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Occurrence and distribution of *Termitomyces* (Basidiomycota, *Agaricales*) in the Western Ghats and on the west coast of India

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This study documents five species of *Termitomyces* distributed in the forests, plantations and grasslands of the Western Ghats and west coast of India. Occurrence and distribution of *Termitomyces* have been assessed based on literature and the present survey. Descriptions of recorded *Termitomyces* species are given along with diagnostic features for identification. Traditional knowledge of *Termitomyces* has been documented based on the experience of a tribal sect and the local population. As termitomycetes are largely uncultivable, strategies are recommended for conservation of their habitat and sustainable harvesting of this human nutritional source as an alternative to plant- and animal-derived foods.

Key words: *Termitomyces*, Western Ghats, distribution, traditional knowledge, tribal food security.

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Studie popisuje pět druhů rodu *Termitomyces*, rozšířených v lesích, plantážích a travinných porostech Západního Ghátu a podél západního pobřeží Indie. Zhodnocení výskytu a rozšíření těchto druhů je založeno na literárních záznamech a aktuálním výzkumu v dané oblasti. Popisy sledovaných druhů jsou doplněny určovacím klíčem rodu *Termitomyces* s diagnostickými znaky. Jsou prezentovány též tradiční poznatky o těchto houbách, založené na zkušenostech místních obyvatel. Vzhledem k tomu, že termitomycety povětšinou nelze uměle pěstovat, je v závěru doporučena strategie ochrany stanovišť pro udržitelné využívání tohoto alternativního zdroje lidské výživy.

INTRODUCTION

Termitophilic fungi are a monophyletic group of gilled mushrooms belonging to the genus *Termitomyces*. They are cultivated through transport of spores by eusocial insects (termites) belonging to the subfamily *Macrotermitinae* (*Isoptera*) using plant material passing their guts (Frøslev et al. 2003). Aanen & Eggleton

(2006) revealed that cultivation of *Termitomyces* by termites originated in the African rain forests as the main centre and migrated to other geographical regions like Asia and Madagascar. However, molecular studies have revealed no identical sequences among the *Termitomyces* between Africa and Asia (Frøslev et al. 2003), demonstrating their geographical difference as well as a possible independent evolution. The life cycles and intricacies of coevolution between termites and *Termitomyces* (asexual and sexual phase) is still being debated (Rouland-Lefevre et al. 2002, Nobre & Aanen 2012). Recently, Nobre & Aanen (2012) argued that the termites harvest asexual spores of fungus along with lignocellulolytic enzymes of fungal and bacterial origin through faeces and foraged plant material to build the comb (fungus garden), which is comparable to an external rumen.

Up to 30 species of the genus *Termitomyces* are known and were accepted in the 10th edition of the Dictionary of the Fungi (Frøslev et al. 2003, Kirk et al. 2008). Until Heim (1942) erected the genus *Termitomyces*, early mycologists assigned this genus to widely different genera like *Armillaria* (Fr.) Staude 1857, *Entoloma* P. Kumm. 1871, *Lentinus* Fr. 1825, and *Pluteus* Fr. 1836, as there are some morphological similarities (Frøslev et al. 2003) with these genera. Termitophilic fungi are represented by giants among the gilled mushrooms like *T. titanicus* (≤ 1 m cap diam.) as well as by small mushrooms like *T. microcarpus* (≤ 2 cm cap diam.; see Piearce 1987, Tibuhwa et al. 2010). *Termitomyces* are an economically valuable natural resource serving as an alternative to plant- and animal-derived foods. Besides nutritional value, many species of *Termitomyces* possess medicinal properties and have industrial applications. For example, *Termitomyces clypeatus* possess a significant quantity of proteins (31 %), carbohydrates (32 %), ascorbic acid (10–14 %) and antioxidants (Ogundana & Fagade 1982, Tibuhwa 2012a). It also produces a variety of enzymes in culture media useful as additives in food, in leavening of bread, in processing silage and in other industrial applications (e.g. clarification of non-citrus fruit juices) (Khowala et al. 1992, Ghorai et al. 2009).

Two-thirds of the species of the genus *Termitomyces* recorded worldwide occur in six states of the Western Ghats and on the west coast of India (19 species, see Tab. 1). Literature review reveals that most of the inventory on *Termitomyces* has been carried out in Kerala State (Farook et al. 2013), which possesses a total of 15 species, followed by Goa (10 species) and Karnataka (9 species). The remaining two states (Tamil Nadu and Maharashtra) have 2 and 3 species, respectively (see Tab. 1 for references). Of these species, *Termitomyces microcarpus* has a wide distribution in six states of the Western Ghats, while *T. cylindricus* (synonym of *T. aurantiacus*; see Tang et al. 2006), *T. fuliginosus* (synonym of *T. robustus*; see Pegler 1977), *T. indicus* (synonym of *T. microcarpus*: see Pegler & Vanhaecke 1994), *T. medius*, *T. perforans* (might be a synonym of one of the small *Termitomyces* species), *T. robustus*, *T. sagittiformis*, and *T. schimperi* are confined to one of the states.

Tab. 1. *Termitomyces* taxa reported from the Western Ghats and west coast of India.

Taxon	**State**	**Reference** (see next page)
T. clypeatus R. Heim (Figs. 1a–f)	Goa	1, 2
	Karnataka	3, present study
	Kerala	5–8
T. cylindricus S.C. He	Karnataka	3
T. entolomoides Heim	Goa	1
	Kerala	5, 6
T. eurrhizus (Berk.) R. Heim (Figs. 2a–c)	Maharashtra	9
	Goa	1
	Karnataka	3, present study
	Kerala	5–8, 10–14
T. fuliginosus R. Heim	Goa	2
T. globulus R. Heim & Gooss.-Font.	Goa	2
	Karnataka	3, 4
	Kerala	5, 8
T. heimii Natarajan (Figs. 2d–f)	Maharashtra	9
	Goa	1, 2
	Karnataka	3, present study
	Kerala	5–7, 10, 11, 13–14
	Tamil Nadu	15–17
T. indicus Natarajan	Karnataka	3
T. le-testui (Pat.) R. Heim	Kerala	8
T. mammiformis R. Heim	Goa	1
	Karnataka	3
	Kerala	5, 8, 14, 18
T. medius R. Heim & Grassé	Goa	1, 2
T. microcarpus (Berk. & Broome) R. Heim (large form, Figs. 3a–c)	Gujarat	19, 20
	Maharashtra	9
	Goa	2
	Karnataka	3, present study
	Kerala	5–8, 10–13, 21–23
	Tamil Nadu	16, 17
T. microcarpus (Berk. & Broome) R. Heim (small form, Figs. 3d–f)	Karnataka	present study
	Kerala	8
T. perforans R. Heim	Kerala	5
T. robustus (Beeli) R. Heim	Kerala	8, 18, 24
T. sagittiformis (Kalchbr. & Cooke) D.A. Reid	Kerala	25
T. schimperi (Pat.) R. Heim	Kerala	8
T. striatus (Beeli) R. Heim	Goa	1
	Kerala	5, 8
T. tylerianus Otieno	Gujarat	20
	Kerala	8
T. umkowaan (Cooke & Massee) D.A. Reid (Figs. 4a–c)	Karnataka	present study
	Kerala	6, 8, 26

