

Exploring the Arbuscular Mycorrhizal Fungal dependency in some common medicinal plants of Asteraceae from Ballavpur Wildlife Sanctuary, West Bengal

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Three medicinal plants viz., *Eclipta alba*, *Elephantopus scaber* and *Vernonia cinerea* of Asteraceae family inhabiting inside Ballavpur Wildlife Sanctuary (BWLS) were investigated for determining the diversity, abundance and distribution of Arbuscular Mycorrhizal Fungi (AMF). Selected plant species exhibited sufficient AMF association indicating mycorrhizal dependency. Maximum root colonization and spore density were noticed in *E. scaber*. Altogether, six AMF genera viz., *Glomus*, *Acaulospora*, *Scutellospora*, *Funnelformis*, *Gigaspora* and *Ambispora* were isolated from the selected plants, of which *Glomus*, *Acaulospora* and *Scutellospora* were commonly associated. Twenty-four different AMF species were identified, of which a maximum of 15 species was recorded in *E. alba* followed by 11 species from *E. scaber* and a minimum of nine species from *V. cinerea*. Among all isolated species of AM fungi, *Glomus intraradices* and *Acaulospora elegans* were found to inhabit all three selected plant rhizosphere. Based on Shannon-Wiener index (H'), *E. scaber* had maximum number of diverse AMF species, and *V. cinerea* had a poor AMF diversity. Significant positive correlations were observed among spore density, species richness, and root colonization, which undoubtedly indicated the role of AMF in influencing plant growth and better adaptability in the lateritic soil of this sanctuary.

Keywords : Arbuscular mycorrhizal fungi, medicinal plants, mycorrhizal dependency, root colonization, spore density

INTRODUCTION

Mycorrhiza signifies a mutualistic relationship between fungi and plant roots and consists of two words: mykes means fungi, and rhiza, means root (Read *et al.* 2000). Broadly, mycorrhizae are classified into Ectomycorrhizae, where fungal partner always remains outside the plant root system, and Endo mycorrhizae, where fungal hyphae enter into the cortical regions of root and produce characteristic arbuscules and vesicles-like structures; moreover, arbuscules are more frequent than vesicles hence mycorrhizae are commonly called as Arbuscular Mycorrhizal Fungi (Strack *et al.* 2003; Priyadarshini *et al.* 2017). More than 90% of higher plants are frequently associated with one or more types of mycorrhizal fungi, indicating their coexistence and

dependency (Denison and Kiers, 2011; Sarkar *et al.* 2014).

Arbuscular mycorrhizal (AM) fungi are obligate symbionts that belong to the phylum Glomeromycota (Schubler *et al.* 2001). They are known for their plant growth-promoting activity through solubilization and mobilization of different minerals by secretion of various enzymes. They enhance nutrient availability, particularly phosphorus (P), nitrogen (N_2), sodium (Na), potassium (K), and calcium (Ca), and mobilization of these minerals via their hyphal networks (Franco-Ramirez *et al.* 2021; Tang *et al.* 2023; Wang *et al.* 2023). AMF also increases root absorption area through its extended mycelium beyond the root region and facilitates water uptake, boosts disease resistance, enhances tolerance to salt and drought, and contributes to soil quality by maintaining microbial diversity (Sun *et al.* 2022; Lutz *et al.* 2023).

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Each plant has its unique AMF dependency, shaped by interplay of soil type, nutrient availability, and soil water content that are crucial for successful and better plant adaptation and survivability. Similarly, not all AMF species contribute equally to plant growth promotion, as each one exhibits a different potential to solubilize and mobilize unavailable nutrients (Zhang *et al.* 2022). This symbiotic association also depends on plant type, fungal colonization capability and their survivability inside the host root system. Ballavpur Wildlife Sanctuary (BWLS) is one of India's oldest wildlife sanctuaries founded in 1977 in Bolpur sub-division of Birbhum district of West Bengal and is spread over 200 hectares. It is well known for conserving spotted deer and Indian Antelope within the fenced area. Characteristic lateritic soil of this sanctuary harbors a vast range of flora, including herbs, shrubs and trees belonging to diverse families (Ganguli *et al.* 2016). Of various plants that thrive in this sanctuary, three plants of Asteraceae viz., *E. alba*, *E. scaber*, and *V. cinerea*, having high ethnomedicinal properties and dominance in nature, were selected for present study. These plants contain several beneficial phytochemicals, including polyphenols, flavonoids, and terpenoids known for their medicinal importance. Arbuscular mycorrhizal fungi could play an important role in survival and luxuriant growth of these plants in this sanctuary as they help plants enriching with increased water and nutrient supply. A high degree of AMF association

might be correlated to better plant growth and indicates AMF dependency (Yuan *et al.* 2023). Present study aims to isolate mycorrhizal fungi and determine their diversity, species richness, degree of root colonization and relative abundance.

