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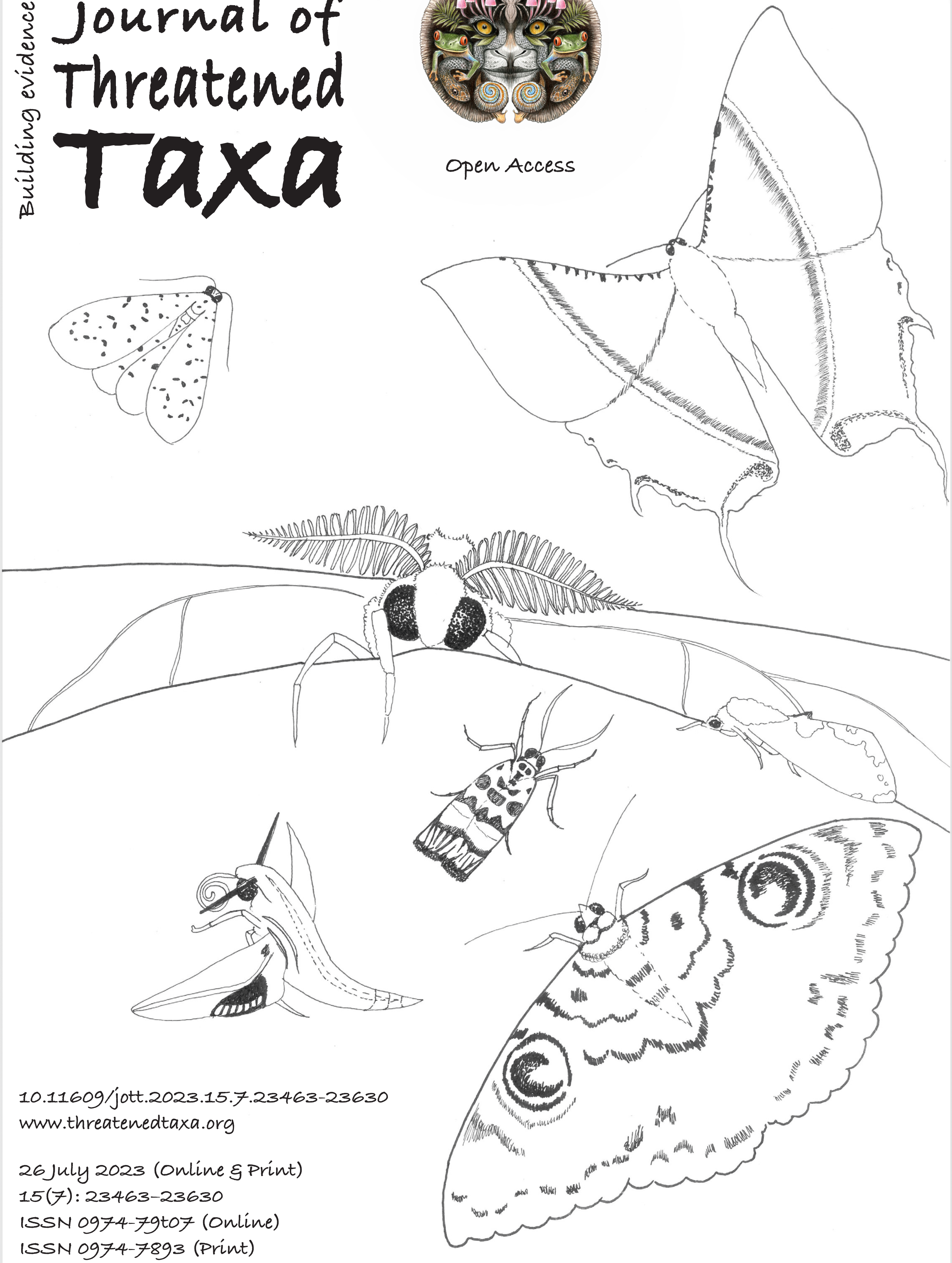

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Cover: Celebrating the unsung heroes—moths, our nocturnal pollinators. © Priyanka Iyer.

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COMMUNICATION

Status of macrofungal diversity in the wet evergreen forests of Agasthyamala Biosphere Reserve, Western Ghats, India

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Abstract: Agasthyamala Biosphere Reserve is a part of Western Ghats (India), has diverse ecosystems and constitutes an important biogeographical 'hotspot' which is well known for its species richness and endemism. Since limited information was available on the mycoflora in this area, a survey was conducted to evaluate the macrofungal diversity in the wet evergreen forests of the Agasthyamala Biosphere Reserve. The survey was carried out during the monsoon and post-monsoon seasons of 2021–2022 and revealed the existence of 62 macrofungal species belonging to 43 genera, 24 families, and eight orders. Out of the eight orders, seven orders belong to the division Basidiomycota and the other order Xylariales belongs to Ascomycota. The family Polyporaceae was identified as the dominant family. The survey also noted the presence of saprotrophic and mycorrhizal fungi. Among the identified species, the maximum density was of *Panellus pusillus* (6.08) followed by *Microporus xanthopus* (5.38). *Microporus xanthopus* (82.14%) exhibited the maximum frequency of occurrence and was identified as the most common species. *Coprinellus disseminatus* was the most abundant species among macrofungi. The assessment of macrofungal diversity using the Shannon biodiversity index resulted in a value of 2.99, indicating a rich and diverse fungal population within the forest. This finding emphasizes the significant role of the forest ecosystem in supporting a wide variety of fungi

Keywords: *Ascomycetes*, *basidiomycetes*, endemism, hotspot, Kerala, mushroom diversity, mycoflora.

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Competing interests: The authors declare no competing interests.

Author details: Ms. K.K Akshaya has completed post graduate in botany and working as junior research fellow. She has undertaken a PhD research in mycology aspects. Dr. A. Karthikeyan is a senior scientist with specialization of mycology, plant pathology and done research aspects of Mycorrhiza. Dr. C. Kunhikanna is a plant taxonomist at present he is holding the charge of director of Institute of Forest Genetics and Tree Breeding, Coimbatore, India.

Author contributions: KKA has done the survey of macrofungi in Agasthayamala forests of Western Ghats of India and also identified the macrofungi. She has written the full part of this manuscript with able guidance of AK. CK helped to identify the plants of Agasthyamala forests and reviewed this manuscript prior to submission.

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INTRODUCTION

Fungi represent a distinct and diverse group of organisms that play a crucial role in ecosystem functioning by participating in various ecological cycles (Schmit & Mueller 2007). They constitute one of the largest communities after insects, highlighting their ecological significance. Fungi exhibit remarkable adaptability in terms of morphology, lifestages, developmental patterns, and habitats. They are capable of colonizing a wide range of environments, including those characterized by extreme conditions such as low or high temperatures, and high concentrations of metals and salts (Cox 2007).

