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Research Article

Diversity and Ecological Role of Mycorrhizal Fungi in Selected Medicinal Plants from Bhopal District: Implications for Sustainable Agriculture

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ABSTRACT

India is endowed with a rich wealth of medicinal plants. They are also increasingly becoming economically important due to the growing demand for herbal products in the domestic and global market. The rhizosphere is a dynamic heterogeneous, continuous and natural habitat in which different types of interactions occurs between soil microbes and plants. The demand for medicinal plants is growing worldwide due to their non-toxic nature, affordability, and lack of side effects. Mycorrhizal fungi have garnered attention for their potential to enhance crop yields, improve soil health, and mitigate climate change impacts. This study aimed to investigate the diversity of vesicular-arbuscular mycorrhizal (VAM) fungi associated with medicinal plants in Bhopal district. A diverse range of VAM fungi was observed in the rhizosphere of several medicinal plants, emphasizing the potential of these fungi to be harnessed for agricultural applications.

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INTRODUCTION

India, with its vast biodiversity, is home to a rich array of medicinal plants that have been historically revered for their therapeutic properties (Guru et al. 2021; Saravanan and Das, 2024). The increasing global and domestic demand for herbal products has further elevated their economic significance, positioning India as a major player in the global trade of medicinal herbs (Nayar and Shastry, 1990;). These plants, rooted in complex soil ecosystems, interact intimately with soil microbes, particularly in the rhizosphere- a dynamic and heterogeneous habitat. The rhizosphere fosters crucial symbiotic relationships, especially between plants and mycorrhizal fungi. Among these, vesicular-arbuscular mycorrhizal (VAM) symbiosis stands out as one of the most widespread and ecologically significant interactions (Saravanan and Das, 2024; Bonfante & Genre, 2010).

Vesicular-Arbuscular Mycorrhizal (VAM) fungi, as obligate biotrophs, cannot grow independently, forming symbiotic associations with plants to secure essential nutrients. These fungi are especially important for their role in the uptake of phosphorus—a critical but often limiting nutrient for plant growth—by transferring it from the soil to the host plant. In exchange, VAM fungi receive carbohydrates produced through the host's photosynthesis (Smith & Read, 1997; Rastogi, 2024). This symbiosis plays a pivotal role in enhancing plant health and productivity, making VAM fungi indispensable to agricultural and ecological systems.

VAM fungi are found across diverse habitats, including aquatic environments and humid tropical regions (Radhika and Rodrigues, 2010; Sieverding, 1991; Rillig et al. 2002). Their ecological importance extends beyond nutrient acquisition, as they also support water relations, plant diversity, and overall ecosystem stability. Notably, VAM fungi offer protection to plants against pathogens and environmental stresses, including soil toxicity, thereby contributing to plant resilience (Ruiz-Lozano and Aroca, 2010).

In recent decades, biofertilizers have emerged as a sustainable alternative to chemical fertilizers, largely driven by concerns over the overexploitation of natural resources and the adverse environmental impacts of conventional farming practices. VAM fungi, as integral components of biofertilizers, offer several advantages, including the reduction of production costs, enhancement of crop yields, and long-term sustainability of agricultural productivity (Gill et al., 2002). This aligns with India's burgeoning role as one of the largest producers of herbal-based pharmaceutical products, positioning the country at the forefront of global initiatives to promote natural and organic farming practices.

Research has demonstrated the widespread occurrence of VAM associations with medicinal plants (Zhang et al. 2023; Basu & Srivastava, 1998). These symbiotic relationships are not only beneficial for plant growth but also for the enhanced productivity of medicinal compounds or active principles in plants (Khan and Ahmad, 2021; Zubek and Blaszkowski, 2009). The extent of these benefits, however, is influenced by the specific fungal species involved in the symbiosis, with some fungi showing a preferential colonization of particular hosts (Bennett and Grotenhuis, 2015). Given the variability in compatibility between host plants and VAM fungi, selecting efficient fungal strains for commercial applications is a key factor for success in biofertilizer development (Smith & Read, 1997).