References. 1: Nandkumar (2013); 2: Anonymus (on-line); 3: Pahlevanlo & Janardhana (2012); 4: Sudheep (2011); 5: Leelavathy et al. (1983); 6: Pradeep & Vrinda (2007); 7: Varghese et al. (2010); 8: Mohanan (2011); 9: Sathe et al. (1980); 10: Sathe & Daniel (1980); 11: Sankaran & Florence (1995); 12: Florence & Yesodharan (1997); 13: Florence & Yesodharan (2000); 14: Florence (2004); 15: Natarajan (1979); 16: Johnsy et al. (2011); 17: Sargunam et al. (2012); 18: Bhavanidevi & Nair (1983); 19: Sidhu (2009); 20: Lahiri et al. (2010); 21: Mohanan (2003); 22: Yesodharan & Sujana (2007); 23: Kavishree et al. (2008); 24: Bilgrami et al. (1991); 25: Vrinda & Pradeep (2009); 26: Vrinda et al. (2002).

Surprisingly, 242 species of macrofungi were documented from the semi-evergreen and moist deciduous forests of Karnataka, but none of them belong to the genus *Termitomyces* (Swapna et al. 2008). It is well known that several edible mushrooms, especially *Termitomyces* species, contribute significantly to tribal food security in the Western Ghats and the west coast region (Sudheep 2011). The main objective of the present study was to document the occurrence and distribution of *Termitomyces* in the Western Ghats and on the west coast of India based on a survey and the literature. Descriptions of the *Termitomyces* found in the present study are given as well as a diagnostic key of most of the species found in the Western Ghats and on the west coast of India.

MATERIAL AND METHODS

Study area. The survey of termitomycetes was carried out in the Western Ghats (Kodagu District, Karnataka State) and on the west coast (Dakshina Kannada District, Karnataka State) during southwest monsoon and post-monsoon seasons (June–November, 2012). *Termitomyces* spp. were recorded in different habitats like coffee agroforests, mixed plantations, *Acacia* monoculture forests, sacred groves, grasslands, paddy fields, playgrounds and natural (evergreen, moist deciduous and shola) forests. The specific locations with *Termitomyces* spp. in the Western Ghats of Kodagu District include: Bramhagiri (11°57' N, 75°59' E), V. Badaga (12°06' N, 75°51' E), B'Shettigeri (12°07' N, 75°52' E), Perambadi (12°08' N, 75°47' E), Bittangala (12°10' N, 75°49' E), Kottoli (12°11' N, 75°47' E), Virajpet (12°11' N, 75°48' E), Bilugunda (12°12' N, 75°49' E), Chembebellur (12°13' N, 75°48' E), Mythadi (12°15' N, 75°45' E), Dubare (12°22' N, 75°54' E), Madikeri (12°26' N, 75°42' E), and Sampaje (12°29' N, 75°33' E). Two locations of the southwest coast of the Dakshina Kannada District showed the occurrence of *Termitomyces* spp. include: Mangalore University Campus (12°48' N, 74°55' E) and the village of Konaje (12°49' N, 74°54' E).

Identification methods. Five *Termitomyces* species recorded in this study were identified based on diagnostic morphological characteristics and

microscopic examinations (Pegler & Vanhaecke 1994, Tibuhwa et al. 2010, De Kesel 2011, Sawhasan et al. 2011, Tibuhwa 2012b, Frøslev on-line). Measurements of pileus (diameter) and stipe (length and diameter) of each species were based on the average and range of 10 independent samples collected on the spot. Basidiospores (length and width) of each species were measured in the laboratory based on a range of 25 spores using a high-power microscope (Olympus CX41RF, magnification 1000×). The fresh specimens were blotted, oven-dried (45 °C) and also fixed in a water-ethanol-formaldehyde mixture (14:5:1) for deposition in the herbarium of the Department of Biosciences, Mangalore University (MUBS).

RESULTS AND DISCUSSION

The study revealed the occurrence of five species of *Termitomyces* (including two forms of *T. microcarpus*, as described below). Details of each species, including habitat, percent occurrence (out of 48 locations surveyed) and vernacular names, are given in Tab. 2. Most of the *Termitomyces* species found in Karnataka (5 out of 9) were recorded in the present study, and a small form of *T. microcarpus* found for the first time in the Western Ghats of Karnataka. Of the termitomycetes, *T. clypeatus*, *T. eurrhizus* and *T. microcarpus* (small form) were frequent; *T. heimii* was common; *T. microcarpus* (large form) and *T. umkowaan* were found to be rare. *Termitomyces clypeatus*, *T. eurrhizus*, *T. heimii*, and both forms of *T. microcarpus* showed wide habitat preference (4–6 habitats), while *T. umkowaan* was restricted to only one habitat (see Tab. 2).

A pronounced or distinct umbo (or papilla) is one of the important diagnostic features of *Termitomyces*. Similarly, the presence (*T. clypeatus*, *T. eurrhizus*, *T. heimii* and *T. umkowaan*) or absence (*T. microcarpus*) of pseudorhizae in termitomycetes also constitutes a distinguishing feature. The length of the hidden pseudorhizae varies from zero to more than a metre, and varies in shape (cylindrical, unevenly widening and narrowing in certain sections). The colour of the pseudorhizae contrasts sharply with the stipe (white to light brown vs. buffy brown to dark brown). Pseudorhizae in termitomycetes are either solid (or stuffed) or hollow, but it was stuffed at the top and hollow at the base in *T. heimii* in our study. The stipe of termitomycetes either has a bulbous base (*T. clypeatus*, *T. eurrhizus* and *T. umkowaan*) or is devoid of it (*T. microcarpus*). In *T. heimii*, the base was broader than the stipe as well as pseudorhiza. Presence of an annulus in termitomycetes also serves as an important character, which ranges from none through squamulose and appendiculate to a thick ring encircling the stipe. In the present study, none of the termitomycetes showed an annulus except for *T. heimii*, which possess a white and thick annulus.

