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The current study focused on the fungal diversity and distribution in the Western Ghats (macrofungi and aquatic hyphomycetes) and west coast (macrofungi) regions of Karnataka based on multiple surveys. Description and distribution pattern of 25 macrofungi recorded in the Western Ghats based on one-time survey have been furnished. Survey, taxonomic descriptions and diagnostic key of termitomycetes those serve as traditional food source in the Western Ghats and west coast are given. Results on the nutritional and bioactive potential of two edible macrofungi *Auricularia auricula-judae* (on wood) and *Termotimyces umkowaan* (on termite mound) are presented. Richness and diversity of aquatic hyphomycetes (water, leaf litter, woody litter and sediments) are compared in three perennial streams of the Western Ghats (V’Badaga, B’Shettigeri and Perambadi).

10.1 Macrofungi - Diversity

**Western Ghats**

*Multiple surveys:* Western Ghats of India is endowed with a variety of tropical habitats consisting of grasslands, Shola forests, deciduous forests, moist-dry deciduous forests, evergreen forests, semi-evergreen forests and scrub jungles at different altitudinal ranges (~500 to 1,200 m asl). Besides, some virgin forests have been preserved as regional heritage (e.g. sacred groves and reserve forests) and a variety of agroforests have been established as part of agriculture (e.g. coffee agroforest and rubber plantation). Western Ghats provide excellent conditions for macrofungal diversity during southwest monsoon and post-monsoon periods. Six months survey (June-November 2012) in reserve forest, Shola...
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forest, sacred grove and coffee agroforest yielded a variety of macrofungi. A total of 157 species belonging to 87 genera was recovered in 24 quadrats (25 x 25 m). A maximum of 53 species occurred in coffee agroforest with the highest exclusive (42 species) as well as core-group species (17 species). Irrespective of locations, the species richness attained two peaks during monsoon. The exclusive species were highest in June, while the core-group species in September. The diversity in locations as well as seasons was similar to species richness. Out of 9256 sporocarps, the coffee agroforest supported the highest (3715 sporocarps) followed by Shola forest (2999 sporocarps), reserve forest (1866 sporocarps) and sacred grove (1676 sporocarps). The richness of sporocarp showed two peaks during monsoon and rarefaction indices of species against sporocarps revealed the highest expected number of species in coffee agroforest. Low species similarity between locations (2.4–8.5%) depicts the uniqueness of macrofungi in each location surveyed due to specific edaphic factors including the richness and diversity of tree species.

This study revealed the occurrence of 47 core-group fungi valuable as edible, medicinal and ectomycorrhizal with preference for mainly wood and woody debris. Based on the present study, there is ample scope to maintain the coffee agroforests established in the Western Ghats in favor of economically valuable macrofungi by maintaining diverse tree species, prevention of erosion, suitable edaphic conditions (temperature, moisture and humidity) and sufficient substrate on the floor (leaf and woody litter). Traditional knowledge of the local dwellers and tribals will be advantageous in sustainable harvest of macrofungi (in reserve forests, Shola forests and sacred groves) and to develop future conservation strategies.

One-time survey: One-time opportunistic inventory projected diverse group of edible, medicinal and ectomycorrhizal fungi especially in the sacred groves and reserve forests. Such biomes deserve more attention towards successful conservation of macrofungi as natural repositories. Domestication of desired macrofungi can be achieved in many agroforests and commercial plantations (e.g. shade-grown coffee, cardamom, cocoa and areca), monocrops (e.g. rubber) and tree-less wetland or semi-wetland field crops (e.g. paddy, sugarcane and banana). According to Brown et al. (2006) based on long-term inventory in the Western Ghats that the habitat degradation is a major threat for macrofungal diversity than the habitat fragmentation. For instance, even though the sacred groves occupied less area in the Western Ghats, they are unique to macrofungal conservation compared to reserve forests and coffee-agroforests. However, this one-time study revealed the highest species richness in coffee-
agroforests than the sacred groves and reserve forests possibly due to the plantation management practices. In shade-preferred coffee-agroforests pruning of shade trees serve as major source of litter and misting during dry seasons supports the growth of macrofungi almost throughout the year. Macro- and micro-morphological description of 25 species of macrofungi (fruit body) is given along with substrate, occurrence and distribution in different parts of the Western Ghats.

