

Article

Morphology and molecular phylogeny reveal five new species of *Laccaria* (Hydnangiaceae, Agaricales) from southern China

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Abstract: The genus *Laccaria* is a kind of cosmopolitan and ecologically important fungal group. Members can form ectomycorrhizal associations with numerous trees, and some species are common edible fungi in local markets. Although some new species from China are recently published, the species diversity of *Laccaria* is still unclear in China. In this study, some samples of *Laccaria* were collected from southern China, morphological characteristics and phylogenetic analyses based on the multilocus dataset of ITS-LSU-*tef1-rpb2* confirmed five new species. *Laccaria miniata*, *L. nanlingensis* and *L. neovinaceoavellanea* were collected from subtropical broad-leaved forests, and *L. rufobrunnea* and *L. umbilicata* were collected from subtropical mixed forests of southwest China. Full descriptions, illustrations, comparison with similar species and phylogenetic analysis are provided.

Citation: Zhang, M.; Gao, X.-L.; Mu, L.-Q. and Deng, W.-Q. Morphology and molecular phylogeny reveal five new species of *Laccaria* (Hydnangiaceae, Agaricales) from southern China. *J. Fungi* **2023**, *8*, x. <https://doi.org/10.3390/xxxxx>

Academic Editor(s):

Received:

Accepted:

Published: date

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Keywords: fungal diversity, molecular systematics, morphology, novel taxa, taxonomy

1. Introduction

Laccaria Berk. & Broome (Agaricales, Hydnangiaceae) is an importance fungal group with high ecological and economical values. Species in *Laccaria* widely reported from every continent except Antarctica, and can form ectomycorrhizal (ECM) relationships with a wide range of trees, such as Betulaceae, Fagaceae, Myrtaceae, Pinaceae and Salicaceae [1–2]. *Laccaria* is considered as a model genus for understanding ectomycorrhizal (ECM) ecology and evolution, some species are reported that can act as pioneer species and can be frequently found in recently disturbed sites and young forest stands, play important roles in primary and secondary succession, and are useful for ecological protection and restoration [1,3–11]. In addition, some *Laccaria* species are edible and common in local markets [12], for example, *L. aurantia*, *L. bicolor*, *L. moshuijun* and *L. vinaceoavellanea* are commercial mushrooms in Sichuan Province, China [13].

In general, *Laccaria* members are mainly characterized by the collybioid to omphaloid basidiocarp; the convex to plane or umbilicate, and usually dry pileus; thick, waxy, sinuate to subdecurrent, often widely spaced lamellae; echinulate basidiospores; the hymenium typically devoid of pleurocystidia; and the clamped hyphae [8,14–18]. It is not difficult to recognize the genus *Laccaria* due to the distinct morphological characters, however, infrageneric species identification is difficult in many instances due to the overlapping morphological features [18–20]. Recent studies show that molecular data is helpful in species identification of this genus [1–2,17–18,20–22]. The discovery of *Laccaria* new species is rapidly increasing in recent years [23]. To date, about 110 species

have been reported worldwide [2,23], but most of them were originally described from Europe and North America [1,8,20,24–29]. In China, 25 *Laccaria* species have been reported, including 17 species originally reported from China [1–2,17,22,30–34].

During the survey of macrofungi in southern and southwestern China, some distinct *Laccaria* samples were collected. Based on morphological feature studies and multilocus phylogenetic analyses, five species **are** confirmed as new to science. Therefore, they **are** formally introduced herein, containing the full morphological descriptions, color photographs, line drawings, comparison with similar species, and a phylogenetic tree to show their placement and uniqueness.

2. Materials and Methods

2.1. Morphological Studies

Photographs of fresh basidiocarps were taken in the field. Specimens were dried and deposited in the Fungarium of Guangdong Institute of Microbiology (GDGM). Descriptions of macro-morphological characters and habitats were obtained from photographs and field notes. Color codes follow Kornerup and Wanscher [35]. Microscopic observations were carried out on tissue sections stained with 5% KOH and 1% aqueous Congo red under a light microscope (Olympus BX51, Tokyo) with magnification up to 1000×. For basidiospore descriptions, **the abbreviation [n/m/p] denotes n spores measured from m basidiomata of p collections**; the notation (a–)b–c(–d) describes basidiospore dimensions, where the range b–c represented 90% or more of the measured values and ‘a’ and ‘d’ were the extreme values; ‘av.’ represents the mean range of basidiospore length × width. Q referred to the length/width ratio of an individual basidiospore and Q_m referred to the average Q value of all basidiospores ± sample standard deviation. All microstructure line-drawings were made based on rehydrated materials.

The scanning electron microscopy (SEM) was applied to observe the surface of basidiospores. Lamellar fragments of the dried specimens were fastened to aluminum stubs and coated gold palladium. Then, they were observed using a field emission scanning electron microscopy (Thermo Scientific Apreo 2S HiVac, Brno, Czech Republic) with an accelerating rate of 5 kV.

2.2. DNA Extraction, PCR Amplification and Sequencing

Genomic DNA samples were extracted from voucher specimens using the Sangon Fungus Genomic DNA Extraction kit (Sangon Biotech Co. Ltd., Shanghai, China), according to the manufacturer’s instructions. Primer pairs ITS1F/ITS4 [36], LR0R/LR7 [37], EF1-983F/ EF1-1967R[38] and bRPB2-6F/bRPB2-7.1R [39] were used to amplify ITS, LSU, *tef1* and *rpb2*, respectively. PCR reactions was performed in a total volume of 25 µl containing 0.5 µl template DNA, 11 µl sterile deionized water, 0.5 µl of each primer and 12.5 µl 2× PCR mix (DreamTaq™ Green PCR Master Mix, Fermentas). Amplification reactions were performed in a Tprofessional Standard thermocycler (Biometra, Göttingen, Germany) under the following conditions: 95 °C for 4 min; then 35 cycles of denaturation at 94 °C for 60 s, annealing at 53 °C (ITS, LSU) /50°C (*tef1*) /52°C (*rpb2*) for 60 s and extension at 72 °C for 60 s; with a final extension at 72 °C for 8 min. The PCR products were electrophoresed on 1% agarose gels and then send for sequencing on an ABI Prism® 3730 Genetic Analyzer (PE Applied Biosystems, Foster, CA, USA) at the Beijing Genomic Institute (BGI) using the same PCR primers. The raw sequences were assembled and checked with SeqMan implemented in Lasergene v7.1 (DNASTAR Inc., USA). The newly generated sequences in this study were submitted to GenBank.

2.3. Phylogenetic Analyses

Sequences generated in this study and those downloaded from GenBank were combined and used for phylogenetic reconstruction. Sequence matrixs of ITS, LSU, *tef1* and *rpb2* were aligned separately with software MAFFT v7 using the E-INS-i strategy [40]

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and manually adjusted in MEGA 6 [41]. The ambiguous aligned regions and introns of the two protein-coding genes of *tef1* and *rpb2* were retained in the final analyses. Phylogenetic analyses were performed in PhyloSuite [42]. Maximum likelihood phylogenies were inferred using IQ-TREE [43] under the Edge-linked partition model (TPM2u+F+R4 for ITS and *rpb2*, TN+F+R3 for LSU, and TIM2e+G4 for *tef1*) for 5000 ultrafast bootstraps [44], as well as the Shimodaira-Hasegawa-like approximate likelihood-ratio test [45]. Bayesian Inference (BI) phylogenies were inferred using MrBayes 3.2.6 [46], the best models of the multilocus datasets were searched via PartitionFinder 2 [47] for each locus, i.e., GTR+F+I+G4 for ITS and *tef1*, K80 + I + G for LSU, and SYM + I + G4 for *rpb2*. BI analysis using 4 chains were conducted by setting generations to 200000 and stoprul command with the value of stopval set to 0.01, trees were sampled every 1000 generations, the initial 25% of sampled data were discarded as burn-in and posterior probabilities (PP) were then calculated from the posterior distribution of the retained Bayesian trees. The phylogenetic trees were visualised in FigTree v1.4.23.

3. Results

3.1. Molecular Phylogeny

The combined dataset (ITS+LSU+*tef1*+*rpb2*) used for phylogenetic analyses consisted of 380 sequences from 185 collections, including 37 sequences (11 for ITS, 11 for nrLSU, 8 for *tef1* and 7 for *rpb2*) newly generated in the present study. The final alignment contained 2802 characters (704, 889, 614 and 595 for ITS, LSU, *tef1* and *rpb2*, respectively). *Mythicomycetes corneipes* (Fr.) Redhead & A.H. Sm. was selected as the outgroup based on recent studies [2,33]. The phylogeny tree derived from the ML analysis with both PP and BS support values, is shown in Figure 1. Phylogenetic analyses showed that *Laccaria* is a well-supported monophyletic group, specimens collected from China in current study formed five highly supported monophyletic lineages within the genus. Three new species, *L. neovinaceoavellanea*, *L. rufobrunnea* and *L. umbilicata* clustered together with *L. diospyricola*, *L. fengkaiensis*, *L. prave*, *L. vinaceoavellanea*, *L. violaceotincta* and *L. yunnanensis*, and formed a well-supported subclade. *Laccaria miniata* showed close relationship with *L. glabripes*, *L. paraphysata* and *L. ohiensis*. Two specimens named *L. nanlingensis* formed a monophyletic clade.