Tab. 2. *Termitomyces* taxa found in the Western Ghats and west coast of India in the present study including habitat, relative abundance (number of occurrences out of 48 locations surveyed) and vernacular names.

Taxon	**Termite-influenced habitats**	**Frequency** (% of total number of locations)	**Vernacular names** (language)
T. clypeatus R. Heim (Figs. 1a–f)	Coffee agroforest, *Areca* plantation, grasslands, bunds of paddy field	56 %	Naikodae (Kannada and Kodava), Pillukum (Kodava)
T. eurrhizus (Berk.) R. Heim (Figs. 2a–c)	Evergreen forest reserve, sacred grove, grassland, bunds of paddy fields, abandoned paddy fields, playground	67 %	Kodaekum (Kodava)
T. heimii Natarajan (Figs. 2d–f)	Evergreen forest reserve, sacred grove, coffee agroforests, buffer zones of playground, grasslands, paddy fields	50 %	Alukum or Alandikum (Kodava)
T. microcarpus (Berk. & Broome) R. Heim – large form (Figs. 3a–c)	Evergreen forest, deciduous forest, shola forest, sacred grove	38 %	Nuchikum or Pullaekum (Kodava)
T. microcarpus (Berk. & Broome) R. Heim – small form (Figs. 3d–f)	Coffee agroforest, grasslands, golf fields, playgrounds	63 %	Katolakum or Akkikum (Kodava)
T. umkowaan (Cooke & Massee) D.A. Reid (Figs. 4a–c)	*Acacia* forest	20 %	Kodaealambu (Tulu)

DESCRIPTIONS

Termitomyces clypeatus R. Heim (Bull. Jard. Bot. Etat. 21: 207, 1951) Figs. 1a–f

Iconography. Pegler & Rayner (1969), Heim (1977), Pegler (1977), Piearce (1987), Van der Westhuisen & Eicker (1990), Härkönen et al. (2003), Tibuhwa (2012b).

Description. Medium to large fleshy agaric with greyish brown cap, strongly spiniform umbo, whitish gills and long stipe with pseudorhiza. Scattered to gregarious on termite mounds or on soil, frequent, odour pleasant, taste excellent, edible. Pileus (4.7)5.2–8.3(10.5) cm diam., at first conical becoming applanate with strongly spiniform to acutely pointed umbo and irregularly lobed margin; at first brownish, fading to greyish brown, buff-brown or ash-brown, paler towards the margin, smooth, fibrillose, silky and viscid or slimy when wet, otherwise dry; context of pileus white, thin and fleshy. Lamellae white to creamy, free, broad, crowded, regular; short gills of 3–4 lengths. Stipe (5.2)6.8–11.2(12.8) × (0.4)0.5–0.8(1.1) cm (epigeal), central, cylindrical and with a slightly swollen or bulbous base near the soil surface with long tapering pseudorhiza downwards; whitish, fibrillose, striate and solid. Annulus absent. Basidiospores (5.5)5.9–6.8(7.1) × (3.6)3.9–4.4(4.6) µm, broadly ellipsoidal, hyaline and smooth.

Termitomyces clypeatus partially resembles *T. tylerianus* in fruit body dimensions, but the former differs in exhibiting a spiniform to acute umbo with a silky pileal surface.

Substrate and distribution. In soil below the fence of a coffee agroforest, and in grasslands (B'Shettigeri, V. Badaga), a playground (Virajpet), on bunds of paddy fields (B'Shettigeri, V. Badaga, Kottoli, Mythadi), Kodagu; on an elevated boundary of *Areca* gardens and bunds of paddy field by the village of Konaje, Mangalore.

Collections examined

India, Goa State. South Goa District, Molem and Sanguem, August 2003, leg. P. Kaur (deposited at Department of Botany, Goa University). – Karnataka State. Kodagu District, Kushalnagar, August 2011, leg. A. Pahlevanlo (deposited at Department of Botany, University of Mysore). – Kodagu District, B'Shettigeri, grasslands, 26 July 2012, leg. N.C. Karun (MUBS 028a). – Mangalore District, Konaje, *Areca* gardens and bunds of paddy field, 14 August 2012, leg. N.C. Karun (MUBS 028b).

Termitomyces eurrhizus (Berk.) R. Heim (Arch. Mus. Hist. Nat. Paris, Sér. 6, 18: 140, 1942) Figs. 2a–c

Iconography. Pegler & Rayner (1969), Pegler (1977), Härkönen et al. (1995, 2003), Tibuhwa et al. (2010), Tibuhwa (2012b).

Description. Large fleshy agaric with vinaceous brown cap, broadly conical umbo, whitish gills and long stipe with pseudorhiza. Solitary or scattered in soil, frequent, odour pleasant, taste excellent, edible. Pileus (4.9)6.4–11.6(14.4) cm diam., at first conico-campanulate becoming applanate, and then upturned with black, broadly conical umbo and thin, silky-striate, irregular, crenulate and incised margin; at first greyish brown, fading to vinaceous brown, paler towards the margin, smooth, radially rugulose and viscid or slimy when wet, otherwise semi-slimy; context of pileus white, thick and fleshy. Lamellae whitish cream, free to adnexed, broad, moderately crowded, regular; short gills of 2–3 lengths. Stipe (6.6)8.5–15.2(16.8) × (0.7)0.8–1.6(1.7) cm (epigeal), central, cylindrical and slightly swollen or bulbous base near the soil surface with long blackish pseudorhiza tapering downwards; creamish white, fibrillose, solid and smooth. Annulus absent. Basidiospores (5.9)6.6–7.9(9.2) × (3.3)3.4–3.9(4.7) µm, broadly ellipsoidal, hyaline and smooth.

Substrate and distribution. Makutta reserve forest (Perambadi), grasslands (B'Shettigeri, V. Badaga, Chembebellur), bunds of paddy field (B'Shettigeri, V. Badaga, Bittangala, Kottoli), uncultivated paddy fields (B'Shettigeri), playground (Virajpet), sacred grove (B'Shettigeri), Kodagu.

