



Review article

Diversity of endophytic fungi isolated from the Rajasthan medicinal plants

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Abstract

Endophytic fungi are the group of microorganisms residing within the plant tissues without exerting any negative effect and are considered as important resources of bio-active secondary metabolites. Despite aiding in the plant growth, nutrient uptake and protection against pathogens, they also produce bio-active compounds with antioxidant, antimicrobial, anticancer, anti-inflammatory and antiviral effects. The state of Rajasthan, characterized by its diverse agro-climatic zones such as the Thar Desert, Aravalli hills and fertile plains, offers a unique habitat for endophytic fungal diversity. This review article encompasses studies from 2008 to 2026 on the diversity, ecological roles and bioactive potential of endophytic fungi found in medicinal plants in Rajasthan. Several fungal genera- including *Alternaria*, *Fusarium*, *Aspergillus*, *Penicillium*, *Cladosporium* and *Nigrospora* have been identified from various host plants of Rajasthan. These fungi display plant growth-promoting traits and produce valuable metabolites like vincristine, vinblastine, resveratrol derivatives, and antimicrobial agents. The review underscores Rajasthan's status as a rich source of endophytic fungi with significant potential in medicine, agriculture, and biotechnology.

Introduction

Nature's vast plant-based resources, long used in traditional therapies, now form a crucial foundation for modern drug innovation, underscoring the importance of natural products in developing therapeutics, particularly for chronic diseases and diverse medical applications (Cragg et al., 2001; Rai et al., 2021; Atanasov et al., 2021). Plants, especially perennials, provide ecological niches for endophytic microorganisms such as fungi, bacteria (Planas-Marquès et al., 2020) and actinomycetes (Berendsen et al., 2018). In 1866, Anton de Bary introduced the term "endophyte," made from the two Greek words *endon* meaning "within", and *phyton* meaning "plant" (de Bary, 1866) and the term itself means that all the microorganisms that inhabit interstitial tissues of plants without causing any harm to the host plant. More explicitly, the term

cites to fungi and bacteria that colonize inter- and intra-cellular spaces of plant tissues for all or part of their life cycle without causing any harm or disease (Hardoim et al., 2015). The term "endophytic fungi" confines to fungal counterparts that live inside the plant tissues for all or part of their wheel of life, signifying a mutually beneficial symbiotic association with the host plant without causing any adverse effects or disease (Hyde et al., 2019; Patchett and Newman, 2021). The existence of endophytic fungi in innumerable plant species reflects their diverse modes of dispersion, while their high environmental adaptability allows them to thrive in a wide range of settings, including marshes, forests, grasslands, deserts and even marine ecosystems (Xu et al., 2020; Aldinary et al., 2021).

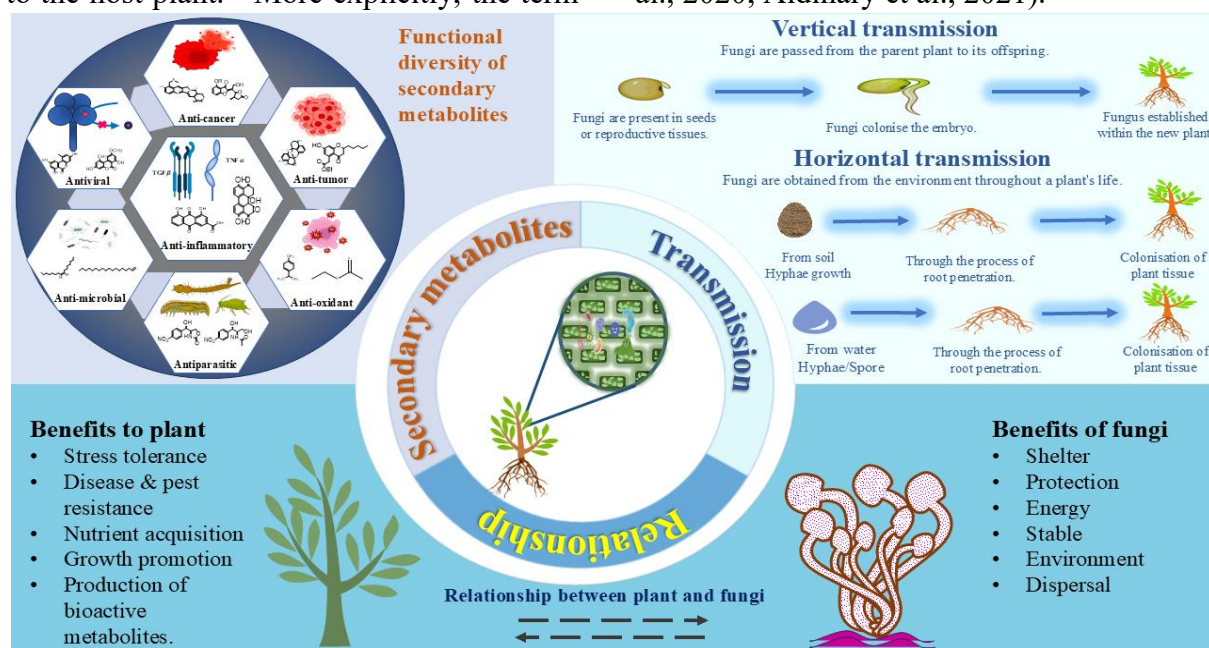


Fig. 1. Functional diversity of secondary metabolites produced by endophytic fungi and their interaction mechanisms with medicinal plants.