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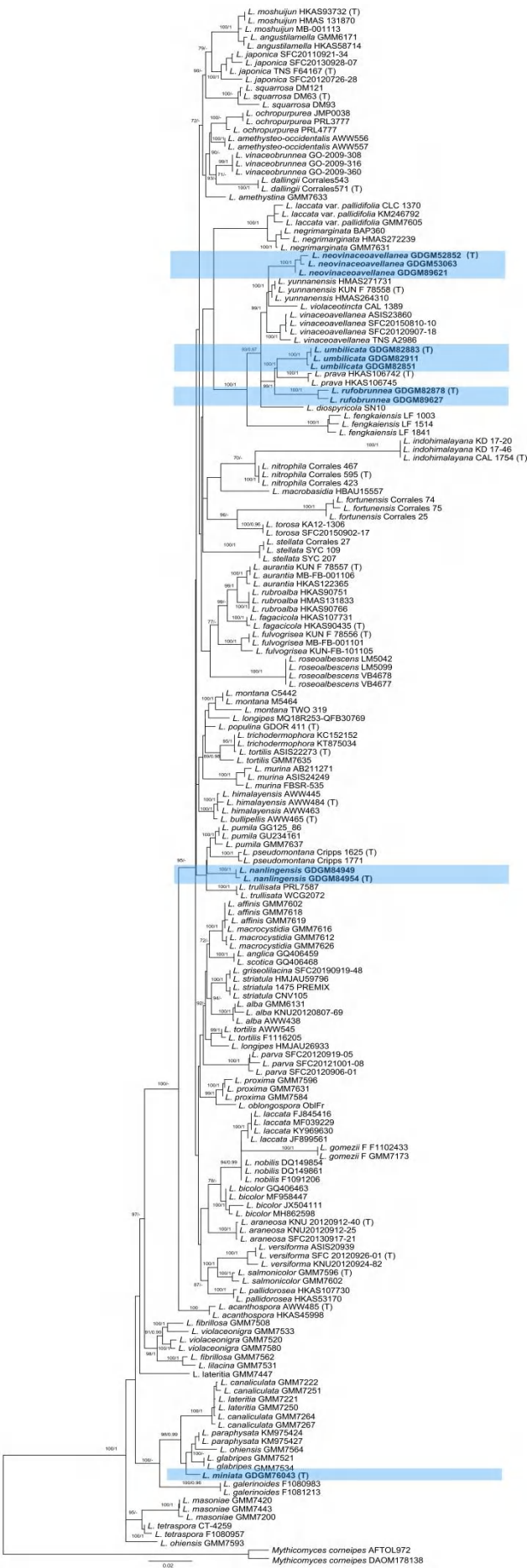


Figure 1. Maximum-Likelihood phylogenetic tree of *Laccaria* generated from the ITS-LSU-*tef1-rpb2* dataset. Bootstrap values (ML≥70%) and Bayesian posterior probabilities (BPP≥0.95) are shown around branches. Sequences from type specimens are marked with (T), and the new species is indicated in bold.

3.2. Taxonomy



Figure 2. Fresh basidiomata of five new species of *Laccaria*. (a–b) *L. miniata* (Type, GDGM76043). (c–d) *L. nanglingensis* (c. GDGM84949; d. Type, GDGM84954). (e–f) *L. neovinaceoavellanea* (e. Type, GDGM52852; f. GDGM89621). (g–h) *L. rufobrunnea* (g. Type, GDGM82787, h. GDGM89627). (i–j) *L. umbilicata* (i. Type GDGM82911, i. GDGM82851). Bars: (a–b) = 20 mm, (c–j) = 50 mm.

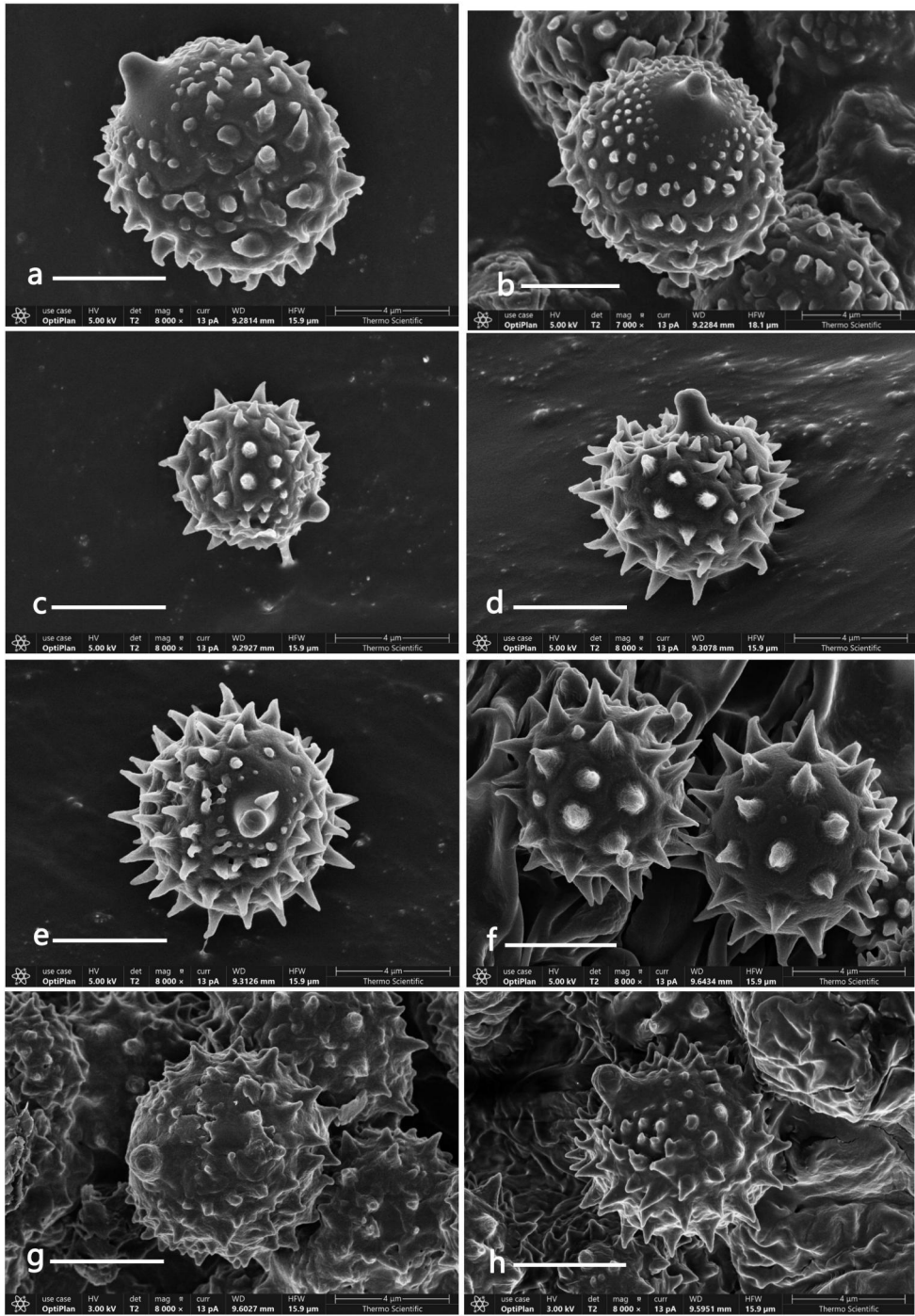


Figure 3. Basidiospores of the five new *Laccaria* species under SEM. (a–b) *L. miniata* (GDGM76043). (c) *L. nanglingensis* (GDGM84954). (d–e) *L. neovinaceoavellanea* (GDGM52852). (f) *L. rufobrunnea* (GDGM82787). (g–h) *L. umbilicata* (GDGM82911). Bars: (a–h) = 4 μm.

Laccaria miniata Ming Zhang, sp. nov.; Figures 2a–b, 3a–b, 4
Fungal Name: FN571672

Diagnosis—*Laccaria miniata* is distinguished by its small red basidiocarps with relatively longer stipites, longer basidia usually with 2 sterigmata (up to 11 μm long),

globose to subglobose basidiospores, and the absence of cheilocystidia and caulocystidia.

Etymology—‘*miniata*’ refers to the red basidiocarp.

Type—CHINA. Guangdong Province, Guangzhou City, Huadu District, Hongxiuquan Reservoir, elev. 150 m, in a broad-leaved forest mainly dominated by Fagaceae trees, [23°27′ N, 113°12′ E, elev. 100 m](#), 14 March 2019, Ming Zhang (GDGM76043), [GenBank: ITS = OR689440, 28S = OR785476](#).