MATERIALS AND METHODS

Assessment of root colonization by AM Fungi

For assessment of root colonization (RC) by AM Fungi, 200g of rhizospheric soil was taken in triplicate from three selected plants of Asteraceae, viz., *E. alba*, *E. scaber* and *V. cinerea* from Ballavpur Wildlife Sanctuary from April to August. Collected soil samples from each plant were taken in separate polythene bags and stored

at 4°C for further study. About 1cm of finer rootlet was cut from the same selected plants. After being washed with tap water, it was preserved in a solution of formaldehyde, glacial acetic acid, and ethanol with a volume ratio of 12.5: 12.5: 200 ml for further study (Yang *et al.* 2019). To study root colonization by AM fungi, previously preserved rootlets were washed with tap water twice and boiled in 10 % KOH solution at 90°C in a water bath for about one hour or until the roots became softened (Phillips and Hayman, 1970). After cooling, KOH solution was decanted and was acidified by mixing sufficient 2 N HCl for 10 minutes. After decanting, rootlets were further treated overnight with 0.05% trypan blue for staining. To determine percentage root colonization (RC), pretreated rootlets were observed under a compound microscope in terms of presence of characteristic arbuscules, vesicles and hyphae. Finally, root colonization percentage of individual plants was calculated (triplicate) with the help of following formula:

$$\% RC = \frac{\text{No. of infected rootlets}}{\text{Total no. of rootlets observed}} \times 100$$

Isolation AMF spore and their identification

Wet sieving and decanting method of Gerdemann and Nicolson (1963) was followed for isolation of AMF Spores. For this, 25 g of rhizosphere soil of each plant was air-dried separately and poured into a 500 ml beaker. About 250 ml of lukewarm water was added to each beaker and stirred properly with the help of a magnetic stir. The soil water solution was then passed from different sieves (500 to 40 μm) arranged from bottom to top to separate AMF spores. For debris-free separation of AM spore, spores from all sieves were taken out in a beaker in a mixed way, and finally, was centrifuged with 10% sucrose solution at 3,000 rpm. Centrifuged spore solution was again sieved, and residues of each respective sieve were collected separately and observed under the ZEISS Primo Star Binocular Microscope. Several characteristics and features of the spores, such as color, size, shape, surface, cell wall structure with number of layers, nature of the spore contents, and hyphal attachment, were considered to identify isolated AMF spores. Spore morphological characters

were observed in a gently pressed slide mounted with PVLG (Poly-Vinyl-Lacto-Glycerol) solution, and based on the above-mentioned criteria, final identification was made with the help of the manual of Schenck and Perez (1990), and the information available at www.invam.caf.wvu.edu website.

Determination of AM diversity and diversity index

To determine the AM diversity of each plant, spore density (SD), relative abundance (RA), species richness (SR) and Isolation frequency (IF) were determined by using the formula mentioned by Chahar and Belose(2018).

Similarly, spore diversity index in terms of Shannon–Wiener index (H'), Simpson index (D) and evenness (E) were determined by using following formulas (Gao and Guo, 2010; Verma and Verma, 2017).

$$H' = \sum_{i=1}^S p_i \ln p_i$$

$$D = \frac{1}{\sum_{i=1}^S (p_i - 1) / (p_i - 1)}$$

$$E = H' / H'_{\max}$$

Where p_i is the proportion of the (i)th species, n_i is the number of individuals of the taxon (i), (N) is the total number of species, and H'_{\max} is $\ln S$ where S is the total number of identified species. All the triplet data were statistically analyzed using one-way ANOVA and Pearson correlation at ($p < 0.05$) level for their significance.

RESULTS AND DISCUSSION

Root colonization and AMF dependency

All three selected plant species showed variable presence of characteristic internal hyphae, vesicles, and arbuscules in the root cortical region, indicating the colonization of AM fungi (Table 1). Several earlier workers reported the presence of these types of fungal structures in the root cortical region and confirmed mycorrhizal association (Bhattacharya *et al.* 2009; Koul *et al.* 2012; Chahar and Belose, 2018). Maximum (68%) percentage of root colonization (RC) was noticed in *E. scaber*, followed by *E. alba* (59%) and minimum (38%) was recorded in *V. cinerea*.