Macrofungi represent a prominent group found in forest ecosystems, within the fungal kingdom. The fruiting bodies of macrofungi, belonging to the phyla Ascomycota and Basidiomycota, can be epigeous (aboveground) or hypogeous (underground) (Chang & Miles 1992). These organisms are characterized by their distinct fruiting body forms, which include cup fungi, jelly fungi, coral fungi, polypores, puffballs, corticoid fungi, and agarics.

It has been estimated that the total existence of fungi is about 1.5–5.1 million species, of which approximately 150,000 fungal species have been reported (Blackwell 2011; Berbee et al. 2017; Wu et al. 2019). Macrofungi have a worldwide distribution, ranging 53,000–110,000 species depending on the plant-to-macrofungi ratio (Mueller et al. 2007). In India, the Himalayan and Western Ghats ranges are the major hotspots of fungal diversity (Manoharachary *et al.* 2005).

Western Ghats is one of the biodiversity hotspots of India that covers an area of 160,000 km^2 which extends 1,600 km running parallel to the western coast of the Indian peninsula distributed in six states such as Gujarat, Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu (UNESCO 2023). Agasthyamala Biosphere Reserve is a part of the Western Ghats, has diverse ecosystems, and constitutes an important biogeographical 'hotspeck'. It is well known for its species richness and endemism. The biosphere reserve is marked by the presence of dominant vegetation like *Palaquium ellipticum* (Dalz.) Baill., *Cullenia exarillata* Robyns, *Elaeocarpus munroii* (Wight) Mast., *Elaeocarpus tuberculatus* Roxb., *Gluta travancorica* Bedd., *Syzygium mundagam* (Bourd.), *Baccaurea courtallensis* (Wight) Mull.Arg., and *Ixora agasthyamalayana* Sivad. & N.Mohanan. The evergreen forests of the biosphere reserve are endowed with many endemics such as *Garcinia travancorica* Bedd., *Garcinia imberti* Bourd., *Humboldtia unijuga* var. *unijuga* Bedd. & var. *trijuga* Joseph & Chandr., and *Syzygium bourdilloni* (Gamble) Rathakr. & Nair (Mohanan & Sivadasan 2002).

Several studies have been carried out in Western Ghats focusing on the diversity, distribution, taxonomy, ecology, nutritional, and bioactive potential of macrofungi (Manimohan & Leelavathy 1988, 1989a,b; Manimohan et al. 1995, 2004, 2007; Pradeep & Vrinda 2010; Puthusseri et al. 2010; Sudheep & Sridhar 2014; Pavithra et al. 2016). The diversity and distribution of macrofungi were investigated by several researchers (Natarajan 1995; Manimohan et al. 2007; Pradeep et al. 2013, 2016). Studies on ectomycorrhizal fungi were conducted by Natarajan & Raman (1983), Mohan (2008), and Mohanan (2014). Hosagoudar & Thomas (2010) conducted a study on foliicolous fungal flora in the Peppara and Neyyar Wildlife Sanctuaries of Agasthyamala Biosphere Reserve. However, the status of macrofungal diversity in the wet evergreen forests of Agasthyamala is limited and requires further investigation and documentation. The present study aims to assess the status of macrofungal diversity in the Agasthyamala Biosphere Reserve area.

MATERIALS & METHODS

Study area

The Agasthyamala Biosphere Reserve is situated at the southernmost tip of the Western Ghats mountain range. Its geographic coordinates range from 8.1333°–9.1666° N & 76.8666°–77.5666° E. Established in 2001, the biosphere reserve covers a total area of 3,500 km^2, with 1,828 km^2 falling within the state of Kerala and 1,672 km^2 within Tamil Nadu. The Agasthyamala Biosphere Reserve encompasses various districts, including Kollam and Thiruvananthapuram in Kerala, and Tirunelveli and Kanyakumari in Tamil Nadu. Within the Kerala region of the reserve, it comprises the Neyyar, Peppara, and Shendurney wildlife sanctuaries, as well as areas such as Achankovil, Thenmala, Konni, Punalur, Thiruvananthapuram Division, and Agasthyavanam Special Division. The region experiences temperatures ranging 18–35°C, and an annual rainfall of 2,400–3,500 mm (Manju et al. 2009).

Survey of macrofungi

The survey was conducted during the monsoon and post-monsoon seasons of 2021–2022 in the wet evergreen forest areas of the Agasthyamala Biosphere Reserve, specifically in the Paruthipally range of Thiruvananthapuram Division, Kerala. The macrofungal