The present study aims to address the need for greater understanding of VAM diversity by exploring the specific associations between VAM fungi and medicinal plants in the Bhopal district. The knowledge gained from this investigation has the potential to contribute significantly to the development of sustainable agricultural practices, particularly in the cultivation of medicinal plants. This research is essential in light of the growing global emphasis on environmentally friendly agricultural practices and the increasing demand for medicinal plants. Comprehensive knowledge of the diversity and ecological roles of VAM fungi can lead to improved agricultural productivity, plant health, and sustainable use of natural resources, reinforcing India's position in the global herbal market.

MATERIAL AND METHODS

Study Areas

The present study was conducted across ten distinct sites in and around Bhopal, India, which included Gyan Vatika, Kaliyasote Dam, Bhoj University Campus, and Mandideep. These sites were selected for their ecological diversity and the presence of various medicinal plants known for their traditional uses.

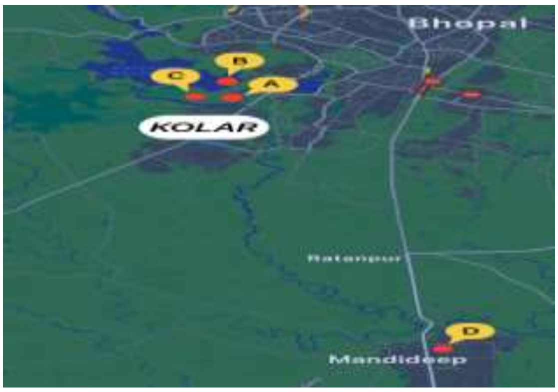

Fig.1. Collection sites of vesicular-arbuscular mycorrhizal (VAM) fungi in and around Bhopal involving A) Gyan Vatika, B) Kaliyasote Dam, C) Bhoj University Campus; and D) Mandideep

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Methods

A total of twenty-five medicinal plants were collected from these locations, with particular emphasis on those with known medicinal properties. The rhizospheric soils of these plants were analyzed to assess the diversity of vesicular-arbuscular mycorrhizal (VAM) fungi. To recover VAM spores from the collected soil samples, the wet sieving and decanting method described by Gerdemann and Nicolson (1963) was employed. This technique allows for the effective separation of VAM spores from soil particles, facilitating a more accurate analysis of the fungal population. The VAM spore population was determined by calculating the total number of spores recovered through this sieving process, which were subsequently collected on filter papers in Petri dishes, following the methodology established by Gour and Adholeya (1994). Additionally, root samples from the collected plants were processed to assess VAM colonization using a modified version of the method outlined by Philips and Hayman (1970). This involved staining the root samples to highlight fungal structures, making it easier to quantify and analyze the extent of mycorrhizal colonization.

Species Identification

To identify the VAM fungi present, morphological characteristics such as spore color, size, and wall structure were meticulously recorded. The taxonomic identification of the VAM fungi was conducted in accordance with the classification frameworks provided by Trappe (1982), Walker (1983), and other mycologists who have contributed to the understanding of mycorrhizal taxonomy.

