

The first report on diversity of AM fungi from *Leucas stelligera* Wall. ex Benth. *Malaxis versicolor* (Lindl.) Abeyw from Matheran Hills, Maharashtra

Aqsa Naik¹, Lakshmi Girish²

^{1,2} Dept. of Botany, Smt. Chandibai Himathmal Mansukhani College, India

ABSTRACT

The present study assesses the diversity and root colonization of arbuscular mycorrhizal (AM) fungi associated with *Leucas stelligera* Wall. ex Benth and *Malaxis versicolor* (Lindl.) from the Matheran Hills of Maharashtra, India. Rhizosphere soil samples were collected during the peak flowering seasons (November and August) over a three-year period (2022–2024). The analysis revealed abundance of spores and higher root colonization by AM fungi in both the plant species. A total of 16 AM fungal species were identified from *L. stelligera* and 20 species from *M. versicolor*, predominantly belonging to the genera *Glomus* and *Acaulospora*, with *Glomus* emerging as the dominant genus. Mean spore density was recorded as 241.34 ± 8.62 and 276.68 ± 24.13 per 50 g of rhizosphere soil for *L. stelligera* and *M. versicolor*, respectively. Root colonization levels averaged $91 \pm 0.74\%$ in *L. stelligera* and $70 \pm 1.33\%$ in *M. versicolor*. Several AM fungal species reported in this study have not been previously documented in other species of *Leucas* or *Malaxis*, highlighting the uniqueness of the fungal communities in this region. This is the first report on AM fungal diversity associated with *L. stelligera* and *M. versicolor*, as well as the first account from Matheran Hills.

Key words: Arbuscular mycorrhizal fungi, *Glomus*, *Acaulospora*, *Leucas stelligera*, *Malaxis versicolor*, Matheran hills.

INTRODUCTION

The symbiotic association of AM fungi with the roots of higher plants is well documented. Various geographical factors affect the diversity of Am fungi and the diverse assemblage of Am fungal species can enhance the ecosystem productivity [1]. These fungi increase the root surface area of the plants which helps them in the maximum absorption of the nutrients. Soil conditions, geographical isolation, climate, habitat helps in shaping the diversity of AM [2, 3,4, 5]. Additionally, Anthropogenic activities also affect the diversity of AM [6]. According to Gollotte [7] the local AMF diversity is influenced by the condition of soil as well as by the host plants.

Moreover, the composition of specific AM fungal communities is influenced by interactions among the host species [8]. The nutritional requirements and physiological activities of the naturally growing plants are highly dependent on the AM fungi [9]. AM fungi plays a crucial role in protecting the plants form abiotic stress while increasing the absorption of more nutrients and water uptake [10,11].

The composition of arbuscular mycorrhizal fungi (AMF) communities in the Western Ghats remains inadequately understood, as comprehensive studies have been limited to specific regions such as Goa and Kerala [12,13]. Matheran is a part of Western Ghats, and the rhizosphere soil has not been so far studied for AM fungal colonization. It is important to examine the geographical patterns and root association of AM fungi with hosts in specific geographical regions, since edaphic conditions often have an impact on AM fungal species in various environments [14].

Empirical investigations revealed a broad spectrum of Arbuscular mycorrhizal (AM) fungal species members of the *Lamiaceae* family, including *Salvia* [15], *Mentha* [16], and various *Leucas* species such as *L. lantana* [17], *L. aspera* [18], and *L. hirta* [19]. Even though the extensive research on AM fungal associations within *Lamiaceae* family, the rhizospheric diversity related of *Leucas stelligera* remains unexplored. Similarly, AM fungal associations and quantification of mycorrhizal colonization was studied in *Malaxis versicolor* (Lindl.) Santapau & Kapadia from *Orchidaceae* [20]. AM fungal association in *Malaxis rheedei* has been documented by Ram et al. [21]. Govindaraj

Bagyalakshmi [22], Sathiyadash *et al.* [23], and Jyothsna *et al.* [24] reported the mycorrhizal associations and root colonization percentages in *M. rheedei*. However, no previous records are available on the distribution of the diversity of arbuscular mycorrhizal (AM) fungi associated with *Leucas stelligera* and *Malaxis versicolor* from the Matheran region. Hence, study seeks to explore and record the AM fungal diversity associated with the rhizosphere soil of *Leucas stelligera* and *Malaxis versicolor* from Matheran forest.

Leucas stelligera has been observed to occur predominantly during the months of October and November, corresponding to its flowering season, while *Malaxis versicolor* typically flowers between July and August each year in Matheran. Therefore, rhizosphere soil samples were collected from both species during their respective flowering periods to assess the density and AM fungal diversity.