Collections examined

India, Karnataka State. Kodagu District, Anekadu, October 2011, leg. A. Pahlevanlo (deposited at Department of Botany, University of Mysore). – Kodagu District, Virajpet, playground, 24 June 2012, leg. N.C. Karun (MUBS 029).

Termitomyces heimii Natarajan (Mycologia 71: 853, 1979) Figs. 2d–f

Iconography. Heim (1942), Natarajan (1979), Buyck (1994), Härkonen et al. (1995, 2003).

Description. Large fleshy agaric with whitish cap, broad greyish brown umbo, pale pinkish gills and long stipe with annulus and pseudorhiza. Gregarious or in small to large troops on termite mounds or on soil, common, odour pleasant, taste excellent, edible. Pileus (9.9)11.7–14.5(16.2) cm diam., at first subglobose to subumbonate with incurved margin, becoming convex to plano-convex with broad, elevated umbo and fissile or split margin; at first white with greyish umbo becoming whitish with greyish brown umbo, smooth, silky, fibrillose and viscid or slimy when moist, otherwise dry; context of pileus white, thick and fleshy. Lamellae at first white, becoming pale-pink with age, free, broad, crowded, regular; short gills of 3–4 lengths. Stipe (9.7)11.8–19.9(21.8) × (2.6)2.7–3.7(3.8) cm (epigeal), central, cylindrical, long and fairly thick base near the soil surface with long, hollow pseudorhiza tapering downwards; whitish, stuffed and smooth. Annulus white, thick and persistent. Basidiospores (5.3)5.5–6.8(7.2) × (4.0)4.2–4.6(4.7) µm, broadly ellipsoidal, smooth and hyaline with pinkish tinge.

Termitomyces heimii is similar to *T. le-testui* in pileus colour and size, but differs in having a broad greyish brown umbo and pale pinkish gills.

Substrate and distribution. Emerging from termite mounds in Makutta reserve forest (Perambadi), coffee agroforest (B'Shettigeri), sacred groves (B'Shettigeri, Kottoli and Bilugunda), buffer zones in playground (Virajpet), a grassland (B'Shettigeri), and paddy fields (Virajpet), Kodagu. It was also seen in termite mounds of the medicinal garden on the Mangalore University Campus.

Collections examined

India, Goa State. North Goa District, Pirol, July 1988, leg. K. Nandkumar (deposited at Department of Botany, Goa University). – Karnataka State. Kodagu District, Kushalnagar, August 2011, leg. A. Pahlevanlo (deposited at Department of Botany, University of Mysore). – Kodagu District, Makutta (Perambadi), forest reserve, 25 August 2012, leg. N.C. Karun (MUBS 030).

Termitomyces microcarpus (Berk. & Broome) R. Heim (Mém. Acad. Sci. Inst. Fr. 64: 72, 1941) – large form Figs. 3a–c

Iconography. Pegler & Rayner (1969), Pegler (1977), Piearce (1987), Van der Westhuisen & Eicker (1990), Härkönen et al. (1995), Tibuhwa et al. (2010), Tibuhwa (2012b).

Description. Medium-sized fleshy agaric with whitish cap, acute umbo, whitish gills and small to long central stipe without pseudorhiza. Gregarious or in large troops in soil, rare, odour pleasant, taste excellent, edible. Pileus (2.0)2.4–4.4(5.1) cm diam., at first campanulate becoming expanded or convex with a small, acute, papillate umbo and irregularly lobed margin; at first whitish

fading to whitish grey / smoky grey, smooth to silky, radially striate and viscid or slimy when wet, otherwise dry; context of pileus smoky white, moderately thick and fleshy. Lamellae white, free to adnexed, broad, sparsely crowded, regular; short gills of 2–3 lengths. Stipe (2.7)2.8–5.7(7.6) × (0.15)0.2–0.35(0.4) cm, central, cylindrical, small to long, slender, slightly tapering towards the apex and without pseudorhiza; whitish, fibrillose, smooth and solid. Annulus absent. Basidiospores (5.9)6.0–6.6(6.8) × (3.4)3.7–3.9(4.2) µm, broadly ellipsoidal, hyaline and smooth.

Termitomyces microcarpus is closely related to *T. medius* in shape of pileus as well as umbo, but *T. microcarpus* differs for being devoid of pseudorhiza.

Substrate and distribution. On soil associated with termite faecal pellets in low-elevation shola forest (Sampaje), sacred grove (Kottoli), evergreen forest (Bramhagiri wild life sanctuary), and deciduous forest (Dubare), Kodagu.

Collections examined

India, Goa State. North Goa District, Pirol, August 2004, leg. K. Nandkumar. – South Goa District, Molem, August 2004, leg. K. Nandkumar (both deposited at Department of Botany, Goa University). – Karnataka State. Kodagu District, Anekadu, October 2011, leg. A. Pahlevanlo (deposited at Department of Botany, University of Mysore). – Kodagu District, Sampaje, shola forest, 22 September 2012, leg. N.C. Karun (MUBS 031).

Notes. From the African region, Frøslev (on-line) and De Kesel (2011) have documented the pileus diameter of *T. microcarpus* being ≤ 2 cm, while Pegler & Vanhaecke (1994) from Southeast Asia, and Tibuhwa (2012b) from Tanzania, considered the pileus diameter to be < 3 cm. The specimen from the Western Ghats in our study showed an average pileus diameter > 3 cm (average 3.4 cm; range 2.0–5.1 cm) and an average stipe length of 5 cm (range 2.7–7.6 cm). The measurement was taken from a troop consisting of approximately 3,500 individuals, visually considering small and large individuals. The authors also observed such variation in pileus and stipe measurements between particular locations in the Kodagu region. It is assumed that geographical difference, environmental conditions (especially soil edaphic features) and species of termite involved in cultivation have a major influence on the dimension of the mushrooms.

Based on the smallest pileus diameter (< 2 cm) as seen in the African region (Frøslev on-line, De Kesel 2011), as well as the length of the stipe (1.3–2.3 cm) of *T. microcarpus* in our study, there seems to exist another forma in *T. microcarpus*. Thus, we have considered describing the features of large and small forms of *T. microcarpus* separately. Details of the small form of *T. microcarpus* are given in the following section.