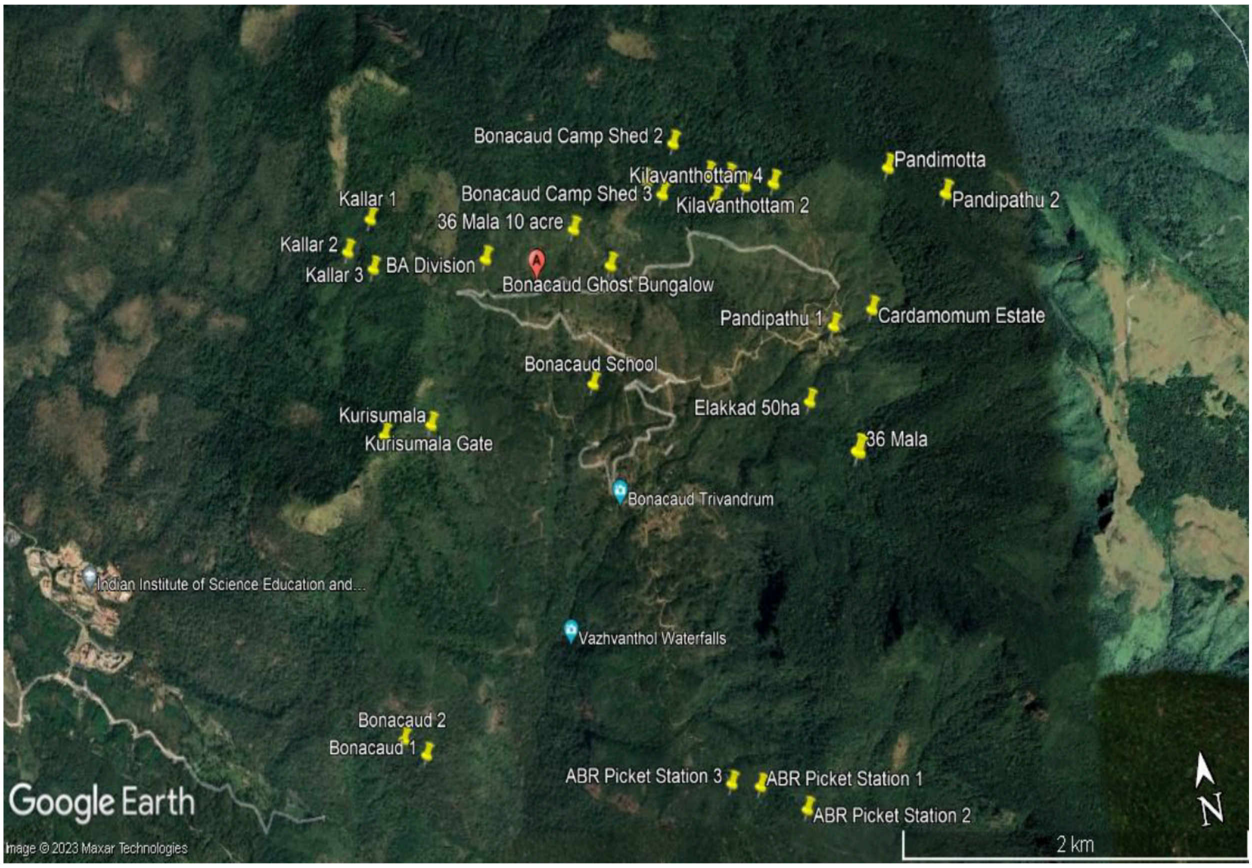

Image 1. Location of study sites on Google Earth.

assessment was carried out using the quadrat method, as described by Harsh (2021). A total of 28 quadrats, each measuring 10 × 10 m, were established in various locations within the forest area. These locations included 36 Mala, Bonacaud Division, Bonacaud, Bonacaud camp shed, Bonacaud School, Cardamom Estate, Elakkad 50 ha, GB Division, Bonacaud Ghost Bungalow, Kallar, Kilavanthottam, Kurushumala, Kurushumala Gate, Pandimotta, Pandipathu, and Bonacaud Picket Station. The selected quadrats exhibited an altitudinal range of 343–1,032 m, as indicated in Table 1 and Image 1.

Macrofungal collection and identification

Macrofungi were photographically recorded in their habitats and the fresh samples were collected with great care in a thermocol box. The macroscopic and ecological characteristics were documented during the collection. A spore print was taken for fleshy mushrooms and noted its color. The samples were dried in a hot air oven at 50 ^{o}C for seven hours and were stored in dry paper covers and labeled with collection numbers for future reference. Specimens were identified with the help of manuals, available literature (Christensen 1968; Ryvarden & Johansen 1980) and online resources like mushroomexpert.com. The nomenclature of the species name is in accordance with the MycoBank database (accessed on 20 January 2023).

Data analysis

The number of sporocarps of each macrofungus in the 10 × 10 m quadrat was enumerated. The quantitative analysis such as frequency, density, and abundance of macrofungal species was calculated by Mishra (1968) as follows:

a. Density: It refers to the numerical strength of a species, and can be calculated using the formula:

$$\text{Density} = \frac{\text{Total number of individuals of a fungal species in all quadrats}}{\text{The total area of the quadrat studied}}$$

b. Frequency (%): Frequency is the degree of dispersion of individual species in an area, which is calculated by the equation:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which the species occurred x 100}}{\text{Total number of quadrats studied}}$$

c. Abundance: indicates the number of individuals

Table 1. Geographic co-ordinates of study sites in Agasthyamala forests.

	Locations	Latitude	Longitude	Altitude
1	36 Mala 10 acre	N 8.69218333°	E 77.18296944°	736 m
2	36 Mala	N 8.67951667°	E 77.18054167°	999 m
3	BA Division	N 8.69185556°	E 77.16231944°	770 m
4	Bonacaud 1	N 8.67007778°	E 77.15408333°	406 m
5	Bonacaud 2	N 8.67104444°	E 77.15293889°	343 m
6	Bonacaud Camp Shed 1	N 8.69279167°	E 77.17595278°	805 m
7	Bonacaud Camp Shed 2	N 8.69504167°	E 77.17340000°	740 m
8	Bonacaud Camp shed 3	N 8.69282222°	E 77.17234444°	730 m
9	Bonacaud School	N 8.68537778°	E 77.16697500°	559 m
10	Cardamom Estate	N 8.68565000°	E 77.18243333°	895 m
11	Elakkad 50 ha	N 8.68229444°	E 77.17858333°	695 m
12	GB Division	N8.69356667°	E 77.17162778°	635 m
13	Ghost House	N 8.69027222°	E 77.16896667°	770 m
14	Kallar 1	N 8.69493333°	E 77.15632222°	648 m
15	Kallar 2	N 8.69384167°	E 77.15466944°	635 m
16	Kallar 3	N 8.69280000°	E 77.15594444°	623 m
17	Kilavanthottam 1	N 8.69196944°	E 77.17507778°	862 m
18	Kilavanthottam 2	N8.69220556°	E 77.17670556°	882 m
19	Kilavanthottam 3	N 8.69315000°	E 77.17493056°	829 m
20	Kilavanthottam 4	N 8.69198889°	E 77.17819167°	947 m
21	Kurushumala	N 8.68520833°	E 77.15527222°	719 m
22	Kurushumala Gate	N 8.68521389°	E 77.15784167°	690 m
23	Pandimotta	N 8.69136389°	E 77.18407222°	1,004 m
24	Pandipath 1	N 8.68534167°	E 77.18038889°	1,032 m
25	Pandipath 2	N 8.68967222°	E 77.18673056°	989 m
26	Picket Station 1	N 8.66555000°	E 77.17373611°	598 m
27	Picket Station 2	N 8.66408056°	E 77.17267778°	546 m
28	Picket station 3	N 8.66590000°	E 77.17113333°	574 m

of different species in the community per unit area. It is calculated by the equation:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats in which the species present}}$$

Species diversity analysis

The macrofungal diversity in different forest areas of Agasthyamala Biosphere Reserve was determined using the Shannon diversity index Magurran (1988).

Shannon diversity index, $H' = -\sum pi \ln pi$

Where pi is the proportion of individuals of a species to the total number of species.

RESULTS

Macrofungal assessment

A comprehensive assessment of macrofungal diversity in the present study revealed the presence of 62 macrofungal species, representing 43 genera, 24 families, and eight orders. Among these, seven orders belonged to the division Basidiomycota, while one order belonged to Ascomycota. The dominant order observed was Agaricales, comprising 33 species, followed by Polyporales with 13 species. Auriculariales accounted for seven species, while Dacrymycetales, Russulales, Tremellales, and Xylariales each had two species, and Boletales had single species (Table 2, Figure 1). The family Polyporaceae exhibited the highest species richness, with nine species recorded, while families such as Schizophyllaceae, Mycenaceae, Serpulaceae, Russulaceae, and Hypoxylaceae displayed a lower number of macrofungi (Table 2).