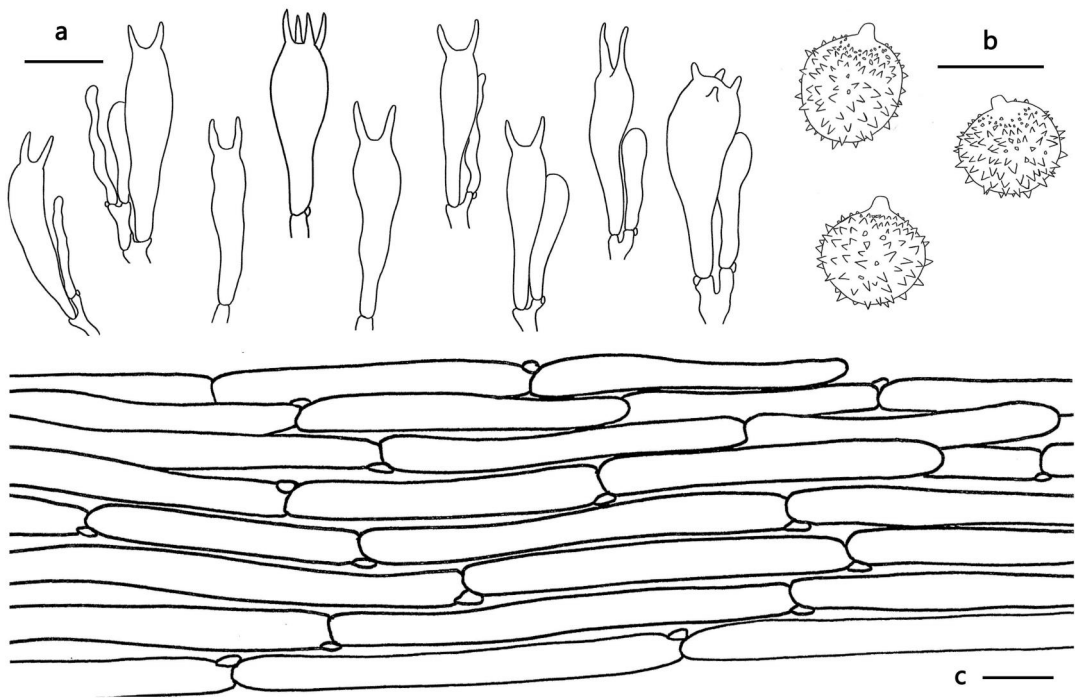


Figure 4. Microscopic features of *Laccaria miniata* (GDGM76043, Holotype). (a) Basidia. (b) Basidiospores (c) Pileipellis. Bars: (a,c) = 20 μ m, (b) = 10 μ m

Basidiocarps small, [omphalinoid](#). Pileus 10–15 mm broad, convex to applanate, hygrophanous, glabrous to subtomtose, red (9A7–11A7), with a deep red (10C8–11C8) center, gradually fading to reddish orange to yellowish red (7A7–8A7) toward margin; margin entire, translucent-striate; context pale red (9A3–11A3). Lamellae sinuate to adnate, distant, pastel red (8A4–10A4), pastel pink (11A4) to red (9A6); lamellulae attenuate. Stipe 35–60 mm long, 1.5–2 mm thick, subcylindrical, subglabrous to fibrillose, sometimes slightly longitudinally striate, red (9A7–11A7) to deep red (10C8–11C8); basal mycelium white to grayish white (1A1–1A2). Odor and taste unknown.

Basidiospores (excluding ornamentation) [60/3/2] 8–10.5(11) $\times$ 8–10 μ m, av. 9.37 $\pm$ 0.83 $\times$ 8.80 $\pm$ 0.60, Q = 1–1.11, Q_m = 1.06 $\pm$ 0.04, globose to subglobose, hyaline, echinate; spines 0.5–1 μ m long, crowded. Basidia 40–58 $\times$ 8–15 μ m, clavate, hyaline, mostly 2-spored, occasionally 4-spored; sterigmata 6–11 μ m long. Pleurocystidia and cheilocystidia not observed. Pileipellis a cutis, composed of appressed, thin to slightly thick-walled (0.5 μ m) filamentous hyphae 5–15 μ m wide, colorless to slightly brownish. Lamellar trama regular, composed of thin-walled filamentous hyphae 5–12 μ m wide. Stipitipellis composed of appressed, parallel, simply septate, thin-walled, colorless, hyphae 3–15 μ m wide. Caulocystidia lacking. Clamp connections present.

Habitat and distribution—Single, scattered or in groups on soil in subtropical broad-leaved forests dominated by Fagaceae (*Castanopsis fissa*, *C. spp.*) trees. Currently known from southern China.

Notes—*Laccaria miniata* is mainly characterized by its tiny pileus, relatively slender stipe (stipe length 3–5 times that of pileus diameter), and the absence of pleurocystidia

and cheilocystidia. On the base of the morphological features given above, the new species can be placed either in sect. *Laccata* or in sect. *Bisporae* of *Laccaria* [48].

Laccaria pumila Fayod, originally reported from France, is similar to *L. miniata* for having small basidiocarps, however, the former differs by its red brown to orange-brown pileus usually fading to buff, pinkish flesh lamellae, interwoven pileipellis hyphae, larger basidiospores measuring (10)11–16.5(20) × (7.8)10–14.5(16) μm, and the north temperate habitations [49]. *Laccaria laccata* (Scop.) Cooke differs by the relatively larger basidiocarps, broadly elliptical basidiospores (8.5–9.5 × 6.7–8 μm), and the north temperate habitations [50–51]. *Laccaria longipes* G.M. Muell., originally reported from North America, also has long stipes, however, *L. longipes* differs by its larger basidiocarp, orange brown to buff pileus, and subglobose to broadly elliptical basidiospores (av. 7.6–7.8 × 6.8–7.2 μm in size) [50].

Phylogentic analysis shows *L. miniata* is close to *L. glabripes* McNabb, *L. ohiensis* (Mont.) Singer and *L. paraphysata* (McNabb) J.A. Cooper. *Laccaria glabripes*, originally reported from New Zealand, differs from *L. miniata* by its flesh pink to reddish brown pileus with a darker center, robust stipe, and shorter 4-spored basidia (32–48 × 7–10.5 μm) [52]; *Laccaria ohiensis*, originally reported from North America, differs by its relatively larger basidiocarp (pileus up to 35–50 mm in diam.), reddish brown to dark reddish brown pileus with finely furfuraceous tomentum on surface, larger basidiospores (9.5–12.5 μm in diam.) and 2-spored basidia (52–53); *L. paraphysata* differs by its relatively larger basidiocarp (pileus up to 35 mm broad), reddish brown to dark reddish brown pileus, irregularly shaped and simple branched paraphyses, and the presenting of cheilocystidia [52]. In addition, *L. paraphysata* currently only known from New Zealand, and grows under native bush and scrub dominated by *Leptospermum* spp. [52].

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Laccaria nanlingensis Ming Zhang, sp. nov.; Figure 2c–d, 3c, 5

Fungal Name: FN571673

Etymology—‘nanlingensis’ refers to the locality of the type species in Nanling National Nature Reserve.

Diagnosis—*Laccaria nanlingensis* is characterized by its relatively larger basidiocarp, orange to brownish red pileus, pale red to grayish red lamellae, small basidiospores (6.5–7.5 × 6–7 μm).

Type—CHINA. Guangdong Province, Shaoguan City, Nanling National Nature Reserve, 24°56′ N, 113°3′ E, elev. 1000 m, 27 March 2021, Ming Zhang (GDGM84954). GenBank: ITS = OR689442, 28S = OR785478, *tef1* = OR826273, *rpb2* = OR835199.

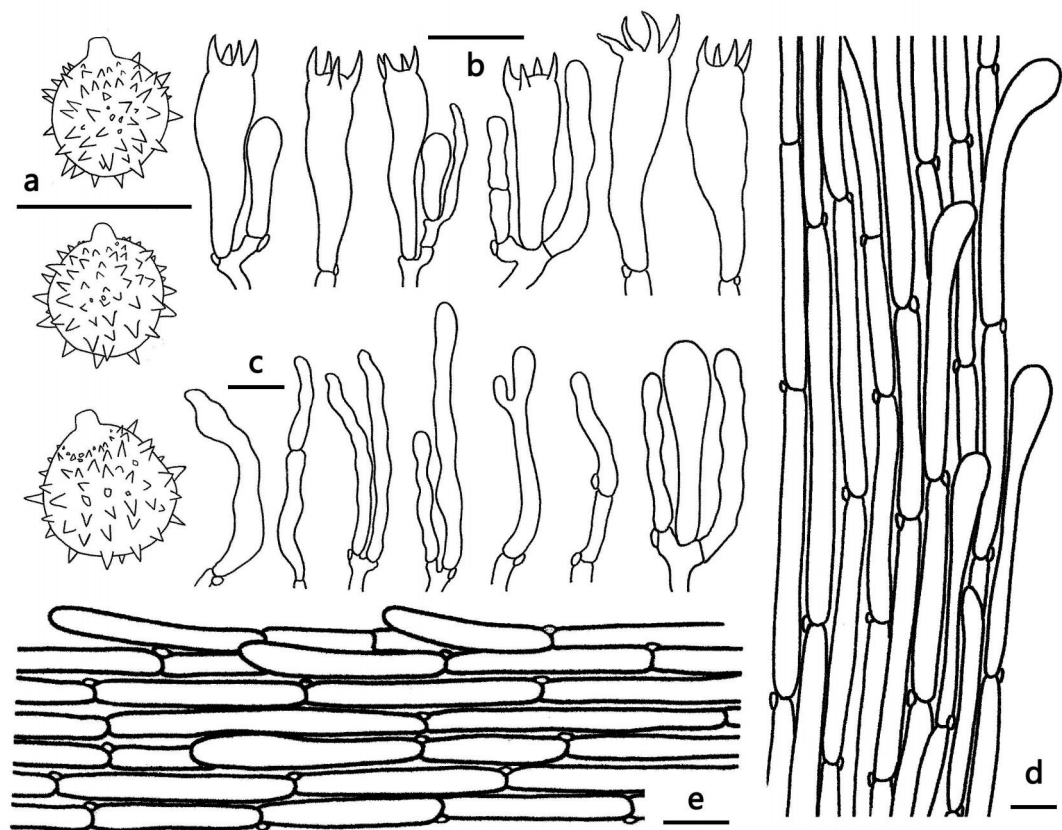


Figure 5. Microscopic features of *Laccaria nanlingensis* (GDGM84954, Holotype). (a) Basidiospores. (b) Basidia. (c) Cheilocystidia. (d) Stipitipellis and caulocystidia. (e) Pileipellis Bars: (a,c,d) = 10 μm ; (b,e) = 20 μm .