Termitomyces microcarpus – small form Figs. 3d–f

Description. Small fleshy agaric with pinkish white cap, papillate umbo, pale pinkish gills and slender central stipe without pseudorhiza. Gregarious or in

small to large troops on faecal pellets of termites in soil, frequent, odour pleasant, taste excellent, edible. Pileus (0.9)1.1–1.2(1.3) cm diam., at first campanulate becoming plano-convex to upturned with a small papillate umbo and irregularly lobed margin; at first whitish turning to pinkish-white or cream-white, smooth, silky to fibrillose, shiny and dry; context of pileus white, thin and fleshy. Lamellae pale pinkish, free to adnexed, sparsely crowded, regular; short gills of 2–3 lengths. Stipe (1.3)1.7–2.1(2.3) × (0.15)0.2–0.25 cm, central, cylindrical, slender; bulbous base attached to faecal pellets of termites; whitish, solid and fibrous. Annulus absent. Basidiospores (4.6)5.0–5.5(5.8) × (2.6)2.9–3.7(4.0) µm, broadly ellipsoidal, hyaline and smooth.

Although this form of *T. microcarpus* closely resembles *T. microcarpus* (large form) especially in lacking pseudorhiza, it differs in having a small pinkish-white pileus and papillate umbo, and fruitbodies emerge directly from termite faecal pellets.

Substrate and distribution. Directly emerging from faecal pellets of termites in coffee agroforest (B'Shettigeri), grasslands, golf fields (Madikeri), and playgrounds (Virajpet), Kodagu.

Collection examined

India, Karnataka State. Kodagu District, B'Shettigeri, coffee agroforest, 20 November 2012, leg. N.C. Karun (MUBS 032).

Notes. Similar to our study, this small form (as *T. microcarpus* f. *microcarpus*) was mentioned by Tibuhwa et al. (2010) while considering micro- and macro-morphological characteristics of 25 species of *Termitomyces* for classification. Similarly, another forma (small form without true umbo) has been reported from the south-west region of the Western Ghats of India by Mohanan (2011). This forma emerges exclusively from termite faecal pellets deposited on leaf litter. In addition to *T. microcarpus* (small form, known as Katolakum or Akkikum in local language) explained above, there is one more forma (also small, known as Kokkalaekum), which is extensively consumed by tribal communities in the Kodagu region of the Western Ghats (Gowda, Kodava, Kuruba, Kudiya, and Yarava). This one resembles *T. microcarpus* f. *microcarpus* reported by Mohanan (2011).

Termitomyces umkowaan (Cooke & Massee) D.A. Reid (Contr. Bolus Herb. 7: 118, 1975) Figs. 4a–c

Iconography. Van der Westhuisen & Eicker (1990), Tibuhwa et al. (2010) and Tibuhwa (2012b).

Description. Large fleshy agaric with yellowish brown cap, obtuse umbo, whitish gills and long stipe with pseudorhiza. Scattered to gregarious on termite mounds or on soil, rare, odour pleasant, taste excellent, edible. Pileus (4.9)5.4–11.2(12.8) cm diam., at first campanulate becoming expanded to shal-

Fig. 1. *Termitomyces clypeatus*: **a** – emerging stage, **b** – expanded stage, **c** – characteristic cap surface, **d** – stipe and gills (India, Western Ghats, B'Shettigeri, 26 Jul. 2012, leg. N.C. Karun, MUBS 028a); *T. clypeatus*: **e** – cap and stipe, **f** – gills (India, west coast, Konaje, 14 Aug. 2012, leg. N.C. Karun, MUBS 028b). Photographs: Namera C. Karun.