These endophytes are reported to produce a diverse array of secondary metabolites that act as vital cellular protectors by neutralising harmful free radicals (Manganyi and Ateba, 2020). These microorganisms are an important and widespread microbial resource found in both terrestrial and aquatic plants encompassing a range of plant groups, including algae, bryophytes, pteridophytes, sponges, gymnosperms, and angiosperms. These microorganisms are distributed globally, from tropical to Arctic regions and inhabit both natural ecosystems and agricultural environments (Kharwar et al., 2011). Notably, endophytes also contribute to the environmental physiology of plants, enhancing their armour and supporting survival mechanisms. Moreover, endophytic fungi also aid in promoting plant growth, mitigating abiotic and biotic stresses, including drought, salinity, extreme temperatures, heavy-metal toxicity, oxidative stress, and provide protection against insects and herbivores (Waller et al., 2005; Khare et al., 2018; Rabiey et al., 2019; Eid et al., 2019). They promote plant growth by inducing physiological, morphological, and biochemical changes in the host plant (Gundel et al., 2010) through the production of phytohormones such as indoleacetic acid (IAA), cytokinins, and indolebutyric acid (IBA). Additionally, fungal endophytes facilitate the transfer of essential nutrients such as potassium (K),

nitrogen (N), and sulphur (S) to the host plant, while obtaining carbon from it in return (Hartley & Gange, 2009; Kiers et al., 2011). Fungal endophytes enter the host plants via stomata, wounds or roots or by directly penetrating tissues through the secretion of hydrolytic enzymes (Esposito & Azevedo, 2004). They are transmitted either vertically through seeds or horizontally via spores (Carroll, 1988). These endophytes have been widely studied across various geographical regions and climatic conditions, and adaptation to specific habitats has resulted in significant diversity (Jin et al., 2017; Adnan et al., 2018). Endophytes can prevent the emergence of resistance mechanisms by overcoming pathogen invasion through secondary metabolites. Secondary metabolites produced by endophytic fungi represent a promising resource for pharmaceutical development due to their anti-inflammatory, anti-tumor, anticancer, and antioxidant activities (Wijesekara & Xu, 2023) as well as antibacterial, anti-fungal, immunosuppressants, antiviral, and antiparasitic activities (Toghiani, 2020). For instance, Taxol, a cancer therapeutic drug, was first isolated from the bark of the *Taxus brevifolia* plant in 1971 and was later reported from the endophytic fungus *Taxomyces andreanae* in 1993 (Stierle et al., 1993). This discovery sparked significant interest in fungal endophytes as a promising source for isolating and characterizing

plant-derived therapeutic molecules (Hammerschmidt et al., 2015, Pandey et al., 2016, Fu et al., 2024, Zhang et al., 2024) which can be structurally classified into various bioactive metabolite groups such as alkaloids, benzopyranones, quinones, peptides, phenols, flavonoids, steroids, terpenoids, tetralones, xanthenes and others (Fadiji & Babalola 2020).

This review summarizes the results of studies on endophytic fungi in Rajasthan from 2008 to 2026. It includes key physiographic regions such as the Aravalli hills, the Eastern plains, and the South-Eastern plateau, while the Thar Desert occupies the largest portion of the state. The state of Rajasthan hosts more than 900 wild plant species, many of which are medicinally important and act as harbors a wide range of endophytic fungi. The extreme environmental conditions, especially in arid and semi-arid areas, contribute to the development of stress-resilient endophytes with specialized metabolic traits. Numerous studies have documented the diversity of endophytic fungi associated with various plant species in Rajasthan, including *Prosopis cineraria* (Gehlot et al., 2008), *Pongamia pinnata* (Tiwari, 2013), *Catharanthus roseus* (Nagda et al., 2017) and *Tinospora cordifolia* (Yadav et al., 2020). These investigations have revealed a wide spectrum of fungal genera such as *Alternaria*, *Fusarium*, *Aspergillus*,

Penicillium and *Cladosporium* many of which are known for producing biologically active compounds. Notably, endophytes like *Piriformospora indica* have demonstrated significant plant growth-promoting effects and enhanced tolerance to environmental stresses such as salinity. Endophytic fungi are gaining attention for producing valuable bio-active compounds, including antioxidants, antimicrobials and anticancer agents like vincristine and vinblastine. It can be inferred that the study of endophytic fungi in Rajasthan not only contributes to understanding of microbial diversity in extreme environments but also opens new avenues for their application in agriculture, medicine and industry.

Occurrence and Diversity of Endophytic Fungi in Plants of Rajasthan

Rajasthan has a rich floral heterogeneity with 911 wild species belonging to 780 genera of 154 families. The state spans about 10.41% of India's land with 342,239 km² area located at the latitude and longitude of 23°04'-30°11' N and 69°29'-78°17' E with largest area covered by Thar Desert (Arora et al., 2009). Many medicinal plants inhabiting different geographical locations of Rajasthan exhibits a huge diversity of fungal genera. In line to this, a medicinal plant *Prosopis cineraria* inhabiting the five territories of the Indian desert (Jodhpur, Jaisalmer, Barmer, Bikaner and Churu) were explored for the isolation and

identification of fungal endophytes. The inner bark of the plant were reported to harbor endophytic fungi belonging to five phyla including *Zygomycetes* (13.6%), *Ascomycetes* (5.6%), *Hyphomycetes* (72.8%), *Coelomycetes* (4%), and sterile fungi (4%). Among the endophytic fungi identified, *Rhizopus stolonifer*, *Mucor racemosus* and *Mucor sp.* belonging to *Zygomycetes*, *Chaetomium globosum* belonging to *Ascomycetes* and *Alternaria sp.*, *Fusarium sp.*, *Penicillium sp.*, *Trichoderma sp.*, *Torula sp.*, *Rhizoctonia sp.*, *Cladosporium herbarum*, *Curvularia lunata*, and *Drechslera tetramera* belonging to *Hyphomycetes* were reported (Gehlot et al., 2008). Similarly, eight endophytic fungal genera including *Alternaria solani*, *Fusarium oxysporum* (15.95%), *Colletotrichum gloeosporioides* (14.39 %), *Curvularia lunata* (9.72%), *Helminthosporium papulosum* (9.33%), *Aspergillus flavus* (6.61%), *Phomopsis viticola* (2.33%), and *Cladosporium cladosporioides* (0.77%) were isolated from the leaves, nodes, and internodes of *Pongamia pinnata* plants collected from 12 regions in Sanganer, Rajasthan (Tiwari and Chittora 2013). In the same year, Tiwari 2013 reported the identification of endophytic fungi inhabiting the leaves and stems of *Pongamia pinnata* collected from the Sanganer region of Rajasthan. The fungal endophytes were found to belong to