Basidiocarps small to medium, omphalinoid. Pileus 30–55 mm broad, convex to appanate, with a shallowly depressed center, dry or hygrophanous, glabrous, orange, reddish orange, orange red, brownish orange to brownish red (5A6–8A6, 6C6–8C6), slightly fading to light orange to pale orange when dry, with obviously radial translucent striate, especially toward margin; margin entire, involute when young, appanate to wavy when old; context pinkish white to purplish white (13A2–14A2). Lamellae sinuate to adnate, distant, concolorous with pileus or darker to pale red to grayish red (9A4–10A4, 9C4–10C4); lamellulae attenuate. Stipe 25–70 mm long, 2–5 mm thick, cylindrical, subglabrous, occasionally slightly longitudinally striate, concolorous with pileus; basal mycelium white. Odor and taste unknown.

Basidiospores (excluding ornamentation) [60/3/2] $6.5\text{--}7.5 \times 6\text{--}7 \mu\text{m}$, av. $6.95 \pm 0.15 \times 6.37 \pm 0.45$, $Q = 1\text{--}1.16$, $Q_m = 1.09 \pm 0.07$, globose to subglobose, hyaline, verrucous, crowded; spines $0.5\text{--}1 \mu\text{m}$ long. Basidia $35\text{--}48 \times 8\text{--}12 \mu\text{m}$, clavate, hyaline, 4-spored; sterigmata $6\text{--}10 \mu\text{m}$ long. Pleurocystidia lacking. Cheilocystidia $40\text{--}60 \times 4\text{--}6 \mu\text{m}$, filamentous to narrowly clavate, thin-walled, colorless and hyaline, abundant. Pileipellis a cutis with repent hyphae, thin to slightly thick-walled ($0.5 \mu\text{m}$) filamentous hyphae $5\text{--}13 \mu\text{m}$ wide, colorless to slightly brownish. Lamellar trama regular, composed of thin-walled filamentous hyphae $5\text{--}10 \mu\text{m}$ wide. Stipitipellis composed of appressed, parallel, simply septate, thin to slightly thick-walled ($0.5 \mu\text{m}$), colorless to yellow-brown hyphae $4\text{--}8 \mu\text{m}$ wide. Caulocystidia $50\text{--}67 \times 7\text{--}9 \mu\text{m}$, clavate, scarce, sometimes subcapitate to irregularly shaped, slightly thick-walled ($0.5 \mu\text{m}$), colorless to yellow-brown, scattered. Clamp connections present.

Habitat and distribution—Single, scattered or in groups on soil in subtropical broad-leaved forests mainly dominated by Fagaceae trees. Currently known from southern China.

Additional specimens examined—China. Guangdong Province, Shaoguan City, Ruyuan County, Nanling National Nature Reserve, [24°56′ N, 113°3′ E](#), elev. 1000 m, 27 March 2017, Ming Zhang (GDGM84949), [GenBank: ITS = OR689441, 28S = OR785477, tef1 = OR826274, rpb2 = OR835198](#).

Notes—*Laccaria fagacicola* Yang-Yang Cui, Qing Cai & Zhu L. Yang, *L. himalayensis* A.W. Wilson & G.M. Muell. and *L. yunnanensis* Popa, Rexer, Donges, Zhu L. Yang & G. Kost are similar to *L. nanlingensis*. However, *L. fagacicola* differs from *L. nanlingensis* by its brownish orange to brownish pileus, relatively larger basidiospores ($7\text{--}9 \times 6.5\text{--}8 \mu\text{m}$) and basidia ($45\text{--}60 \times 9\text{--}12 \mu\text{m}$) [2]. *Laccaria himalayensis* differs by its larger basidiospores (av. $8.1\text{--}9.0 \mu\text{m}$), and growing in mixed temperate alpine conifer forest with *Abies*, *Acer*, *Larix*, *Pinus* and *Salix* [1]. *Laccaria yunnanensis* differs in having larger basidiocarps, brownish to flesh-colored pileus, flesh-colored lamellae, relatively larger basidiospores ($8\text{--}9 \times 8\text{--}10 \mu\text{m}$), and the presence of pleurocystidia ($55\text{--}65 \times 15\text{--}25 \mu\text{m}$) [22]. In addition, *L. torosa* H.J. Cho & Y.W. Lim also resembles *L. nanlingensis*; however, *L. torosa*, reported from Korea, differs in having larger basidiocarps, orange-brown to brown pileus fading to pale orange buff when dry or old, and larger basidiospores ($8\text{--}9 \times 8\text{--}9.5 \mu\text{m}$) [54].

Phylogenetic analysis (Fig. 1) showed that two specimens labeled as *L. nanlingensis* clustered together as an independent clade in the genus *Laccaria*, although its relationship to other *Laccaria* species is unclear.

Based on the morphological features such as the dry or hygrophanous and reddish orange to brownish red pileus, the brownish red to grayish red lamellae, globose basidiospores with $Q = 1\text{--}1.16$, and the 4-spored basidia, *L. nanlingensis* can be placed in the *Laccaria* sect. *Laccata* [48].

Laccaria neovinaceoavellanea Ming Zhang & X.L. Gao, sp. nov.; Figure 2i, 3d–e, 6.

Fungal Name: FN571685

Diagnosis—*Laccaria neovinaceoavellanea* is distinctive by its pastel pink to pale violet pileus with a depressed center, globose to subglobose basidiospores with spines up to $2 \mu\text{m}$ long, and the presence of clavate, subcapitate to irregularly shaped caulocystidia.

Etymology—‘neovinaceoavellanea’ refers to the species similar to *L. vinaceoavellanea*.

Type—CHINA. Jiangxi Province, Ganzhou City, Congyi County, Yangling National Forest Park, [25°37′ N, 114°19′ E](#), elev. 400 m, 31 August 2016, Ming Zhang (GDGM52852), [GenBank: ITS = OR689447, 28S = OR785479](#).

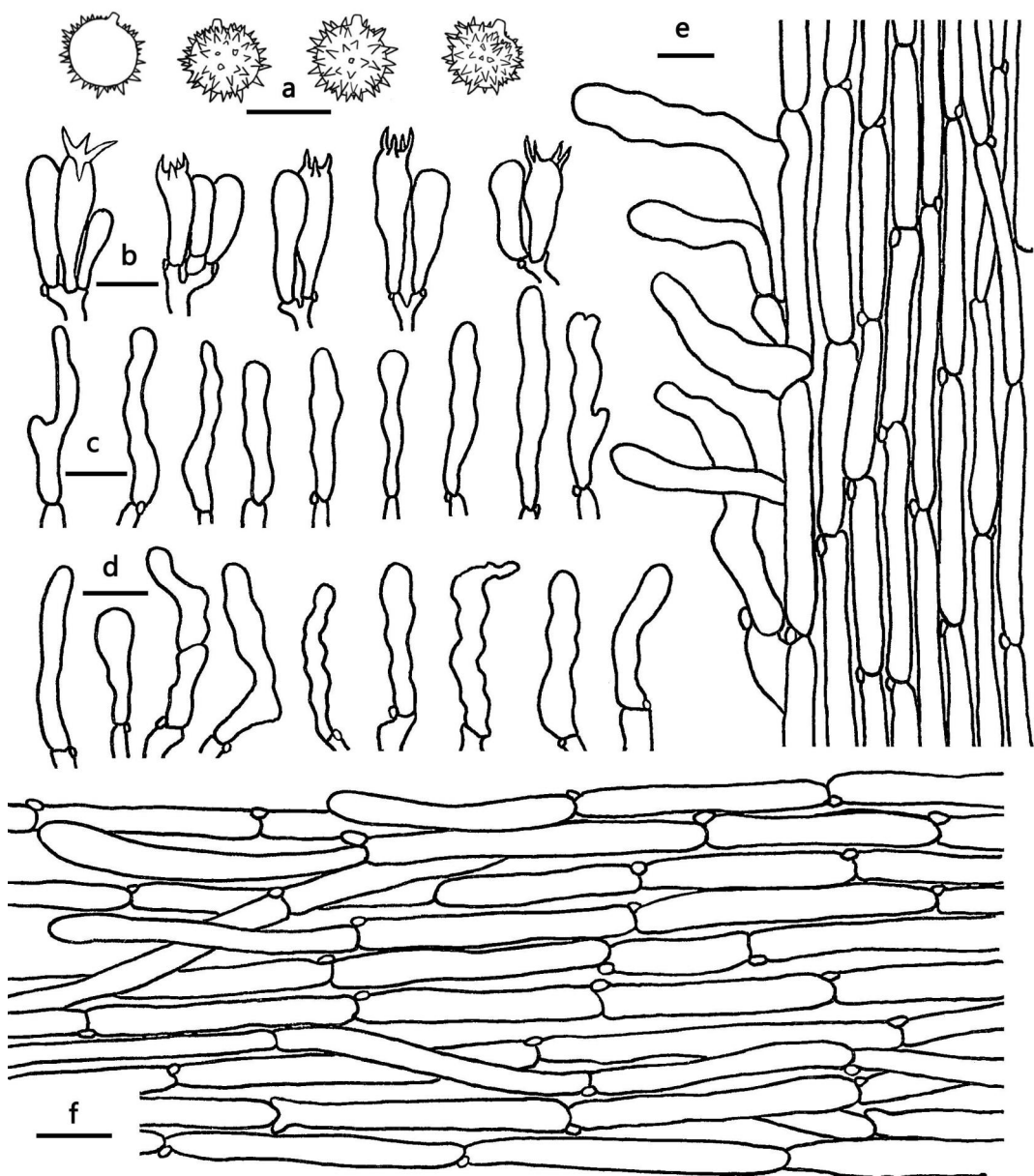


Figure 6. Microscopic features of *Laccaria neovinaceoavellanea* (GDGM52852, Holotype). (a) Basidiospores. (b) Basidia. (c) Cheilocystidia. (d) Caulocystidia. (e) Pileipellis. (f) Stipitipellis. Bars: (a, e) = 10 μm; (b–d, f) = 20 μm.