Ecological preference of macrofungi

The present study revealed that the maximum numbers of species (55) were saprophytes and a few species were mycorrhizal (seven) in nature. Mycorrhizal macrofungi were found in the soil, associated with the roots of higher angiosperm species (Table 3).

Quantitative analysis

The quantitative study of the macrofungal species showed that maximum density was represented by the species *Panellus pusillus* (6.08), followed by *Microporus xanthopus* (5.38). The maximum frequency of occurrence was exhibited by *Microporus xanthopus* (82.14%), followed by *Stereum ostrea* (42.86%), *Auricularia delicata* (32.14%), and *Dacryopinax spathularia* (25%). *Microporus xanthopus* was the most frequent species present in the Agasthyamala forests. *Coprinellus disseminatus* was the most abundant species of macrofungi (Table 4).

Species diversity analysis

The species diversity of macrofungi was calculated using the Shannon diversity index. The Shannon diversity index for macrofungi in the wet evergreen forests of Agasthyamala was found to be 2.99 (Table 5).

The current study enumerated a total of 62 macrofungal species which are edible, medicinal,

Table 2. Distribution of macrofungi in their respective family and order.

	Species	Family	Order
1	*Amanita vaginata* (Bull.) Lam.	Amanitaceae	Agaricales
2	*Amauroderma rugosum* (Blume & T.Nees) Torrend	Ganodermataceae	Poyporales
3	*Anthracophyllum archeri* (Berk.) Pegler	Omphalotaceae	Agaricales
4	*Anthracophyllum* sp.	Omphalotaceae	Agaricales
5	*Auricularia delicata* (Fr.) heim	Auriculariaceae	Auriculariales
6	*Auricularia mesenterica* (Dicks.) Pers.	Auriculariaceae	Auriculariales
7	*Auricularia* sp. 1	Auriculariaceae	Auriculariales
8	*Auricularia* sp. 2	Auriculariaceae	Auriculariales
9	*Auricularia* sp. 3	Auriculariaceae	Auriculariales
10	*Campanella caesia* Romagn.	Marasmiaceae	Agaricales
11	*Campanella tristis* (G. Stev.) Segedin	Marasmiaceae	Agaricales
12	*Chlorophyllum molybdites* (G. Mey.) Massee	Agaricaceae	Agaricales
13	*Clavulinopsis fusiformis* (Soweby) Corner	Clavariaceae	Agaricales
14	*Coprinellus domesticus* (Bolton) Vilgalys, Hopple & Jacq.Johnson	Psathyrellaceae	Agaricales
15	*Coprinellus disseminatus* (Pers.) J.E.Lange	Psathyrellaceae	Agaricales
16	*Crepidotus variabilis* (Pers.) P. Kumm.	Crepidotaceae	Agaricales
17	*Cyptotrama asprata* (Berk.) Redhead & Ginns	Physalacriaceae	Agaricales
18	*Cuphophyllus pratensis* (Schaeff.) Bon	Hygrophoraceae	Agaricales
19	*Dacrymyces palmatus* (Schwein.) Burt	Dacryomycetaceae	Dacrymycetales
20	*Dacryopinax spathularia* (Schwein) G.W.Martin	Dacryomycetaceae	Dacrymycetales
21	*Daedaleopsis confragosa* (Bolton) J.Schrot	Fomitopsidaceae	Polyporales
22	*Daldinia concentrica* (Bolton) Ces. & De.Not.	Hypoxylaceae	Xylariales
23	*Earliella scabrosa* (Pers.) Glib. & Ryvarden	Polyporaceaea	Polyporales
24	*Exidia glandulosa* (Bull.) Fr.	Auriculariaceae	Auriculariales
25	*Exidia recisa* Ditmar (Fr.)	Auriculariaceae	Auriculariales
26	*Ganoderma applanatum* (Pers.) Pat.	Ganodermataceae	Polyporales
27	*Ganoderma* sp.	Ganodermataceae	Polyporales
28	Gill fungi 1	Marasmiaceae	Agaricales
29	Gill fungi 2	Marasmiaceae	Agaricales
30	*Hexagonia tenuis* (Hook.) Fr.	Polyporaceaea	Polyporales
31	*Hymenopellis radicata* (Relhan) R.H.Petersen	Physalacriaceae	Agaricales
32	*Lentinus* sp. 1	Agaricaceae	Agaricales
33	*Lentinus* sp. 2	Agaricaceae	Agaricales
34	*Lentinus* sp. 3	Agaricaceae	Agaricales
35	*Lentinus tigrinus* (Bull.) Fr.	Agaricaceae	Agaricales
36	*Lenzites acuta* Berk.	Polyporaceaea	Polyporales
37	*Leucoagaricus rubrotinctus* (Peck) Singer	Agaricaceae	Agaricales
38	*Leucocoprinus fragilissimus* (Berk. & M.A.Curtis) Pat.	Polyporaceaea	Polyporales
39	*Macrolepiota procera* (Scop.) Singer	Agaricaceae	Agaricales
40	*Marasmiellus* sp.	Marasmiaceae	Agaricales
41	*Marasmius haematocephalus* (Mont.) Fr.	Marasmiaceae	Agaricales
42	*Marasmius siccus* (Schwein.) Fr.	Marasmiaceae	Agaricales
43	*Marasmius* sp.	Marasmiaceae	Agaricales
44	*Microporellus dealbatus* (Berk. & M.A.Curtis)	Polyporaceaea	Polyporales
45	*Microporus xanthopus* (Fr.) Kuntze.	Polyporaceaea	Polyporales
46	*Mucronella bresadolae*(Quel.) Corner	Clavariaceae	Agaricales
47	*Panellus pusillus* (Pers. Ex Lev.) Burds. & O.K.Mill.	Mycenaceae	Agaricales
48	*Pleurotus* sp. 1	Pleurotaceae	Agaricales
49	*Pleurotus* sp. 2	Pleurotaceae	Agaricales
50	*Pleurotus* sp. 3	Pleurotaceae	Agaricales
51	*Pleurotus* sp. 4	Pleurotaceae	Agaricales
52	*Polyporus grammocephalus* Berk.	Polyporaceaea	Polyporales
53	*Pycnoporus sanguineus* (L.) Murrill	Polyporaceaea	Polyporales
54	*Russula cyanoxantha* (Schaeff.) Fr.	Russulaceae	Russulales
55	*Schizophyllum commune* Fr.	Schizophyllaceae	Agaricales
56	*Serpula similis* (Berk. & Broome) Ginns	Serpulaceae	Boletales
57	*Stereum ostrea* (Blume & T.Nees) Fr.	Stereaceae	Russulales
58	*Termitomyces microcarpus* (Berk. & Broome) R.Heim	Lyophyllaceae	Agaricales
59	*Trametes gibbosa* (Pers.) Fr.	Polyporaceaea	Polyporales
60	*Tremella fuciformis* Berk.	Tremellaceae	Tremellales
61	*Tremella mesenterica* Retz.	Tremellaceae	Tremellales
62	*Xylaria longipes* Nitschke	Xylariaceae	Xylariales

Table 3. List of macrofungi recorded in the forests of Agasthyamala with their habitat, mode of nutrition and associate.