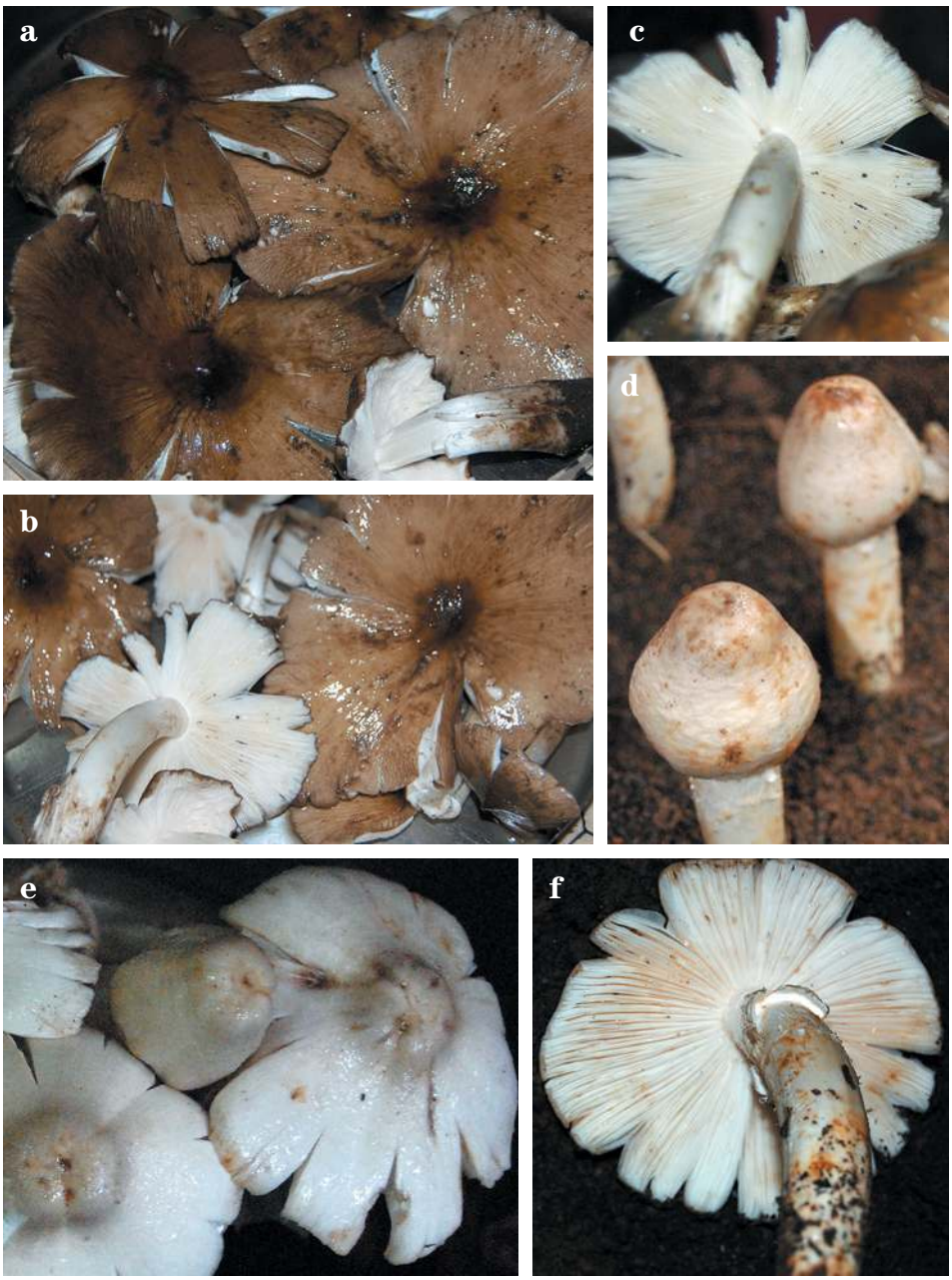

Fig. 2. *Termitomyces eurrhizus*: **a, b** – characteristic cap, **b, c** – gills (India, Western Ghats, Virajpet, 24 Jun. 2012, leg. N.C. Karun, MUBS 029); *T. heimii*: **d** – emerging stage, **e** – expanded cap with prominent cylindrical to clavate umbo, **f** – gills with annulus (India, Western Ghats, Perambadi, 25 Aug. 2012, leg. N.C. Karun, MUBS 030). Photographs: Namera C. Karun.

Fig. 3. *Termitomyces microcarpus* (large form): **a, b** – gregarious mature fruitbodies, **c** – stipe and gills (India, Western Ghats, shola forest of Sampaje, Kodagu, 22 Sep. 2012, leg. N.C. Karun, MUBS 031); *T. microcarpus* (small form): **d** – early stage of spawn with asexual granules with immature fruitbodies developed on termite faecal pellets, **e** – mature fruitbodies with silky cap, **f** – gills (India, Western Ghats, B'Shettigeri, 20 Nov. 2012, leg. N.C. Karun, MUBS 032). Photographs: Namera C. Karun.

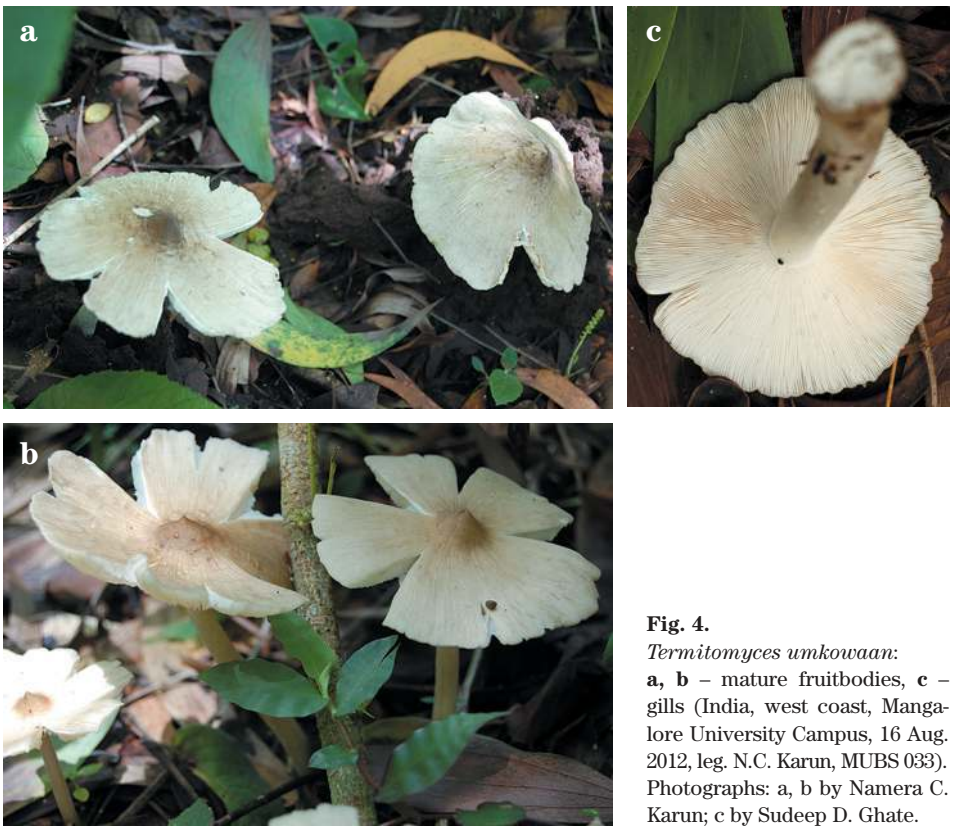

Fig. 4.
Termitomyces umkowaan:
a, b – mature fruitbodies, **c** – gills (India, west coast, Mangalore University Campus, 16 Aug. 2012, leg. N.C. Karun, MUBS 033). Photographs: a, b by Namera C. Karun; c by Sudeep D. Ghate.

lowly convex and later upturned with spiniform to broadly conical umbo and straight to incised or split margin; at first greyish yellow, fading to yellowish brown, radially wrinkled, smooth and viscid or slimy when wet, otherwise dry; context of pileus white to creamy, moderately thick and fleshy. Lamellae white, free, broad, crowded, regular; short gills of 3 lengths. Stipe (6.4)6.6–10.4(13.2) × (0.6)0.7–1.4(1.5) cm (epigeal), central, cylindrical, long; slightly swollen or bulbous base near the soil surface, with a long and rust-brown pseudorhiza tapering downwards; whitish, fibrillose and stuffed. Annulus absent. Basidiospores (6.6)6.8–7.9(9.2) × (4.2)4.5–4.7(5.0) µm, broadly ellipsoidal, hyaline and smooth.

Substrate and distribution. On soil associated with termite mounds in *Acacia* dominated forest, Mangalore University Campus (Mangalore).

Collection examined

India, Karnataka State. Dakshina Kannada District, Mangalore, Mangalore University Campus, *Acacia* dominated forest, 16 August 2012, leg. N.C. Karun (MUBS 033).