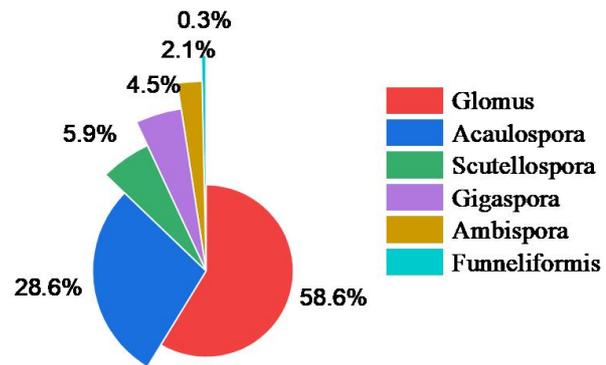


Fig.1: Overall relative abundance of different AMF genera.

Similarly, *E. scaber* showed a maximum percentage of vesicles and arbuscules compared to the other two selected plants. A higher root colonization percentage, vesicles and arbuscules indicate higher mycorrhizal dependency (Kumar *et al.* 2019). Rajkumar *et al.* (2012), while working on mycorrhizal dependency in *E. alba* and *E. scaber* of Western Ghat of Karnataka region, noticed a very high (95.5% and 94%, respectively) root colonization. However, Saranya and Nagarajan (2017) reported comparatively lower root colonization in *E. scaber* (40%) and in *V. cinerea* (42%) in the lake region of Kerala district indicated that root colonization differ in different edaphic conditions.

Spore density and Relative abundance

In 25 g of rhizosphere soil, a maximum (108) spore density was noticed in *E. alba* followed by *E. scaber* (96), and a minimum (86) was recorded in *V. cinerea* (Table 1). Occurrence of an adequate number of AMF spores in rhizospheric soil emphasizes the degree of its symbiotic association. Altogether, six different genera, viz., *Glomus*, *Acaulospora*, *Scutellospora*, *Funneliformis*, *Gigaspora* and *Ambispora* were isolated from all three selected plant species with different relative abundance (RA) (Table 2). Overall relative abundance of particular genus was observed to be maximum (58.62) in *Glomus*, followed by *Acaulospora* (28.62), *Scutellospora* (5.86), *Gigaspora* (4.48), *Funneliformis* (2.06) and minimum (0.34) was noticed in *Ambispora* (Fig. 1). Based on high RA, *Glomus* and *Acaulospora* were considered as dominant AMF genera of this sanctuary. Lower