	Species	Habitat	Nutrition	*Associate
1	*Amanita vaginata* (Bull.) Lam.	Soil	Mycorrhizal	+
2	*Amauroderma rugosum* (Blume & T.Nees) Torrend	Soil	Saprotrophic	-
3	*Anthracophyllum archeri* (Berk.) Pegler	Dead twig	Saprotrophic	-
4	*Anthracophyllum* sp.	Dead twig	Saprotrophic	-
5	*Auricularia delicata* (Fr.) Heim	Dead wood	Saprotrophic	-
6	*Auricularia mesenterica* (Dicks.) Pers.	*Gordonia obtusa*	Saprotrophic	+
7	*Auricularia* sp. 1	Deadwood	Saprotrophic	-
8	*Auricularia* sp. 2	Deadwood	Saprotrophic	-
9	*Auricularia* sp. 3	Deadwood	Saprotrophic	-
10	*Campanella caesia* Romagn.	Fallen twig	Saprotrophic	-
11	*Campanella tristis* (G.Stev.) Segedin	Deadwood	Saprotrophic	-
12	*Chlorophyllum molybdites* (G.Mey.) Massee	Soil	Saprotrophic	-
13	*Clavulinopsis fusiformis* (Soweby) Corner	Soil	Saprotrophic	-
14	*Coprinellus domesticus* (Bolton) Vilgalys, Hopple & Jacq.Johnson	Deadwood	Saprotrophic	-
15	*Coprinellus disseminatus* (Pers.) J.E.Lange	Soil	Saprotrophic	-
16	*Crepidotus variabilis* (Pers.) P.Kumm.	*Gordonia obtusa*	Saprotrophic	+
17	*Cyptotrama asprata* (Berk.) Redhead & Ginns	Soil	Saprotrophic	-
18	*Cuphophyllus pratensis* (Schaeff.) Bon	Soil	Mycorrhizal	+
19	*Dacrymyces palmatus* (Schwein.) Burt	Dead wood	Saprotrophic	-
20	*Dacryopinax spathularia* (Schwein) G.W.Martin	Deadwood	Saprotrophic	-
21	*Daedaleopsis confragosa* (Bolton) J.Schrot	Dead wood	Saprotrophic	-
22	*Daldinia concentrica* (Bolton) Ces. & De.Not.	Deadwood	Saprotrophic	-
23	*Earliella scabrosa* (Pers.) Glib. & Ryvarden	Dead wood	Saprotrophic	-
24	*Exidia glandulosa* (Bull.) Fr.	Dead wood	Saprotrophic	-
25	*Exidia recisa* Ditmar (Fr.)	Dead wood	Saprotrophic	-
26	*Ganoderma applanatum* (Pers.) Pat.	Dead wood	Saprotrophic	-
27	*Ganoderma* sp.	Dead wood	Saprotrophic	-
28	Gill fungi 1	Dead wood	Saprotrophic	-
29	Gill fungi 2	Dead wood	Saprotrophic	-
30	*Hexagonia tenuis* (Hook.) Fr.	Dead wood	Saprotrophic	-
31	*Hymenopellis radicata* (Relhan) R.H.Petersen	Soil	Saprotrophic	-

	Species	Habitat	Nutrition	*Associate
32	*Lentinus* sp. 1	Dead wood	Saprotrophic	-
33	*Lentinus* sp. 2	Dead wood	Saprotrophic	-
34	*Lentinus* sp. 3	Dead wood	Saprotrophic	-
35	*Lentinus tigrinus* (Bull.) Fr.	Dead wood	Saprotrophic	-
36	*Lenzites acuta* Berk.	Dead wood	Saprotrophic	-
37	*Leucoagaricus rubrotinctus* (Peck) Singer	Soil	Mycorrhizal	+
38	*Leucocoprinus fragilissimus* (Berk. & M.A.Curtis) Pat.	Soil	Saprotrophic	
39	*Macrolepiota procera* (Scop.) Singer	Soil	Mycorrhizal	+
40	*Marasmiellus* sp.	Dead wood	Saprotrophic	-
41	*Marasmius haematocephalus* (Mont.) Fr.	Dead wood	Saprotrophic	-
42	*Marasmius siccus* (Schwein.) Fr.	Dead wood	Saprotrophic	-
43	*Marasmius* spp.	Dead wood	Saprotrophic	-
44	*Microporellus dealbatus* (Berk. & M.A.Curtis)	Dead wood	Saprotrophic	-
45	*Microporus xanthopus* (Fr.) Kuntze.	Dead fallen twig	Saprotrophic	-
46	*Mucronella bresadolae* (Quel.) Corner	*Ficus exasperata*	Saprotrophic	+
47	*Panellus pusillus* (Pers. Ex Lev.) Burds. & O.K.Mill.	Dead wood	Saprotrophic	-
48	*Pleurotus* sp. 1	Dead wood	Saprotrophic	-
49	*Pleurotus* sp. 2	Dead wood	Saprotrophic	-
50	*Pleurotus* sp. 3	Dead wood	Saprotrophic	-
51	*Pleurotus* sp. 4	Dead wood	Saprotrophic	-
52	*Polyporus grammocephalus* Berk.	Dead wood	Saprotrophic	-
53	*Pycnoporus sanguineus* (L.) Murrill	Dead wood	Saprotrophic	-
54	*Russula cyanoxantha* (Schaeff.) Fr.	Soil	Mycorrhizal	+
55	*Schizophyllum commune* Fr.	Dead wood	Saprotrophic	-
56	*Serpula similis* (Berk. & Broome) Ginns	*Elaeocarpus munroii*	Mycorrhizal	+
57	*Stereum ostrea* (Blume & T.Nees) Fr.	Dead wood	Saprotrophic	-
58	*Termitomyces microcarpus* (Berk. & Broome) R.Heim	Soil	Mycorrhizal	-
59	*Trametes gibbosa* (Pers.) Fr.	Dead wood	Saprotrophic	-
60	*Tremella fuciformis* Berk.	Fallen twig	Saprotrophic	-
61	*Tremella mesenterica* Retz.	Dead wood	Saprotrophic	-
62	*Xylaria longipes* Nitschke	Dead wood	Saprotrophic	-

*: (+)—associated with tree| (-)—non associated with tree.

