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On the *Scleroderma* in southwest India

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ABSTRACT

The gasteroid genus *Scleroderma* (Bolateles) (Basidiomycota) has a wide geographic distribution with ectomycorrhizal, edible, medicinal and extremophilic traits. *Scleroderma* spp. in the Indian subcontinent were found in 11 states in the Himalayas (eastern and western), northwest, northeast, central region, Western Ghats and the Deccan plateau in association with a wide variety of host tree species. The present study provided a description and keys to eight species of *Scleroderma* found in southwest India. These *Scleroderma* spp. in southwest India ectomycorrhizal with seven native (*Artocarpus heterophyllus, Canarium strictum, Dysoxylum binectariferum, Gnetum ula, Macaranga peltata, Memecylon umbellatum* and *Vateria indica*) and two exotic (*Acacia auriculiformis* and *A. mangium*) tree species. They showed distribution in different habitats (forests, sacred groves, arboretum, paddy fields and termite mounds). Among them, based on the tribal knowledge, three species are edible (*S. citrinum, S. dictyosporum* and *S. polyrhizum*). *Scleroderma* spp. being adapted to extreme habitats, further exhaustive studies will help to harness their mutualistic ability, edibility and bioactive potential. Being extremophiles, they are the ideal macrofungi to promote the rehabilitation of forests and plantations in the future.

Key words: Ectomycorrhizae, mushrooms, mutualism, sacred groves, scrub jungles, tree species, Western Ghats

1. INTRODUCTION

Global fungal diversity estimates span between 0.5 and 9.9 million based on morphological and molecular insights (Cannon, 1997; May, 2000; Blackwell, 2011). However, reasonably accepted diversity is either 5.1 million (median of 0.5–9.9 million) or 2.2–3.8 million (O'Brien *et al*., 2005; Blackwell, M. 2011; Hawksworth and Lücking, 2017). Such estimates mainly rely on angiosperm plant-fungal ratios, which differ between geographic locations (1:6 to 1:33) (Fröhlich and Hyde, 1999). Mueller (2007) predicts global macrofungi as 53,000–110,000 based on plant-macrofungal ratio. Recently, Hawksworth (2019) predicts the global macrofungal species between 220,000 and 380,000 based on 10% of the total fungal estimate (2.2–3.8 million). Among the macrofungi, the ectomycorrhizal (EM) fungi (ascomycetes, basidiomycetes and mucoromycetes) occupy vital significance owing to their association with several tree species. The approximate global assessment of EM fungi ranges

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from 20,000 to 25,000 based on their association with 6,000 plant species (Rinaldi et al., 2008; Tedersoo et al., 2010).

The EM fungi have a long history of their origin between ~200 and ~50 mya (Sridhar and Karun, 2019). According to Wolfe and Pringle (2012), the EM fungal mutualism was established with tree species due to the loss of fungal lignocellulose-degrading genes of saprotrophic fungi. So far, the highest number of EM fungi have been reported from the Holarctic than in other regions (Tedersoo et al., 2010). In the Indian subcontinent, EM fungal studies have been carried out in several major ecosystems (e.g., Himalayas, Western Ghats, Central India and Deccan Plateau) (Sharma, 2009, 2017; Kumar and Atri, 2018). Based on Hawksworth's (2019) prediction of EM fungi (i.e. 10% of total fungi), India (with a total of 96,000 species of fungi) consists of at least 9,600 EM fungi. However, with 14,500 known species of fungi, the known EM fungi should be 1,450 species. A recent assessment, predicts the occurrence of EM fungi in the Western Ghats of India is up to 240 species associated with about 80 tree species (ratio, 1:3) (Sridhar and Karun, 2019).

Among the macrofungi, the EM fungi have a prime position owing to their multifarious benefits such as tree nourishment, edibility, medicinal value and withstand extreme climatic conditions (Guzmán et al., 2013; Mark et al., 2017; Vaario and Matsushita, 2021). The genus *Scleroderma* is cosmopolitan generalist EM fungi with a broad host range and dispersal capabilities (up to 40 tree species) (Sims et al., 1997; Mark et al., 2017; Wilson et al., 2012; Leonardi et al., 2018; Zhang et al., 2020). They are also known to occupy extreme or ruderal habitats (e.g. mining, coal waste, xeric and sand dunes) and withstand drought conditions (Mark et al. 2017). The Index Fungorum (2022) lists 197 records of 132 spp. of *Scleroderma*. Including the present study, up to 13 species of *Scleroderma* have been reported from the Indian subcontinent in association with a variety of natural and exotic tree species (Table 1). The current study aimed to discuss the occurrence of eight species of *Scleroderma* in southwest India with emphasis on their mutualistic association with native and exotic tree species.

Table 1. Reports on distribution of *Scleroderma* from the Indian subcontinent.

Species	Habitat and geographic location	Remarks	Reference
Scleroderma areolatum Ehrenb.	Chhittisgarh	Ectomycorrhizal with tree species: *Shorea robusta*	Sharma et al., 2009
	Chada and Bajaag (Madhya Pradesh)	Sal forests; Edible	Sharma et al., 2010
	Sacred grove, Kadnur (Karnataka)	–	Karun & Sridhar, 2016
	Scrub jungles of west coast, Konaje (Karnataka)	Ectomycorrhizal with tree species: *Acacia auriculiformis*, *A. mangium* and *Macaranga peltata*	Present study
	Devikulam (Kerala)	Ectomycorrhizal with tree species: *Eucalyptus grandis* and *E. tereticornis*	Mohanan, 2011
	Kodaikanal wildlife sanctuary (Tamil Nadu)	Inedible	Thulasinathan et al., 2018
S. aurantium L. Pers.	Rawalakot (Jammu and Kashmir)	Poisonous	Gardezi, 2005
S. bovista Fr.	Mount Abu (Rajasthan)	Ectomycorrhizal with tree species: *Eucalyptus* sp., *Grevellea robusta* and *Pinus roxburghii*	Chouhan & Panwar, 2021
	Chhittisgarh	Ectomycorrhizal with tree species: *Shorea robusta*	Sharma et al., 2009
	Dindori and Mandia (Madhya Pradesh)	Sal forests; Edible	Sharma et al., 2010
	B'Shettigeri, Kodagu (Karnataka)	Ectomycorrhizal with grasses and weeds in abandoned paddy fields	Present study