eight different genera, including *Alternaria alternata*, *Fusarium sp.*, *Colletotrichum sp.*, *Helminthosporium sp.*, *Curvularia sp.*, *Aspergillus sp.*, *Cladosporium sp.*, and *Phomopsis sp.*, along with five mycelia sterilia types. Among all the identified genera, *A. alternata* displayed the maximum colony frequency. Subsequently, a total of 448 endophytic fungal isolates were obtained from the roots and leaves of *Rhus mysorensis* plants collected from 10 different regions in Sanganer, Rajasthan. The morphological identification revealed isolates to belong to eight genera, including *Fusarium sp.*, *Colletotrichum sp.*, *Alternaria sp.*, *Helminthosporium sp.*, *Curvularia sp.*, *Aspergillus sp.*, *Cladosporium sp.*, and *Phomopsis sp.*, with the maximum number of isolates belonging to the genus *Fusarium* (Tiwari and Lodha, 2014). In the same line, another study by Tiwari 2018 reported the isolation and identification of *Alternaria alternata* from the root of *Rhus mysorensis* with the help of morphometry. In 2022, the endophytic fungus *Aspergillus niger*, isolated from various parts of the *Albizia lebbeck (L.) Benth.* plant collected in Jaipur, Rajasthan, is a highly potent producer of extracellular enzymes including amylase, protease, lipase, laccase, cellulase, and gelatinase and exhibits highly efficient bio-remediation activity such as reduction of biochemical oxidation demand (BOD), blood strain removal, biodegradability of vegetable, dye

decolourisation, saccharification of bagasse and paper, and complete extraction of silver from the waste x-ray films (Mathur et al.,2022). In the same year, endophytic fungi isolated from *Cassia senna* (L.) plants sourced from Jodhpur, Rajasthan, such as *Phellinus carbaeoquercicola*, *Aspergillus caespitosus*, and various *Aspergillus* and *Fusarium* species, have been identified as viable sources for the extraction of sennoside drugs (Upasani et al.,2022). More recently, endophytic fungi isolated from the cultivated ferns, *Marsilea quadrifolia* (Marsileaceae) and *Nephrolepis cordifolia* (Nephrolepidaceae), collected from Jaipur, Rajasthan (26°89'00.8"N, 75°81'77.23"E) exhibited considerable diversity, including *Aspergillus fumigatus* (16.25 %), *Bipolaris sp. 1* (15.62 %), *Aspergillus nidulans* (10.62 %), *Alternaria sp.* (10 %), *Aspergillus niger* (9.37 %), *Cladosporium tenuissimum* (8.12 %), *Aspergillus flavus* (5.62 %), *Cladosporium sp.* (5.62 %), *Nigrospora oryzae* (4.37 %), *Chaetomium globosum* (3.12 %), *Bipolaris sp. 2* (2.5 %), *Phoma sp.* (1.87 %), *Curvularia sp.* (1.87 %), *Candida sp.* (1.25 %), *Blastomyces sp.* (1.25 %), and *Aureobasidium sp.* (1.25 %) (Yadav et al., 2024). In 2025, 42 fungal strains isolated from the petiole, leaves, and stems of *Aegle marmelos* (L.) Correa, several exhibited potent amylolytic, proteolytic, cellulolytic, and lipolytic activities, demonstrating robust metabolic capabilities essential for

macromolecule breakdown, host colonisation, and potential biotechnological applications (Irra et al.,2025). In more recent years, *Aspergillus niger*, *A. flavus*, *Mucor sp.*, *Mycelia sterilia*, *Penicillium sp.*, *Yeast*, *Fusarium oxysporum*, *F. verticillioides*, *Alternaria alternata*, *Curvularia sp.*, and *Trichothecium sp.* fungi isolated from *Foeniculum vulgare* seeds were collected from Rajasthan, New Delhi, Uttar Pradesh, West Bengal, and Puducherry, encompassing urban, semi-urban, and rural areas of India (Mahata et al., 2026).

Synergistic potential of fungal endophytes on plant biomass and thermotolerance

The endophytic fungus, *Piriformospora indica*, isolated from *Boswellia serrata* Roxb. plant collected from the Aravalli ranges in Rajasthan was reported to display bio-priming potential to improve plant growth in terms of height, chlorophyll content, number of leaves and root length (Suthar and Purohit 2012). Furthermore, co-inoculation of *Piriformospora indica* with rice plants demonstrated significant salt stress tolerance potential by producing antioxidant enzymes thereby improving the plant growth and yield under saline conditions (Bagheri et al., 2013). Another study on the root endophyte, *Piriformospora indica*, the HOG1 homologue (PiHOG1) was shown to be

essential for osmotic stress tolerance and plant-fungal interaction. Functional expression in yeast restored osmotolerance, while knockdown lines exhibited reduced activation of salinity-responsive genes, impaired root colonization in rice under salt stress, and decreased plant growth and physiological parameters. Overall, PiHOG1 plays a key role in fungal salinity signaling, successful root colonization, and enhancement of host plant salt stress tolerance (Jogawat et al., 2016). Apart from salt tolerance, several fungal endophytes were reported to display thermotolerance also. A total of 507 fungal endophytes were recovered from fifteen different plant samples including *Tecomella undulata*, *Prosopis juliflora*, *Prosopis cineraria*, *Crotalaria burhia* Hamilt., *Acacia jacquemontii* Benth., *Acacia catechu*, *Acacia nilotica*, *Acacia leucophloea* (Roxb.), *Acacia tortilis* (Forssk.), *Dactyloctenium scindicum* Boiss., *Dactyloctenium aegyptium*, *Lasiurus scindicus* Henrard, *Molinia caerulea*, *Polygonum glabrum*, and *Salvadora persica* collected from the Thar Desert, Rajasthan. Out of 507 fungal isolates, only six isolates demonstrated thermotolerance at 40-45°C. These included *Aspergillus flavus* from *Acacia jacquemontii*, *Chaetomium luteum* from *Acacia leucophloea*, *Aspergillus flavus* and *Aspergillus niger* from *Acacia tortilis*, *Aspergillus sp.* and *Chaetomium sp.* from *Lasiurus scindicus*, and *Aspergillus sp.*

from *Salvadora persica* (Sangamesh et al., 2018).