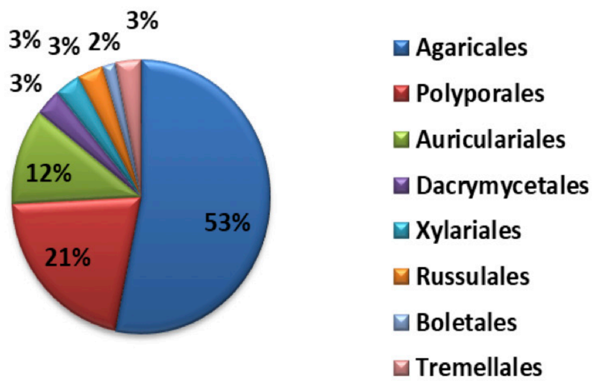

Figure 1. Percentage of distribution of macrofungi in different orders.

ectomycorrhizal, saprotrophic and toxic (e.g., *Chlorophyllum molybdites*) belonging to 43 genera, 24 families and eight orders from Agasthyamala Forests. These forests provide fairly undisturbed natural habitats for a variety of macrofungi. Among them, seven orders belong to Basidiomycota and one order, Xylariales, comes under Ascomycota. Polyporaceae is the largest family with nine genera followed by Marasmiaceae (Eight genera), Agaricaceae and Auriculariaceae (Seven genera each), Pleurotaceae (Four genera), Ganodermataceae (Three genera), Omphalotaceae, Clavariaceae, Physalacriaceae, Dacryomycetaceae and Tremellaceae (Two genera each) and all remaining families like Schizophyllaceae, Mycenaceae, Coprinaceae, Serpulaceae were represented by a single genus each. The order Agaricales was dominant (33 species), followed by Polyporales (13 species), Auriculariales (Seven species), Dacrymycetales, Russulales, Tremellales, and Xylariales each having two species and Boletales having only one species.

The quantitative analysis of macrofungi revealed that *Panellus pusillus* (6.08) showed the maximum density followed by *Microporus xanthopus* (5.38). The maximum frequency of occurrence was exhibited by *Microporus xanthopus* (82.14%) followed by *Stereum ostrea* (42.86%), *Auricularia delicata* (32.14%) and *Dacryopinax spathularia* (25%). *Microporus xanthopus was identified as the most common species in the forests of* Agasthyamala. *Coprinellus disseminatus* was the most abundant species. The Shannon diversity index for macrofungi was calculated and found to be 2.99, indicating rich fungal biodiversity and less human interference in this area.

DISCUSSION

The Indian region is renowned for hosting four biodiversity hotspots. The Western Ghats and Sri Lanka are renowned biodiversity hotspots, attracting scientific exploration due to their rich variety of life forms. Among these, macrofungi, including mushrooms and polypores, hold immense importance as edible and medicinal species, with significant bio-prospecting potential. Additionally, macrofungi play a crucial role in ecosystem functioning by aiding in the formation of humus and nutrient recycling on the forest floor. Although previous studies have reported a wide range of agarics and other fungi from the evergreen and semi-evergreen forests of the Nilgiri Biosphere Reserve and the Kodagu region, further research is necessary to comprehensively document the macrofungal diversity in these areas.

Several studies have been conducted in the region, including those by Tapwal et al. (2013), Gogoi & Prakash (2015), and Vishwakarma et al. (2017), which are similar in nature. The findings of our study align with previous research, particularly regarding the dominance of the Agaricales order, as reported by Tapwal et al. (2013). Senthilarasu (2014) observed that Agaricales is the most dominant order, followed by Polyporales. Gogoi & Prakash (2015) reported the highest number of Agaricales. Our study confirms the ecological preference of the species, with the majority being saprophytic and a few exhibiting mycorrhizal characteristics, consistent with the findings of Tapwal et al. (2013). Notable macrofungi such as *Amanita vaginata*, *Cuphophyllus pratensis*, *Leucoagaricus rubrotinctus*, *Macrolepiota procera*, *Russula cyanoxantha*, *Serpula similis*, and *Termitomyces microcarpus* were identified as ectomycorrhizal fungi, known to enhance soil nutrient status, water availability, and disease resistance (Waring & Running 2007; Harsh 2021). The symbiotic association between fungi and plant roots contributes to the survival, growth, and development of plants, aiding in the absorption of minerals, particularly phosphate and water, from the soil (Jorgensen & Shoulders 1967; Marks & Kozlowski 1973; Onguene & Kuyper 2001). The extensive underground network of mycorrhizal fungal hyphae enhances the overall well-being of the ecosystem, making mycorrhiza the most efficient nutrient uptake system in nature (Onguene & Kuyper 2001). The presence of both saprophytic and mycorrhizal fungi in the study area indicates a healthy condition of the forest (Tapwal et al. 2013).

Macrofungi that inhabit woody substrates can be categorized as either saprophytic or plant pathogenic,

Table 4. Density, frequency and abundance of macrofungi of Agasthyamala forests.