West coast

The southwest coast of India consists of valleys and mountains in the proximity of the Arabian Sea with several distinct biomes (coastal sand dunes, estuaries, mangroves, oceanic/estuarine islands, sacred groves, scrub jungles, grasslands, arboreta, monoculture plantations, mixed plantations and medicinal gardens) in lateritic region with different soil textures (mainly sandy loam, loamy sand and loam). The inventory focused on the diversity of macrofungi in an arboretum and three plantations (Acacia, Areca and cashew) of the southwest coast during monsoon (June–September, 2012) and early post-monsoon (October–November, 2012) seasons. A total of 79 macrofungi belonged to 53 genera was recovered from total area of 15,000 m². The highest number of macrofungi were confined to the arboretum than the plantations (25 vs. 14–21 species), so also the core-group species (9 vs. 2–6 species). The richness of species as well as sporocarps were highest during June and decreased towards November. The macrofungal diversity was highest in Areca plantation and during monsoon period (August/September). Low species similarity was seen between the arboretum and plantations (0–12.8%), while it was increased from June through November (3.6–42.9%) revealing the habitats chosen have less overlap of macrofungi. About 50% of macrofungi possess economic value as ectomycorrhizal (25 species), edible (17 species) and medicinal (10 species).

This multiple survey revealed the dependence of macrofungi on the type of location and vegetation gives ample scope for their beneficial management towards sustainable harvest of macrofungi. Due to steep and eroding terrain, the forests and plantations of southwest coast require specific management strategies (e.g. rainwater harvest and water conservation by terracing, construction of trenches and bunds). Practice of maintaining a strip of forest zone will be usually followed in some areas to cater the needs of green manure, organic debris for plantations seems to play an important role in macrofungal richness and diversity. Retention of organic matter (leaf, wood and other litter) on the soil in forests and
plantations supports the growth of macrofungi during rainy season. Deliberate burning for
deweeding or other purposes should be discouraged in forests and plantations as it is
detrimental to macrofungal population. This study revealed nearly 26 species (encompassing
nine core-group species) as new records to the west coast of India. Up to nine species of
commercially viable macrofungi were also recovered outside the locations surveyed (edible:
Clitocybe gibba, Lentinus dicholamellatus, Phallus merulinus, Pleurotus djamor, P. eöus,
Termitomyces eurrhizus, T. heimii and T. schimperi; ectomycorrhizal: Amanita elata). Thus,
the coastal forests and plantations are potential source of economically valuable macrofungi
and deserves ecofriendly insight to derive more benefits.

**Western Ghats vs. West coast**

Both regions were evaluated for macrofungi using same technique, almost same time
(June-November 2012) and equal area (25x25 m quadrat; 24 quadrats; 15,000 m²)
enshancing reserve forests and plantations. The Western Ghats yielded 157 species (in 87
genera), while west coast yielded 79 species (in 53 genera) (~50% species in the west coast).
The total sporocarps was higher in the Western Ghats than in the west coast (9256 vs. 4820
sporocarps) (~52% sporocarps in the west coast). The Western Ghats consists of 57 core­
group species compared 28 species in the West coast (~50% core-group species in the west
coast). A highest of 53 species with 3751 sporocarps were recorded in the coffee agroforestry
in the Western Ghats against 25 species with 2496 sporocarps in arboratum of the west coast
(~50% species and ~66% sporocarps in the west coast). In the Western Ghats 47 species are
new records, while 26 species in the west coast (~55% new records in the west coast). These
figures show that the Western Ghats are rich in the macrofungal diversity as well as richness
compared to the west coast. However, both regions showed low similarities between their
locations surveyed indicates their uniqueness in diversity and distribution of macrofungi.
Both regions consists of several macrofungi under core-group species as edible, medicinal
and mycorrhizal.