MATERIAL AND METHODS

Description of the plant

Leucas stelligera Wall ex Benth. (Starry Leucas, Burumbi, Goma) belongs to the family *Lamiaceae*, it is an erect branched herb, dense many flowered terminal and axillary whorls and found mostly in the Western Peninsula of India [25]. The plant is herbaceous, erect, branched, softly pubescent, 0.6-1 m high; stem and branches quadrangular and hairy. Leaves are 5-10 X 1.5-2.5 cm, obtuse or sub-acute, elliptic or oblong-lanceolate, obtusely serrate green on top, and pale underneath, long, soft hair covers the base, which taper into the petiole, which is 3-10mm long. Sessile flowers in thick terminal and axillary whorls with numerous flowers that can be sometime 4 cm in diameter. Calyx pubescent, teeth about 1.5 mm long, linear, soft. Corolla white, rather less than 10 mm long, lips of limb nearly equal, the upper surface is thickly covered with long white hair, the middle lobe of the lower lip sub-orbicular. Fruit is nutlets 2 mm long, oblong- obovoid, rounded at the apex. Flowering: November [26]. The plants were collected from Matheran hill, Raigad, Maharashtra Situated in the Western Ghats at an altitude of about 800 m (2,625 ft) above sea level



Figure 1: a. *Leucas stelligera* Wall. ex Benth. b. *Malaxis versicolor* (Lindl.)

Malaxis versicolor (Lindl.) Abeyw is one of the greatly varying species in the Western Ghats. It is terrestrial, lithophytic, and infrequently epiphytic. The stem is sheathed in a greenish-purple sheath and stands erect, 3–25 cm tall, with a slight swollen base. There are three to five leaflets, which can be broadly ovate, elliptic-lanceolate, or ovate-lanceolate. Length of petioles: 2–6 cm. The inflorescence is 8–35 cm long. It shows pedicellate yellow flowers with a tinge of purple when they are young, maturing into deep reddish-purple flowers measuring 4x4 mm in diameter. Shows the Green, 3.5 ×1-1.5 mm bracts. While the petals are purple, entire, reduplicate, reniform, slightly curved, and fan-shaped, the sepals are uneven, purple, and obtuse. While flowering occurs from July – August and fruiting occurs from September -March, [27].

Collection and processing of the soil

To examine the spore diversity in *Leucas stelligera* and *Malaxis versicolor* soil from the root zone area was collected during their respective flowering seasons (November for *L. stelligera* and August for *M. versicolor*) over the period 2022–2024. The soil samples were kept at 4°C in zip locked polythene bag till further analysis. The root samples taken for the analysis of colonization and later fixed with FAA.

Estimation of AM fungal colonization and isolation of spores

Spore Isolation

Am fungal spores were isolated by sieving decanting technique of Gerdeman and Nicolson [28]. 50gms of rhizosphere soil were added to 500 ml of water. The soil suspension was allowed to stand undisturbed to facilitate the settling of soil particles at the bottom. The supernatant was then passed through different mesh sizes such as 210µm, 120µm, 103µm, 4.5µm, 2.5µm to collect the spores. It is then isolated on Whatman's filter paper No.1. The trapped spores or sporocarps were observed under the stereomicroscope after mounting in PVLG.

Examination of root colonization

The collected roots were washed and further examination was performed by the Phillips and Hayman method [29]. Firstly, the roots were washed and then kept in 10% KOH at 121°C for 10 minutes and then treated with 5N HCl for 3-4 minutes then again after washing with water they kept overnight in trypan (0.05%) blue for staining. Mounting of spores was done in PVLG. The percentage of root colonization was recorded after the analysis.

$$\text{Root colonization percentage} = \frac{\text{No. of infected root fragments}}{\text{Total No. of fragments seen}} \times 100$$

Identification of the isolated AM spores

Identification of spores and sporocarps was done by using manuals of Schencz and Perez [30] also by using standard sites such as www.invam.caf.wvu.edu and www.zor.zut.edu based on colour, hyphae, shield, wall layers etc. The identification of spores was confirmed by Dr. V. Mohan, Scientist- G and Head (RETD), University of Madras, Chennai.

RESULTS AND DISCUSSION

The dominant species of AM fungi associated with the rhizosphere soil of *Leucas stelligera* and *Malaxis versicolor* are presented in Table 2. A total of 16 AM fungal species in the rhizosphere of *L. stelligera* (fig. 3.) and 20 species associated with *M. versicolor* (Fig.4) were recorded. *Leucas stelligera* and *Malaxis versicolor* exhibited mean spore densities of 241.34 ± 8.62 and 276.68 ± 24.13 per 50 g of rhizosphere soil, respectively. Over the three-year period of study, the mean root colonization rates recorded were $91.00 \pm 0.74\%$ for *L. stelligera* and $70.00 \pm 1.33\%$ for *M. versicolor* (Table. 1) (Fig.2). The increased colonization in hosts may be due to the release of oxidizable compounds, which may attract the Am fungi [31]. Since variety of factors such as moisture, pH, temperature of soil, hosts, seasonal variations of spore germination, hence the current study did not found a co relation between the colonization rate and spore density [32, 33]. According to Bever [34], the host species can provide either positive or negative feedback on the sporulation of several AM fungi. Low soil nutrient content, good aeration, undisturbed soil, or ideal moisture levels that provided enough time for mycorrhizal spore colonization could also be the cause of the high AM spore density in the present study [35].