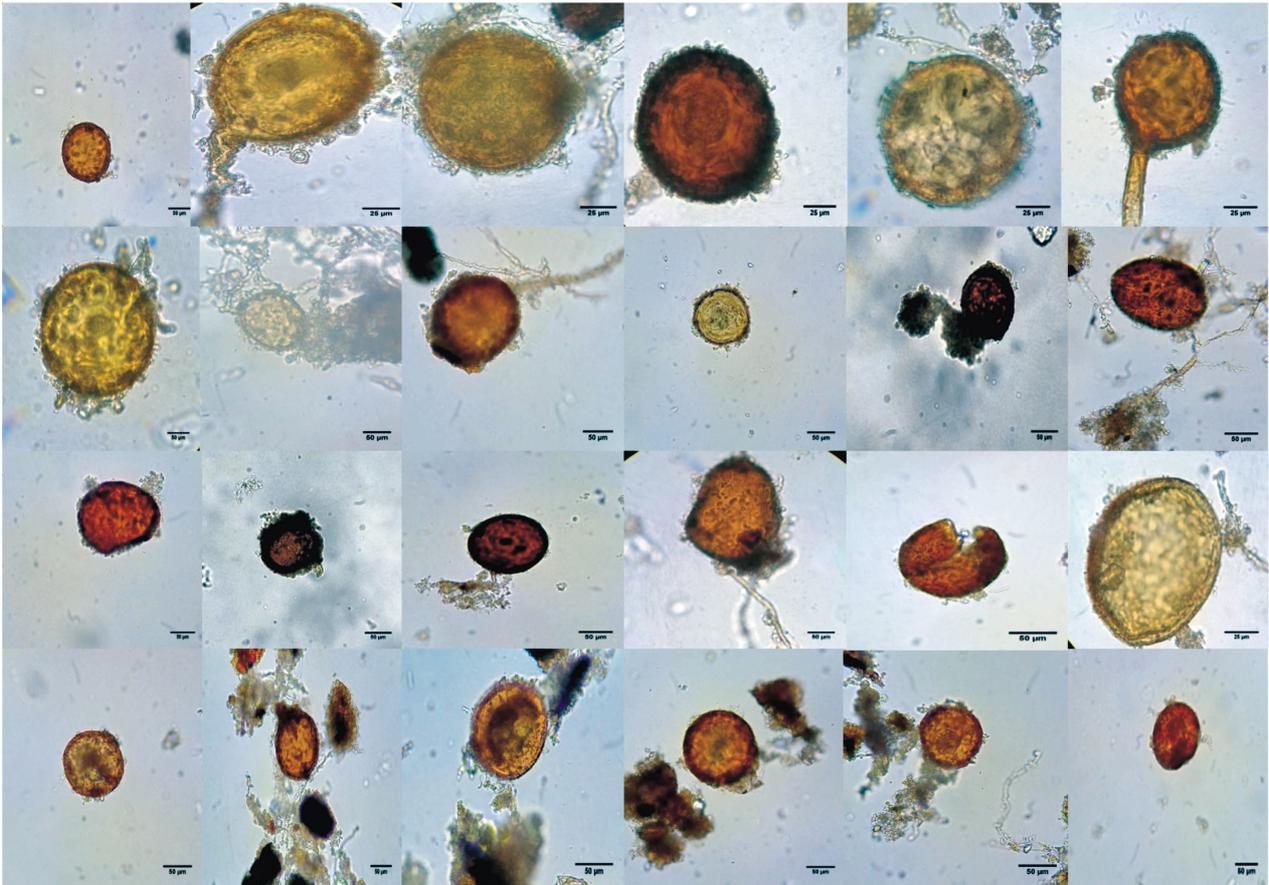
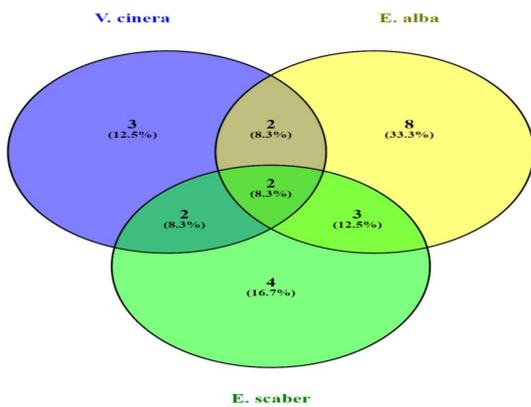
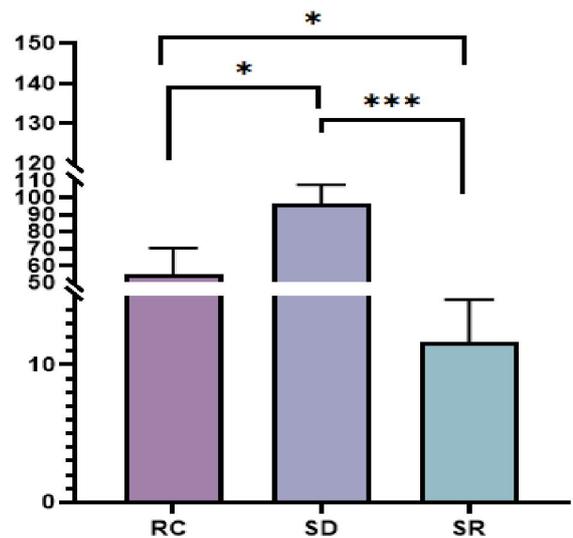


Fig 2: Microphotograph of various isolated AMF spores from three selected species of Asteraceae. A-J represent 10 species of *Glomus* (A= *G. clarum*, B= *G. constrictum*, C= *G. fasciculatum*, D=*G. macrocarpum*, E=*G. intraradices*, F= *G. hoi*, G=*Glomus* sp1, H= *Glomus* sp2, I= *Glomus* sp3, J= *Glomus* sp4),K-Q represent 7 species of *Acaulospora* (K=*A. elegans*, L=*A. mella*, M=*A. nicolsonii*, N= *Acaulospora* sp1, O= *Acaulospora* sp2, P= *Acaulospora* sp3, Q= *Acaulospora* sp4), R=*Ambispora* sp., S=*Funnelformis* sp., T=*Gigaspora margarita*, U=*Gigaspora* sp., V= *Scutellospora pellucida*, W=*Scutellospora* sp1 and X= *Scutellospora* sp2.



Arabic number inside the circle represents number of common and unique AMF species and value in parentheses indicates their % contribution.