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	Chandhakkunnu, Kuppadi and Nadukani (Kerala)	Ectomycorrhizal with tree species: *Eucalyptus deglupta, E. grandis* and *E. tereticornis*	Mohanan, 2011
S. cepa Pers.	Wildlife sanctuary, Jorhat (Assam)	–	Gogai & Vipin, 2015
	West Midnapur, Ramnagar and Kasaphltala forests (West Bengal)	Gregarious around *Eucalyptus globulus* trees	Pradhan et al., 2011
	Makutta reserve forest, Kodagu (Karnataka)	Ectomycorrhizal with tree species: *Memecylon umbellatum*	Present study
	Kodaikanal wildlife sanctuary (Tamil Nadu)	Inedible	Thulasinathan et al., 2018
S. citrinum Pers.	Lopara, Palmar, Deharna and Nath (Jammu and Kashmir)	Ectomycorrhizal; Not-eaten	https://admin.jammuuniversity.ac.in/departments/botony/Project_YashPal.pdf
	Rajouri (Jammu and Kashmir)	–	Anand & Chowdhry, 2013
	Udaipur (Rajasthan)	–	Kamal, 2013
	Mount Abu (Rajasthan)	Ectomycorrhizal with tree species: *Grevellea robusta* and *Pinus roxburghii*	Chouhan & Panwar, 2021
	Wildlife sanctuary, Jorhat (Assam)	–	Gogai & Vipin, 2015
	Assam	–	Paul et al., 2019
	Nagaland	Inedible	Ao et al., 2016
	East Khasi hills (Meghalaya)	–	Borthakur & Joshi, 2017
	Kodagu (Karnataka)	Ectomycorrhizal with tree species: *Artocarpus heterophyllus, Dysoxylum malabaricum* and *Schefflera racemosa*; Edible	Karun & Sridhar, 2017
	Scrub jungle, B'Shettigeri, Kodagu (Karnataka)	Ectomycorrhizal with climber and tree species: *Artocarpus heterophyllus, Gnetum ula* and *Dysoxylum binectariferum*; Edible	Present study
	Arboretum and *Areca* plantation of West coast, Konaje (Karnataka)	Ectomycorrhizal	Karun & Sridhar 2014
	Scrub jungles and dry deciduous forests, Bangalore area (Karnataka)	Ectomycorrhizal	Pushpa & Purushothama, 2012
	Scrub jungles of west coast, Konaje (Karnataka)	Ectomycorrhizal and medicinal	Greeshma et al., 2016

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	Sand dunes of west coast, Someshwara (Karnataka)	Ectomycorrhizal with tree species: *Acacia auriculiformis* and *Casuarina equisetifolia*	Ghate & Sridhar, 2016
	Chandhakkunnu, Iringolkav and Wadakkanchary (Kerala)	Ectomycorrhizal with tree species: *Acacia auriculiformis, A. mangium, Eucalyptus deglupta, E grandis, E. tereticornis* and *Vateria indica*	Mohanan, 2011
	Kodaikanal (Tamil Nadu)	Ectomycorrhizal with tree species: *Pinus patula*	Natarajan & Kannan, 1979
	Nilgiri Hills (Tamil Nadu)	Ectomycorrhizal with tree species: *Pinus patula*	Mohan, 2008
	Walayar valley (Tamil Nadu)	–	Venkatachalapathi & Paulsamy, 2016
	Kodaikanal wildlife sanctuary (Tamil Nadu)	Inedible	Thulasinathan et al., 2018
S. dictyosporum Pat.	Sacred grove in Kottoli, Kodagu (Karnataka)	Ectomycorrhizal with climber and tree species: *Gnetum ula* and *Memecylon umbellatum*; Edible	Present study
S. fuscum (Corda) E. Fisch.	Chhittisgarh	Ectomycorrhizal with tree species: *Shorea robusta*	Sharma et al., 2009
	Dindori (Madhya Pradesh)	Sal forests; Edible	Sharma et al., 2010
S. hypogaeum Zeller	Kinnaur (Himachal Pradesh)	Ectomycorrhizal with tree species: *Pinus gerardiana*	Tapwal et al., 2021
S. macrorrhizon Wallr.	West Midnapur and Ramnagar forests (West Bengal)	-	Pradhan et al., 2011
S. polyrhizum (J.F. Gmel.) Pers.	Janakpur, Deharna and Marwah (Jammu and Kashmir)	Not edible	https://admin.jammuuniversity.ac.in/departments/botony/Project_YashPal.pdf
	Kinnaur (Himachal Pradesh)	Ectomycorrhizal with tree species: *Pinus gerardiana*	Tapwal et al., 2021
	B'Shettigeri, Kodagu (Karnataka)	Ectomycorrhizal with climber and tree species: *Gnetum ula* and *Memecylon umbellatum*; Edible	Present study
	Brahmagiri and Pambadumshola (Kerala)	Ectomycorrhizal with tree species: *Eucalyptus grandis, E. tereticornis* and *Vateria indica*	Mohanan, 2011
S. sinnamariense Mont.	Chhittisgarh	Ectomycorrhizal with tree species: *Shorea robusta*	Sharma et al., 2009
	Dindori (Madhya Pradesh)	Sal forests; Edible	Sharma et al., 2010
S. texense Berk.	Chhittisgarh	Ectomycorrhizal with tree species: *Shorea robusta*	Sharma et al., 2009
	Chanda, Mandha,	Sal forests; Edible	Sharma et al., 2010

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	Mawai and Baiyar (Madhya Pradesh)		
	Bisle Ghat, Sakleshpura (Karnataka)	–	Present study
S. verrucosum (Bull.) Pers.	Loharna (Jammu and Kashmir)	Inedible	https://admin.jammuuniversity.ac.in/departments/botony/Project_YashPal.pdf
	Wildlife sanctuary, Jorhat (Assam)	–	Gogai & Vipin, 2015
	Labhandi (Chhittisgarh)	Occurred on lateritic soil and Edible	Ahlawat et al., 2008
	Gurguripal forest, Medinipur (West Bengal)	Inedible	Singha et al., 2017
	Sacred groves, Bettoli; coffee agroforests, V'Badaga (Karnataka)	Ectomycorrhizal with tree species: *Canarium strictum, Holigarna nigra* and *Vateria indica*; Edible	Karun et al., 2014
	Chickpet, Kodagu (Karnataka)	Ectomycorrhizal with tree species: *Vateria indica*	Present study
	Arboretum of West coast, Konaje (Karnataka)	Ectomycorrhizal	Karun & Sridhar 2014
	Arboretum and botanical garden of West coast, Konaje (Karnataka)	Ectomycorrhizal and medicinal	Pavithra et al., 2016
	Scrub jungles, Konaje (Karnataka)	Ectomycorrhizal with tree species: *Canarium strictum* and *Vateria indica*	Present study
	Ingar, Periya and Vattavada (Kerala)	Ectomycorrhizal with tree species: *Acacia auriculiformis, A. mangium, Eucalyptus deglupta, E. grandis, E. tereticornis* and *Vateria indica*	Mohanan, 2011

2. KEY TO SPECIES

1. Basidiocarp with false stipe and the huge mass of rhizomorphs….. 3
2. Basidiocarp without false stipe and without huge rhizomorphs……4

3a. Basidiocarp with rigid, long psuedostipe surmounting a spherical hammer head-like fertile structure……..…*S. verrucosum*

3b. Basidiocarp with or without short stout pseudostipe with orange-brown exoperidium studded with fine scales…….……...*S. areolatum*