Table 1: The percentage of root colonization, mean AM spore density

Sr. No	Host species	AM structure present in root			Average percent of root colonization	No. of AM species recorded	Mean spore density/50gm of rhizosphere soil
		H	V	A			
1.	<i>Leucas stelligera</i>	+	+	-	91 ± 0.737	16	241.34 ± 8.621
2.	<i>Malaxis versicolor</i>	+	-	-	70 ± 1.34	20	276.68 ± 24.131

Where, #H – Hyphae, V-Vesicles, A- Arbuscules; +: Present, -: Absent, ±: Standard deviation

Table 2: Diversity of spores

Sr. No.	Name of the plant	Am fungal spores
1	<i>Leucas stelligera</i>	a. <i>Glomus geosporum</i> b. <i>Glomus caledonium</i> c. <i>Glomus claroideum</i> d. <i>Glomus multicaulae</i> e. <i>Glomus fulvus</i> f. <i>Glomus albidum</i> g. <i>Glomus macrocarpum</i> h. <i>Glomus occultum</i> i. <i>Glomus fecundisporum</i> j. <i>Glomus pubescens</i> k. <i>Glomus constrictum</i> l. <i>Glomus microcarpum</i> m. <i>Glomus intraradice</i> n. <i>Acualospora scrobiculata</i> o. <i>Acaulospora laevis</i> p. <i>Glomus aggregatum</i> (sporocarp)
2	<i>Malaxis versicolor</i>	a. <i>Glomus pubescens</i> , b. <i>Acualospora denticulate</i> , c. <i>Glomus multisubstensum</i> , d. <i>Glomus occultum</i> , e. <i>Glomus convolutum</i> , f. <i>Glomus albidum</i> , g. <i>Glomus fecundisporum</i> , h. <i>Glomus multicaulae</i> , i. <i>Glomus intraradices</i> , j. <i>Glomus geosporum</i> , k. <i>Glomus macrocarpum</i> , l. <i>Acaulospora scrobiculata</i> , m. <i>Glomus monosporum</i> , n. <i>Glomus fasciculatum</i> , o. <i>Glomus microcarpum</i> , p. <i>Glomus caledonium</i> , q. <i>Glomus deserticola</i> , r. <i>Glomus constrictum</i> , s. <i>Glomus diaphanum</i> , t. <i>Glomus multisubstensum</i>

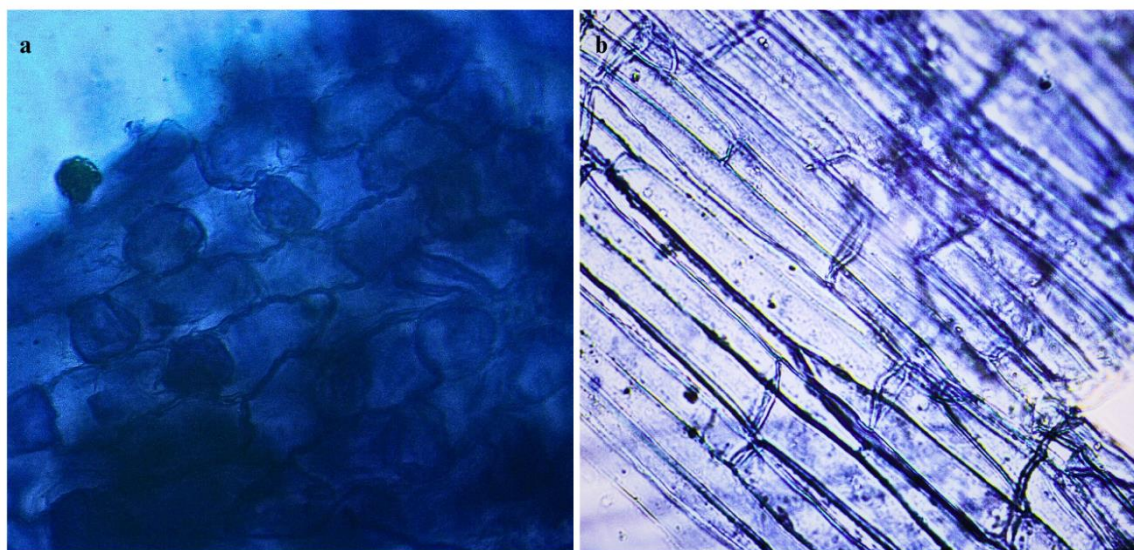


Fig: 2 Mycorrhizal infection in roots of a. *Leucas stelligera* Wall. ex Benth. b. *Malaxis versicolor* (Lindl.) Abeyw