Basidiocarps small, omphalinoid. Pileus 15–40 mm broad, convex to applanate, with a depressed center, dry or hygrophanous, subglabrous to subtomentosus, pastel pink, rose, purplish pink to pale violet (11A3–16A3) at mass, grayish magenta to dull violet (13D3–15D3) at center, with obviously radial translucent-striate, especially toward margin; margin entire, involute when young, applanate to wavy when old; context white to pinkish white or purplish white (13A2–14A2). Lamellae sinuate to adnate, distant, concolorous with pileus or paler; lamellulae attenuate. Stipe 30–70 mm long, 2–5 mm thick, cylindrical, subglabrous to fibrillose, occasionally slightly longitudinally striate, pastel red, rose to purplish pink (8A4–14A4); basal mycelium white. Odor and taste unknown.

Basidiospores (excluding ornamentation) [30/2/2] 7–8 × 7–8 μm, av. = 7.6 ± 0.4 × 7.35 ± 0.42, Q = 1–1.14, Q_m = 1.04 ± 0.04, globose to subglobose, hyaline; spines 1–2 μm long, 0.8–1.5 μm wide at base. Basidia 30–50 × 10–14 μm, clavate, hyaline, 4-spored; sterigmata

4–6 µm long. Pleurocystidia lacking. Cheilocystidia 25–50 × 4–8 µm, filamentous to narrowly clavate, thin-walled, colorless and hyaline, abundant. Pileipellis a cutis with repent and occasionally suberect, thin to slightly thick-walled (0.5 µm) filamentous hyphae 6–18 µm wide, colorless to slightly brownish. Lamellar trama regular, composed of thin-walled filamentous hyphae 5–10 µm wide. Stipitipellis composed of appressed, parallel, simply septate, thin to slightly thick-walled (0.5 µm), colorless to yellow-brown hyphae 3–8 µm wide. Stipe trama composed of longitudinally arranged, infrequently branching, simple septate, thin-walled, colorless hyphae 3–8 µm wide. Caulocystidia 30–50 × 5–10 µm, clavate, sometimes subcapitate to irregularly shaped, slightly thick-walled (0.5 µm), colorless to yellow-brown, scattered. Clamp connections present.

Habitat and distribution—Single, scattered or in groups on soil in subtropical broad-leaved forests mainly dominated by Fagaceae. Currently known from southwestern and southern China.

Additional specimens examined—China. Jiangxi Province, Ganzhou City, Congyi County, Yangling National Forest Park, [25°37' N, 114°19' E](#), elev. 400 m, 2 September 2016, Ming Zhang (GDGM53063), [GenBank: ITS = OR689448, 28S = OR785480](#); Yunnan Province, Chuxiong Yi Autonomous Prefecture, Lufeng County, Guangtong Town, [25°14' N, 101°46' E](#), elev. 2200 m, 29 August 2022, Xue-lian Gao 16 (GDGM89621), [GenBank: ITS = OR689449, 28S = OR785481](#).

Notes—*Laccaria amethystina* Cooke and *L. vinaceoavellanea* Hongo are morphologically similar to *L. neovinaceoavellanea*. *Laccaria amethystina* is different by a initially purple pileus gradually fading to buff or brownish, dark purple lamellae, finely to coarsely hairy or scaly stipe concolorous with pileus, and relatively larger basidiospores (7–10 µm in diam.) ornamented with longer spines (1.5–3 µm long) [8,28,55–56]. *Laccaria vinaceoavellanea* differs by a larger basidiocarp (pileus up to 60 mm broad), grayish buff, brownish vinaceous to vinaceous-buff pileus with furfuraceous at margin, and relatively larger basidiospores (7.4–9.2 × 7.4–9.2 µm) [8,57].

Phylogenetic analysis (Fig. 1) showed that *L. neovinaceoavellanea* is closely related to *L. vinaceoavellanea*, *L. violaceotincta* K.P.D. Latha, K.N.A. Raj & Manim. and *L. yunnanensis*. However, *L. violaceotincta*, originally reported from India, differs by its strongly hygrophane and glabrous pileus, reddish gray or violet gray stipe covered with fine fibrils, and the presence of both 2- and 4-spored basidia [53]. *Laccaria yunnanensis* differs by its brownish to flesh-colored basidiocarp, flesh-colored lamellae, and larger basidiospores measuring (7.5)8–9 × (7.5)8–10 µm [22].

Based on the morphological features such as the purplish pink to pale violet basidiocarps, globose basidiospores with $Q = 1\text{--}1.14$, 4-spored basidia, and the colorless to slightly brownish pileipellis hyphae, *L. neovinaceoavellanea* can be placed in the *Laccaria* sect. *Violaceae* [48].

Laccaria rufobrunnea Ming Zhang & X.L. Gao, sp. nov.; Figures 2e–f, 3f, 7

Fungal Name: FN571674

Diagnosis—*Laccaria rufobrunnea* is distinctive in the genus *Laccaria* by its brownish orange to brownish red pileus, pastel red to purplish pink lamellae, white to pinkish white stipe, and the absence of caulocystidia.

Etymology—‘*rufobrunnea*’ refers to the brownish red pileus color.

Type: China. Yunnan Province, Chuxiong Yi Autonomous Prefecture, Nanhua County, 25°15'N, 101°16' E, elev. 1900 m, 26 August 2020, Ming Zhang (GDGM82878), [GenBank: ITS = OR689443, 28S = OR785482, tef1 = OR826272, rpb2 = OR835197](#).

Basidiocarps small, [omphalinoid](#). Pileus 12–35 mm broad, convex to subapplanate, hygrophane, glabrous, brownish orange to brownish red (6C7–9C7), with a darker center, usually fading to brownish yellow (5C7) in dry condition; margin entire, involute to incurved when young, incurved to decurved when old, [obscurely](#) translucent-striate; context brownish gray (5C2–8C2). Lamellae sinuate to adnate, distant, pastel red, pink to purplish pink (10A4–14A4), usually changing pinkish white to purplish white in dry

condition or old (10A2–14A2); lamellulae attenuate. Stipe 20–40 mm long, 3–5 mm thick, cylindrical, subglabrous, occasionally slightly longitudinally striate, white to pinkish white (7A2–10A2); basal mycelium white. Odor and taste unknown.

Basidiospores (excluding ornamentation) [60/3/2] 8–9 × 7–8 μm, av. 8.15 ± 0.23 × 7.57 ± 0.5, Q = 1–1.14, Q_m = 1.08 ± 0.06, globose to subglobose, hyaline, echinate, crowded; spines 1–2 μm long. Basidia 40–54 × 10–15 μm, clavate, hyaline, 4-spored; sterigmata 5–7 μm long. Pleurocystidia lacking. Cheilocystidia 35–50 × 3–7 μm, filamentous to narrowly clavate, thin-walled, colorless and hyaline, abundant. Pileipellis a cutis with repent hyphae, thin to slightly thick-walled (0.5 μm) filamentous hyphae 5–12 μm wide, colorless to slightly brownish. Lamellar trama regular, composed of filamentous hyphae 3–6 μm wide. Stipitipellis composed of appressed, parallel, simply septate, thin to slightly thick-walled (0.5 μm), colorless to yellow-brown hyphae 3–9 μm wide. Stipe trama composed of longitudinally arranged, infrequently branching, simple septate, thin-walled, colorless hyphae 3–9 μm wide. Caulocystidia lacking. Clamp connections present.