**Termitomycetes**

*Termitomyces* have been considered as paleo-tropical genus among agarics due to
their dominance in tropics. This group of mushrooms has drawn the major attention of
mycologists, entomologists and food technologists as they are edible. Their cultivation occurs
through symbiotic association with termites and commonly erupts in permanent and
temporary termite mounds. *Termitomyces clypeatus* possess significant quantity of proteins (31%), carbohydrates (32%), ascorbic acid (10–14%) and antioxidant potential (Ogundana and Fagade, 1982; Tibuhwa, 2012). It also produces a variety of enzymes in culture media useful as additives in food-softening, processing of feed (silage), leavening bread and industrial applications (clarification of non-citrus fruit juices) (Khowala *et al.*., 1992, Ghorai *et al.*, 2009). About two-third of the species of *Termitomyces* recorded worldwide are known to occur in the Western Ghats and west coast (19 species) revealing the conditions suitable for a variety of termitomycetes.

The present study documented five species of *Termitomyces* spp. occurring in the forests, plantations and grasslands of the Western Ghats and west coast. Descriptions of five *Termitomyces* are given along with their distribution and diagnostic key up to 23 species based on the present study and literature. So far, the keys on *Termitomyces* were based on the color of cap, shape of umbo, nature of stipe and pseudorhizae. In addition to the above features, characteristics of annulus is used in developing the new key to accommodate almost all the *Termitomyces* occurring in the Western Ghats and west coast (except for *T. perforans*). Although some taxa are not distinctly classified as separate species, based on the current observations, they can be clearly demarcated with specific characteristic features.

Traditional knowledge by the tribal sect and local population on the *Termitomyces* has been documented. Termitomycetes have become part and parcel of tribal life in the Western Ghats. *Ex situ* cultivation of termitomycetes is a challenging task as they are obligate symbionts with termites. However, there is ample scope for conservation and sustainable harvest of this natural nutritional source. It is necessary for informal protection of traditions of tribals and native people for sustainability and their food security. As an alternate protein-energy source in developing countries, habitat preservation, sustainable exploitation and further research on termitomycetes will be more rewarding.

### 10.2 Macrofungi - Nutritional potential

Unlike nutritional quality assessments in cultivated mushrooms, assessments in wild mushrooms are difficult. *Auricularia auricula-judae* as well as *Termitomyces umkowaan* occur in different parts of the Western Ghats and west coast of India and serve as food source. However, their nutritional advantages have not been systematically investigated. *Auricularia auricula-judae* occurs in large quantities especially on the medium and large standing wood or fallen logs in forest floor. *Termitomyces umkowaan* erupts in large numbers in visible or invisible termite mounds. Crude protein content in uncooked and cooked *A.*
auricula was low (6.1–6.4%) and did not altered significantly on cooking, which matches with protein content in cereals. Crude lipid were also low (1.6–1.7%), not significantly altered on cooking and its content corresponds with another report from the Western Ghats (Johnsy et al., 2011). It is likely the protein and lipid contents of Auricularia are dependent on the type of woody substrate in the forests and needs further insight. Protein content in T. umkowaan is comparable with other termitomycetes (T. eurrhizus, T. globulus, T. mammiformis and T. striatus) and several edible legumes (Cajanus, Cicer, Phaseolus and Vigna). Relatively crude lipid content in T. umkowaan is higher than A. auricula (4.5–4.6 vs. 1.6–1.7%). The crude fibre content in Auricularia as well as Termitomyces was high in both uncooked and cooked samples. However, both mushrooms are poor in mineral contents.