Endophytic fungi: Nature's hidden pharmacopeia

Despite immense potential of fungal endophytes in exhibiting tolerance to abiotic and biotic factors, they are considered to be reservoir of pharmaceutically important modalities also. A study reported the identification of five endophytic fungi including *Fusarium incarnatum*, *Emericella nidulans* (formerly *Emericella nariicolor*), *Fusarium solani*, *Aspergillus tubingensis*, and *Nigrospora* from *Commiphora wightii* plant collected from the Akal Wood Fossil Forest in Jaisalmer, Rajasthan. Out of the five endophytes, *Nigrospora sp.* was found to secrete bostrycin (1) and deoxybostrycin (2) which was found to exhibit anticancer properties (Xia et al., 2011; Bhatia et al 2015). Subsequently, endophytic fungi, *Penicillium sp.* and *Aspergillus sp.*, isolated from leaves, stems, and flowers of *Calotropis procera* collected from Udaipur, Rajasthan exhibited strong antioxidant activity viz. 81.16 % and 80.97 % respectively by DPPH assay. Their extracts were found to comprise 130.50 and 94.91 µg/mg total flavonoids, and 9.16 and 12.13 µg/mg total phenolics respectively (Nagda et al., 2016). Furthermore, *Aspergillus sp.* isolates CRIL-1A and CRIL-1B, recovered from the roots and leaves of *Catharanthus*

roseus inhabiting Udaipur, Rajasthan exhibited moderate antioxidant activity of 47.74% and 44.28%, respectively. Their extracts contained 0.298 µg/mg and 0.699 µg/mg total flavonoids along with 0.171 µg/mg and 0.183 µg/mg total phenolic content. Both of the isolates were further subjected to the α -amylase inhibitory activities, of which CRIL-1B displayed dose dependent α -amylase inhibitory activity (Nagda et al., 2017). Apart from antioxidant effects, endophytic fungus *Alternaria* GFAV15 from *Tinospora cordifolia* inhabiting Jaipur region was reported to produce methyl palmitate (methyl ester) with strong antimicrobial activity against *Staphylococcus aureus* and *Escherichia coli* (Yadav et al., 2020).

In the same year, *Gossypium arboreum* L. (Desi cotton) plant collected from the different regions of Rajasthan and other states of India, such as Haryana and Punjab. Twenty-three fungal strains isolated from the desi cotton plant were evaluated against common cotton pathogens *Corynespora cassiicola* and *Fusarium solani*. The isolated fungal strains identified by the ITS region analysis were dominated by *Curvularia* and *Nigrospora*. Among all, the isolates of *Nigrospora sphaerica* (CEL 5, CEL 19) were the best against *C. cassiicola* displaying 49.38 % and 46.30 % growth inhibition, whereas *N. oryzae* (CEL 2) exhibited 43.06 % growth inhibition against

F. solani. Moreover, *N. sphaerica* (CEL 19) were observed to produce antibiosis and GC/MS analysis revealed four antimicrobial volatile organic compounds (VOCs) including 1,3-diethyl benzene (**4**) 1,4-diethyl benzene (**5**), m-Ethylacetophenone (**6**), and p-cymene-7-ol (**7**) (Hiremani et al., 2020).

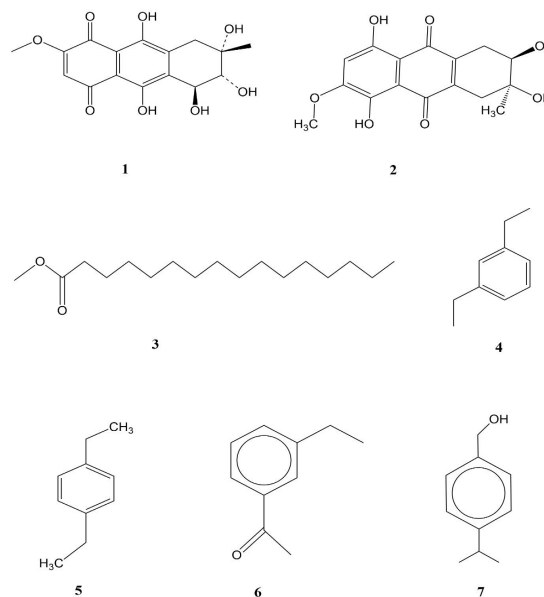


Fig.2. Bioactive secondary metabolites isolated from endophytic fungi showing diverse activities, including anticancer, antibacterial, and α -amylase inhibitory effects.

In the same line, t-resveratrol (**8**) and α -viniferin (**9**) were purified from *Aspergillus stellifer*, an endophytic fungus sourced from the leaves, stems, and fruits of three grapevine species (*Vitis vinifera*, *Vitis quinquangularis*, and *Cayratia trifolia*) collected across the various Indian states including Rajasthan, Gujarat, and Maharashtra. There was an increase in *A. stellifer* growth during cultivation. Similarly, the maximum value of biomass $1.98 \pm$

1.7 was obtained on the 7th day with the highest production of t-resveratrol and α -viniferin to be 300 $\mu\text{g/L}$ and 324 $\mu\text{g/L}$, respectively, which were achieved on the 9th day of fermentation (Roat and Saraf 2020). Notably, vincristine (**10**) and vinblastine (**11**), the potent anticancer alkaloids, were also isolated from *Fusarium oxysporum*, an endophytic fungus obtained from the leaves of *Catharanthus roseus*.

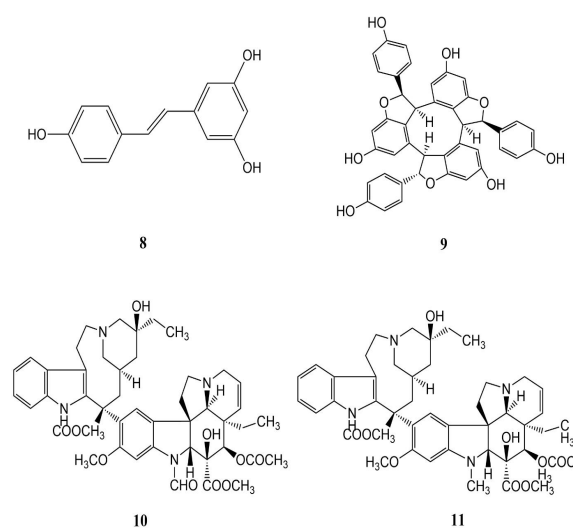


Fig.3. Bioactive secondary metabolites isolated from endophytic fungi showing diverse activities, including anticancer and antibacterial activity.