Fig. 3: Relationship among isolated AM species of three selected plants through Venn diagram.



* = $P \leq 0.05$, ** = $P \leq 0.01$ and *** = $P \leq 0.001$.

Fig 4: Correlation among RC, SD and SR of AMF present in selected species of Asteraceae.

Table 1: Root Infection and spore density of AM fungi in selected plants of Asteraceae family

Plant species	AMF Root Infection			Spore Density
	Root Colonization (%)	Arbuscule (%)	Vesicle (%)	
<i>V. cinerea</i>	38 ± 2.05	5 ± 1.15	8 ± 2.08	86 ± 4.54
<i>E. alba</i>	59 ± 2.62	4 ± 0.58	10 ± 1.73	108 ± 4.64
<i>E. scaber</i>	68 ± 3.09	9 ± 1.00	17 ± 2.51	96 ± 4.49

± - standard deviation of mean

Table 2: Relative abundance of different AMF genera isolated from selected plants.

Plant species	Relative abundance of different AMF genera					
	<i>Glomus</i>	<i>Acaulospora</i>	<i>Scutellospora</i>	<i>Funneliformis</i>	<i>Gigaspora</i>	<i>Ambispora</i>
<i>V. cinerea</i>	59.30	33.72	5.81	1.16	-	-
<i>E. alba</i>	62.96	19.44	8.33	-	3.70	5.55
<i>E. scaber</i>	53.33	34.97	3.12	-	9.37	-
Isolation frequency	100	78	56	44	22	11
Species richness	10	7	3	2	1	1
Overall RA	58.62	28.62	5.86	4.48	2.06	0.34

(-) indicate absence of particular genera

RA values (below 10) of other genera, such as *Scutellospora*, *Gigaspora*, *Funneliformis* and *Ambispora* signified their uneven distribution in soils of these selected plants. Variability in AMF spore density and species composition in different plant species might be due to specificity in plant-fungal interaction and soil parameters (Rajkumar *et al.* 2012; Parihar *et al.* 2019). Moreover, Bhattacharya *et al.* (2009) recorded lower spore density and species richness than our current study in *E. alba*. Piszczek *et al.* (2019) reported higher root colonization and spore density in members of Asteraceae in comparison to our present study. A similar kind of spore density in *E. scaber* and higher in the case of *V. cinerea* was reported by Saranya and Nagarajan (2017).

Species richness and spore isolation frequency

Altogether, twenty-four different AMF species belonging to six genera were isolated from all selected plants. Maximum species richness (15) was noticed in *E. alba*, having six species of *Glomus*, four species of *Acaulospora*, two species of both *Scutellospora* and *Gigaspora* and a single species of *Ambispora* were isolated and identified (Table 4). Similarly, eleven species were isolated from *E. scaber* of which five species of *Glomus*, four of *Acaulospora* and a single species of *Gigaspora* and *Scutellospora*. A minimum number of nine species was isolated from *V. cinerea*, where four species of *Glomus*, three of *Acaulospora*, and a single species of

Table 3. Species richness, AMF genera and their species isolated from selected plants of Asteraceae family.

Plant species	Species richness	Isolated AMF genera with species
<i>V. cinerea</i>	9	<i>Glomus</i> : <i>G. macrocarpum</i> , <i>G. fasciculatum</i> , <i>G. intraradices</i> , <i>G. sp1</i> , <i>Acaulospora</i> : <i>A. elegans</i> , <i>A. nicolsonii</i> , <i>A. sp1</i> , <i>Scutellospora</i> : <i>S. pellucida</i> <i>Funneliformis</i> : <i>F. sp.</i>
<i>E. alba</i>	15	<i>Glomus</i> : <i>G. macrocarpum</i> , <i>G. intraradices</i> , <i>G. clarum</i> , <i>G. constrictum</i> , <i>G. sp2</i> , <i>G. sp3</i> , <i>Acaulospora</i> : <i>A. mella</i> , <i>A. elegans</i> , <i>A. sp2</i> , <i>A. sp3</i> <i>Scutellospora</i> : <i>S. pellucida</i> , <i>S. sp1</i> <i>Gigaspora</i> : <i>Gi. margarita</i> , <i>Gi. sp1</i> <i>Ambispora</i> : <i>Am. sp1</i>
<i>E. scaber</i>	11	<i>Glomus</i> : <i>G.intraradices</i> , <i>G. fasciculatum</i> , <i>G. hoi</i> , <i>G.clarum</i> , <i>G. sp4</i> , <i>Acaulospora</i> : <i>A. elegans</i> , <i>A. nicolsonii</i> , <i>A. mella</i> , <i>A. sp4</i> <i>Scutellospora</i> : <i>S. sp2</i> <i>Gigaspora</i> : <i>Gi. margarita</i> ,

Table 4: Different diversity indices of isolated AMF spores in selected plants.