4a. Basidiocarp small to medium……...5

4b. Basidiocarp medium to large……....6

5. Basidiocarp with sub-spherical to irregularly rounded structure studded with dark scales and greyish-brown peridium.....*S. bovista*

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6a. Basidiocarp with finely grooved to ridged pored yellowish exoperidium
……..*S. polyrhizum*
6b. Basidiocarp with orange-brown spongy exoperidium growing on termite mound in aerial parts of live *Gnetum ula*.....*S. dictyosporum*
6c. Basidiocarp with yellowish-brown leathery exoperidium decorated with coarse scales
…….....*S. citrinum*
6d. Basidiocarp with yellowish-brown scaly to leathery dented exoperidium with fishy odour…….....*S. cepa*
6e. Basidiocarp with greyish-brown scales all over the peridium…..…*S. texense*

3. DESCRIPTION

***Scleroderma areolatum* Ehrenb., *Sylv. Mycol. Berol. (Berlin), 15*, 27 (1818) (Fig. 1).**

Basidiocarp: Small to medium, with or without pseudostipe, orange-brown, scaly, globose to sub-globose, sessile, 18-34 × 22-35 mm (n=10). Occur in small troops, annual, particolous, infrequent, odour and taste not distinctive. At first, small epigeous studs develop into sub-spherical structures bearing orange-brown or brownish peridium with fine scales and are attached to the soil by a dense mass of rhizomorphs. At maturity, the fruit body bulges into sub-spherical or pear-shaped bearing thick, tough, leathery exoperidium covered with smooth, dark-brown appressed scales leaving a dotted and netted design. On aging, the fruit body ruptures at the apex and opens up by an irregular fissure showing purple-brown powdery gleba with thick pale inner layers of endoperidium which partly curls out.

Basidia and basidiospores: Basidia hyaline, 11-16 × 15-30 µm (n=25) with 4-6 sterigmata, basidiospores spherical, blackish-brown or dark-brown, echinulate, spiny, 9-11 µm (n=25).

Habitat and distribution: Gregarious, ectomycorrhizal with *A. auriculiformis, Acacia mangium* and *Macaranga peltata* in scrub jungles of Mangalore university campus, Konaje, Mangalore (Karnataka), India (ScarKon-WGMRF), June 25, 2012, Namera C. Karun.

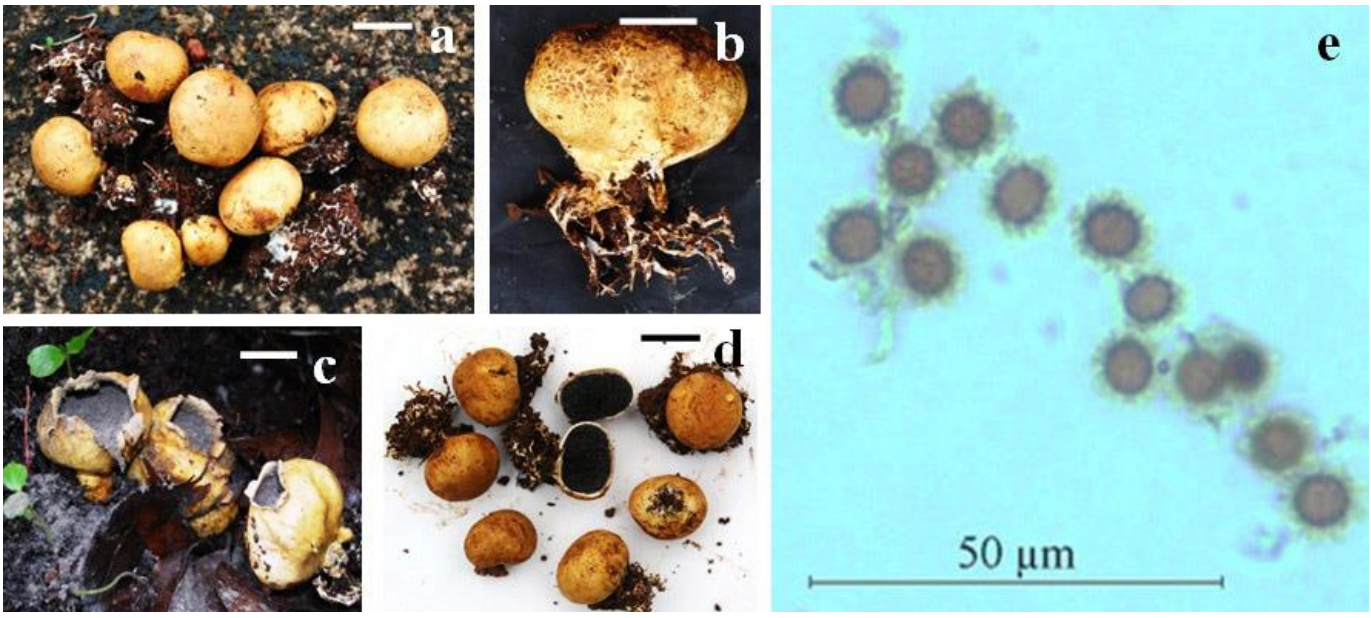

Figure 1. A group of immature basidiocarps of *Scleroderma areolatum* (a), matured sub-spherical basidiocarp with dense rhizomorphs (b), ruptured basidiocarps (c and d) and spiny basidiospores (e) (Scale bar: a-d, 20 mm; e, 50 µm).

***Scleroderma bovista* Fr., *Syst. Mycol. (Lundae) 3*, 48 (1829) (Fig. 2).**

Basidiocarp: Small to medium, greyish-brown or pale-brown, scaly, sub-spherical, 13-43 × 15-48 mm (n=8). Dispersed in small troops, caespitose, annual, particolous, infrequent, odour and taste not distinctive. At first, small epigeous studs develop into sub-spherical structures bearing greyish-brown or pale-brown peridium with dark scales and are attached to the soil by a few non-crowdy rhizomorphs. At maturity, the fruit body bulges sub-spherically to irregularly pear-shaped bearing thin, tough, leathery

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exoperidium covered with rough, dark-brown scales leaving dotted and netted patterns. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure releasing snuff-brown or pale-green powdery gleba with thin, pale inner layers of endoperidium.

Basidiospores: Globose with chocolate tinge, 10-15 µm (n=25), reticulate with curved spines.

Habitat and distribution: Sparsely distributed and associated with grasses and weeds in an abandoned paddy fields B'Shettigeri, Virajpet, Kodagu (Karnataka) India (ScboVi-WGMRF), July 15, 2012, Namera C. Karun.