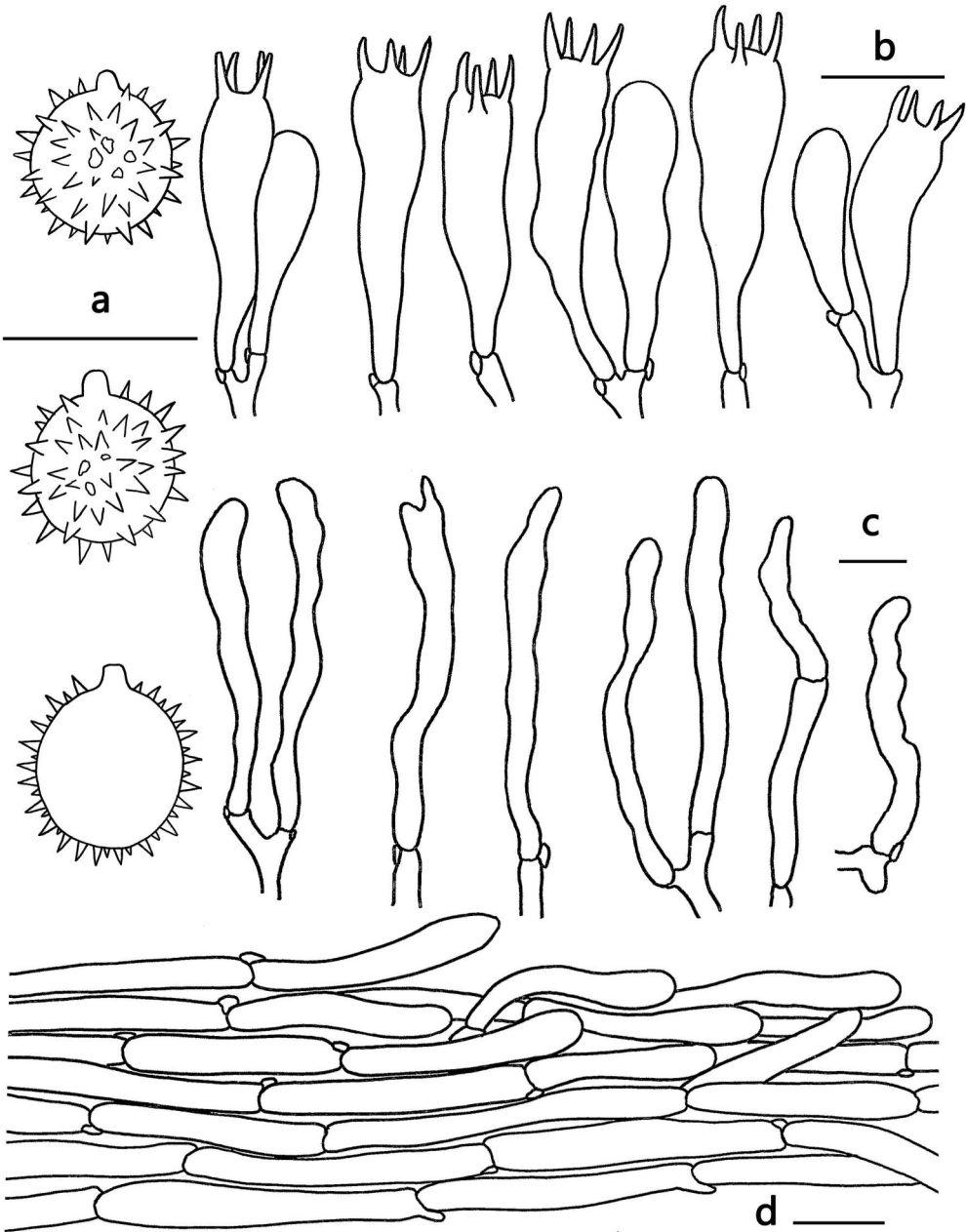


Figure 7. Microscopic features of *Laccaria rufobrunnea* (GDGM82878, Holotype). (a) Basidiospores. (b) Basidia. (c) Cheilocystidia; (d) Pileipellis. Bars: (a,c) = 10 µm; (b,d) = 20 µm.

Habitat and distribution—Single, scattered or in groups on soil in subtropical mixed forests mainly dominated by Fagaceae trees (such as: *Quercus yunnanensis*, *Q. variabilis*, *Castanopsis hystrix*, *Castanopsis* spp.) and pine trees (such as: *Pinus khasys*, *Pinus yunnanensis*). Currently known from southwestern China.

Additional specimen examined—China. Yunnan Province, Chuxiong Yi Autonomous Prefecture, Lufeng County, Guangtong Town, 25°13' N, 101°46' E, elev. 2200 m, 29 August 2022, Xue-lian Gao 26 (GDGM89627), [GenBank: ITS = OR689444, 28S = OR785483](#).

删除[Z]: Yunnan Province, Chuxiong Yi Autonomous Prefecture, Nanhua County, elev. 1900 m, 26 August 2020, Ming Zhang (GDGM82878);

Notes—*Laccaria rufobrunnea* is characterized by its brownish orange to brownish red pileus, pastel red to purplish pink lamellae, white to pinkish white stipe, and the absence of caulocystidia. On the base of morphological features described above, *L. rufobrunnea* can be placed in *Laccaria* sect. *Violaceae* [48].

Phylogenetic analysis supported *L. rufobrunnea* as a distinct lineage in *Laccaria*, and close to *L. prava* Fang Li and *L. umbilicata* Ming Zhang. However, *L. prava* differs by its larger basidiocarp (pileus up to 7.5 cm broad), reddish white to pastel red pileus with strongly striate or rugulose-sulcate, reddish white to grayish red lamellae, longer stipe and smaller basidiospores measuring 6.5–7.5 × 7–8 µm [33]; *L. umbilicata* differs by its pale orange to light orange pileus, orange white to pinkish white lamellae without purple tinge, broader basidiospores (8–10 µm in diam.) and the present of caulocystidia (present study).

Laccaria umbilicata Ming Zhang, sp. nov.; Figures 2g–h, 3g–h, 8.

Fungal Name: FN 571682

Diagnosis—*Laccaria umbilicata* is characterized by a pale orange to light orange colored pileus, white to orange white stipe, globose to subglobose basidiospores (7)8–10 × (7)8–10 µm, and the absence of pleurocystidia.

Etymology—‘*umbilicata*’ refers to the umbilicate pileus.

Type—China. Yunnan Province, Chuxiong Yi Autonomous Prefecture, Nanhua County, 25°15'N, 101°16' E, elev. 1990 m, 26 August 2020, Ming Zhang (GDGM82911), [GenBank: ITS = OR689446, 28S = OR785486, tef1 = OR826268, rpb2 = OR835192](#).

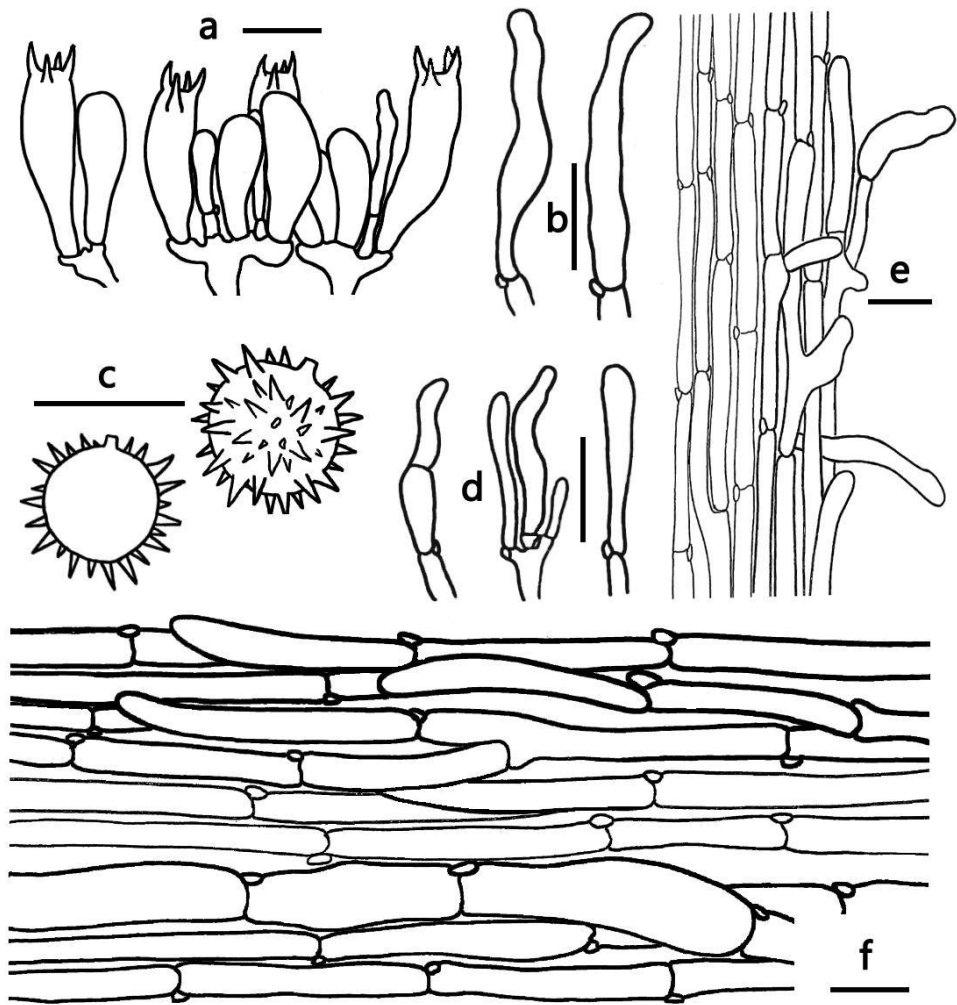


Figure 8. Microscopic features of *Laccaria umbilicata* (GDGM82911, Holotype). (a) Basidia. (b) Cheilocystidia. (c) Basidiospores. (d) Caulocystidia. (e) Stipitipellis and caulocystidia. (f) Pileipellis. Bars: (a,b,d) = 20 µm; (c,e,f) = 10 µm.

