungal activity

All the endophytic fungi have shown moderate to strong antifungal inhibition against the tested pathogens. Their inhibition activity increases with increasing incubation period. Highest inhibition was shown by *Mucor* sp. against *N. oryzae* (93.59%) and lowest inhibition by *Curvularia* sp. against *C. capsici* (48.45%) (Table2).

The differential efficacy may be due to the unique metabolism and diverse bioactive compounds produced by different endophytic fungal isolates, affecting the primary cellular metabolism of pathogens differently. In addition to their antimicrobial action, these metabolites often cause morphological anomalies in the fungal hyphae, such as distorted tips and cytoplasmic leakage, which help in inhibiting the growth of the disease-causing agents (Manathunga *et al.* 2024). Besides, in most cases, antibiosis, competition for nutrients, and direct parasitism are mechanisms most often responsible for effective interactions against latent pathogens. The production of bioactive substances and the secretion of extracellular enzymes highlight a multifaceted strategy for biological control that would allow their assessment through dual culture assays measuring the capacity of inhibition. Many species of *Trichoderma* and *Fusarium* are reported to be effective antagonistic species and show strong inhibiting power against a wide range of agricultural pathogens (Toghueo, 2020; Rajani *et al.* 2021). Research into the *Phoma* and *Xylaria* genera has similarly reported more potential biocontrol candidates (Rai *et al.* 2020; Meshram and Nischitha, 2025). The dual culture assay is a foundational method for rapidly and quantitatively assessing direct antimicrobial activity. It allows researchers to measure the inhibition of radial growth in an efficient, high-throughput way while facilitating the analysis of antagonistic interactions between endophytes and target pathogens. It has been established that *Mucor lusitanicus* has good biocontrol capacity as it inhibits the *Fusarium oxysporum* and *Alternaria solani* with the secretion of bioactive compounds (Alejandre-Castañeda *et al.* 2023). According to a research, this antagonism has been related to the production of the siderophore rhizoferrin (Dhuldhaj and Pandya, 2021). The benefit of utilising endophytes is that they are adapted to their plant environments and can continue to survive without harming the plant host. They are therefore potential candidates for developing bioformulations for plant disease management.

CONCLUSION

This study reveals that endophytic fungi are associated with the *E. prostrata* stem part. The use of the dual culture method effectively demonstrated the antagonistic potential of the isolated endophytic fungi. These findings not only enhance our understanding of plant- microbe interactions but also open up new avenues for the development of eco-friendly biocontrol agents and therapeutic compounds. Findings from our study highlight the importance of metabolomic profiling to identify the specific secondary metabolites responsible for these antagonistic activities, which could lead to their development as sustainable agrochemicals. Future investigations should focus on the activation of silent biosynthetic gene clusters that could be synthesised through co-culture technology to produce effective antimicrobial compounds. The endophytic fungal isolates should also be screened *in vivo* for their performance under different environmental conditions in order to establish their efficacy and safety for field application on a large scale. The application of advanced, next-generation sequencing will help understand the genetic variations and functional heterogeneity of those communities to enhance their biocontrol potential. Lastly, the identification of bioactive compounds produced by these fungi is necessary for the development of reliable, sustainable biocontrol measures for global food security.

DECLARATION

Conflictof Interest.Authors declare no conflict of interest in this research.

REFERENCES

Adeleke, B. S., Babalola, O. O. 2021. Pharmacological potential of fungal endophytes associated with medicinal plants: A review. *J. Fungi* **7:**147. https://doi.org/10.3390/jof7020147

Alejandre-Castañeda, V., Patiño-Medina, J. A., Guzman-Perez, J. B., Valle-Maldonado, M. I., Villegas, J., Solorio-Alvarado, C. R., Ruiz-Herrera, L.F., Ortiz-Alvarado, R., Macías-Sánchez, K., Ramírez-Díaz, M.I., Meza-Carmen, V. 2023. Role of the nonribosomal peptide synthetase siderophore enzyme (Rfs) of *Mucor lusitanicus* in controlling the growth of fungal phytopathogens. *Can. J. Microbiol.* **69**: 185-198. https://doi.org/10.1139/cjm-2022-0203