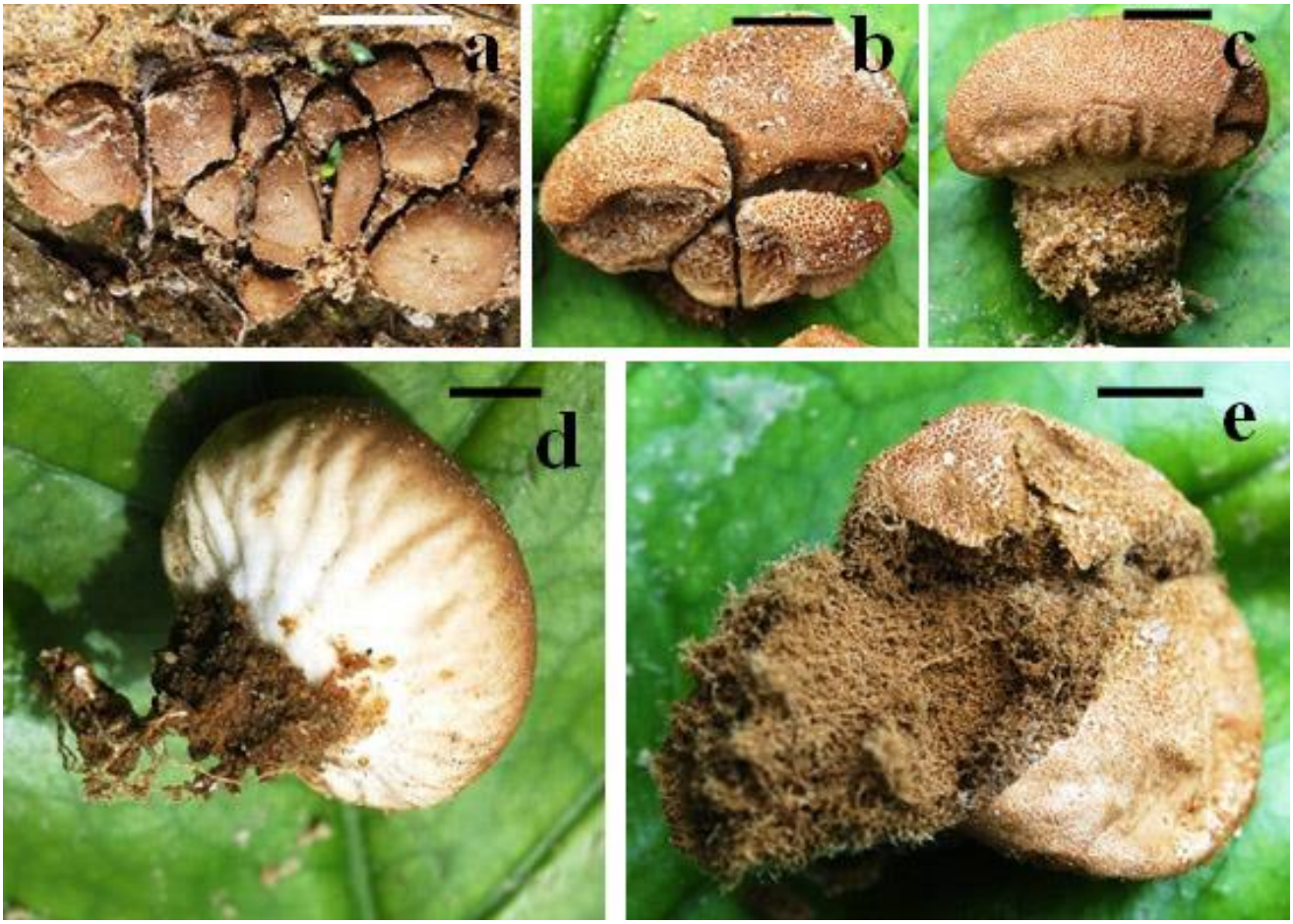

Figure 2. A bunch of immature and mature basidiocarps of *Scleroderma bovista* (a), close-up view of basidiocarps (b), basidiocarp with rhizomorphs (c and d) and ruptured basidiocarp (e) (Scale bar: 20 mm).

***Scleroderma cepa* Pers., *Syn. Meth. Fung. (Göttingen), 1,* 155 (1801) (Fig. 3).**

Basidiocarp: Medium to large, yellowish-brown, scaly to leathery, sub-spherical, 21-30 × 24-87 mm (n=9). Solitary or in small troops, caespitose, annual, particolous to humicolous, infrequent, fishy odour and taste not distinctive. At first, small epigeous studs develop into irregularly sub-spherical structures bearing brownish-orange, scaly to leathery peridium and attached to the soil by a few non-crowdy mycelial cords. At maturity, the fruit body bulges sub-spherically bearing thick, smooth, tough to leathery, yellowish-brown exoperidium with dents all over (scales are removed by heavy showers or autodigest). On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure showing pale-brown powdery gleba with thick dark-yellow inner layers of endoperidium curling outward.

Basidia and basidiospores: Basidia hyaline, 16-26 × 25-35 µm (n=25) with 4 strigmata, basidiospores spherical, yellowish-brown, 7-12 µm (n=25).

Habitat and distribution: Gregarious, ectomycorrhizal with *Memecylon umbellatum* in Makutta reserve forest, Perambadi, Virajpet, Kodagu (Karnataka), India (SccePe-WGMRF), July 01, 2012, Namera C. Karun.