Morphological identification of the fungus was performed using lactophenol cotton blue staining, while molecular confirmation involved Sanger sequencing of the internal transcribed spacer (ITS) region. The isolate was observed to yield 66.5 mg and 75.5 mg of vincristine and vinblastine respectively per litre of fermented broth as determined by MS/MS and ESI-MS

spectrometry (Ashraf et al. 2021). However, vincristine was also successfully isolated from the endophytic fungus *Nigrospora zimmermanii*, which was obtained from the leaves of the medicinal plant *Catharanthus roseus*. The plant samples were collected in Rajasthan at geographic coordinates 27.55329° N, 76.63419° E. Molecular identification of the fungal isolate was carried out using Internal Transcribed Spacer (ITS) sequencing, confirming its taxonomic identity. The study demonstrated that the maximum yield of vincristine from the fungal extract was 5.344 $\mu\text{g/ml}$, highlighting the potential of endophytic fungi as an alternative, sustainable source for producing valuable anticancer compounds (Birat et al., 2022). In the same year, the endophytic fungus *Chaetomium LAV15*, was isolated from the leaves of *Tinospora cordifolia* collected at Khatipura Garden, Jaipur, Rajasthan (26.917238° N, 75.759450° E), and was accurately identified through morphological and microscopic characterization using lactophenol cotton blue staining, complemented by molecular identification based on ITS sequencing. The isolate demonstrated notable antioxidant activity, evidenced by a DPPH radical scavenging value of 60.64 ± 0.112 , along with appreciable total phenolic content (9.307 ± 0.0095) and total flavonoid content (5.43 ± 0.0360), indicating its potential as a promising natural source of bioactive

compounds (Yadav et al., 2022). More recently, the endophytic fungus *Xylaria rohrensis* was isolated from *Wrightia tinctoria* and identified as a highly potent, metabolically diverse organism with significant biological efficacy. Extensive chemical profiling using FTIR and GC-MS revealed a rich array of bioactive metabolites, including terpenoids, fatty acids, and esters, which contribute to its exceptionally high phenolic and flavonoid content and strongly correlate with its pronounced antioxidant and antibacterial activities (Yadav et al., 2025). In 2026, nine endophytic fungi- *Alternaria alstroemeriae*, *Chaetomium meridiolense*, *Epicoccum thailandicum*, *Xylaria ellisii*, *Nigrospora osmanthi*, *Diaporthe terebinthifolii*, *Phomopsis tuberivora*, *Curvularia buchloës*, and *Corynespora torulosa* were isolated from the *Sterculia urens* plant, collected from southern Rajasthan, and tested for antioxidant and antibacterial properties. *Chaetomium meridiolense* showed the strongest activity, with high levels of phenolics and flavonoids. GC-MS analysis revealed terpenoid and phenolic metabolites. Statistical analysis confirmed that phenolic compounds drive the observed bioactivity (Yadav et al., 2026).

Conclusion

Endophytic Fungi, the vast and unexplored mycobiota, hidden inside the plant systems are known to represent a rich microbial community that is primarily shaped by

diverse agro-climatic conditions ranging from the arid Thar Desert to varying altitudes/areas of the Aravalli hills/down towards fertile plains. These fungi associate directly with specific medicinal and native plants to form mutualisms, that play significant roles in plant growth, nutrient acquisition, stress tolerance, and resistance against pathogens. Various types of endophytic fungi have been reported all around the world, with numerous investigations conducted between 2008 and 2024 from the state of Rajasthan, India that document genera including *Alternaria*, *Fusarium*, *Aspergillus*, *Penicillium*, *Cladosporium*, *Nigrospora* and *Piriformospora*, several of which synthesized rich variety of secondary metabolites with antioxidant, antimicrobial, anticancer, immunomodulatory and anti-inflammatory activity. Endophytic fungi have strong pharmaceutical potential as sustainable sources of bioactive metabolites, as evidenced by the discovery of therapeutically important compounds. This also highlights their ecological and biotechnological importance, with respect to their adaptability to inhospitable environmental conditions in Rajasthan. Nevertheless, high-throughput molecular/genomic/cultivation measures remain a necessity to truly harness this interfacing microbial diversity for usage in drug development, agricultural and industrial industries.

References

1. Cragg, G. M., & Newman, D. J. (2001). Natural product drug discovery in the next millennium. *Pharmaceutical biology*, 39(sup1), 8-17. <https://doi.org/10.1076/phbi.39.s1.8.0009>
2. Rai, S. N., Singh, P., Steinbusch, H. W. M., Vamanu, E., Ashraf, G., & Singh, M. P. (2021). The Role of Vitamins in Neurodegenerative Disease: An Update. *Biomedicines*, 9(10), 1284. <https://doi.org/10.3390/biomedicines9101284>.
3. Atanasov, A. G., Zotchev, S. B., Dirsch, V. M., & Supuran, C. T. (2021). Natural products in drug discovery: advances and opportunities. *Nature reviews Drug discovery*, 20(3), 200-216. <https://doi.org/10.1016/j.sajb.2022.05.028>.
4. Planas-Marquès, M., Kressin, J. P., Kashyap, A., Panthee, D. R., Louws, F. J., Coll, N. S., & Valls, M. (2020). Four bottlenecks restrict colonization and invasion by the pathogen *Ralstonia solanacearum* in resistant tomato. *Journal of Experimental Botany*, 71(6), 2157-2171. <https://doi.org/10.1093/jxb/erz562>.
5. Berendsen, R. L., Vismans, G., Yu, K., Song, Y., de Jonge, R., Burgman, W. P., ... & Pieterse, C. M. (2018). Disease-induced assemblage of a plant-beneficial bacterial consortium. *The ISME journal*, 12(6), 1496-1507. <https://doi.org/10.1038/s41396-018-0093-1>.
6. de Bary, A. (1866). *Morphologie und physiologie der pilze, flechten und myxomyceten* (Vol. 1). Engelmann.
7. Hardoim, P. R., Van Overbeek, L. S., Berg, G., Pirttilä, A. M., Compant, S., Campisano, A., ... & Sessitsch, A. (2015). The hidden world within plants: ecological and evolutionary considerations for defining functioning of microbial endophytes. *Microbiology and molecular biology reviews*, 79(3), 293-320. <https://doi.org/10.1128/mmmbr.00050-14>.
8. Hyde, K. D., Xu, J., Rapior, S., Jeewon, R., Lumyong, S., Niego, A. G. T., ... & Stadler, M. (2019). The amazing potential of fungi: 50 ways we can exploit fungi industrially. *Fungal Diversity*, 97(1), 1-136. <https://doi.org/10.1007/s13225-019-00430-9>.
9. Patchett, A., & Newman, J. A. (2021). Comparison of plant metabolites in root exudates of *Lolium perenne* infected with different strains of the fungal endophyte *Epichloë festucae* var. *lolii*. *Journal of Fungi*, 7(2), 148. <https://doi.org/10.3390/jof7020148>.
10. Xu, L. L., Ling, X. F., Zhao, S. J., Wang, R. F., & Wang, Z. T. (2020). Distribution and diversity of endophytic fungi in *Gentiana rigescens* and cytotoxic activities. *Chinese herbal*