	Species	Density	Frequency (%)	Abundance
1	*Amanita vaginata* (Bull.) Lam.	0.03	7.14	1.50
2	*Amauroderma rugosum* (Blume & T.Nees) Torrend	0.01	3.57	1.00
3	*Anthracophyllum archeri* (Berk.) Pegler	2.69	17.86	53.80
4	*Anthracophyllum* sp.	2.21	14.29	55.25
5	*Auricularia delicata* (Fr.) Heim	2.39	32.14	26.56
6	*Auricularia mesenterica* (Dicks.) Pers.	0.24	7.14	12.00
7	*Auricularia* sp. 1	0.4	3.57	40.00
8	*Auricularia* sp. 2	0.15	3.57	15.00
9	*Auricularia* sp. 3	0.35	3.57	35.00
10	*Campanella caesia* Romagn.	0.03	3.57	3.00
11	*Campanella tristis* (G.Stev.) Segedin	0.4	14.29	10.00
12	*Chlorophyllum molybdites* (G.Mey.) Massee	0.03	3.57	3.00
13	*Clavulinopsis fusiformis* (Soweby) Corner	0.06	3.57	6.00
14	*Coprinellus domesticus* (Bolton) Vilgalys, Hopple & Jacq.Johnson	1.34	10.71	44.67
15	*Coprinellus disseminatus* (Pers.) J.E.Lange	0.6	3.57	60.00
16	*Crepidotus variabilis* (Pers.) P.Kumm.	0.14	10.71	4.67
17	*Cyptotrama asprata* (Berk.) Redhead & Ginns	0.05	14.29	1.25
18	*Cuphophyllus pratensis* (Schaeff.) Bon	0.04	7.14	2.00
19	*Dacrymyces palmatus* (Schwein.) Burt	1.19	14.29	29.75
20	*Dacryopinax spathularia* (Schwein) G.W.Martin	2.42	25.00	34.57
21	*Daedaleopsis confragosa* (Bolton) J.Schrot	0.13	14.29	3.25
22	*Daldinia concentrica* (Bolton) Ces. & De.Not.	0.02	7.14	1.00
23	*Earliella scabrosa* (Pers.) Glib. & Ryvarden	1.02	17.86	20.40
24	*Exidia glandulosa* (Bull.) Fr.	0.01	3.57	1.00
25	*Exidia recisa* Ditmar (Fr.)	0.11	7.14	5.50
26	*Ganoderma applanatum* (Pers.) Pat.	0.05	7.14	2.50
27	*Ganoderma* sp.	0.07	7.14	3.50
28	Gill fungi 1	0.35	3.57	35.00
29	Gill fungi 2	0.15	3.57	15.00
30	*Hexagonia tenuis* (Hook.) Fr.	0.6	32.14	6.67
31	*Hymenopellis radicata* (Relhan) R.H.Petersen	0.01	3.57	1.00
32	*Lentinus* sp. 1	0.21	3.57	21.00
33	*Lentinus* sp. 2	0.41	3.57	41.00
34	*Lentinus* sp. 3	0.02	3.57	2.00
35	*Lentinus tigrinus* (Bull.) Fr.	0.04	3.57	4.00
36	*Lenzites acuta* Berk.	0.23	17.86	4.60
37	*Leucoagaricus rubrotinctus* (Peck) Singer	0.05	7.14	2.50
38	*Leucocoprinus fragilissimus* (Berk. & M.A.Curtis) Pat.	0.01	3.57	1.00
39	*Macrolepiota procera* (Scop.) Singer	0.01	3.57	1.00
40	*Marasmiellus* sp.	0.25	7.14	12.50
41	*Marasmius haematocephalus* (Mont.) Fr	0.1	17.86	2.00
42	*Marasmius siccus* (Schwein.) Fr.	0.03	3.57	3.00
43	*Marasmius* spp.	0.04	7.14	2.00
44	*Microporellus dealbatus* (Berk. & M.A.Curtis)	0.01	3.57	1.00
45	*Microporus xanthopus* (Fr.) Kuntze.	5.38	82.14	23.39
46	*Mucronella bresadolae*(Quel.) Corner	0.27	3.57	27.00
47	*Panellus pusillus* (Pers. Ex Lev.) Burds. & O.K.Mill.	6.08	28.57	76.00
48	*Pleurotus* sp. 1	0.07	3.57	7.00
49	*Pleurotus* sp. 2	0.07	3.57	7.00
50	*Pleurotus* sp. 3	0.01	3.57	1.00
51	*Pleurotus* sp. 4	0.02	3.57	2.00
52	*Polyporus grammocephalus* Berk.	0.01	3.57	1.00
53	*Pycnoporus sanguineus* (L.) Murrill	0.79	10.71	26.33
54	*Russula cyanoxantha* (Schaeff.) Fr.	0.01	3.57	1.00
55	*Schizophyllum commune* Fr.	0.89	10.71	29.67
56	*Serpula similis* (Berk. & Broome) Ginns	0.09	3.57	9.00
57	*Stereum ostrea* (Blume & T.Nees) Fr.	1.34	42.86	11.17
58	*Termitomyces microcarpus* (Berk. & Broome) R.Heim	1.79	14.29	44.75
59	*Trametes gibbosa* (Pers.) Fr.	0.02	7.14	1.00
60	*Tremella fuciformis* Berk.	0.01	3.57	1.00
61	*Tremella mesenterica* Retz.	0.33	7.14	16.50
62	*Xylaria longipes* Nitschke	0.01	3.57	1.00

Table 5. Diversity of macrofungal species by Shannon index.

	Species	Density	Pi ln pi
1	*Amanita vaginata* (Bull.) Lam.	0.03	-0.01
2	*Amauroderma rugosum* (Blume & T.Nees) Torrend	0.01	0.00
3	*Anthracophyllum archeri* (Berk.) Pegler	2.69	-0.19
4	*Anthracophyllum* spp.	2.21	-0.17
5	*Auricularia delicata* (Fr.) Heim	2.39	-0.18
6	*Auricularia mesenterica* (Dicks.) Pers.	0.24	-0.03
7	*Auricularia* sp. 1	0.4	-0.05
8	*Auricularia* sp. 2	0.15	-0.02
9	*Auricularia* sp. 3	0.35	-0.05
10	*Campanella caesia* Romagn.	0.03	-0.01
11	*Campanella tristis* (G.Stev.) Segedin	0.4	-0.05
12	*Chlorophyllum molybdites* (G.Mey.) Massee	0.03	-0.01
13	*Clavulinopsis fusiformis* (Soweby) Corner	0.06	-0.01
14	*Coprinellus domesticus* (Bolton) Vilgalys, Hopple & Jacq.Johnson	1.34	-0.12
15	*Coprinellus disseminatus* (Pers.) J.E.Lange	0.6	-0.07
16	*Crepidotus variabilis* (Pers.) P.Kumm.	0.14	-0.02
17	*Cyptotrama asprata* (Berk.) Redhead & Ginns	0.05	-0.01
18	*Cuphophyllus pratensis* (Schaeff.) Bon	0.04	-0.01
19	*Dacrymyces palmatus* (Schwein.) Burt	1.19	-0.11
20	*Dacryopinax spathularia* (Schwein) G.W.Martin	2.42	-0.18
21	*Daedaleopsis confragosa* (Bolton) J.Schrot	0.13	-0.02
22	*Daldinia concentrica* (Bolton) Ces. & De.Not.	0.02	0.00
23	*Earliella scabrosa* (Pers.) Glib. & Ryvarden	1.02	-0.10
24	*Exidia glandulosa*(Bull.) Fr.	0.01	0.00
25	*Exidia recisa* Ditmar (Fr.)	0.11	-0.02
26	*Ganoderma applanatum* (Pers.) Pat.	0.05	-0.01
27	*Ganoderma* sp.	0.07	-0.01
28	Gill fungi 1	0.35	-0.05
29	Gill fungi 2	0.15	-0.02
30	*Hexagonia tenuis* (Hook.) Fr.	0.6	-0.07
31	*Hymenopellis radicata* (Relhan) R.H.Petersen	0.01	0.00
32	*Lentinus* sp. 1	0.21	-0.03
33	*Lentinus* sp. 2	0.41	-0.05
34	*Lentinus* sp. 3	0.02	0.00
35	*Lentinus tigrinus* (Bull.) Fr.	0.04	-0.01
36	*Lenzites acuta* Berk.	0.23	-0.03
37	*Leucoagaricus rubrotinctus* (Peck) Singer	0.05	-0.01
38	*Leucocoprinus fragilissimus* (Berk. & M.A.Curtis) Pat.	0.01	0.00
39	*Macrolepiota procera* (Scop.) Singer	0.01	0.00
40	*Marasmiellus* sp.	0.25	-0.03
41	*Marasmius haematocephalus* (Mont.) Fr	0.1	-0.02
42	*Marasmius siccus* (Schwein.) Fr.	0.03	-0.01
43	spp.	0.04	-0.01
44	*Microporellus dealbatus* (Berk. & M.A.Curtis)	0.01	0.00
45	*Microporus xanthopus* (Fr.) Kuntze.	5.38	-0.28
46	*Mucronella bresadolae*(Quel.) Corner	0.27	-0.04
47	*Panellus pusillus* (Pers. Ex Lev.) Burds. & O.K.Mill.	6.08	-0.30
48	*Pleurotus* sp. 1	0.07	-0.01
49	*Pleurotus* sp. 2	0.07	-0.01
50	*Pleurotus* sp. 3	0.01	0.00
51	*Pleurotus* sp. 4	0.02	0.00
52	*Polyporus grammocephalus* Berk.	0.01	0.00
53	*Pycnoporus sanguineus* (L.) Murrill	0.79	-0.08
54	*Russula cyanoxantha* (Schaeff.) Fr.	0.01	0.00
55	*Schizophyllum commune* Fr.	0.89	-0.09
56	*Serpula similis* (Berk. & Broome) Ginns	0.09	-0.02
57	*Stereum ostrea* (Blume & T.Nees) Fr.	1.34	-0.12
58	*Termitomyces microcarpus* (Berk. & Broome) R.Heim	1.79	-0.15
59	*Trametes gibbosa* (Pers.) Fr.	0.02	0.00
60	*Tremella fuciformis* Berk.	0.01	0.00
61	*Tremella mesenterica* Retz.	0.33	-0.04
62	*Xylaria longipes* Nitschke	0.01	0.00
Shannon diversity index, H' = 2.99			