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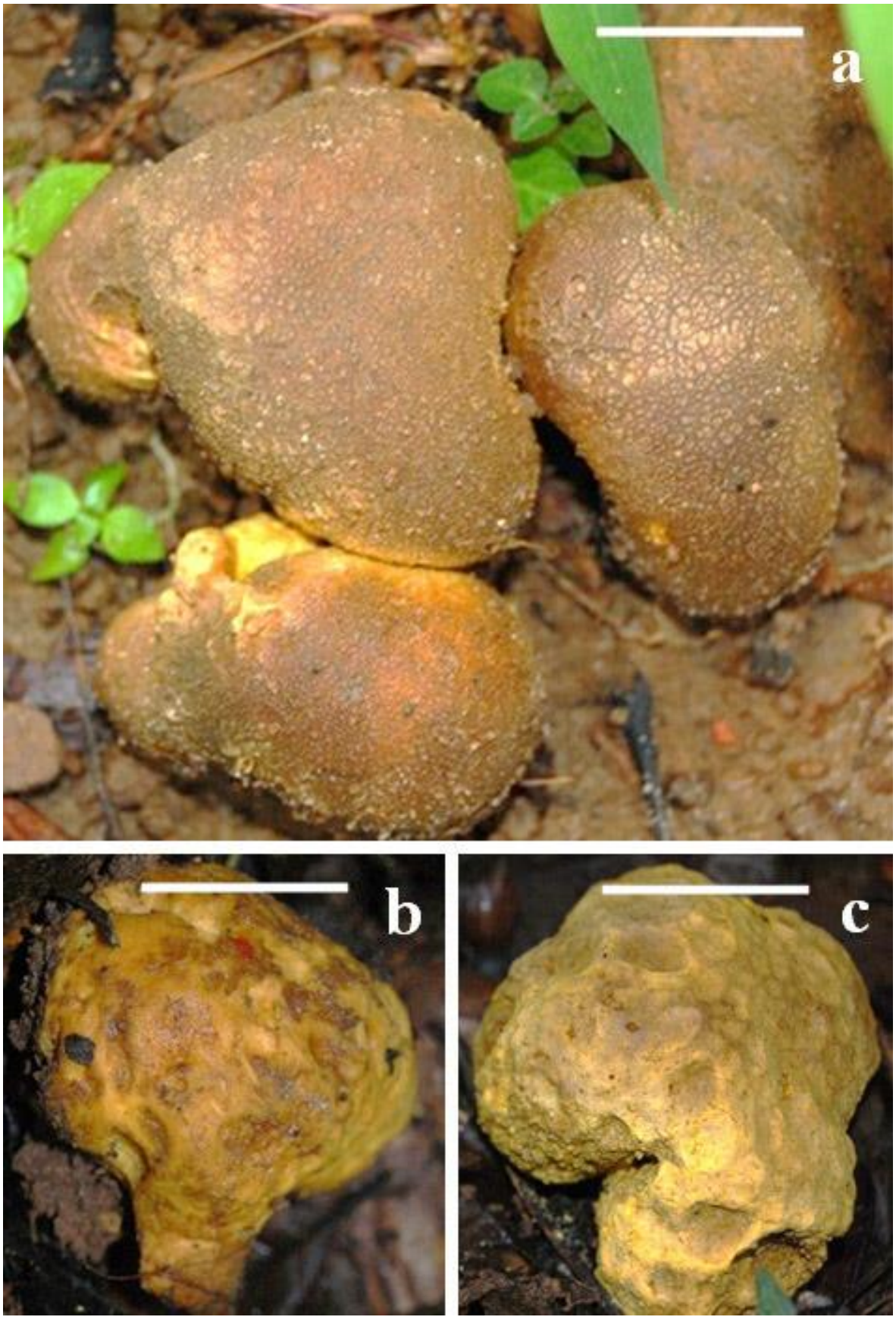

Figure 3. A bunch of matured basidipcarps of *Scleroderma cepa* (a) and surface view of sub-spherical basidiocarps (b and c) (Scale bar: 20 mm).

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***Scleroderma citrinum* Pers., *Syn. Meth. Fung. (Göttingen), 1,* 153 (1801) (Fig. 4).**

Basidiocarp: Medium to large, yellowish-brown, sub-spherical, hard, coarsely scaly 45-75 × 51-79 mm (n=7). Solitary or in small troops, annual, particolous to humicolous, rare, odour almond-like, taste excellent, edible when young. At first, small partly hypogeous studs develop into sub-spherical structures bearing yellowish-brown peridium decorated with coarse scales, attached to the soil or humans by a few non-crowdy mycelial cords. At maturity, the fruit body bulges sub-spherically bearing thick, tough, leathery exoperidium covered with brown cracked pyramidal warts with coarse scales. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure showing the purple-black or brownish-black powdery gleba and thick creamish inner layers of endoperidium curl outward.

Basidia and basidiospores: Basidia hyaline, pyriform, 8-11 × 15-31 µm with 4 sterigmata (n=25), basidiospores yellowish-brown, spherical, spiny 9-13 µm (n=25).

Habitat and distribution: Ectomycorrhizal with *Dysoxylum binectariferum* sacred grooves of Kottoli and *Artocarpus heterophyllus* in the scrub jungle in association with *Gnetum ula*, B'Shettigeri Virajpet, Kodagu (Karnataka), India (ScciBS-WGMRF), June 01, 2012, Namera C. Karun.

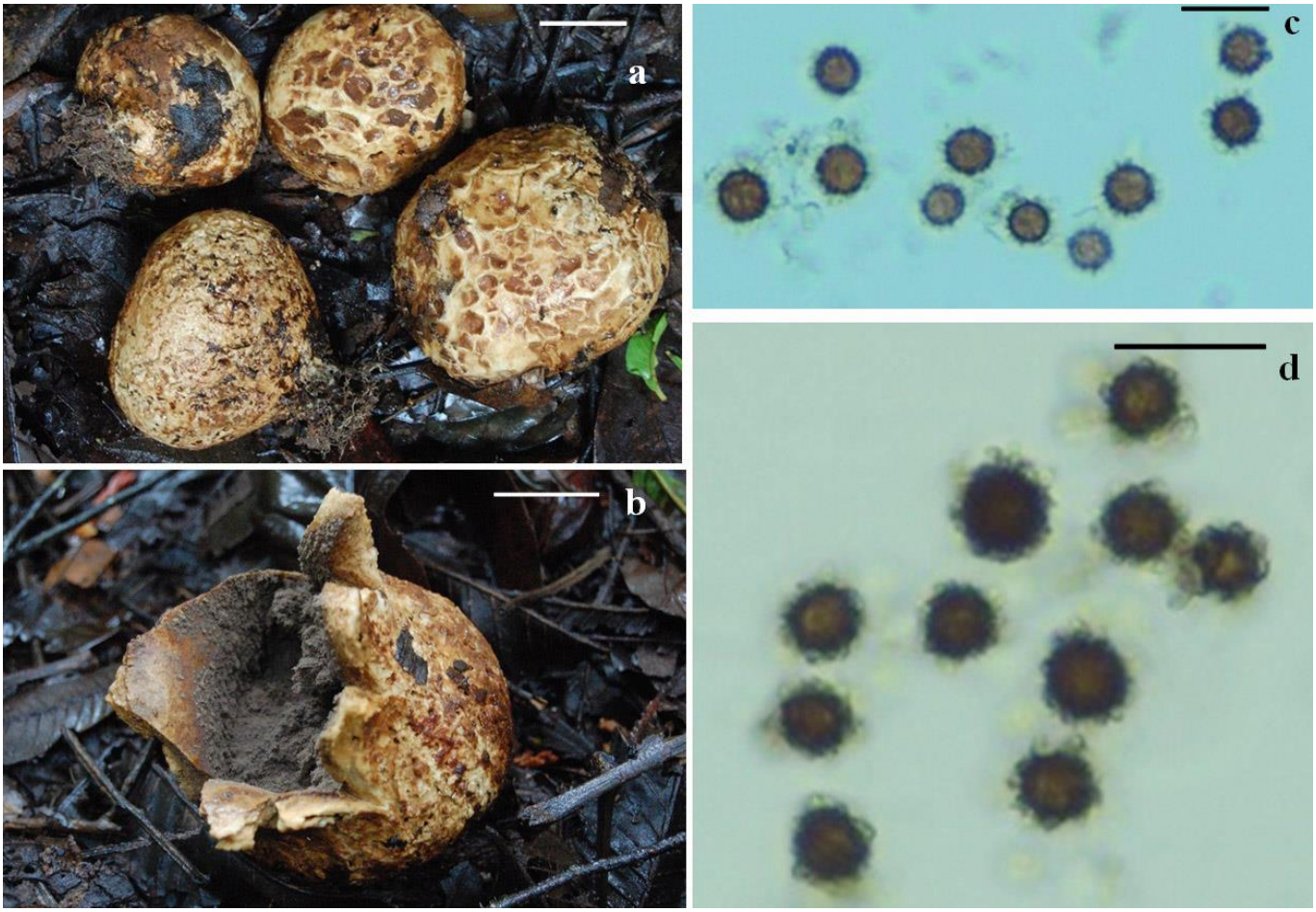

Figure 4. A group of basidiocarps of *Scleroderma citrinum* showing peridial warts (a), ruptured basidiocarp (b) and spiny basidiospores (c and d) (Scale bar: a and b, 20 mm; c and d, 20 µm).