N o t e s. Although *T. umkowaan* is considered a synonym of *T. eurrhizus* because of possessing dark pseudorhiza, it differs in having a distinct spiniform to obtuse umbo. However, *T. eurrhizus* is also known to exhibit a sharp umbo (cf. Pegler & Vanhaecke 1994). Besides, our study reveals gregarious growth of *T. umkowaan*, whereas *T. eurrhizus* grows solitarily or scattered. The specimens of *T. umkowaan* obtained in our study have a semi-gelatinous layer on the pileus only under moist conditions, while *T. eurrhizus* shows a thick gelatinous layer under moist as well as dry conditions. According to Tibuhwa (2012b), *T. umkowaan* differs by having clavate to pyriform cystidia and somewhat larger basidiospores compared to *T. eurrhizus*. Further research, especially the use of molecular markers, is necessary to resolve the taxonomic status of *T. umkowaan* and *T. eurrhizus*.

DIAGNOSTIC FEATURES

A diagnostic key is presented for 23 species of *Termitomyces* based on the present collections, literature and descriptions by Pegler & Vanhaecke (1994), Tibuhwa et al. (2010), De Kesel (2011), Tibuhwa (2012b), and Frøslev (on-line). So far, keys to *Termitomyces* were constructed based on colour of the cap, shape of the umbo, and nature of stipe and pseudorhiza. In addition to the above-mentioned features, we also have considered the characteristics of an annulus in developing the following key for almost all the *Termitomyces* occurring in the Western Ghats and on the west coast of India (except for *T. perforans*, see Tab. 1). Although some taxa are not distinctly classified as separate species (see Introduction and notes to descriptions), based on the current observations, they can be delimited by specific features. In such cases, the key provides the specific name and an indication of possible synonyms.

Key to *Termitomyces*

1a Pileus small, less than 5 cm diam. 2
1b Pileus medium, 5–10 cm diam. 7
1c Pileus large, over 10 cm diam. 10
2a Fruitbody without pseudorhiza 3
2b Fruitbody with pseudorhiza 4
3a Pileus 2–5 cm diam., white, creamy or ash-grey, and with a dark spiniform or acute papillate umbo ..... *T. microcarpus* (large form)
3b Pileus 0.5–2 cm diam., whitish, pale pinkish white or creamy, and with or without papillate umbo ..... *T. microcarpus* (small form)
3c Pileus 3–5 cm diam., white to creamy, umbo brown papillate, stipe with very short, stout rooting base ..... *T. indicus**
4a Annulus absent 5
4b Annulus present 6

5a Pileus bluish black, rimose and with obtusely conical umbo ..... *T. entolomoides*
5b Pileus buffy brown and smooth, umbo sharply pronounced ..... *T. medius*
6a Pileus creamy white with appressed or upturned brown scales and with unpronounced to undeveloped umbo ..... *T. reticulatus*
6b Pileus greyish brown or pale orange, smooth, with dark spiniform umbo ..... *T. radicatus*
7a Annulus present 8
7b Annulus absent 9
8a Pileus whitish, pale-brown or whitish grey, rimose with few velar remnants and blackish brown, scrobiculate, mammiform umbo ..... *T. mammiformis*
8b Pileus greyish, smooth, with dark, warty, strongly spiniform umbo ..... *T. spiniformis*
8c Pileus brownish, greyish brown, radially striate, with broadly pointed non-scrobiculate umbo ..... *T. striatus* f. *annulatus*
9a Pileus pale creamy brown, concentrically scrobiculate, umbo mammiform ..... *T. robustus*
9b Pileus brownish orange, concentrically scrobiculate, umbo obtuse ..... *T. fuliginosus***
9c Pileus dull orange or tawny brown with pale margin, smooth to slightly fibrillose, globose, umbo low or absent ..... *T. globulus*
9d Pileus ash-grey or greyish brown with pale margin, silky, umbo acutely pointed, stipe bulbous near the soil surface ..... *T. clypeatus*
9e Pileus grey, greyish brown, brownish or ochraceous brown, radially striate, umbo broadly pointed or conical ..... *T. striatus*
9f Pileus greyish brown, smooth, umbo bluntly pointed or poorly developed, stipe bulbous near the soil surface with yellowish green pseudorhiza ..... *T. cylindricus*
9g Pileus greyish sepia with dull margin, smooth, umbo obtuse, stipe creamy white passing into brown fusoid pseudorhiza ..... *T. sagittiformis*
10a Annulus present 11
10b Annulus absent 12
11a Pileus creamy brown, covered by small brown granular squamules at disc and with pronounced, cylindrical-clavate umbo ..... *T. le-testui*
11b Pileus ash-grey (> 30 cm diam.), sub-squamulose, with broad umbo ..... *T. titanicus*
11c Pileus covered by thick, grey, woolly veil hiding the umbo beneath ..... *T. lanatus*
11d Pileus whitish, smooth, with greyish brown, broad umbo ..... *T. heimii*
11e Pileus creamy white or whitish, covered by thick, persistent, velar squamules throughout, lacking a mucronate umbo ..... *T. schimperi*
12a Pileus yellowish brown or greyish yellow, smooth to radially wrinkled, umbo spiniform to sharply pointed, stipe bulbous near the soil surface, with long rust-brown pseudorhiza ..... *T. umkowaan****
12b Pileus dark greyish brown or vinaceous brown, smooth to radially rugulose, umbo blackish brown, broadly pointed, stipe bulbous near the soil surface, with long black pseudorhiza ..... *T. eurrhizus*
12c Pileus smoky white or greyish white, smooth to striate, umbo brown, pointed to conical, stipe bulbous near the soil surface, with long, pale creamish pseudorhiza ..... *T. tylerianus*

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* considered a synonym of *Termitomyces microcarpus* (Pegler & Vanhaecke 1994)
** considered a synonym of *Termitomyces robustus* (Pegler 1977)
*** considered a possible synonym of *Termitomyces eurrhizus* (cf. Pegler & Vanhaecke 1994)

ECOLOGY AND CONSERVATION

Mutualistic association

Our study revealed the occurrence of termitomycetes in association with termites either in permanent termite mounds or in temporary termite colonies. In their combs, a specific microenvironment is created by the termites for cultivation of termitophilic fungi (Srivastava et al. 2012). Understanding the precise conditions might help ex-situ simulation for production and exploitation of termitomycetes. Termitomycetes are gregarious in and around permanent termite mounds, whereas solitary or scattered on ruminant-grazed land (grasslands), playgrounds, abandoned paddy fields and bunds of paddy fields. Some termitomycetes (both forms of *T. microcarpus*) prominently erupt wherever ruminant dung lies on the ground or at locations strongly influenced by ruminant activity (e.g. surroundings of cattle sheds, farmhouses and grasslands), therewith indicating the relationship between ruminants, termites and termitomycetes. Termite colonies take advantage of digested or partially digested lignocellulosic material in ruminant dung for cultivation of termitomycetes. In our study, *T. clypeatus* mainly preferred grassland in the Kodagu region, while it occurs in permanent termite mounds in the west coast region. Permanent termite mounds were preferred by *T. heimii* in Kodagu as well as the west coast region. Similarly, *T. umkowaan* also preferred the surroundings of permanent termite mounds in the west coast region. The other termitomycetes (*T. eurrhizus*, *T. microcarpus*) preferred mainly open places in forests and buffer zones (grasslands / paddy fields adjacent to forests) without prominent termite mounds.