- medicines, 12(3), 297–302.
<https://doi.org/10.1016/j.chmed.2020.03.007>.
11. Aldinary, A. M., Abdelaziz, A. M., Farrag, A. A., & Attia, M. S. (2021). WITHDRAWN: Biocontrol of tomato Fusarium wilt disease by a new *Moringa* endophytic *Aspergillus* isolates.
<https://doi.org/10.1016/j.matpr.2021.03.423>.
 12. Manganyi, M. C., & Ateba, C. N. (2020). Untapped Potentials of Endophytic Fungi: A Review of Novel Bioactive Compounds with Biological Applications. *Microorganisms*, 8(12), 1934.
<https://doi.org/10.3390/microorganisms8121934>.
 13. Kharwar, R. N., Mishra, A., Gond, S. K., Stierle, A., & Stierle, D. (2011). Anticancer compounds derived from fungal endophytes: their importance and future challenges. *Natural product reports*, 28(7), 1208–1228.
<https://doi.org/10.1039/c1np00008j>.
 14. Waller, F., Achatz, B., Baltruschat, H., Fodor, J., Becker, K., Fischer, M., Heier, T., Hückelhoven, R., Neumann, C., von Wettstein, D., Franken, P., & Kogel, K. H. (2005). The endophytic fungus *Piriformospora indica* reprograms barley to salt-stress tolerance, disease resistance, and higher yield. *Proceedings of the National Academy of Sciences of the United States of America*, 102(38), 13386–13391.
<https://doi.org/10.1073/pnas.0504423102>.
 15. Khare, E., Mishra, J., & Arora, N. K. (2018). Multifaceted Interactions Between Endophytes and Plant: Developments and Prospects. *Frontiers in microbiology*, 9, 2732.
<https://doi.org/10.3389/fmicb.2018.02732>.
 16. Rabiey, M., Hailey, L. E., Roy, S. R., Grenz, K., Al-Zadjali, M. A. S., Barrett, G. A., & Jackson, R. W. (2019, November 1). Endophytes vs tree pathogens and pests: can they be used as biological control agents to improve tree health? *European Journal of Plant Pathology*. Springer Netherlands.
<https://doi.org/10.1007/s10658-019-01814-y>.
 17. Eid, A. M., Salim, S. S., Hassan, S. E. D., Ismail, M. A., & Fouda, A. (2019). Role of endophytes in plant health and abiotic stress management. In *Microbiome in plant health and disease: challenges and opportunities* (pp. 119-144). Singapore: https://doi.org/10.1007/978-981-13-8495-0_6.
 18. Gundel, P.E., Martínez-Ghersa, M.A., Batista, W.B. and Ghersa, C.M. (2010), Dynamics of *Neotyphodium* endophyte infection in ageing seed pools:

- incidence of differential viability loss of endophyte, infected seed and non-infected seed. *Annals of Applied Biology*, 156: 199-209. <https://doi.org/10.1111/j.1744-7348.2009.00379.x>.
19. Hartley, S. E., & Gange, A. C. (2009). Impacts of plant symbiotic fungi on insect herbivores: mutualism in a multitrophic context. *Annual review of entomology*, 54(1), 323-342. <https://doi.org/10.1146/annurev.ento.54.110807.090614>.
 20. Kiers, E. T., Duhamel, M., Beesetty, Y., Mensah, J. A., Franken, O., Verbruggen, E & Bücking, H. (2011). Reciprocal rewards stabilize cooperation in the mycorrhizal symbiosis. *science*, 333(6044), 880-882. [DOI: 10.1126/science.1208473](https://doi.org/10.1126/science.1208473).
 21. Esposito, E., & Azevedo, J. L. D. (2004). Fungos: uma introdução à biologia, bioquímica e biotecnologia.
 22. Carroll, G. (1988). Fungal endophytes in stems and leaves: from latent pathogen to mutualistic symbiont. *Ecology*, 69(1), 2-9. <https://doi.org/10.2307/1943154>.
 23. Jin, T., Wang, Y., Huang, Y., Xu, J., Zhang, P., Wang, N., Liu, X., Chu, H., Liu, G., Jiang, H., Li, Y., Xu, J., Kristiansen, K., Xiao, L., Zhang, Y., Zhang, G., Du, G., Zhang, H., Zou, H., Zhang, H., Xu, X. (2017). Taxonomic structure and functional association of foxtail millet root microbiome. *GigaScience*, 6(10), 1–12. <https://doi.org/10.1093/gigascience/gix089>.
 24. Adnan, Mohd, Alshammari, Eyad, Ashraf, Syed Amir, Patel, Kartik, Lad, Kishan, Patel, Mitesh, Physiological and Molecular Characterization of Biosurfactant Producing Endophytic Fungi *Xylaria regalis* from the Cones of *Thuja plicata* as a Potent Plant Growth Promoter with Its Potential Application, *BioMed Research International*, 2018, 7362148, 11 pages, 2018. <https://doi.org/10.1155/2018/7362148>.
 25. Wijesekara, T., & Xu, B. (2023). Health-Promoting Effects of Bioactive Compounds from Plant Endophytic Fungi. *Journal of fungi (Basel, Switzerland)*, 9(10), 997. <https://doi.org/10.3390/jof9100997>.
 26. Toghuelo, R. M. K. (2020). Bioprospecting endophytic fungi from *Fusarium* genus as sources of bioactive metabolites. *Mycology*, 11(1), 1–21. <https://doi.org/10.1080/21501203.2019.1645053>.
 27. Stierle, A., Strobel, G., & Stierle, D. (1993). Taxol and taxane production by *Taxomyces andreanae*, an endophytic fungus of Pacific yew. *Science (New York, N.Y.)*, 260(5105), 214–216. <https://doi.org/10.1126/science.8097061>.