***Scleroderma dictyosporum* Pat., *Bull. Soc. Mycol. Fr. 12,* 135 (1896) (Fig. 5)**

Basidiocarp: Medium to large, orange-brown, smooth, soft or spongy, sub-spherical structure associated with termite mound with a few thin mycelial strands, 40-86 × 45-90 mm (n=6). Solitary or in small troops, annual, lignicolous to humicolous to coprophilous, rare, odour almond-like, taste excellent, edible when young. At first, small partly hypogeous to epigeous studs develop into sub-spherical structures bearing smooth, soft, orange-brown or cinnamon-brown peridium attached to the termite mound in the aerial part of an endangered gymnosperm *Gnetum ula* by a few non-crowdy mycelial cords. At maturity, the fruit body bulges sub-

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spherically bearing thick, smooth to tough, spongy exoperidium. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure revealing the purple-black powdery gleba and thick creamish inner layers of endoperidium curl outward.

Basidiospores: Spherical, dark-brown or purple-black, smooth surface, 7-9 µm (n=25).

Habitat and distribution: Ectomycorrhizal with *Gnetum ula* associated with a termite mound and also with *Memecylon umbellatum*, in a sacred groove, Kottoli, Virajpet, Kodagu (Karnataka), India (ScdiKot-WGMRF), June 30, 2012, Namera C. Karun.

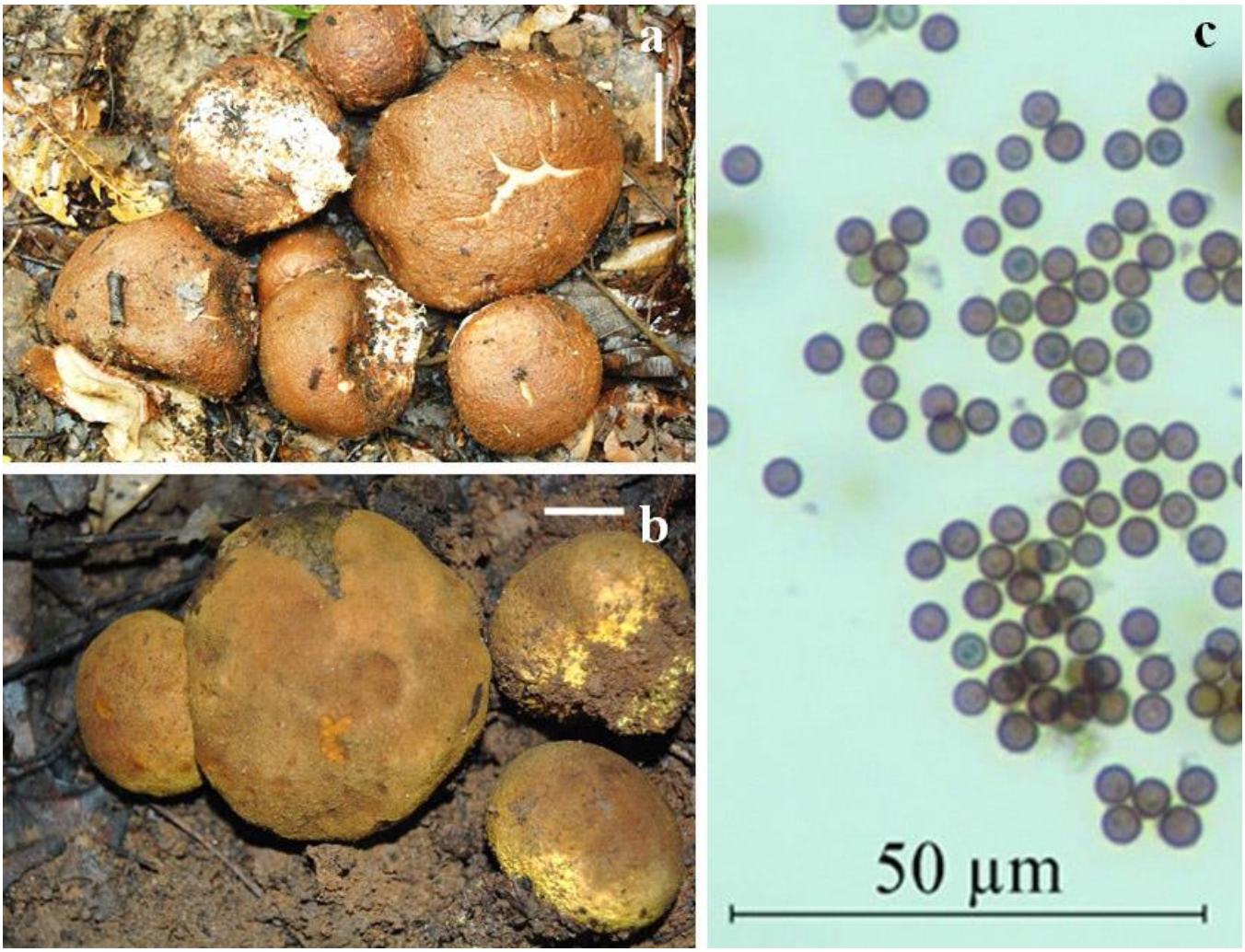

Figure 5. A group of basidiocarps of *Scleroderma dictyosporum* (a and b) and smooth basidiospores (c) (Scale bar: a and b, 20 mm; c, 50 µm).

***Scleroderma polyrhizum* (J.F. Gmel.) Pers., *Syn. Meth. Fung. (Göttingen), 1,* 156 (1801) (Fig. 6).**

Basidiocarp: Medium to large, yellowish, smooth to leathery, globose 55-105 mm (n=9). Solitary or in small troops, annual, particolous to humicolous, rare, odour almond-like, taste excellent, edible when young. At first, small partly hypogeous to epigeous studs develop into a sub-spherical structure bearing smooth, soft creamish-yellowish peridium attached to soil or humans by a few non-crowdy mycelial cords. At maturity, the fruit body bulges sub-spherically bearing thick, tough, smooth, pale yellowish exoperidium finely grooved and ridged and pored throughout. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure showing the violet-grey powdery gleba and thick darker yellow inner layers of endoperidium curls outward.