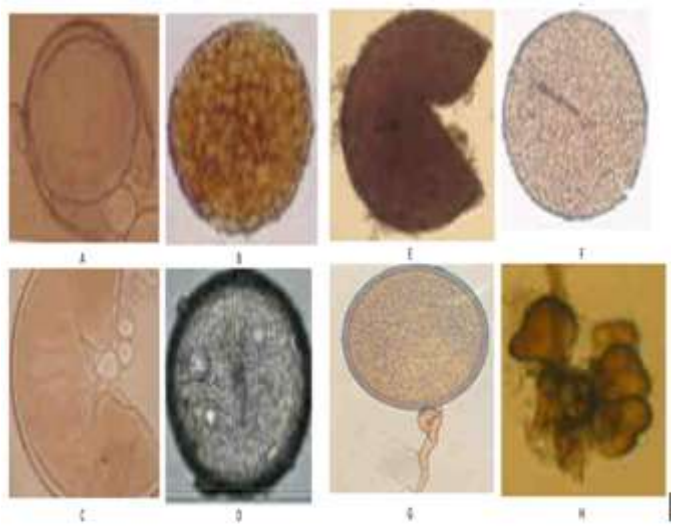
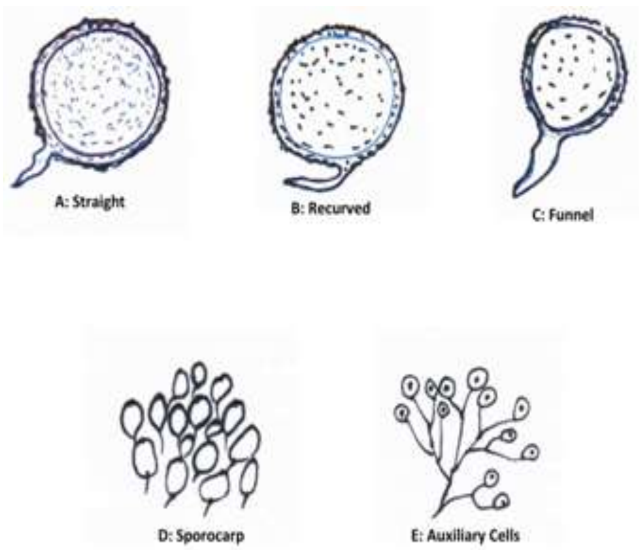


Fig. 2. A: *Aculospora appendiculata*
B: *Aculospora foveata*
C: *Aculospora relnnii*
D: *Aculospora scrobiculala*
E: *Aculospora spinosa*
F: *Aculospora delicate*
G: *Gigaspora margarita*
H: *Gigaspora rosea* (400X).



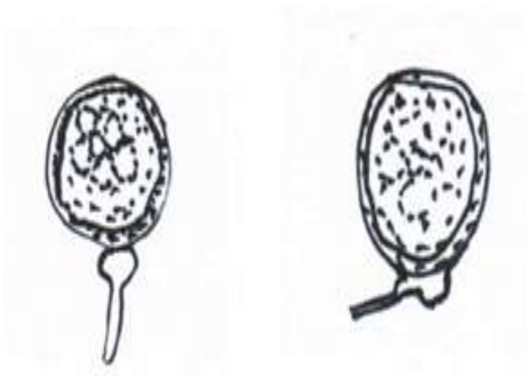


Fig. 3. Gigaspora and Sclerocystis

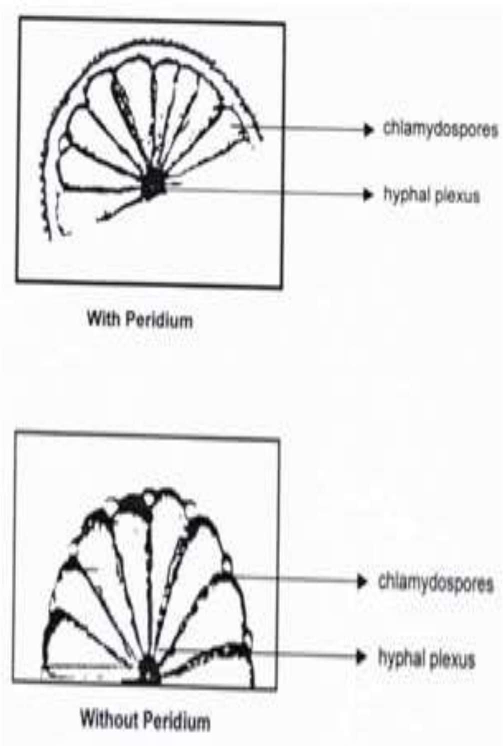


Fig. 4. Cross section of Sporocarp.