28. Hammerschmidt, L., Ola, A., Mueller, W. E., Lin, W., Mándi, A., Kurtán, T., & Aly, A. H. (2015). Two new metabolites from the endophytic fungus *Xylaria* sp. isolated from the medicinal plant *Curcuma xanthorrhiza*. *Tetrahedron Letters*, 56(10), 1193-1197. <https://doi.org/10.1016/j.tetlet.2014.12.120>.
29. Pandey, S. S., Singh, S., Babu, C. V., Shanker, K., Srivastava, N. K., & Kalra, A. (2016). Endophytes of opium poppy differentially modulate host plant productivity and genes for the biosynthetic pathway of benzyloisoquinoline alkaloids. *Planta*, 243(5), 1097-1114. <https://doi.org/10.1007/s00425-016-2467-9>.
30. Fu, Y., Li, X., Yuan, X., Zhang, Z., Wei, W., Xu, C., ... & Gu, C. (2024). *Alternaria alternata* F3, a novel taxol-producing endophytic fungus isolated from the fruits of *Taxus cuspidata*: isolation, characterization, taxol yield improvement, and antitumor activity. *Applied Biochemistry and Biotechnology*, 196(4), 2246-2269. <https://doi.org/10.1007/s12010-023-04661-0>.
31. Zhang, B., Huang, Z. pu, Si, Y., Zhang, K. tao, Xu, X. rong, Chen, J. hong, ... Zhang, X. mei. (2024). A new 1,4-benzoxazine derivative produced by endophytic *Colletotrichum gloeosporioides* B-142. *Natural Product Research*, 38(8), 1341–1346. <https://doi.org/10.1080/14786419.2022.2141735>.
32. Fadiji, A. E., & Babalola, O. O. (2020). Elucidating mechanisms of endophytes used in plant protection and other bioactivities with multifunctional prospects. *Frontiers in bioengineering and biotechnology*, 8, 467. <https://doi.org/10.3389/fbioe.2020.00467>.
33. Gehlot, P., Bohra, N. K., & Purohit, D. K. (2008). Endophytic mycoflora of inner bark of *Prosopis cineraria*—a key stone tree species of Indian desert. *Am Eur J Bot*, 1(1), 01-04.
34. Tiwari K. (2013). Frequency distribution and assessment of genetic diversity of novel endophyte *Alternaria alternata* accessions isolated from *Pongamia pinnata* L. *Pakistan journal of biological sciences : PJBS*, 16(19), 1004–1009. <https://doi.org/10.3923/pjbs.2013.1004.1009>.
35. Nagda, V., Gajbhiye, A., & Kumar, D. (2017). Isolation and characterization of endophytic fungi from *Calotropis procera* for their antioxidant activity. *Asian J Pharm Clin Res*, 10(3), 254-258. DOI: <http://dx.doi.org/10.22159/ajpcr.2017.v10i3.16125>.

36. Yadav, V., Singh, A., Mathur, N., & Yadav, R. (2020). Isolation and characterization of *Alternaria* GFAV15, an endophytic fungus from green fruit of *Tinospora cordifolia* (Willd.) Miers from semi-arid region. *South African Journal of Botany*, 134, 343-348. <https://doi.org/10.1016/j.sajb.2020.04.003>.
37. Arora, J., Goyal, S., & Ramawat, K. G. (2009). Biodiversity, biology and conservation of medicinal plants of the Thar Desert. *Desert plants: biology and biotechnology*, 3-36. https://doi.org/10.1007/978-3-642-02550-1_1.
38. Tiwari, K., & Chittora, M. (2013). Assessment of genetic diversity and distribution of endophytic fungal communities of *Alternaria solani* isolates associated with the dominant *Karanja* plants in Sanganer Region of Rajasthan. *Springerplus*, 2(1), 313. <https://doi.org/10.1186/2193-1801-2-313>.
39. Tiwari K. (2013). Frequency distribution and assessment of genetic diversity of novel endophyte *Alternaria alternata* accessions isolated from *Pongamia pinnata* L. *Pakistan journal of biological sciences : PJBS*, 16(19), 1004–1009. <https://doi.org/10.3923/pjbs.2013.1004.1009>.
40. Tiwari, K., & Lodha, P. (2014). Isolation, frequency distribution and diversity of novel endophytic fungal communities of *Fusarium* species in *Rhus mysorensis* L. from Sanganer region of Rajasthan. *Elixir Bio Technology*, 74, 26731-26734.
41. Tiwari, K. (2018). Novel Fungal Endophyte *Alternaria alternata* Isolated from the Endangered Plant *Rhus mysorensis* in Sanganer Region of Rajasthan, India. *International Journal of Environmental Sciences & Natural Resources*, 8(1), 16-18. DOI: 10.19080/IJESNR.2018.08.555728.
42. Mathur, P., Ghosh, U., Chetani, R., Chaturvedi, P., Sharma, C., & Bhatnagar, P. (2022). Enzymatic bioprospecting of endophytic *Aspergillus niger* isolated from *Albizia lebbeck* (L.) Benth. *South African Journal of Botany*, 148, 580-587. [10.1016/j.sajb.2022.05.033](https://doi.org/10.1016/j.sajb.2022.05.033).
43. Upasani, V. N., Dharmil, N. V., Shrivastava, N., Srivastava, A., & Sharma, S. (2022). Isolation and Identification of Endophytic Fungi from *Cassia senna* L.: A Medicinal plant. *Indian J Pharm Sci*, 84(6), 1602-1607.
44. Yadav, A. L., Joshi, Y., & Bansal, P. (2024). Exploring the Diversity of Culturable Foliar Endophytic Fungi in Two Cultivated Ferns: *Marsilea quadrifolia*, (Marsileaceae) and