Many essential amino acids in uncooked and cooked Auricularia and Termitomyces are higher or comparable with soybean, wheat and FAO-WHO (1991) recommended standards. Pressure-cooking significantly decreased the in vitro protein digestibility in both mushrooms indicating partial cooking or other methods of cooking need to be followed. The protein efficiency ratios (PER) of both mushrooms were ≥2 (2–3.9) indicate the usefulness of these mushrooms in protein nourishment. Dominance of oleic and palmitic acids in both mushrooms is comparable with other wild mushrooms in India (Longvah and Deosthale, 1998; Kavishree et al., 2008). In cooked A. auricula, presence of linolenic acid (ω-3) indicates its improved quality. Although T. umkowaan is devoid of linolenic acid, in uncooked as well as cooked samples highest quantity of linoleic acid (ω-6) was present and significantly increased on cooking. In addition, it also possesses docosahexaenoic acid (ω-3), which also significantly increased on cooking.

These two mushrooms possess considerable amount of fibre, low lipid, moderate quantity of carbohydrates, high quantity of essential amino acids and many essential fatty acids. These features qualify both mushrooms as ideal food source for human consumption. As these mushrooms will erupt all of a sudden in good quantities, future studies should concentrate on suitable indigenous technology to collect, process and preserve them without loss of nutritional and bioactive qualities.

10.3 Macrofungi - Bioactive potential

The total antioxidant activity was higher in A. auricula than in T. umkowaan without significant decrease on cooking, while it decreased significantly up to 50% in the latter. It is possible that polysaccharides of A. auricula might be responsible for higher total antioxidant
activity in uncooked as well as cooked samples as reported by Zhang et al. (2011). Metal-ion chelating capacity prevents lipid peroxidation leading to deterioration of food, which results in arthritis and cancer (Gordon, 1990; Halliwell et al., 1995). In the present study, ferric-ion chelating activity was higher in T. umkowaan than in A. auricula with significant decrease on cooking. The DPPH radical-scavenging activity was higher in A. auricula than in T. umkowaan with significant decrease on cooking only in A. auricula. The reducing power was also higher in uncooked than in cooked mushrooms with significant decrease on cooking.

In spite of low total phenolics and tannins, uncooked as well as cooked A. auricula showed higher total antioxidant activity, DPPH radical-scavenging capacity and reducing power than T. umkowaan. It is likely the quantities of flavonoids, vitamin C and L-DOPA in A. auricula could be responsible for such results. Similarly, high quantities of total phenolics, tannins, vitamin C and L-DOPA especially in uncooked T. umkowaan might be responsible for good total antioxidant activity as well as ferrous-ion chelating capacity. Interestingly, although total phenolics, tannins, flavonoids, vitamin C and L-DOPA contents were lower in cooked than in uncooked T. umkowaan, the ferric-ion chelating capacity as well as the DPPH radical-scavenging activities were considerably high in cooked samples denotes the possibilities of involvement of other bioactive principles which are not affected by pressure-cooking. Uncooked and cooked samples of both mushrooms did not show trypsin inhibition activity as well possesses minimum hemagglutination activity and such qualities are nutritionally advantageous.

Antioxidant stress and atherosclerosis happens due to dyslipidemia, which can be combated using functional diet developed by blending polysaccharide derived from A. auricula with processed Hawthorn fruits (Crataegus) (ratio, 4:1%) (Luo et al., 2009). It showed increased radical-scavenging, inhibition of low density lipoprotein-cholesterol oxidation, lowered serum total cholesterol and low atherogenic index. Microwave-assisted extraction of polysaccharides from A. auricula (showed no influence on their structure and molecular weight) possess remarkable in vitro antioxidant activity and safe to use in food products based on toxicological evaluation (Zeng et al., 2012).