Chand, K., Shah, S., Sharma, J., Paudel, M. R., Pant, B. 2020. Isolation, characterization, and plant growth-promoting activities of endophytic fungi from a wild orchid *Vanda cristata*. *Plant Signal.Behav.***15**: 1744294. https://doi.org/10.1080/15592324.2020.1744294

Chauhan, N. M., Gutama, A. D., Aysa, A. 2019. Endophytic fungal diversity isolated from different agro-ecosystem of Enset (*Ensete ventericosum*) in Gedeo zone, SNNPRS, Ethiopia. *BMC Microbiol.* **19**: 172. https://doi.org/10.1186/s12866-019-1547-y

Darwish, A. M., Balbool, B.,Nouh, F. A. A. 2024. Industrially important enzymes of endophytic fungi. In: *Endophytic Fungi* (pp. 157-179). Academic Press. https://doi.org/10.1016/B978-0-323-99314-2.00014-0

Dezam, A. P. G., Vasconcellos, V. M., Lacava, P. T.,Farinas, C. S.2017. Microbial production of organic acids by endophytic fungi. *Biocatal. Agricult. Biotechnol.* **11**282-287. https://doi.org/10.1016/j.bcab.2017.08.001

Dhuldhaj, U.,Pandya, U. 2021. Diversity, function, and application of fungal iron chelators (Siderophores) for integrated disease management. In: *Role of microbial communities for sustainability* (pp. 259-288). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-15-9912-5_10

Gopane, B., Tchatchouang, C. D. K., Regnier, T., Ateba, C. N.,Manganyi, M. 2024. Bioactivity and enzymatic properties of culturable endophytic fungi associated with black seeds (*Nigella sativa* L.). *J. Appl. Pharmaceut. Sci.* **14**: 102-110.

Hashem, A. H., Attia, M. S., Kandil, E. K., Fawzi, M. M., Abdelrahman, A. S., Khader, M. S., Khodaira, M.A., Emam, A.E., Goma, M.A.,Abdelaziz, A. M. (2023). Bioactive compounds and biomedical applications of endophytic fungi: a recent review. *Microbial Cell Factories* **22**: 107. https://doi.org/10.1186/s12934-023-02118-x

Huong, N. T. M., Hoai, P. T. T., Thao, P. T. H., Huong, T. T.,Chinh, V. D. 2022. Growth stimulation, phosphate resolution, and resistance to fungal pathogens of some endogenous fungal strains in the rhizospheres of medicinal plants in Vietnam. *Molecules* **27**: 5051. https://doi.org/10.3390/molecules27165051

Kango, N., Jana, U. K.,Choukade, R. 2019. Fungal enzymes: sources and biotechnological applications. In: *Advancing Frontiers in Mycology &Mycotechnology: Basic and Applied aspects of fungi* Singapore: Springer Singapore.pp. 515-538. https://doi.org/10.1007/978-981-13-9349-5_21

Kaur, H., Gill, P. K. 2019. Microbial enzymes in food and beverages processing. In: *Engineering tools in the Beverage Industry* .Woodhead Publishing. (pp. 255-282). https://doi.org/10.1016/B978-0-12-815258-4.00009-3

Khalil, A. M. A., Hassan, S. E. D., Alsharif, S. M., Eid, A. M., Ewais, E. E. D., Azab, E., Gobouri, A.A., Elkelish, A.,Fouda, A. 2021. Isolation and characterization of fungal endophytes isolated from medicinal plant *Ephedra pachyclada* as plant growth-promoting. *Biomolecules* **11**: 140. https://doi.org/10.3390/biom11020140

Kumar, A., Verma, V., Dubey, V. K., Srivastava, A., Garg, S. K., Singh, V. P.,Arora, P. K. 2023. Industrial applications of fungal lipases: a review. *Front. Microbiol.* **14:** 1142536. https://doi.org/10.3389/fmicb.2023.1142536

Majhi, P., Pradhan, U., Toppo, A., Shukla, A. K. 2025. Fungal endophytes: An insight into diversity, stress tolerance, biocontrol and plant growth-promoting potentials. *Curr. Microbiol.* **82**: 283. https://doi.org/10.1007/s00284-025-04266-2