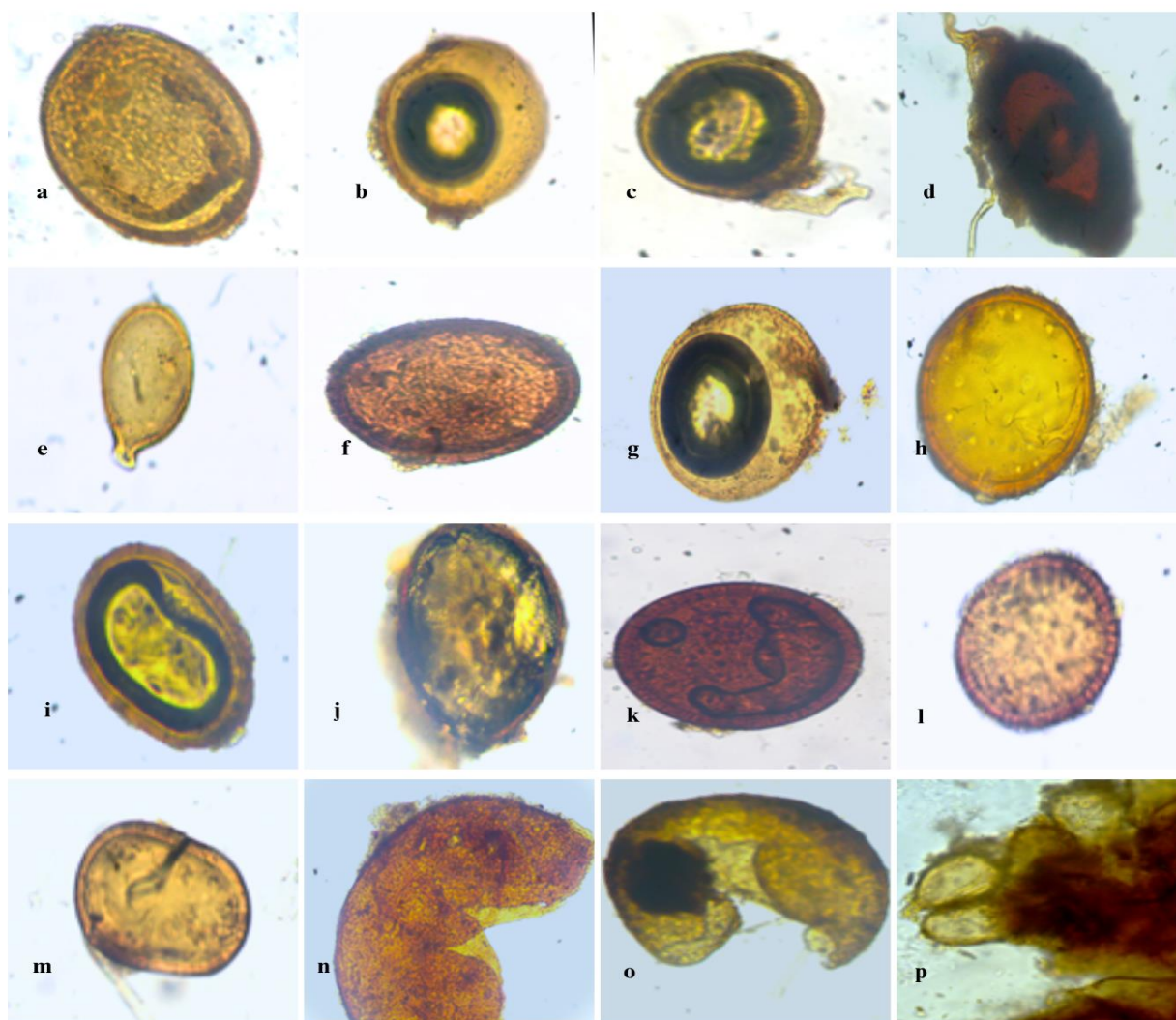


Figure 3: AMF diversity in *Leucas stelligera* Wall. ex Benth : a. *Glomus geosporum* b. *Glomus caledonium* c. *Glomus claroideum* d. *Glomus multicaulae* e. *Glomus fulvus* f. *Glomus albidum* g. *Glomus macrocarpum* h. *Glomus occultum* i. *Glomus fecundisporum* j. *Glomus pubescens* k. *Glomus constrictum* l. *Glomus microcarpum* m. *Glomus intraradice* n. *Aculospora scrobiculata* o. *Acaulospora laevis* p. *Glomus aggregatum* (sporocarp)