The products derived out of uncooked A. auricula and T. umkowaan will be more beneficial than from the cooked ones. Besides, the nutritional qualities (e.g. proximal features and minerals) will be reduced in pressure-cooked mushrooms. In addition to medicinal uses, there are several innovative applications of wild mushrooms for health benefits especially to develop functional foods. For instance, blending purified polysaccharide flour derived from A. auricula at 9% level with bread resulted in marked increase in the antioxidant property.
(DPPH radical-scavenging) without affecting the nutritional and sensory qualities (Fan et al., 2006). It is proposed that alternate methods of cooking (e.g. partial/microwave cooking) rather than conventional pressure-cooking may be feasible to retain maximum bioactive potential with good nutritional qualities.

10.4 Aquatic hyphomycetes - Diversity

Most of the studies on aquatic hyphomycetes in the Western Ghats are confined to study the occurrence and diversity in leaf litter and foam. Instead, the present study documented aquatic hyphomycetes in different samples from three perennial streams located at altitude ranging from 765–845 m asl. The samples considered for survey include leaf litter, woody litter (bark and cambium), sediment and water. Species richness and diversity in the streams studied were neither too low like mountain streams and nor too high as mid-altitude streams in the Western Ghats (Sridhar et al., 1992; Raviraja et al., 1998). Ten species were common to all samples studied (Alatospora acuminata, Anguillospora longissima, Cylindrocarpon sp., Flagellospora curvula, F. penicillioides, Isthmotricladia gombakiensis, Lunulospora curvula, L. cymbiformis, Triscelophorus acuminatus and T. monosporus). Five of them are the top conidia producers (Anguillospora longissima, Flagellospora curvula, F. penicillioides, Lunulospora curvula and L. cymbiformis). Based on the percent conidial contribution, six species can be considered as core-group species (Anguillospora longissima, Flagellospora curvula, F. penicillioides, Lunulospora curvula and L. cymbiformis and L. cymbiformis-like species). A total of 8, 6, 5 and 2 species was confined only to water, woody litter, leaf litter and sediments, respectively and these species seem to be selective in their niches in the streams deserve further study. The present study advocates evaluating different substrates in the streams to understand the diversity of aquatic hyphomycetes. There is a need to evaluate the whole Western Ghats lotic habitats for diversity and ecological functions of aquatic hyphomycetes.

10.5 Conclusions and outlook

There is a general notion that the Western Ghats has ideal ecological set up for sampling as well as cultivation of mushrooms. In addition to the earlier inventories, the present explorations further emphasized on the richness and diversity of macrofungi of the Western Ghats and west coast as there are several new records. There are many potential locations those need intense survey. For example, Shola forests and grasslands are less
explored compared to other biomes. Similarly, *Myristica* swamps, dipterocarp stands, bamboo thickets and riparian zones are also least concentrated for macrofungal exploration. Besides, some of the habitats like peat bogs, herbivore/carnivore dung, tree holes, dead insects/larvae and agricultural/plantation waste dumps (e.g. *Areca*, coffee, coconut, paddy and pepper) are of special interest for macrofungal exploration. Wood depots consisting of a variety of wood logs are also repositories of variety of macrofungi in single location. Macrofungal composition in other coastal biomes like sand dunes, mangroves and oceanic/estuarine islands are meagre (Ghate *et al.*, 2014).

Many macrofungi in the Western Ghats and west coast are the dominant edible/medicinal/mycorrhizal species. Termitomycetes in the Western Ghats are of special concern as they serve as non-conventional protein-energy source of tribals and village dwellers. Occurrence of edible/mycorrhizal *Amanita* sp. and *Astraeus hygrometricus* and allied species needs special attention as they are delicacy of rural dwellers. Although truffles are available in the Western Ghats, their knowledge is poor or restricted to the tribals. It is interesting to note the occurrence of edible *Phallus merulinus* available gregariously on the monocot debris in mixed plantations of the west coast (Sridhar and Karan, 2013; see Appendix 1). Besides health benefits, knowledge on their bioactive compounds in fruit bodies as well as in laboratory cultures will have more applied value. Entomophagous fungus *Ophiocordyceps nutans* in the Western Ghats have been recorded for the first time and proposed it as a flagship species in view of its medicinal value similar to *Cordyceps* spp. (Karan and Sridhar, 2013; see Appendix 1). More intense exploration on ectomycorrhizal fungi will be of immense value in aforestation.