Manathunga, K. K., Gunasekara, N. W., Meegahakumbura, M. K., Ratnaweera, P. B., Faraj, T. K.,Wanasinghe, D. N. (2024). Exploring endophytic fungi as natural antagonists against fungal pathogens of food crops. *J. Fungi***10**: 606. https://doi.org/10.3390/jof10090606

Mattoo, A. J.,Nonzom, S. 2022. Endophytes in lignin valorization: A novel approach. *Front. Bioengineer. Biotechnol.***10**: 895414. https://doi.org/10.3389/fbioe.2022.895414

Meshram, P. A., Nischitha, R. 2025. Harnessing the bioactive potential of endophytic *Xylaria* species: a comprehensive review on natural drug discovery and biotechnological applications. *Physiol. Mol. Plant Pathol.***140**: 102963. https://doi.org/10.1016/j.pmpp.2025.102963

Mishra, R., Kushveer, J. S., Revanthbabu, P., & Sarma, V. V. (2019). Endophytic fungi and their enzymatic potential. In: *Advances in Endophytic fungal research: Present status and future challenges*. Cham: Springer International Publishing, pp. 283-337. https://doi.org/10.1007/978-3-030-03589-1_14

Mohamed, A. H., Balbool, B. A., Abdel-Azeem, A. M. 2021. *Aspergillus* from different habitats and their industrial applications. In: *Industrially Important Fungi for Sustainable Development: Volume 1: Biodiversity and Ecological Perspectives* Cham: Springer International Publishing, pp. 85-106.https://doi.org/10.1007/978-3-030-67561-5_3

Naik, S.. B., Abrar, S., Krishnappa, M. 2019. Industrially important enzymes from fungal endophytes. *Recent Advancement in White Biotechnology Through Fungi: Volume 1: Diversity and Enzymes Perspectives*, 263-280. https://doi.org/10.1007/978-3-030-10480-1_7

Nongthombam, K. S., Mutum, S. S., Pandey, R. R. 2024. In vitro biological activities of an endophytic fungus, *Trichoderma* sp. L2D2 isolated from *Anaphalis contorta*. *Ind. J. Microbiol.* **64**: 1757-1768. https://doi.org/10.1007/s12088-024-01232-7

Patil, A. G., Khan, K., Aishwarya, S., Padyana, S., Huchegowda, R., Reddy, K. R., Pais, R., Dsouza, H. A. R., J. Madhavi, Yadav, A. N., Raghu, A. V., & Zameer, F. (2022). Fungal amylases and their industrial applications. In: *Industrially Important Fungi for Sustainable Development: Volume 2: Bioprospecting for Biomolecules*. Cham: Springer International Publishing, pp. 407-434. https://doi.org/10.1007/978-3-030-85603-8_11

Pereg, L., McMillan, M. 2015. Scoping the potential uses of beneficial microorganisms for increasing productivity in cotton cropping systems. *Soil Biol. Biochem.* **80:**349-358. https://doi.org/10.1016/j.soilbio.2014.10.020

Potshangbam, M., Devi, S. I., Sahoo, D., Strobel, G. A. 2017. Functional characterization of endophytic fungal community associated with *Oryza sativa* L. and *Zea mays* L. *Front.Microbiol.* **8**: 325. https://doi.org/10.3389/fmicb.2017.00325

Rai, M., Gade, A., Zimowska, B., Ingle, A. P., Ingle, P. 2020. Harnessing the potential of novel bioactive compounds produced by endo-phytic *Phoma* spp.-biomedical and agricultural applications. *Acta Scientiarum Polonorum. Hortorum Cultus* **19**: 31-45. https://doi.org/10.24326/asphc.2020.6.3

Rajani, P., Rajasekaran, C., Vasanthakumari, M. M., Olsson, S. B., Ravikanth, G., Shaanker, R. U. 2021. Inhibition of plant pathogenic fungi by endophytic *Trichoderma* spp. through mycoparasitism and volatile organic compounds. *Microbiologic.Res.* **242**: 126595. https://doi.org/10.1016/j.micres .2020.126595