Basidiospores: Spherical, sub-reticulated, spiny, 7-12 µm (n=25).

Habitat and distribution: Ectomycorrhizal with *Memecylon umbellatum* in association with *Gnetum ula* in the forests of B'Shettigeri, Virajpet, Kodagu (Karnataka), India (ScpoBS-WGMRF), July 12, 2012, Namera C. Karun.

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Figure 6. A pair of immature basidiocarps of *Scleroderma polyrhizum* (a), mature basidiocarp with the grooved surface (b), spent basidiocarp (c) and opened basidiocarps (d) (Scale bar, a-d, 20 mm).

***Scleroderma texense* Berk. *London J. Bot. 4,* 308 (1845) (Fig. 7).**

Basidiocarp: Medium to large with greyish-brown scales, sub-spherical 24-46 × 38-58 mm (n=10). Solitary or in small troops, annual, particolous to humicolous, infrequent, odour and taste not distinctive. At first, small epigeous studs develop into irregularly sub-spherical structures bearing greyish-brown, scaly to leathery peridium attached soil by a few non-crowdy mycelial cords. At maturity, the fruit body bulges sub-spherically bearing thick, scaly, tough to leathery, yellowish exoperidium with cracked greyish brown scales rolled out all over the peridium. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure revealing the violaceous-brown or greyish powdery gleba and thick dark-yellow inner layers of endoperidium curled outward.

Basidia and basidiospores: Basidia hyaline, sub-globose, 11-16 × 38-52 µm (n=25), 4 sterigmata, basidiospores 7.5-10.5 µm (n=25), yellowish-brown with dense spines.

Habitat and distribution: Sparse occurrence in the forests of Bisle Ghat, Sakaleshpur (Karnataka), India (ScteBG-WGMRF), November 28, 2019, S. Mahadevakumar.

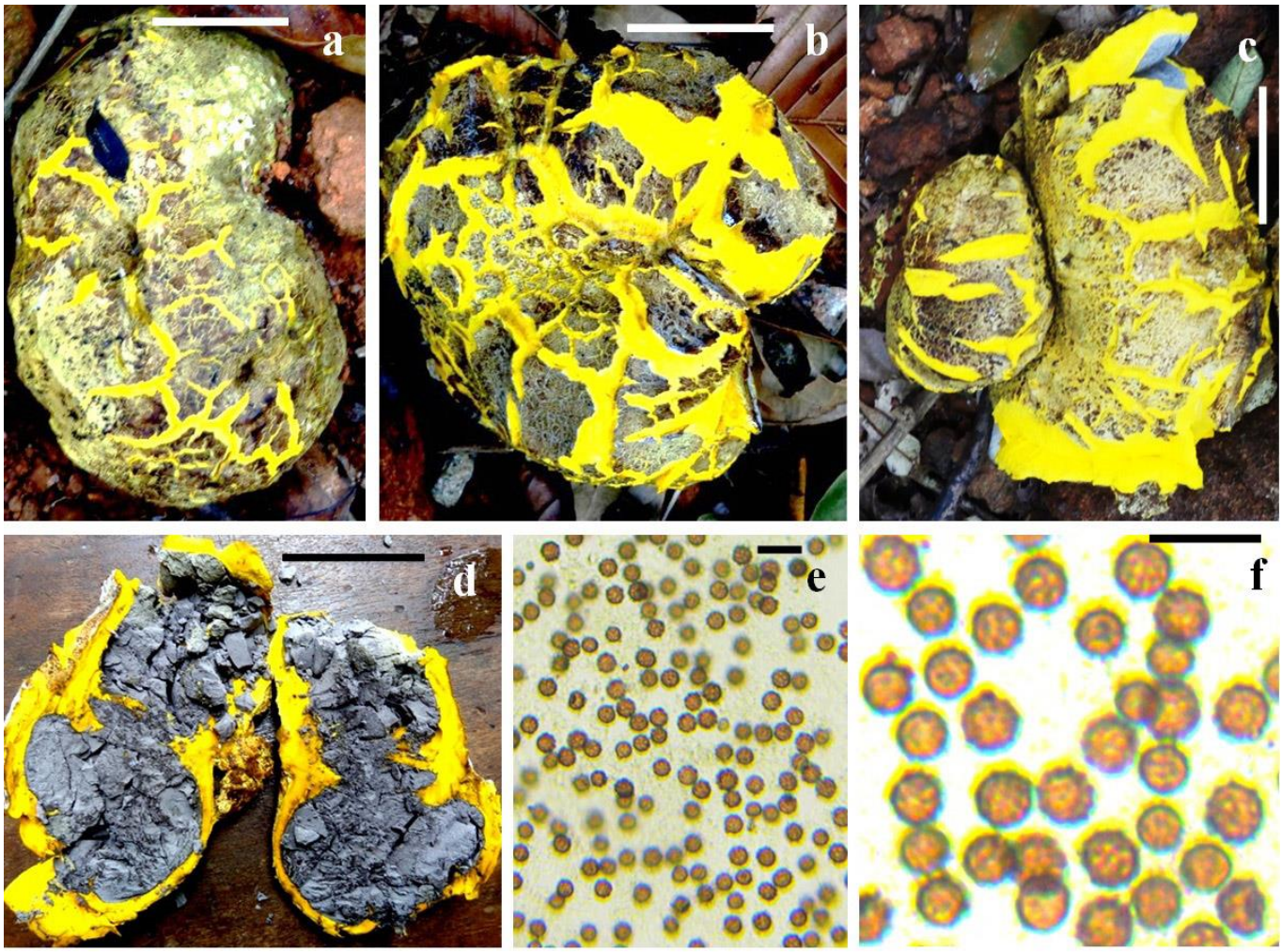

Figure 7. Immature and mature basidiocarps of *Scleroderma texense* (a-c), opened basidiocarp (d) and spiny basidiospores (e and f) (Scale bar: a-d, 20 mm; e and f, 20 μm).

***Scleroderma verrucosum* (Bull) Pers., *Syn. Meth. Fung. (Göttingen), 1*, 154 (1801) (Fig. 8).**

Basidiocarp: Small to medium, with long pseudostipe, sub-globose, orange-brown, scaly, fertile head surmounting on a thick-ribbed and grooved stem 22-41 × 38-78 mm (n=9). Occur in small troops, annual, particolous to humicolous, infrequent, taste and odour not distinctive. At first, small partly hypogeous to epigeous studs develop into spherical or hammer head-like structures bearing orange-brown to ochre-brown, scaly peridium tapering into a thick cylindrical stipe attached to soil or humus by a dense mass of rhizomorphs. At maturity, the sporocarp bulges bearing a spherical, thin, leathery exoperidium decorated with small brownish scales and further narrow down into a hard, thick-ribbed, grooved stem-like stipe broad at the base. On aging, the fruit body ruptures at the apex, cracks open by an irregular fissure revealing the coffee-brown or olive-brown powdery gleba and hard thin pale inner layers of endoperidium.