- Nephrolepis cordifolia (Nephrolepidaceae). DOI: 10.36460/Kavaka/60/2/2024/1-10.
45. Irra, D., Kumar, S. R., & Mohan, S. M. (2025). Fungal Endophytes in *Aegle marmelos* (L.) Correa: Approach for Histological Localization and Enzymes Estimation. *Research Journal of Biotechnology* 20, 8. <https://doi.org/10.25303/208rjbt054063>.
 46. Mahata, P. K., Dass, R. S., Gunti, L., & Thorat, P. A. (2026). Studies on seed-borne fungi, *Aspergillus* diversity, and their detection using beta-tubulin gene sequences in *Foeniculum vulgare* seeds in India. *Frontiers in Microbiology*, 17, 1782984. <https://doi.org/10.3389/fmicb.2026.1782984>.
 47. Suthar, R. K., & Purohit, S. D. (2012). Biopriming of micropropagated *Boswellia serrata* Roxb. plantlets--Role of endophytic root fungus *Piriformospora indica*. *Indian Journal of Biotechnology*, 11(3), 304-308.
 48. Bagheri, A. A., Saadatmand, S., Niknam, V., Nejadstari, T., & Babaeizad, V. (2013). Effect of endophytic fungus, *Piriformospora indica*, on growth and activity of antioxidant enzymes of rice (*Oryza sativa* L.) under salinity stress. *Int. J. Adv. Biol. Biomed. Res.*, 1(11), 1337-1350. <http://www.ijabbr.com>.
 49. Jogawat, A., Vadassery, J., Verma, N., Oelmüller, R., Dua, M., Nevo, E., & Johri, A. K. (2016). PiHOG1, a stress regulator MAP kinase from the root endophyte fungus *Piriformospora indica*, confers salinity stress tolerance in rice plants. *Scientific reports*, 6(1), 36765. <https://doi.org/10.1038/srep36765>.
 50. Sangamesh, M. B., Jambagi, S., Vasanthakumari, M. M., Shetty, N. J., Kolte, H., Ravikanth, G & Uma Shaanker, R. (2018). Thermotolerance of fungal endophytes isolated from plants adapted to the Thar Desert, India. *Symbiosis*, 75(2), 135-147. <https://doi.org/10.1007/s13199-017-0527-y>.
 51. Xia XueKui, X. X., Li Qing, L. Q., Li Jia, L. J., Shao ChangLun, S. C., Zhang JianYe, Z. J., Zhang YongGang, Z. Y., & She ZhiGang, S. Z. (2011). Two new derivatives of griseofulvin from the mangrove endophytic fungus *Nigrospora* sp.(Strain No. 1403) from *Kandelia candel* (L.) Druce. DOI: [10.1055/s-0030-1271040](https://doi.org/10.1055/s-0030-1271040).
 52. Bhatia, A., Bharti, S. K., Tripathi, T., Mishra, A., Sidhu, O. P., Roy, R., & Nautiyal, C. S. (2015). Metabolic profiling of *Commiphora wightii* (guggul) reveals a potential source for pharmaceuticals and nutraceuticals. *Phytochemistry*, 110, 29-36.

- <https://doi.org/10.1016/j.phytochem.2014.12.016>.
53. Nagda, V., Gajbhiye, A. Y., & Kumar, D. In vitro antioxidant and alphaamylase inhibition activity of plant associated fungi isolated from *Catharanthus roseus*. *Industrial Crops and Products*, 114-122.
 54. Hiremani, N. S., Verma, P., Gawande, S. P., Sain, S. K., Nagrale, D. T., Salunkhe, V. N., ... & Waghmare, V. N. (2020). Antagonistic potential and phylogeny of culturable endophytic fungi isolated from desi cotton (*Gossypium arboreum* L.). *South African Journal of Botany*, 134, 329-335.
<https://doi.org/10.1016/j.sajb.2020.03.008>.
 55. Roat, C., & Saraf, M. (2020). Isolation and characterization of t-resveratrol and α -viniferin, a bioactive secondary metabolite of an endophytic fungus *Aspergillus stellifer* ab4, from *Vitis vinifera*. *The Journal of Microbiology, Biotechnology and Food Sciences*, 9(4), 708.
 56. Ashraf, J., Sharma, M., & Biswas, D. (2021). Separation, purification and characterization of vincristine and vinblastine from *Fusarium oxysporum*, an endophytic fungus present in *catharanthus roseus* leaves . *Journal of Advanced Scientific Research*, 12(01 Suppl 2), 128-136. Retrieved from <https://sciencesage.info/index.php/JASR/article/view/1195>.
 57. Birat, K., Binsuwaidan, R., Siddiqi, T. O., Mir, S. R., Alshammari, N., Adnan, M., Nazir, R., Ejaz, B., Malik, M. Q., Dewangan, R. P., Ashraf, S. A., & Panda, B. P. (2022). Report on Vincristine-Producing Endophytic Fungus *Nigrospora zimmermanii* from Leaves of *Catharanthus roseus*. *Metabolites*, 12(11), 1119.
<https://doi.org/10.3390/metabo12111119>.
 58. Yadav, V.D., Singh, A., & Mathur, N. (2022). Isolation, identification and antioxidant potential of culturable endophytic fungus *Chaetomium LAV15* associated with leaves of *Tinospora cordifolia*.
 59. Yadav, G., Sonigra, P., Nagda, A., Mehta, T., Sahoo, A., Meena, M., & Swapnil, P. (2025). Phytochemical and bioactive insights into endophytic fungi from *Wrightia tinctoria* with emphasis on *Xylaria rohrensis* metabolites potential. *Scientific Reports*.
<https://doi.org/10.1038/s41598-025-29883-6>.
 60. Yadav, G., Meena, M., & Sonigra, P. (2026). Bioactivity screening of endophytic fungi from *Sterculia urens* and GC-MS metabolites profiling of the potent isolate *Chaetomium meridiolense*. *Scientific Reports*, 16(1), 8752. <https://doi.org/10.1038/s41598-026-39125-y>.