Ripa, F. A., Cao, W. D., Tong, S., Sun, J. G. 2019. Assessment of plant growth promoting and abiotic stress tolerance properties of wheat endophytic fungi. *BioMed Res. Inter.* **2019**: 6105865. https://doi.org/10.1155/2019/6105865

Rungjindamai, N., Jones, E. G. 2024. Why are there so few basidiomycota and basal fungi as endophytes? A review. *J. Fungi* **10**: 67. https://doi.org/10.3390/jof10010067

Salem, M. M., Mohamed, T. M., Shaban, A. M., Mahmoud, Y. A. G., Eid, M. A., El-Zawawy, N. A. 2024. Optimization, purification and characterization of laccase from a new endophytic *Trichoderma harzianum* AUMC14897 isolated from *Opuntia ficus-indica* and its applications in dye decolorization and wastewater treatment. *Microbial Cell Factories* **23**: 266. https://doi.org/10.1186/s12934-024-02530-x

Saxena, S., Dufossé, L., Deshmukh, S. K., Chhipa, H.,Gupta, M. K. 2024. Endophytic fungi: a treasure trove of antifungal metabolites. *Microorganisms* **12**: 1903. https://doi.org/10.3390/microorganisms12091903

Shetty, K. G., Rivadeneira, D. V., Jayachandran, K., Walker, D. M. 2016. Isolation and molecular characterization of the fungal endophytic microbiome from conventionally and organically grown avocado trees in South Florida. *Mycological Progress***15**: 977-986. https://doi.org/10.1007/s11557-016-1219-3

Sopalun, K., Iamtham, S. 2020. Isolation and screening of extracellular enzymatic activity of endophytic fungi isolated from Thai orchids. *South Afr. J. Bot.* **134**: 273-279. https://doi.org/10.1016/j.sajb.2020.02.005

Sunitha, V. H., Devi, D. N.,Srinivas, C. 2013. Extracellular enzymatic activity of endophytic fungal strains isolated from medicinal plants. World J. Agricult. Sci.**9**: 01-09. https://doi.org/10.5829/idosi.wjas.2013.9.1.72148

Timalsina, D.,Devkota, H. P. 2021. *Eclipta prostrata* (L.) L. (Asteraceae): ethnomedicinal uses, chemical constituents, and biological activities. *Biomolecules* **11**: 1738. https://doi.org/10.3390/biom11111738

Toghueo, R. M. K. 2020. Bioprospecting endophytic fungi from *Fusarium* genus as sources of bioactive metabolites. *Mycology* **11**:1-21. https://doi.org/10.1080/21501203.2019.1645053

Unuofin, J. O., Okoh, A. I.,Nwodo, U. U. 2019. Aptitude of oxidative enzymes for treatment of wastewater pollutants: a laccase perspective. *Molecules* **24**: 2064. https://doi.org/10.3390/molecules24112064

Watanabe, T. 2010. Pictorial Atlas of soil and seed fungi, 3rd edn. *CRC Press*. https://doi.org/10.1201/ebk1439804193

Wijesekara, T., Xu, B. 2023. Health-promoting effects of bioactive compounds from plant endophytic fungi. *J. Fungi* **9**: 997. https://doi.org/10.3390/jof9100997

Yao, Z., Chen, Y., Wang, G., Hong, Y., Jiang, S., Jiang, X., Zhao, F., Zhou, C., Zhou, Y., Tang, H., Zhu, M., Ding, J., Li, C., Xu, W., Guo, W., Zhang, J., Li, Y., Zhu, X. 2026. Ascomycetous Endophytic Fungi Drive Root Fungal Community Assembly in Wheat Under Moderate Drought. *J. Fungi***12**: 82. 10.3390/jof12020082

Younas, H., Younas, F. 2025. Phytohormone production by endophytic fungi. In: *Fungal Endophytes Volume I: Biodiversity and Bioactive Materials*. Singapore: Springer Nature Singapore, pp. 385-413. https://doi.org/10.1007/978-981-97-7312-1_14