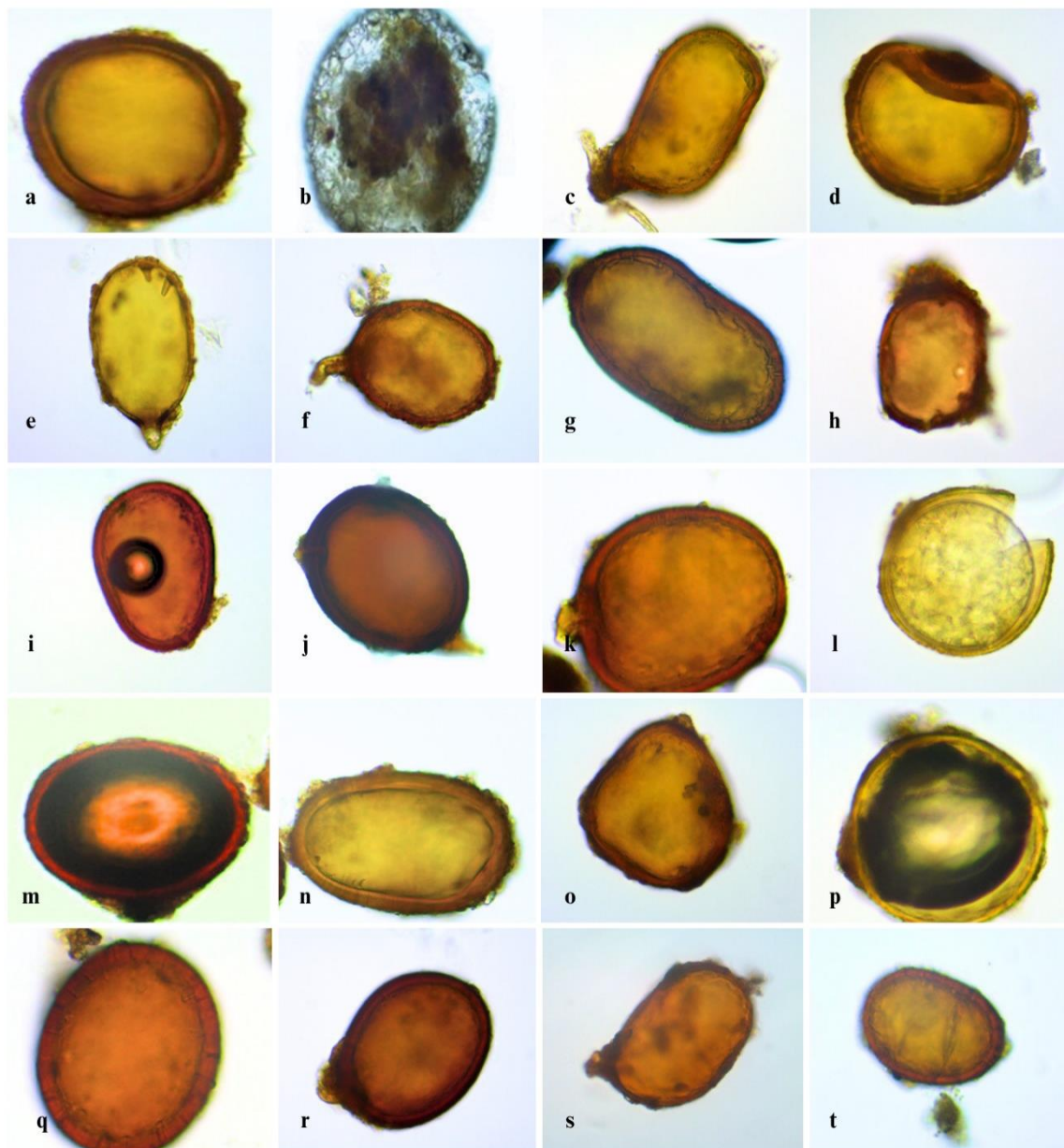


Figure 4: AMF diversity in *Malaxis versicolor* (Lindl.) Abeyw : a. *Glomus pubescens*, b. *Acaulospora denticulate*, c. *Glomus multisubstensum*, d. *Glomus occultum*, e. *Glomus convolutum*, f. *Glomus albidum*, g. *Glomus fecundisporum*, h. *Glomus multicaulae*, i. *Glomus intraradices*, j. *Glomus geosporum*, k. *Glomus macrocarpum*, l. *Acaulospora scrobiculata*, m. *Glomus monosporum*, n. *Glomus fasciculatum*, o. *Glomus microcarpum*, p. *Glomus caledonium*, q. *Glomus deserticola*, r. *Glomus constrictum*, s. *Glomus diaphanum*, t. *Glomus multisubstensum*

Previous studies on *Leucas lantana* have reported the presence of various AM fungal species, including *Acaulospora foveata*, *A. laevis*, *A. bireticulata*, *A. denticulata*, *Entrophospora* sp., *Glomus ambisporum*, *G. clavisporum*, *G. fasciculatum*, *G. macrocarpum*, *G. magnicauli*, *G. mosseae*, *G. pallidus*, *G. pansihalos*, *G. sinuosum*, *Sclerocystis ceremoides*, and *Scutellospora* sp. [36]. Rajkumar et al. [37] reported *G. rubiforme*, *G. luteum*, *G. fasciculatum*, *G. manihotis*, *A. denticulate*, *Gigaspora* sp. from *Leucas hirta* and *G. fasciculatum*, *A. myriocarpa*, *A. scrobiculata* from *Leucas hirta*. *A. laevis* and *G. luteum* were reported from *Leucas aspera* [38]. Also studies on various *Leucas* species have demonstrated associations with a diverse range of AM fungal species. In present study, except for *Acaulospora scrobiculata*, *A. laevis*, and *Glomus macrocarpum*, which were also reported in earlier *Leucas* species, all other AM fungal spores identified in *L. stelligera* were distinct, suggesting a unique assemblage of AM fungi potentially influenced by host-specific traits or environmental conditions.