There is a gap in the current knowledge about the impact of forest degradation or fragmentation on macrofungi. According to Norden and Appelqvist (2001), macrofungi prefers old-growth forests than the new forests. For example, Natarajan *et al.* (2005) showed that distinct succession pattern of ectomycorrhizal fungi in the old (11–17 years) than in the young (3–7 years) dipterocarp forests in the Western Ghats. More intense studies are warranted on the diversity of macrofungi in pure forest stands like dipterocarps and bamboo in the Western Ghats. So far, least attention has been focused to study the diversity of coprophilous, entomophagous, termitophilous and hypogeous (e.g. truffles) macrofungi in the Western Ghats.

Several human interferences affect the macrofungal richness and diversity in the Western Ghats and west coast. Monoculture plantations may not be suitable compared to polyculture plantations and agroforestry/social forestry. Similarly, shade-less plantations may
be detrimental to the macrofungi due to less input of plant detritus. Use of extensive amount of pesticides and synthetic fertilizers declines macrofungi. Clear cutting and erosion affect macrofungal diversity as they are largely dependent on the old growth forests. Fire episodes devastate the forest ecosystem as well as wipe out the epigeous macrofungi.

There are no specific strategies for harvesting and conservation of macrofungi in the Western Ghats and west coast. According to Halme and Kotiaho (2012) each geographical location has specific edaphic features, which governs the yield of macrofungi depending on the time and frequency of field survey. For each biome, it is necessary to earmark substrate, time and frequency of sampling for maximum recovery of macrofungi. In addition, phase-wise long-term studies on macrofungi are warranted for a comprehensive knowledge to develop whole region mapping. Such mapping helps in understanding the functional diversity of macrofungi in relation to the forest/plantation and in turn implementation of conservation strategies for optimum economic benefits. Traditional knowledge of local people and tribals should not be ignored to fill the knowledge gap on the importance of macrofungi.

Similar to macrofungi, the Western Ghats are known for a variety of aquatic hyphomycetes. Approximately one-fourth of known aquatic hyphomycetes are occurring in the Western Ghats (~80 vs. ~320 species). Interestingly, up to 70 species were collected in a single location Sampaje stream in the foothill location of the Western Ghat (~500 m asl). This outlier location seems to be an important type locality for many more aquatic hyphomycetes. However, aquatic hyphomycetes occur beyond their normal aquatic territory and its life cycle becomes more complicated due to several reports in semi-aquatic/terrestrial habitats (Selosse et al., 2008; Sridhar, 2009; Fig. 10.1). Dispersal of aquatic hyphomycetes takes place by unexpected routes (e.g. streamside terrestrial litter, foam and aquatic fauna) (Bärlocher, 1981; Sridhar and Kaveriappa, 1987; Selosse et al., 2008; Sridhar and Sudheep, 2011). A preliminary study revealed the presence of typical aquatic hyphomycetes in mist samples during southwest monsoon season in the Western Ghats especially from the mid-altitudes. Such conidia are probably the products of foliar endophytes or transferred from the foam accumulated at the high altitude streamlets as aerosols.

Human interference certainly influences the aquatic hyphomycetes in the Western Ghats (e.g. pollutants and clear channelling). No major studies have been performed on the impact of pollutants on aquatic hyphomycetes and their functions in the Western Ghats. There are several gaps on the aquatic hyphomycetes of the Western Ghats, which needs conventional and molecular approaches. Clearly, more critical observations are required especially in different aquatic habitats of the Western Ghats to answer many questions. It is
Fig. 10.1. Ecological niches of aquatic hyphomycetes
necessary to enforce an integrated approach for the whole Western Ghat mapping of aquatic hyphomycetes due to availability of a vast number of streamlets in different biomes throughout the Western Ghats at different altitudinal ranges.

10.6 References