Basidiocarps small, **omphalinoid**. Pileus 10–28 mm broad, convex to applanate, a depressed center, dry or hygrophanous, glabrous, pale yellow, pale orange to light orange (4A3–6A3, 4A5–6A5), slightly changing light brown to brown (5D7–6D7) when in dry condition, especially toward margin; margin entire, involute when young, applanate when old, with obscurely translucent-striate; context white to orange white (5A1–5A2). Lamellae sinuate to adnate, distant, orange white, to pinkish white (5A2–7A2), sometimes pale orange to pastel red in dry conditions (5A3–7A3); lamellulae attenuate. Stipe 20–40 mm long, 2–3 mm thick, cylindrical, subglabrous, occasionally slightly longitudinally striate, white, yellowish white to orange white (4A2–5A2); basal mycelium white. Odor and taste unknown.

Basidiospores (excluding ornamentation) [60/3/2] (7)8–10 × (7)8–10 µm, av. 9.03 ± 0.75 × 8.67 ± 0.82, Q = 1–1.125, Q_m = 1.04 ± 0.06, globose to subglobose, hyaline, echinate; spines 1.5–3 µm long, up to 2 µm wide at base, crowded. Basidia 40–45 × 10–14 µm, clavate, hyaline, 4-spored; sterigmata 6–10 µm long. Pleurocystidia lacking. Cheilocystidia 30–47 × 3–8 µm, filamentous to narrowly clavate, thin-walled, colorless and hyaline, abundant. Lamellar trama subregular, composed of thin-walled filamentous hyphae 3–6 µm wide. Pileipellis a cutis with repent and occasionally suberect, thin to slightly thick-walled (ca. 0.5–1 µm) filamentous hyphae 3–18 µm wide, colorless to slightly brownish. Subhymenium composed of filamentous hyphae 3–10 µm wide. Stipitipellis composed of appressed, parallel, simply septate, thin to slightly

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thick-walled (0.5 µm), colorless to yellow-brown hyphae 3–8 µm wide. Stipe trama composed of longitudinally arranged, infrequently branching, simple septate, thin-walled colorless hyphae 3–8 µm wide. Caulocystidia 28–38 × 4–6 µm, clavate, sometimes subcapitate, slightly thick-walled (0.5 µm), colorless to yellow-brown, scattered. Clamp connections present.

Habitat and distribution—Single, scattered or in groups on soil in subtropical mixed forests mainly dominated by *Pinus yunnanensis* Franchet, mixed with a small number of Fagaceae trees. Currently only known from southwestern China.

Additional specimens examined—China. Yunnan Province, Chuxiong Yi Autonomous Prefecture, Nanhua County, 25°15'N, 101°16' E, elev. 2000 m, 26 August 2020, Ming Zhang (GDGM82883), GenBank: ITS = OR689445, 28S = OR785485, tef1 = OR826270, rpb2 = OR835194; same locality and data (GDGM82851), GenBank: 28S = OR785484, tef1 = OR826271, rpb2 = OR835195.

Notes—*Laccaria umbilicata* can be easily distinguished from other *Laccaria* species by its pale orange to light orange pileus with a depressed center, orange white to pinkish white lamellae, white to orange white stipe, and the absence of pleurocystidia. On the base of morphological features described above, the new species can be placed in *Laccaria* sect. *Laccata* [48].

Laccaria alba Zhu L. Yang & Lan Wang is morphologically similar to *L. umbilicata*, however, *L. alba* differs by its white to whitish basidiocarp, pinkish lamellae and smaller caulocystidia measuring 10–15 × 4–6 µm [30].

Phylogenetically, three specimens named as *L. umbilicata* formed a distinct lineage in *Laccaria*, and sister to *L. prava*, however, *L. prava* can be easily distinguished by its larger basidiocarps (pileus up to 7.5 cm broad) and smaller basidiospores (6.5–7.5 × 7–8 µm) [33]. The two species together with *L. diospyricola*, *L. fengkaiensis*, *L. neovinaceoavellanea*, *L. rufobrunnea*, *L. violaceotincta*, *L. vinaceoavellanea* and *L. yunnanensis* formed a well supported Asian distribution subclade (BS/BPP=100%/1). Among which, *L. diospyricola* and *L. violaceotincta* originally reported from southwestern India, *L. vinaceoavellanea* reported from Japan, and the others from China.

4. Discussion

Laccaria is a monophyletic group in the family Hydnangiaceae [2, 23, 58]. Five species level lineages representing five new species from China were uncovered in the *Laccaria* clade.

Previous studies based on morphological characteristics divided *Laccaria* into several different infrageneric classifications [14,48,59–60]. For example, Bon [59] and Ballero and Contu [60] divided the genus *Laccaria* into three sections (sect. *Maritimae*, sect. *Amethystinae* and sect. *Laccata*), and the section *Laccata* was further divided into several subgroups. Singer [14] recognized five stirps (stirp *Trullissata*, stirp *Amethystina*, stirp *Laccata*, stirp *Galerinoides*, and stirp *Purpureobadia*) in *Laccaria*. While, Pázmány [48] established two subgenera (subg. *Maritimae* and subg. *Laccata* ‘as *Laccaria*’) in the genus *Laccaria*, and the subg. *Laccata* was further divided into five sections (sect. *Bisporae*, sect. *Laccata*, sect. *Obscurae*, sect. *Purpureobadia* and sect. *Violaceae*). However, those systematic arrangements were often unstable, unnatural and contradictory, and were not supported by phylogenetic studies based on DNA sequences. Thus, the infrasubgeneric classification of *Laccaria* is still unclear, and more studies are needed to improve it.

Because of species in *Laccaria* are very similar in morphology, and the characters of some species change greatly in different growth stages and humidity conditions, which brings difficulties to species identification. The basidiospore dimensions play a crucial roles for species identification in most macrofungi groups, but in *Laccaria*, this character may be confusing, because some species share similar size and shape basidiospores. For example, the five new species described above all share with globose to subglobose basidiospores with Q value between 1 to 1.1, and the size of basidiospores between 7–10 µm in diam. except *L. nanlingensis*. However, the length and density of spines on the

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spore surface can be a useful distinguishing feature, for example, *L. acanthospora*, *L. alba* and *L. angustilamella* have longer spines can up to 5–6 µm long, while *L. miniata* and *L. prava* have shorter spines which less than 1 µm long (see table 1).

In addition, basidia size and whether they are 2 or 4-spored can be useful distinguishing features. Most species of *Laccaria* have 4-spored basidia, while *L. echinospora*, *L. fraterna* and *L. nigra* have 2-spored basidia, *L. aurantia* and the new species *L. miniata* have both 2- and 4-spored basidia which is infrequent in *Laccaria*.

Additionally, the ecological information such as host plant species and habitat are also important, and can provide useful clues for species identification. *Laccaria miniata* and *L. nanlingensis* collected from subtropical broad-leaved forests of southern China, and could be associated with trees of Fagaceae; *L. rufobrunnea* and *L. umbilicata* distributed in subtropical mixed forests (which mainly dominated by Fagaceae trees and pine trees) of southwest China; and *L. neovinaceoavellanea* can naturally distributed in subtropical broad-leaved forests of southern and southwestern China, and can form symbiotic relationship with Fagaceae trees. On the basis of our study, the main morphological characters and ecological information of each species in *Laccaria* described from China are summarized in Table 1.

Although many species of *Laccaria* have been reported in China, most species are mainly reported from southwestern regions, and the species recognition of *Laccaria* in China is still in its infancy, especially in the tropical and subtropical areas. In the past, many Chinese samples of *Laccaria* were inaccurately labeled as *L. laccata*, *L. bicolor*, *L. amethystea* and *L. vinaceoavellanea* [61–64]. Phylogenetic studies have made some species well understood in China, and the discovery of new species in *Laccaria* is rapidly increasing [2,17,21–22,31–34,54]. However, the distribution of *L. amethystea*, *L. bicolor* and *L. laccata* in China still need to be investigated. A broader taxon sampling coupled with both molecular and morphological data are needed to fully understand the species diversity of *Laccaria* in China.

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Table 1. A morphological comparison of species in *Laccaria* described from China.