N. Raman and N. Nagarajan [39] were the first to report *Glomus aggregatum* and *Glomus mosseae* in association with *Malaxis rheedi*. In contrast, the other AM fungal species found in *Malaxis versicolor* appear to be unique and have not been recorded in any other *Malaxis* sp.

The dominance of *Glomus* sp. in the host trees of in the Western Ghats region was documented by Muthukumar and Manian [40] and Vasanthakrishna *et al.* [41]. Consistent with these findings, the present study identified *Glomus* as the most prevalent AM fungal genus associated with both *Leucas stelligera* and *Malaxis versicolor*. This dominance may be attributed to the evolutionary adaptability of *Glomus*, which is believed to have developed efficient and versatile symbiotic mechanisms with a broad variety of host plants as part of a co-evolutionary process [42].

Members of the genera *Acaulospora* and *Glomus* are known to produce spores more rapidly than genera such as *Gigaspora* and *Scutellospora*. Some AM fungi develops mycelia but produce relatively few spores, particularly those from families other than *Acaulosporaceae* and *Glomeraceae*. This may explain the observed dominance of *Acaulospora* and *Glomus* species in the present study [43,44]. Moreover, evidence suggests that plants can actively select specific AM fungal partners, resulting in distinct AM fungal communities even among individuals of the same species [45,46]. The present findings further suggest that the symbiotic association of AM fungi with *L. stelligera* and *M. versicolor* is likely governed more by host preference than strict host specificity, in line with earlier observations by Smith and Read [47] and Yang *et al.* [48].

CONCLUSION

Present study, the genus *Glomus* was consistently prominent, indicating its ecological adaptability and possible co-evolution with a variety of plant species. When compared to those found in other species of *Leucas* and *Malaxis*, the unique AM fungal assemblages found in the study suggest that selection of host by fungus is influenced by regional soil and microclimatic conditions. The dominance of fast-sporulating genera such as *Glomus* and *Acaulospora* is due to their adaptive advantage in colonizing diverse hosts. The documentation of AM fungal associations with *L. stelligera* and *M. versicolor* contributes to the understanding of host–fungus interactions in less-studied medicinal and endemic species. Specifically, the identified AM fungal taxa, particularly those from the genus *Glomus*, could be utilized in the development of targeted AM fungal inoculants aimed at enhancing plant growth, improving nutrient uptake, and potentially increasing the biosynthesis of secondary metabolites during cultivation of these species.

REFERENCES

1. Prasad, K. 2017. "Biology, Diversity and Promising Role of Mycorrhizal Endophytes for Green Technology." In *Endophytes: Biology and Biotechnology*, edited by D. K. Maheshwari, Vol. 1, 267–301. Sustainable Development and Biodiversity 15. Springer International Publishing.
2. Koske, R. 1987. "Distribution of VA mycorrhizal fungi along a latitudinal temperature gradient." *Mycologia* 79: 55–68.
3. Lugo, M. A., M. Ferrero, E. Menoyo, M. C. Estevez, F. Sineriz, and A. Anton. 2008. "Arbuscular mycorrhizal fungi and rhizospheric bacteria diversity along an altitudinal gradient in south American puna grassland." *Microbial Ecology* 55: 705–713.
4. Li, L. F., T. Li, Y. Zhang, and Z. W. Zhao. 2010. "Molecular diversity of arbuscular mycorrhizal fungi and their distribution patterns related to host-plants and habitats in a hot and arid ecosystem, southwest China." *FEMS Microbiology Ecology* 71: 418–427.
5. Van der Gast, C. J., P. Gosling, B. Tiwari, and G. D. Bending. 2011. "Spatial scaling of arbuscular mycorrhizal fungal diversity is affected by farming practice." *Environmental Microbiology* 13: 241–249.
6. Öpik, M., A. Vanatoa, E. Vanatoa, M. Moora, J. Davison, J. M. Kalwij, U. Reier, and M. Zobel. 2010. "The online database MaarjAM reveals global and ecosystemic distribution patterns in arbuscular mycorrhizal fungi (Glomeromycota)." *New Phytologist* 188: 223–241.
7. Gollotte, A., D. van Tuinen, and D. Atkinson. 2004. "Diversity of arbuscular mycorrhizal fungi colonising roots of the grass species *Agrostis capillaris* and *Lolium perenne* in a field experiment." *Mycorrhiza* 14: 111–117.
8. Hausmann, N. T., and C. V. Hawkes. 2009. "Plant neighborhood control of arbuscular mycorrhizal community composition." *New Phytologist* 183: 1188–1200.
9. Rajkumar, H. G., S. H. S. Seema, and C. P. Sunil Kumar. 2012. "Diversity of arbuscular mycorrhizal fungi associated with some medicinal plants in Western Ghats of Karnataka region, India." *World Journal of Science and Technology* 2(1): 13–20.
10. Miransari, M. 2010. "Contribution of arbuscular mycorrhizal symbiosis to plant growth under different types of soil stress." *Plant Biology* 12: 563–569.
11. Evelin, H., R. Kapoor, and B. Giri. 2009. "Arbuscular mycorrhizal fungi in alleviation of salt stress: a review." *Annals of Botany* 104: 1263–1280.
12. Khade, S. W., and B. F. Rodrigues. 2003. "Arbuscular mycorrhizal fungi associated with two endemic plants in Western Ghats of Goa, India." *Mycorrhiza News* 15(4): 15–17.
13. Muthukumar, T., and K. Udaiyan. 2000. "Arbuscular mycorrhizas of plants growing in the Western Ghats region, South India." *Mycorrhiza* 9(6): 297–313. <https://doi.org/10.1007/s005720050276>.
14. Gollotte, A., D. van Tuinen, and D. Atkinson. 2004. "Diversity of arbuscular mycorrhizal fungi colonising roots of the grass species *Agrostis capillaris* and *Lolium perenne* in a field experiment." *Mycorrhiza* 14: 111–117.