as documented by Mueller et al. (2007). In the present study, several saprophytic fungi were identified, including *Polyporus grammocephalus*, *Pycnoporus sanguineus*, *Stereum ostrea*, and *Microporellus dealbatus*. Senn-Irlet et al. (2007) reported that approximately 50% of macrofungi found in forests are involved in wood decay processes. Saprophytic macrofungi play a crucial role in carbon and nutrient recycling within ecosystems (Gates, 2009). They can be further classified into three types based on their wood degradation mechanisms: soft rot fungi, white rot fungi, and brown rot fungi. White rot fungi, such as *Pycnoporus sanguineus*, *Trametes gibbosa*, *Earliella scabrosa*, and *Microporellus dealbatus*, are predominant in the studied area. These fungi, belonging to both Ascomycota and Basidiomycota, are responsible for breaking down lignin, cellulose, and hemicellulose in wood. They are unique in their ability to degrade lignin, distinguishing them from other organisms. In contrast, brown rot fungi primarily degrade cellulose and hemicellulose while leaving the lignin relatively intact.

Image 2. a–l Sporocarps of macrofungi within their habitat in the wet evergreen forests of Agasthyamala: a—*Polyporus grammocephalus* | b—*Microporus xanthopus* | c—*Ganoderma applanatum* | d—*Leucoagaricus rubrotinctus* | e—*Hexagonia tenuis* | f—*Dacryopinax spathularia* | g—*Cuphophyllus pratensis* | h—*Mucronella bresadolae* | i—*Pycnoporus sanguineus* | j—*Amanita vaginata* | k—*Cyptotrama asprata* | l—*Macrolepiota procera*. © K.K. Akshaya.

Notably, brown rot fungi like *Dacryopinax spathularia*, were also observed in this study. An interesting characteristic of brown rot fungi is their formation of bracket-shaped fruiting bodies on dead wood.

Termitomyces microcarpus is the most common edible mushroom used by the local people of

Agasthyamala. The local people named the mushroom 'Areekoonu' (Malayalam: rice mushroom). Mushrooms are rich in protein, vitamins, and minerals and are used as a substitute for animal protein (Chang & Buswell 1996).

The sporocarps of macrofungi show diverse forms in their morphology like jelly fungi, polypores, agarics, and coral fungi. The present study reports jelly fungi such as *Tremella fuciformis*, *Exidia recisa*, and *Tremella mesenterica*. Polypores like *Microporus xanthopus,* and *Polyporus grammocephalus,* Agarics such as *Leucoagaricus rubrotinctus*, *Amanita vaginata*, *Chlorophyllum molybdites* and coral fungi include *Clavulinopsis fusiformis*.

The Shannon diversity index was calculated and found to be 2.99, indicating that the study area has high fungal biodiversity. The rich mycoflora of the wet evergreen forests of Agasthyamala is due to less human interference.

The fruiting behavior of macrofungi is influenced by various factors, including elevation, latitude, and their impact on temperature and precipitation (Ohenoja 1993). Macrofungi exhibit distinct patterns of sporocarp production, occurring in different seasons and across extensive geographic areas with notable elevation changes. The presence of specific vegetation types plays a crucial role in determining the species richness and composition of macrofungi in a given area. Grasslands, deserts, forests, tundra, and other habitats harbor characteristic macrofungal species adapted to their respective environments. The abundance and diversity of macrofungi are closely linked to the composition of plant species, as plants serve as vital constituents and energy sources within the ecosystem, supporting the growth and development of most macrofungi. Furthermore, the distribution of ectomycorrhizal fungi, which establish symbiotic relationships with plant roots, often aligns with specific forest types (Natel & Neumann 1992).

The fungal community responds to changes in climatic conditions in the form of changes in fruiting patterns, productivity, fruit body size, geographical distribution, and phenological patterns. Such changes have a strong impact on their functional attributes like modifying carbon cycling, altering bacterial community, and disrupting mycorrhizal associations with effects reflecting up to higher trophic levels. Long-term ecological monitoring studies help to provide valuable insights in ecology, environmental change, natural resource management, and biodiversity conservation. Therefore, understanding the factors that trigger sporocarp community response to climate at species level is very important to predict future species composition and abundance under global climate change scenario.

CONCLUSION

Macrofungi play a crucial role in the ecosystem by significantly influencing soil nutrition, organic carbon levels, and the well-being of surrounding vegetation. Despite the limited availability of reports on macrofungal diversity in the Western Ghats region of India, this study aimed to fill this knowledge gap by generating essential baseline data on higher fungi. The findings of this study revealed that the Agasthyamala Biosphere Reserve exhibits a remarkable richness of fungal diversity, particularly in its wet evergreen forests. The presence of such rich fungal diversity serves as an indicator of the overall health and vitality of these forests. Consequently, the baseline data obtained from this study serves as a valuable resource for understanding and assessing the species richness of macrofungi within these forest ecosystems, contributing to their conservation and management.

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