The activity of ruminants (e.g. cow, buffalo, sheep and goat) is common in grassland and buffer zones of Kodagu as well as the west coast region. Physical disruption of lignocellulose by termite mastication supports further degradation by fungal enzymes (Nobre et al. 2010). Such symbiosis augments the degradation and turnover of lignocellulosic substrate in grasslands, on agricultural land and in forests. Based on the role of enzymes in tripartite association (bacteria – fungi – termites), Nobre & Aanen (2012) considered the termite mound as an external rumen. Besides, some termite workers (e.g. *Odontotermes formosanus*) show higher cellulase activity in their faeces than the symbiotic *Termitomyces* denoting the role of gut-derived and acquired enzymes (bacteria and fungi; see Yang et al. 2004, Deng et al. 2008). There seems to be a specificity or selection between the termites and *Termitomyces*. For instance, colonies of the termite *Macrotermes natalensis* are associated with a single, sexually reproducing and horizontally transmitted lineage of a *Termitomyces* symbiont (de Fine Licht et al. 2006, Aanen et al. 2007). Recent molecular research by Makonde et al. (2013) based on termite guts and termite combs also revealed that emergence of a particular *Termitomyces* species is due

to monoculture by a specific termite population. In view of such specificity, it is necessary to follow the species of termites which exist in forest and buffer zones of Kodagu and the west coast region of India to exploit their beneficial association.

Traditional knowledge and habitat conservation

Knowledge on *Termitomyces* with tribal and local populations is utmost important in identifying the habitats and to develop strategies for habitat conservation. For instance, the Kaani tribe in the Western Ghats of Tamil Nadu is dependent on the forest ecosystem for their nutritional security, which is partially met by *Termitomyces* mushrooms (Johnsy et al. 2011, Sargunam et al. 2012). Similarly, tribes like the Gowda, Kodava, Kuruba, Kudiya and Yarava, living in hilly parts of the Kodagu region, are experts in collecting mushrooms and aware of the specific localities and the seasonal availability of termitomycetes. Occasionally, a giant, *T. titanicus*-like mushroom also appears and is utilised as food by tribal people in the Kodagu region. Nowadays it is rarely found, possibly due to forest degradation, as this mushroom is strongly silvicolous. As *T. titanicus* has no prominent umbo, some people are scared that it is poisonous. The first author of this paper collected *T. titanicus*-like termitomycetes twice (weighing up to 1 kg each) about 6–7 years ago in bamboo thickets consisting of termite hills near Virajpet in the Kodagu region. Recently another species, *Termitomyces globulus*, was sampled with the help of tribals of Kaiga forests on the west coast of India for nutritional assessment (Sudheep 2011).

Bhagwat et al. (2005) documented 153 macrofungi (in forest reserves, sacred groves and coffee plantations) from a narrow strip of the Kodagu region with the highest number of macrofungi in sacred groves. Every village in Kodagu District consists of 1–12 sacred groves. Based on the survey and occurrence, Pahlevanlo & Janardhana (2012) considered the belt of Alanahalli and Kushalnagar in the Kodagu region to be the hotspots of *Termitomyces* as the tribals extract illegally (as trading minor forest products is prohibited by the Government) up to two tonnes (*T. mammiformis*) annually for their livelihood. A study by Pahlevanlo & Janardhana (2012) reveals that the harvesting of *Termitomyces* from the Western Ghats is exhaustive and points at the extent of anthropogenic pressure on their natural habitats. Another termitomycete in the Kodagu region very frequently sold by tribals is *T. heimii*, which occurs gregariously in forest areas with termite mounds. It is collected immediately after thunderstorms during the early southwest monsoon period (June–August). Similarly, other species (*T. clypeatus*, *T. eurrhizus* and *T. umkowaan*) also occur during the early monsoon season, but they are not as abundant as *T. heimii* and *T. mammiformis*. *Termitomyces microcarpus* (large and small forms) occur in troops in the late rainy season (September–December) in the Kodagu region, and are eaten by almost all Kodava

communities only privately, as they are laborious to collect and process. Thus, the tribals and local people should be trained to understand the importance of termitomycetes in human nutrition and the impact of anthropogenic pressure caused by overexploitation, and to initiate sustainable harvest and habitat restoration.

Future concerns

Termitomyces is a paleo-tropical genus among the genera of gilled mushrooms, and of major interest to mycologists, entomologists and food technologists. Nearly 330 species of termites assigned to the subfamily *Macrotermitinae* distributed in Africa and Asia are involved in cultivation of termitomycetes (Müller et al. 2005), which shows the widespread mutualistic symbiotic association. As termitomycetes are obligate symbionts with termites, ex-situ cultivation is a challenging task. However, suitable in-situ conditions could be maintained or restored in termite gardens based on the experience of expanding the natural cultivation of termitomycetes. Specific strategies to preserve small pockets rich in *Termitomyces* on cultivated lands (e.g. coffee, *Areca* and paddy farms) are necessary. A recent report states that urban regions in Karnataka (Bangalore City) were also endowed with *T. clypeatus* and *T. microcarpus* (Pushpa & Purushothama 2012). This gives scope for in-situ maintenance and sustainable harvesting even in urban habitats.

Caution should be paid to exploitation of termitomycetes in their natural habitats for commercial benefits. Harvesters should not destroy the location of interest for termitomycetes while harvesting and should allow their further growth and dissemination. Biodiversity conservation strategies will be beneficial if we include explicit and informal protection of traditions of tribals and native people in a specific region for sustainability and food security. Concerning alternate protein-energy nutritional sources especially in developing countries in Africa and Asia, habitat preservation, sustainable exploitation and research focused on termitomycetes will be highly rewarding.

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