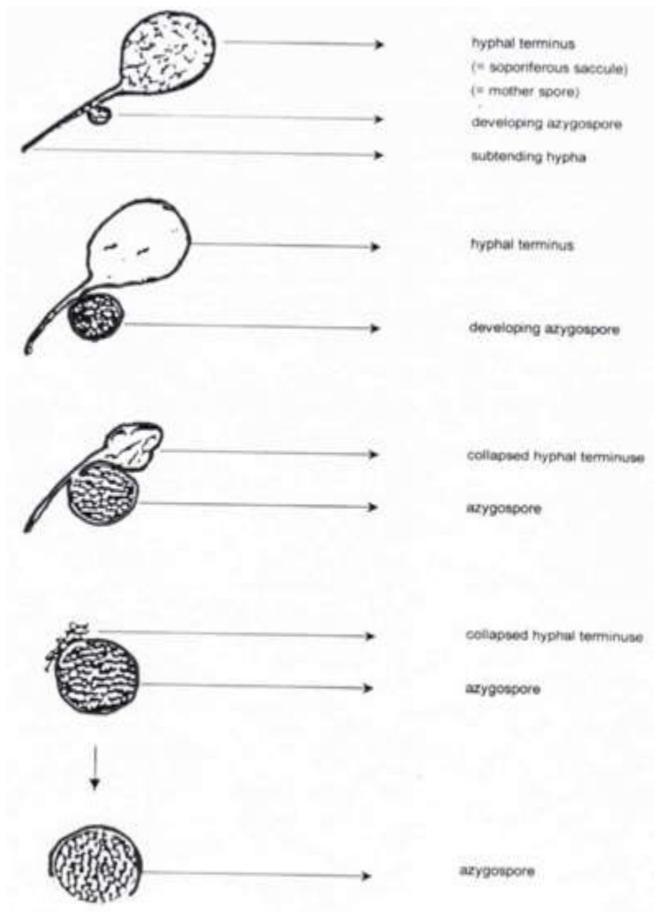


Fig. 5.

Azygospore development of Acoulotporo

Figures 2-5 depict the development stages of a fungal spore, specifically an azygospore, which is a type of spore formed in the Vesicular-Arbuscular Mycorrhizal (VAM) fungi group. Here's an explanation based on the visible stages:

Details in the Figure:

1. **Initial Stage:**
   - The process begins with the hyphal terminus, which is where the fungal hypha (the thread-like structure of the fungus) develops a sac-like structure known as the sporiferous saccule or mother spore.

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- An azygospore starts to develop from the terminus of the hypha.

2. **Development Phase:**

- The azygospore continues to grow and differentiate, supported by the subtending hypha.
- The hypha may remain attached as the spore matures, or it can collapse as the spore reaches maturity.

3. **Maturation:**

- The collapsed hyphal terminus indicates that the hyphal connection to the spore is no longer functional, leaving the mature azygospore as a free-standing reproductive unit.
- The mature spore has thickened walls, which provide protection as the spore becomes a resting stage, ready for germination when environmental conditions are favorable.

These diagrams are helpful in illustrating the reproductive mechanisms of VAM fungi, particularly in studies related to the identification and classification of VAM fungal species based on their spore morphology. You can use this diagrams were used to demonstrate the unique features of spore development that were observed in the fungal species collected from sampling sites. It could explain the morphological details of spore formation across different species of VAM fungi, which supports the diversity analysis in this research.

RESULTS AND DISCUSSION

In this study, 25 medicinal plants were examined for vesicular-arbuscular mycorrhizal (VAM) associations across ten different sites in Bhopal district. A total of 30 fungal species representing four genera (*Acaulospora*, *Gigaspora*, *Glomus*, and *Sclerocystis*) were identified. The genus *Glomus* exhibited the highest species diversity with 12 distinct species, followed by *Acaulospora* (6 species), *Scutellospora* (5 species), *Sclerocystis* (4 species), and *Gigaspora* (3 species). Among these, three species—*Glomus zingiber sp. nov.*, *Scutellospora bhojpurensis sp. nov.*, and *Scutellospora indiana sp. nov.*—were described for the first time.