Basidiospores: Spherical olive-brown, spiny basidiospores, 9-14 μm (n=25).

Habitat and distribution: Ectomycorrhizal with *Canarium strictum* in coffee agroforest, Chickpet, Virajpet, Kodagu, and *Vateria indica* in the Arboretum, Mangalore University campus, Konaje, Mangalore (Karnataka), India (ScveKon-WGMRF), June 30, 2012, Namera C. Karun.

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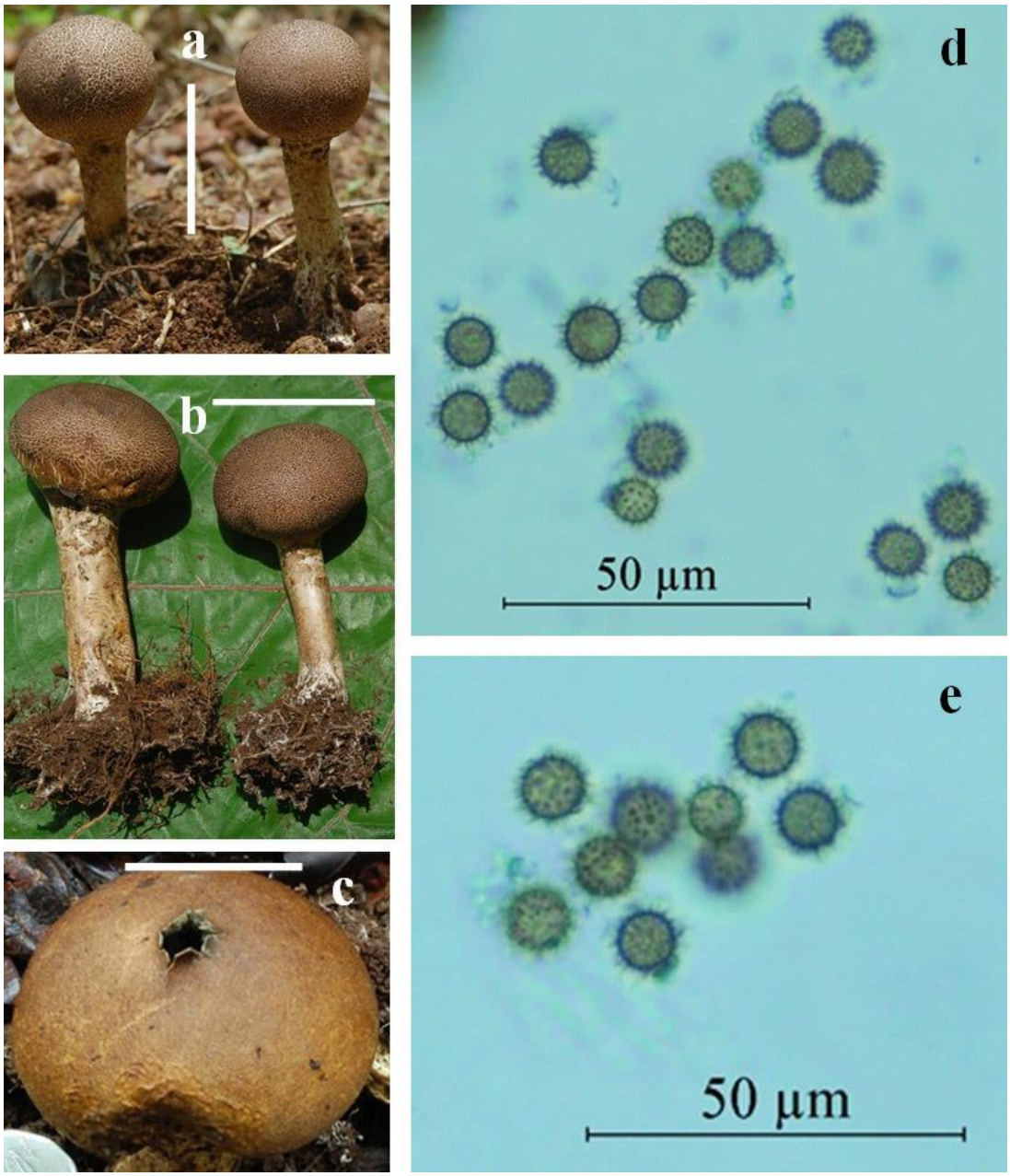

Figure 8. Immature basidiocarps of *Scleroderma verrucosum* (a), maturing basidiocarps with dense rhizomorphs (b), ruptured basidiocarp (c) and spiny basidiospores (d and e) (Scale bar: a-c, 20 mm; d and e, 50 µm).

4. DISCUSSION

Scleroderma occupied a prominent position among the EM fungi owing to their wide distribution in natural as well as ruderal habitats with a broad host range (up to 40 spp.) (Zhang et al., 2020). In the Indian subcontinent, reports on 13 species of *Scleroderma* reveals their association with up to 14 native (11 genera: *Artocarpus, Canarium, Dysoxylum, Gnetum, Holigarna, Macaranga, Memecylon, Pinus, Schefflera, Shorea* and *Vateria*) and eight exotic (4 genera: *Acacia, Casuarina, Eucalyptus* and *Grevellea*) tree species (Table 1). *Scleroderma* spp. found in this study occurred in different ecosystems (forests, sacred groves, arboretum, paddy fields and termite mounds). *Scleroderma citrinum* has associated with the highest number of tree species (15 spp.) followed by *S. verrucosum* (8 spp.), *S. areolatum* and *S. bovista* (6 spp. each). The current study added seven native (*Artocarpus heterophyllus, Canarium strictum, Dysoxylum binectariferum, Gnetum ula, Macaranga peltata, Memecylon umbellatum* and *Vateria indica*) and two exotic (*Acacia auriculiformis* and *A. mangium*) tree species as hosts of *Scleroderma*. Among the eight species found in the current study, based on ethnic knowledge, three species are edible (*S. citrinum, S. dictyosporum* and *S. polyrhizum*). Such edibility will be confirmed by the tribals in Kodagu of the Western Ghats owing to the growth of *Scleroderma* in association with lianas *Gnetum ula*.

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5. CONCLUSION

The present study provided a description and keys to eight species of *Scleroderma* found in southwest India. It has added seven native and two exotic tree species as ectomycorrhizal with *Scleroderma* spp. A deeper understanding of the distribution of extremophilic *Scleroderma* in different ecosystems, the range of host tree species and their applications (mutualism, edibility and bioactive potential) in southwest India will shed light on their future utilization in forestry, nutrition and health prospects. Special emphasis is warranted to exploit the benefits of *Scleroderma* spp. in the rehabilitation of forests and plantations.

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Authors' contributions

All authors contributed equally.

Ethical approval

Eight species of *Scleroderma* were identified in the study from southwest India. The ethical guidelines are followed in the study for species observation & identification.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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