Plant species	Shannon-Weiner index (H')	Simpson's index (D)	Evenness (E)
<i>V. cinerea</i>	0.89	0.53	0.64
<i>E. alba</i>	1.09	0.55	0.68
<i>E. scaber</i>	1.22	0.59	0.88

Scutellospora and *Funneliformis* were noticed. Species richness of particular AMF genera was also found to vary, and maximum number of 10 species were isolated that belonged to the genus *Glomus* followed by *Acaulospora* (7), *Scutellospora* and *Gigaspora* (2), and minimum one species was noticed in genera of *Funneliformis* and *Ambispora* (Table 3) (Fig. 2). Isolation frequency (IF) of AMF genera mainly depends on the relative abundance and species richness present in a particular plant rhizosphere. During this study, maximum IF value (100%) corresponded to the genus *Glomus*, followed by *Acaulospora* (78%), *Scutellospora* (56%), *Gigaspora* (44%), *Funneliformis* (22%) and minimum (11%) was recorded in *Ambispora* (Table 3). Among all isolated species of AM fungi, *Glomus intraradices* and *Acaulospora elegans*

were mostcommon AMF species found to be present in all three selected plant rhizosphere (Fig. 3). Beside these two common AMF species, *V. cinerea* shared two common species viz., *Glomus macrocarpum* and *Scutellospora pellucida* only with *E. alba* and two common species viz., *Glomus fasciculatum* and *Acaulospora nicolsonii* only with *E. scaber* and also exhibited three unique species viz., *Glomus sp1*, *Acaulospora sp1*, *Funneliformis sp.* Similarly, *E. alba* exhibited three species viz., *Glomus clarum*, *Acaulospora mella*, and *Gigaspora margarita* common to only *E. scaber* with eight unique species viz., *Glomus constrictum*, *Glomus sp2*, *Glomus sp3*, *Acaulospora sp2*, *Acaulospora sp3*, *Scutellospora sp1*, *Ambispora sp1*, *Gigaspora sp1*. Plant *E. scaber* with four unique species viz.,

Glomus hoi, *Glomus* sp4, *Acaulospora* sp4, *Scutellospora* sp2 and rest AMF species were common to other selected plants. Based on IF, *Glomus*, *Acaulospora* and *Scutellospora* were considered as common AM fungi and found to be associated with all three selected plants; whereas, other three genera are less common for this sanctuary. Several earlier workers also noted the dominance of *Glomus* and *Acaulospora* in most of the plants (Thapa *et al.* 2015; Kumar *et al.* 2019); however, other AM genera may vary from region to region. Our present investigation revealed *Glomus* as a predominating genus of AM fungi in this area and agreed with the data of other plants belonging to Asteraceae by earlier workers (Bhattacharya *et al.* 2009; Dhar *et al.* 2015; Sokornova *et al.* 2022).

Diversity index of AM fungi and statistical analysis

Highest value (1.22) of Shannon-Wiener index (H') in *E. scaber* indicated that it harbored maximum number of diverse AMF species than other two selected plants of Asteraceae, whereas *V. cinerea* with lowest H' value signified poor diversity of AMF species among all three selected plants of Asteraceae (Table 4). Based on spore density and relative abundance of AMF, calculated values of Simpson's index of dominance (D) were 0.53, 0.55 and 0.59 in *E. alba*, *V. cinerea* and *E. scaber*, respectively; indicating a balanced diversity of AM fungi in those selected plants. Even distribution of AM fungi was much prevailing in *E. scaber* as Evenness (E) was measured to be highest (0.88) as compared to *E. alba* (0.68) and *V. cinerea* (0.64) (Table 4). It was evident from the above indices that AM fungal community of *E. scaber* was much more diverse and prominent in occurrence than other two selected plant species of Asteraceae.

Statistical analysis of the current study revealed a very high significance (P -value=0.0002) and strong positive correlation ($r=0.99$) between spore density and species richness at 0.05 level (Fig. 4). Similarly, root colonization and species richness also showed highly significant (P -value=0.0087) and positive correlation ($r=0.53$) at the same probability level. A positive ($r=0.64$) significant (P -value=0.0189) correlation value was

recorded at the same probability level between root colonization and spore density in all three selected plants of Asteraceae. A non-significant but strong positive correlation ($r=0.90$) at 0.05 level was also observed between relative abundance (RA) and isolation frequency (IF) of AM fungal genera.