The rhizospheric soil of *Withania somnifera* exhibited the highest VAM fungal diversity, followed by *Aloe barbadensis*, *Ajuga bracteosa*, *Abrus precatorius*, and *Asparagus racemosus*. In contrast, *Zingiber officinale* supported the least fungal diversity. Furthermore, the spore population of *Withania somnifera* was the highest, with significant spore populations also observed in the soils of *Aloe barbadensis*, *Allium sativum*, and *Ocimum sanctum*.

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Table 1: VAM Fungi Identified in Medicinal Plants across Different Sites

Plant Species	Major VAM Species Found
Withania somnifera	*Glomus faciculatum, Glomus mosseae, Acaulospora appendiculata*
Aloe barbadensis	*Glomus monosporum, Gigaspora gigantea*
Ajuga bracteosa	*Glomus reticulatum, Acaulospora foveata*
Abrus precatorius	*Acaulospora scrobiculata, Glomus intraradices*
Asparagus racemosus	*Scutellospora nigra, Acaulospora appendiculata*
Allium sativum	*Glomus tunicatum, Glomus aggregatum*
Ocimum sanctum	*Acaulospora spinosa, Glomus faciculatum*
Zingiber officinale	*Glomus zingiber sp. nov., Scutellospora pellucida*

Table 2: Root Colonization Percentage by VAM Fungi

Plant Species	Root Colonization (%)
Ajuga bracteosa	80
Allium sativum	75
Abrus precatorius	72
Chenopodium album	70
Asparagus racemosus	68
Achyranthus aspera	65
Ocimum sanctum	64
Adhatoda vasica	60
Boerhaavia diffusa	29

The results of this study confirm the high diversity of VAM fungi in medicinal plants across the selected sites in Bhopal. The dominance of Glomus species is consistent with previous studies, which have frequently reported Glomus as the most prevalent genus in both natural and managed ecosystems (Smith and Read, 1997; Bonfante and Genre, 2010). The high colonization rates observed in plants such as Ajuga bracteosa and Allium sativum underscore the importance of VAM symbiosis in enhancing nutrient uptake, particularly phosphorus, which is crucial for plant growth (Hampp and Schaeffer, 1995).

A noteworthy finding of this study is the identification of three novel species—Glomus zingiber sp. nov., Scutellospora bhojpurensis sp. nov., and Scutellospora indiana sp. nov.—which have not been previously reported. The identification of these new species highlights the unexplored potential of VAM fungi in Indian ecosystems, particularly in relation to medicinal plants. Similar findings have been reported in other tropical and subtropical regions, where the diversity of VAM fungi is high (Zubek and Blaszkowski, 2009).

Comparatively, the spore population and species diversity of VAM fungi in this study were higher than those reported by Harley and Smith (1983). and Zubek and Blaszkowski (2009) in their assessments of mycorrhizal associations with medicinal plants. This could be attributed to the diverse climatic and edaphic conditions across the different sampling sites, which provide a variety of niches for VAM fungal species.

The variation in root colonization percentages observed in different plants suggests that certain plant species may be more selective in their mycorrhizal associations. For instance, Boerhaavia diffusa exhibited significantly lower root colonization compared to other plants, indicating potential differences in host preference or environmental compatibility (Smith and Read, 2008)

CONCLUSION

This study reveals a rich diversity of VAM fungi associated with medicinal plants in Bhopal district, with Glomus species being the most prevalent. The discovery of new species contributes to the growing knowledge of mycorrhizal biodiversity in India. Given the critical role of VAM fungi in nutrient acquisition and plant growth, these findings emphasize the potential for utilizing VAM fungi in biofertilizer formulations to promote sustainable agriculture. Further research is required to explore the commercial application of these fungi in enhancing the productivity of medicinal plants.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest

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