Species	Habit	Pileus dimater	Pileus color	Lamellae color	Spores size	References
<i>L. acanthospora</i>	On sandy banks in mixed temperate alpine forest. Distributed in Tibet.	4–15 mm	orange	light orange	7–10×7–10 µm (av. 8.3–8.4×8.9–9.2 µm); Spines 2–6 µm long	[21]
<i>L. alba</i>	In mixed forests with <i>Abies</i> , <i>Betula</i> , <i>Fraxinus</i> , <i>Picea</i> , <i>Pinus</i> , <i>Quercus</i> , <i>Tilia</i> and <i>Ulmus</i> . Distributed in Yunnan.	7–32 mm	reddish–brown to orange, fading to buff	pink–salmon	7–10 × 7–11 µm (av. 8.5 × 8.6 µm); Spines 1–5 (–6) µm	[21]
<i>L. angustilamella</i>	In forests dominated by <i>Quercus</i> and <i>Lithocarpus</i> . Distributed in Yunnan.	20–30 mm	pinkish flesh-colored, slightly darker on radial striations, fading to buff with age or on drying	pinkish	(8)8.5–11.5(12)×(7.5)8–11 µm (av. 9.2 ± 0.8×8.6 ± 0.8 µm); Spines (2.0) 2.5–5 µm long	[30]
<i>L. anthracina</i>	In mixed forest, near <i>Pinus wallichiana</i> . Distributed in Tibet.	25–65 mm	dark grayish brown, dark brownish gray to brownish black, fading to grayish brow after drying	pinkish brown	(6.5)7–9.5(11)×(6.5)7–9(10.5) µm; Spines 1.5–2.5 µm long	[34]
<i>L. aurantia</i>	In mixed broad-leaved forests dominated by <i>Quercus</i> and <i>Lithocarpus</i> . Distributed in Yunnan.	35–40 mm	vividly orange	orange	(8)9–10 (11)×(7) 8–10 µm; Spines (0.75) 1–1.5 (1.75) µm	[22]
<i>L. bullipellis</i>	In mixed temperate alpine conifer forest with <i>Abies</i> , <i>Picea</i> , <i>Pinus</i> , <i>Rhododendron</i> , <i>Sorbus</i> and <i>Gamblea</i> . Distributed in Tibet.	22 mm	brown to orange–brown	brown to orange–brown	6–9 × 6–10 µm (av. 8.3 µm); Spines 1–2 µm long	[21]
<i>L. fagacicola</i>	In subtropical broad-leaved forests with trees of Fagaceae. Distributed in Yunnan.	20–45 mm	brownish orange to brownish	brownish orange	(6.5)7–9(10)×6.5–8(9) µm, (av. 7.7 ± 0.6×7.4 ± 0.5); Spines 1–2(2.5) µm long	[2]
<i>L. fengkaiensis</i>	In broad–leaved forests	50–90 mm	orange white, pale orange when	pastel red to	5.2–6.3 × 5.1–6.3 µm;	[33]

	dominated by Fagaceae, such as <i>Lithocarpus haipinii</i> , <i>L. litseifolius</i> , <i>L. glaucus</i> , <i>L. uvariifolius</i> , <i>Castanopsis fissa</i> , and <i>C. faberi</i> . Distributed in Guangdong.		young, light orange to pale red, pastel red with age	grayish red	Spines 0.5–1.2 µm long	
<i>L. fulvogrisea</i>	In mixed broad-leaved forests with <i>Quercus</i> , <i>Eucalyptus</i> , <i>Lithocarpus</i> and <i>Ficus</i> . Distributed in Yunnan.	<30 mm	Gray with a violet to reddish brown tinge	initially whitish, grayish to brownish with age	(7.5) 8–10 × 8–11 (7.5) µm; Spines (1.5) 1.7–2.5 µm long	[22]
<i>L. himalayensis</i>	In mixed temperate alpine conifer forest with <i>Abies</i> , <i>Acer</i> , <i>Larix</i> , <i>Pinus</i> and <i>Salix</i> . Distributed in Tibet.	6–34 mm	brown at disk orange–pink toward margin	orange–pink	6.5–10 µm (av. 8.1–9 µm); Spines (0.5–) 1–3 µm	[21]
<i>L. miniata</i>	In subtropical mixed forests with trees of Fagaceae (<i>Castanopsis fissa</i> , <i>C. spp.</i>) and Pinaceae (<i>Pinus massoniana</i>). Distributed in Guangdong.	10–15 mm	red at mass, with a deep red center, fading to reddish orange to yellowish red toward margin	pastel red, pastel pink to red	8–10.5(11) × 8–10 µm, (av. 9.37 ± 0.83 × 8.8 ±0.6); Spines 0.5–1 µm long	Present study
<i>L. moshuijun</i>	In subtropical mixed forests with <i>Piuns yunnanensis</i> , <i>Cunninghamia lanceolata</i> and other broad-leaved trees. Distributed in Guizhou.	Up to 30 mm	violet to bluish with brown tinge at centre.	deep violet	(7.5)8–9 × (8)9–10 µm; Spines 1–1.5 µm	[32]
<i>L. nanlingensis</i>	In subtropical broad-leaved forests mainly dominated by Fagaceae trees. Distributed in Guangdong.	30–55 mm	orange, reddish orange, orange red, brownish orange to brownish red, fading to light orange to pale orange when dry	concolorous with pileus or darker to pale red to grayish red	6.5–7.5 × 6–7 µm, av. 6.95 ± 0.15 × 6.37±0.45; Spines 0.5–1 µm long.	Present study
<i>L. negrimarginata</i>	In mixed temperate alpine conifer forest with <i>Abies</i> , <i>Acer</i> , <i>Larix</i> , <i>Pinus</i> , <i>Quercus</i> and <i>Salix</i> . Distributed in Tibet.	5–15 mm	orange–brown fading to buff; squamules dark blackish brown to dark brown.	pale pink to pinkish gray	7–10 × 6–10 µm (av. 7.8–9 × 7.4–8.9 µm); Spines up to 2 µm	[21]
<i>L. pallidorosea</i>	In subtropical broad-leaved forests with trees of Fagaceae. Distributed in Yunnan.	10–25 mm	Brownish to pinkish at center, becoming cream to white towards margin	white to pinkish	(6)7–9(10)×(6)6.5–8.5(9) µm, (av. 8 ± 0.7 × 7.75 ± 0.6); Spines 1.5–2 (3) µm long	[2]
<i>L. prava</i>	In broad-leaved forests dominated by Fagaceae, such as <i>Lithocarpus glaber</i> , <i>L. corneus</i> , <i>Cyclobalanopsis pachyloma</i> , <i>Castanopsis faberi</i> and <i>C. fissa</i> . Distributed in Guangdong.	30–75 mm	pastel red, pale red to reddish white, even to white with age or on drying.	reddish white to grayish red	6.5–7.5 × 7–8 µm; Spines 0.5–1 µm long	[33]
<i>L. rubroalba</i>	In a tropical forest dominated by Fagaceae and other broad-leaf trees. Distributed in Yunnan.	22–40 mm	reddish white when moist or young, becoming white to paler when dry.	flesh–colored	(5) 6–9 (10) × 5–7 (8) µm; Spines 1.2–2.7 µm long	[17]
<i>L. rufobrunnea</i>	In subtropical mixed forests mainly dominated by Fagaceae trees and pine trees. Distributed in Yunnan.	12–35 mm	brownish orange to brownish red, usually fading to brownish yellow in dry condition	pastel red, pink to purplish pink, usually changing pinkish white to purplish white in dry condition	8–9 × 7–8 µm, av. 8.15 ± 0.23 × 7.57 ±0.5; spines 1–2 µm long	Present study
<i>L. salmonicolor</i>	In mixed temperate alpine forest with <i>Betula</i> , <i>Larix</i> and <i>Picea</i> . Distributed in Tibet.	10–35 mm	reddish–brown, to pale brown–buff	pinkish salmon	7.5–10 µm (av. 8.5 µm); Spines 1–3 µm long	[21]
<i>L. umbilicata</i>	In subtropical mixed forests mainly dominated by <i>Pinus yunnanensis</i> , mixed with a small number of Fagaceae trees. Distributed in Yunnan.	10–28 mm	pale yellow, pale orange to light orange, changing light brown to brown when in dry condition	orange white, to pinkish white, sometimes pale orange to pastel red in dry conditions	(7)8–10 × (7)8–10 µm, av. 9.03 ± 0.75 × 8.67 ±0.82; Spines 1.5–2 (2.5) µm long	Present study
<i>L. neovinaceoa vellanea</i>	In subtropical broad–leaved forests dominated by Fagaceae. Distributed in Jiangxi.	15–40 mm	pastel pink, rose, purplish pink to pale violet at mass, grayish magenta to dull violet at center	concolorous with pileus or paler	7–8 × 7–8 µm, av. 7.6 ± 0.4 × 7.35 ±0.42; Spines 1–2 µm long	Present study
<i>L. yunnanensis</i>	In subtropical forests.Distributed in Yunnan.	60–100 mm	brownish to flesh–colored	flesh–colored	(7.5)8–9 × (7.5)8–10 µm; Spines 1–1.5 µm long	[22]

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Author Contributions: Conceptualization, M.Z.; methodology, M.Z.; performing the experiment, M.Z.; formal analysis, M.Z.; validation, M.Z., X.-L.G., L.-Q.M. and W.-Q.D.; resources, M.Z.; writing—original draft preparation, M.Z.; writing—review and editing, M.Z., X.-L.G. and L.-Q.M.; visualization, M.Z.; supervision, M.Z.; project administration, Z.M.; funding acquisition, Z.M. and W.-Q.D. All authors have read and agreed to the published version of the manuscript..

Funding: This research was supported by the National Natural Science Foundation of China (nos. 32070020, 31970024), the Science & Technology Fundamental Resources Investigation Program (Grant No.2022FY100500), the Science and Technology Planning Project of Guangdong Forestry Bureau (LC-2021124), and the Chuxiong State Financial Market Supervision and Management special fund project (Chu Caixing [2020] 91-2130106).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://www.ncbi.nlm.nih.gov/genbank/>, and <https://www.ncbi.nlm.nih.gov/genbank/>..

Acknowledgments: We express our gratitude to Mr. Li-Qiang Wu and Xi-Shen Liang for their help during field collections. Thanks are given to Mrs. Xue-Jiao You for her help in the scanning electron microscopy (SEM) of basidiospores.

Conflicts of Interest: The authors declare that there are no conflicts of interest.

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