CONCLUSION

Arbuscular mycorrhizal fungi forms obligate mutualistic symbiotic relationships with roots of maximum land plants and making them a key driver of terrestrial plant communities. Several recent studies insight the importance of arbuscular mycorrhizal fungi for better plant growth and survival. This current study also emphasizes AMF dependency in all three selected plants of Asteraceae family within BWLS as these plant contains diverse AMF species and prominent mycorrhizal root infection. Positive correlation for root colonization and spore density, emphasizing mutualistic relationship and mycorrhizal dependency for plant survival. Maintaining AMF diversity of this sanctuary is essential for conservation of native plants in its natural habitat and safeguarding soil health.

DECLARATION

Conflict of Interest. Authors declare no conflict of interest.

REFERENCES

- Bhattacharya, D., Chakraborty, M. R., Chatterjee, N. C., Sengupta, C. 2009. A Survey on VAM Status in Roots of Some Medicinal Plants of Alipurduar, West Bengal. *Inter. J. Plant Protect.* **2**: 45–47.
- Chahar, S., Belose, S. 2018. AM Fungal Diversity in selected medicinal trees of Sanjay Gandhi National Park, Borivali, Mumbai, India. *Int. J. of Life Sci.* **6**: 517–522.
- Denison, R. F., Kiers, E. T. 2011. Life histories of symbiotic rhizobia and mycorrhizal fungi. *Curr. Biol.* **21**: 775–785.
- Dhar, P. P., Al-Qarawi, A. A., Mridha, M. A. U. 2015. Arbuscular mycorrhizal fungal association in asteraceae plants growing in the arid lands of Saudi Arabia. *J. Arid Land* **7**: 676–686.
- Franco-Ramírez, A., Pérez-Moreno, J., Sánchez-Viveros, G., Cerdán-Cabrera, C. R., Almaraz-Suárez, J. J., Cetina-Alcalá, V. M., Alarcón, A. 2021. Mobilization and transfer of nine macro-and micronutrients to *Pinus greggii* seedlings via arbuscular mycorrhizal fungi. *Revista Mexicana de Biodiversidad* **92**: 923238.
- Ganguli, S., Gupta (Joshi), H., Bhattacharya, K. 2016. Vegetation structure, species diversity and regeneration status in Ballavpur wildlife sanctuary, west Bengal, India. *Environ. Forest.* **99**: 43067–43074.
- Gao, Q. M., Guo, L. D. 2010. A comparative study of arbuscular