15. Chen, H., H. Wu, B. Yan, H. Zhao, F. Liu, and H. Zhang. 2018. "Core microbiome of medicinal plant *Salvia miltiorrhiza* seed: A rich reservoir of beneficial microbes for secondary metabolism?" *International Journal of Molecular Sciences* 19: 672. <https://doi.org/10.3390/ijms19030672>.
16. Tanvir, Burni, Subhan Ullah, Zahid Fazal, Sakina Bibi, Ali Hazrat, and Khan Sher. 2020. "Arbuscular Mycorrhizal Fungi (AMF) effects on growth and nutritional performance of *Mentha arvensis* L. at various levels of rock phosphate amendments." *Bioscience Research* 17: 1730–1742.
17. RACHANA
18. Anubrata, D., and Jayashree, D. 2012. "Mycorrhizal biodiversity in *Leucas aspera* (Willd.) Link." *International Journal of Science and Research* 3(6): 147–150.
19. Rajkumar, H. G., S. H. S. Seema, and C. P. Sunil Kumar. 2012. "Diversity of arbuscular mycorrhizal fungi associated with some medicinal plants in Western Ghats of Karnataka region, India." *World Journal of Science and Technology* 2(1): 13–20.
20. Bagyalakshmi, G., T. Muthukumar, K. Sathiyadash, and V. Muniappan. 2010. "Mycorrhizal and dark septate fungal associations in shola species of Western Ghats, southern India." *Mycoscience* 51: 44–52.
21. Ram, T. A., M. R. Reddy, and V. V. S. S. R. Murthy. 1999. "Occurrence of vesicular arbuscular mycorrhiza in terrestrial orchids." *Journal of Orchid Society of India* 13(1–2): 73–75.
22. Bagyalakshmi, G., T. Muthukumar, K. Sathiyadash, and V. Muniappan. 2010. "Mycorrhizal and dark septate fungal associations in shola species of Western Ghats, southern India." *Mycoscience* 51: 44–52.
23. Sathiyadash, K., T. Muthukumar, E. Uma, and R. R. Pandey. 2012. "Mycorrhizal association and morphology in orchids." *Journal of Plant Interactions* 7(3): 238–247. <https://doi.org/10.1080/17429145.2012.699105>
24. Jyothsna, B. S., Radha Mahendran, Manish Raj Mishra, Sanjay Dey, and Deepti Srivastava. 2024. "Study of Morphology and Orchid Mycorrhizal Associations in *Malaxis rheedei*." *Journal of Applied Biology & Biotechnology* 12(3): 185–189. <https://doi.org/10.7324/JABB.2024.172466>.
25. Yadav, S. R., and M. M. Sardesai. 2002. *Flora of Kolhapur District*. Rajhuns Printing Press, Kolhapur, p. 381.
26. Almeida, M. R. 1998. *Flora of Maharashtra, Vol. 2*. Blatter Herbarium, St. Xavier's College, Mumbai, 102, 207, 208, 282.
27. Santapau, H., and Z. Kapadia. 1964. *The Orchids of Bombay*. Government of Maharashtra.
28. Gerdemann, J. W., and Y. H. Nicolson. 1963. "Spores of mycorrhizae Endogone species extracted from soil by wet sieving and decanting." *Transactions of the British Mycological Society* 46: 235–244.
29. Philips, J. M., and D. S. Hayman. 1970. "Improved procedures for clearing roots and staining parasitic and vesicular–arbuscular mycorrhizal fungi." *Transactions of the British Mycological Society* 55: 158–160.
30. Schenck, M. C., and Y. Perez. 1990. *Manual for the Identification of VA Mycorrhizal Fungi*. INVAM, Gainesville, USA, 280 pp.
31. Huang, X. F., J. M. Chaparro, K. F. Reardon, R. F. Zhang, Q. R. Shen, and J. M. Vivanco. 2014. "Rhizosphere interactions: root exudates, microbes, and microbial communities." *Botany* 92(4): 267–275.
32. García, I. V., and R. E. Mendoza. 2008. "Seasonal variation of arbuscular mycorrhizal fungi in temperate grasslands along a wide hydrologic gradient." *FEMS Microbiology Ecology* 65(1): 76–86. <https://doi.org/10.1111/j.1574-6941.2008.00498.x>.
33. Kumar, A., C. Mangla, A. Aggarwal, and V. Parkash. 2010. "Arbuscular Mycorrhizal Fungal Dynamics in the Rhizospheric Soil of Five Medicinal Plant Species." *Middle-East Journal of Scientific Research* 6(3): 281–288.
34. Bever, J. D. 2002. "Host-specificity of AM fungal population growth rates can generate feedback on plant growth." *Plant and Soil* 244(1–2): 281–290. <https://doi.org/10.1023/A:1020221600584>.
35. Usharani, K., D. Muthukumar, and K. Udaiyan. 2016. "Diversity and colonization potential of arbuscular mycorrhizal fungi in medicinal plants of southern Eastern Ghats, India." *Mycorrhiza* 26(3): 223–239. <https://doi.org/10.1007/s00572-015-0668-2>.
36. Rachna Verma, , Ashwani Tapwal, Dinesh Kumar, Vipin Parkash, and Sunil Puri. 2019. "Vesicular Arbuscular Mycorrhizal Diversity in Some Important Ethnomedicinal Plants of Western Himalaya." *Medicinal Plants* 11, no. 3: 279–285. <https://doi.org/10.5958/0975-6892.2019.00036.4>.
37. Rajkumar, H. G., S. H. S. Seema, and C. P. Sunil Kumar. 2012. "Diversity of arbuscular mycorrhizal fungi associated with some medicinal plants in Western Ghats of Karnataka region, India." *World Journal of Science and Technology* 2(1): 13–20.
38. Koul, K. K., Shuchi Agarwal, and Rafiq Lone. 2012. "Diversity of Arbuscular Mycorrhizal Fungi Associated with the Medicinal Plants from Gwalior-Chambal Region of Madhya Pradesh-India." *American-Eurasian Journal of Agricultural & Environmental Sciences* 12(8): 1004–1011.
39. Raman, N., and N. Naga. 1999. "Mycorrhizal Association of Orchids in a Tropical Forest of Southern India." *Journal of Tropical Forest Science* 11(3): 548–553.
40. Muthukumar, T., and S. Manian. 1993. "Vesicular arbuscular mycorrhizae in tropical tree species of the Western Ghats." *Indian Journal of Microbiology* 33(2): 135–139.
41. Vasanthakrishna, M., M. C. Siddappa, and A. N. Purohit. 1994. "Distribution of vesicular-arbuscular mycorrhizal fungi under different tree species in Western Ghats forests of Karnataka." *Mycorrhiza News* 6(4): 10–12.
42. Van der Heijden, M. G. A., J. N. Klironomos, M. Ursic, P. Moutoglis, and R. Streitwolf-Engel. 1998. "Mycorrhizal fungal diversity determines plant productivity and ecosystem variability." *Nature* 396: 69–72.

43. Hart, M. M., and R. J. Reader. 2002. "Taxonomic basis for variation in the colonization strategy of arbuscular mycorrhizal fungi." *New Phytologist* 153(2): 335–344.
44. Piotrowski, J. S., T. Denich, J. N. Klironomos, J. M. Graham, and M. C. Rillig. 2004. "The effects of arbuscular mycorrhizas on soil aggregation depend on the interaction between plant and fungal species." *New Phytologist* 164(2): 365–373.
45. Aldrich-Wolfe, L. 2007. "Distinct mycorrhizal communities on new and established hosts in a transitional tropical plant community." *Ecology* 88: 559–566.
46. Yang, G., D. Zhang, X. Liu, and Z. Wang. 2012. "Host plant species determines the composition of arbuscular mycorrhizal fungal communities in the rhizosphere of citrus." *Plant and Soil* 357(1–2): 363–371. <https://doi.org/10.1007/s11104-012-1173-0>.
47. Smith, S. E., and D. J. Read. 2008. *Mycorrhizal Symbiosis*. 3rd ed. Academic Press.
48. Yang, Y., J. Zhang, X. Liu, and Y. Wan. 2010. "Host plants exert a greater influence on arbuscular mycorrhizal fungal communities than soil type in a degraded sandy grassland in northern China." *Soil Biology and Biochemistry* 42(10): 1661–1667. <https://doi.org/10.1016/j.soilbio.2010.06.001>.