- mycorrhizal fungi in forest, grassland and cropland in the Tibetan Plateau, China. *Mycology* **1**: 163–170.
- Gerdemann, J. W., Nicolson, T. H. 1963. Spores of mycorrhizal Endogone species extracted from soil by wet sieving and decanting. *Trans. Brit. Mycologic. Soc.* **46**: 235–244.
- Koul, K., Agarwal, S., Lone, R. 2012. Diversity of Arbuscular Mycorrhizal Fungi Associated With the Medicinal Plants from Gwalior-Chambal Region of Madhya Pradesh-India. *School of Stud. Bot.* **12**: 1004–1011.
- Kumar, A., Parkash, V., Gupta, A., Aggarwal, A. 2019. Biodiversity of arbuscular mycorrhizal fungi associated with selected medicinal plants of Hamirpur district of Himachal Pradesh, India. *The J. Phytopharmacol.* **8**: 306–311.
- Lutz, S., Bodenhausen, N., Hess, J., Valzano-Held, A., Waelchli, J., Deslandes-Hérol, G., Schlaeppli, K., van der Heijden, M. G. A. 2023. Soil microbiome indicators can predict crop growth response to large-scale inoculation with arbuscular mycorrhizal fungi. *Nature Microbiol.* **8**: 2277–2289.
- Parihar, M., Rakshit, A., Singh, H. B., Rana, K. 2019. Diversity of arbuscular mycorrhizal fungi in alkaline soils of hot sub humid eco-region of Middle Gangetic Plains of India. *Acta Agriculturae Scandinavica, Section B - Soil Plant Sci.* **69**: 386–397.
- Phillips, J. M., Hayman, D. S. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Brit. Mycologic. Soc.* **55**: 158–161.
- Piszczek, P., Kuszewska, K., B³aszkowski, J., Sochacka-Obrucenik, A., Stojakowska, A., Zubek, S. 2019. Associations between root-inhabiting fungi and 40 species of medicinal plants with potential applications in the pharmaceutical and biotechnological industries. *Appl. Soil Ecol.* **137**: 69–77.
- Priyadarshini, V., Muthumari, G., Hariram, N. 2017. Occurrence of VAM fungi in Kalasalingam University campus. *J. Med. Plants Stud.* **5**: 101–105.
- Rajkumar, H., Seema, H., Sunil Kumar C. P. 2012. Diversity of arbuscular mycorrhizal fungi associated with some medicinal plants in Western Ghats of Karnataka region, India. *World J. Sci. Technol.* **2**: 13–20.
- Read, D. J., Duckett, J. G., Francis, R., Ligrone, R., Russell, A. 2000. Symbiotic fungal associations in 'lower'land plants. *Philosophical Trans. Royal Society of Lond. Series B: Biologic. Sci.* **355**: 815–831.
- Saranya Babu Jayaprakash, C. M., Nagarajan, N. 2017. Studies on mycorrhizal biodiversity in medicinal plant species of Pookode Lake area, Wayanad, India. *Ann. Plant Sci.* **6**: 1835–1844.
- Sarkar, U., Choudhary, B. K., Sharma, B. K. 2014. Vascular Arbuscular Mycorrhizal (VAM) Spore Diversity and Density Across the Soil of Degraded Forest and Rubber Plantation in Tripura , India. *American-Eurasian J. Agric. Environ. Sci.* **14**: 1080–1088.
- Schenck, N. C., Peirez, Y. 1990. *Manual for the identification of VA mycorrhizal fungi* (3rd ed). Synergistic Publications.
- Schubler, A., Schwarzott, D., Walker, C. 2001. A new fungal phylum, the Glomeromycota: phylogeny and evolution. *Mycologic. Res.* **105**: 1413–1421.
- Sokornova, S., Malygin, D., Terentev, A., Dolzhenko, V. 2022. Arbuscular Mycorrhiza Symbiosis as a Factor of Asteraceae Species Invasion. *Agron.* **12**: 1–16.
- Strack, D., Fester, T., Hause, B., Schliemann, W., Walter, M. H. 2003. Arbuscular mycorrhiza: Biological, chemical, and molecular aspects. *J. Chem. Ecol.* **29**: 1955–1979.
- Sun, D., Yang, X., Wang, Y., Fan, Y., Ding, P., Song, X., Yuan, X., Yang, X. 2022. Stronger mutualistic interactions with arbuscular mycorrhizal fungi help Asteraceae invaders outcompete the phylogenetically related natives. *New Phytol.* **236**: 1487–1496.
- Tang, B., Man, J., Lehmann, A., Rillig, M. C. 2023. Arbuscular mycorrhizal fungi benefit plants in response to major global change factors. *Ecol. Lett.* **26**: 2087–2097.
- Thapa, T., De, U. K., Chakraborty, B. 2015. Association and root colonization of some medicinal plants with Arbuscular Mycorrhizal Fungi. *J. Med. Plants Stud.* **3**: 25–35.
- Verma, R. K., Verma, P. 2017. Species Diversity of Arbuscular Mycorrhizal (AM) Fungi in Dalli-Rajhara Iron Mine Overburden Dump of Chhattisgarh (Central India). *Inter. J. Curr. Microbiol. Appl. Sci.* **6**: 2766–2781.
- Wang, L., Zhang, L., George, T. S., Feng, G. 2023. A core microbiome in the hyphosphere of arbuscular mycorrhizal fungi has functional significance in organic phosphorus mineralization. *New Phytol.* **238**: 859–873.
- Yang, Q., Zhao, Z., Bai, Z., Hou, H., Yuan, Y., Guo, A., Li, Y. 2019. Effects of mycorrhizae and water conditions on perennial ryegrass growth in rare earth tailings. *RSC Advances* **9**: 10881–10888.
- Yuan, M. L., Zhang, M. H., Shi, Z. Y., Yang, S., Zhang, M. G., Wang, Z., Wu, S. W., Gao, J. K. 2023. Arbuscular mycorrhizal fungi enhance active ingredients of medicinal plants: a quantitative analysis. *Front. Plant Sci.* **14**: 1–12.
- Zhang, M., Yang, M., Shi, Z., Gao, J., Wang, X. 2022. Biodiversity and Variations of Arbuscular Mycorrhizal Fungi Associated with Roots along Elevations in Mt. Taibai of China. *Diversity* **14**: 626.