MycoKeys 46: 55–96 (2019)
doi: 10.3897/mycokeys.46.31470
http://mycokeys.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
MycoKeys
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New and noteworthy boletes from subtropical and tropical China

Hui Chai[1], Zhi-Qun Liang[2], Rou Xue[1], Shuai Jiang[3], Shi-Hong Luo[4], Yong Wang[1], Lu-Ling Wu[1], Li-Ping Tang[5], Yun Chen[3], Deng Hong[1], Nian-Kai Zeng[1]

1 *College of Pharmacy-Transgenic Laboratory, Hainan Medical University, Haikou 571199, China* **2** *College of Materials and Chemistry Engineering, Hainan University, Haikou 570228, China* **3** *Hainan Yinggeling National Nature Reserve, Baisha, 572800, China* **4** *College of Bioscience and Biotechnology, Shenyang Agricultural University, Shenyang 110866, China* **5** *School of Pharmaceutical Sciences and Yunnan Key Laboratory of Pharmacology for Natural Products, Kunming Medical University, Kunming, 650500, China*

Corresponding author: *Nian-Kai Zeng* (niankaiz@163.com)

Academic editor: *O. Raspé* | Received 8 November 2018 | Accepted 9 January 2019 | Published 18 February 2019

Citation: Chai H, Liang Z-Q, Xue R, Jiang S, Luo S-H, Wang Y, Wu L-L, Tang L-P, Chen Y, Hong D, Zeng N-K (2019) New and noteworthy boletes from subtropical and tropical China. MycoKeys 46: 55–96. https://doi.org/10.3897/mycokeys.46.31470

Abstract

The morphology, ecology, and phylogenetic relationships of specimens of the family Boletaceae from subtropical and tropical China were investigated. Four species, *Butyriboletus huangnianlaii*, *Lanmaoa macrocarpa*, *Neoboletus multipunctatus*, and *Sutorius subrufus*, are new to science. *Chalciporus radiatus* and *Caloboletus xiangtoushanensis* are redescribed. *Caloboletus guanyui* is proposed to replace *Boletus quercinus* Hongo, an illegitimate later homonym. The recently described *Tylopilus callainus* is synonymized with the Japanese *Boletus virescens*, and the new combination *T. virescens* (Har. Takah. & Taneyama) N.K. Zeng et al. is proposed. Moreover, *Neoboletus* is treated as an independent genus based on evidence from morphology and molecular phylogenetic data in the present study, and many previously described taxa of *Sutorius* are recombined into *Neoboletus*: *N. ferrugineus* (G. Wu et al.) N.K. Zeng et al., *N. flavidus* (G. Wu & Zhu L. Yang) N.K. Zeng et al., *N. hainanensis* (T.H. Li & M. Zang) N.K. Zeng et al., *N. obscureumbrinus* (Hongo) N.K. Zeng et al., *N. rubriporus* (G. Wu & Zhu L. Yang) N.K. Zeng et al., *N. sanguineoides* (G. Wu & Zhu L. Yang) N.K. Zeng et al. , *N. sanguineus* (G. Wu & Zhu L. Yang) N.K. Zeng et al., and *N. tomentulosus* (M. Zang et al.) N.K. Zeng et al.

Keywords

Molecular phylogeny, morphology, new taxa, taxonomy

Introduction

Boletaceae Chevall. (Boletales) is a large, cosmopolitan family with abundant species. Many of them are interesting and important for their mycorrhizal relationships with trees, edibility, medicinal value, and toxicity (Wang et al. 2004; Roman et al. 2005; Wu et al. 2013; Chen et al. 2016). In China, species of Boletaceae have received much attention by mycologists, and many taxa have been discovered across the country (Chiu 1948; Zang 2013; Zeng et al. 2013, 2016, 2017; Liang et al. 2016, 2017; Wu et al. 2016a). However, the diversity of species still remains poorly known in subtropical and tropical China, a biodiversity hotspot. During field trips in the past several years, many collections of boletes have been made in subtropical and tropical China. Evidence from morphology, molecular phylogenetic analyses, and ecological data indicate that these collections belong to *Butyriboletus* D. Arora & J.L. Frank, *Caloboletus* Vizzini, *Chalciporus* Bataille, *Lanmaoa* G. Wu & Zhu L. Yang, *Neoboletus* Gelardi et al., *Sutorius* Halling et al., and *Tylopilus* P. Karst. Thus, they are described/redescribed in an effort to (i) further demonstrate the species diversity in subtropical and tropical China, (ii) resolve some taxonomic quandaries in Boletaceae.

Materials and methods

Abbreviations of generic names used in the study

The abbreviations of *Boletus*, *Butyriboletus*, *Caloboletus*, *Chalciporus*, *Crocinoboletus*, *Lanmaoa*, *Neoboletus*, *Sutorius*, *Tylopilus* mentioned in this work are *B.*, *But.*, *C.*, *Ch.*, *Cr.*, *L.*, *N.*, *S.* and *T.*, respectively.

Collection sites and sampling

Specimens were collected from subtropical and tropical China including Hainan and Fujian Provinces. Specimens examined are deposited in the Fungal Herbarium of Hainan Medical University (FHMU), Haikou City, Hainan Province, China, the Herbarium of Cryptogams, Kunming Institute of Botany, Chinese Academy of Sciences (HKAS), and the Mycological Herbarium of Pharmacy College, Kunming Medical University (MHKMU).

Morphological studies

The macroscopic descriptions are based on detailed notes and photographs taken from fresh basidiomata. Color codes are from Kornerup and Wanscher (1981). Sections of the pileipellis were cut radial-perpendicularly and halfway between the center and

margin of the pileus. Sections of the stipitipellis were taken from the middle part along the longitudinal axis of the stipe. Five percent KOH was used as a mounting medium for microscopic studies. All microscopic structures were drawn by freehand from rehydrated material. The number of measured basidiospores is given as *n*/*m*/*p*, where *n* represent the total number of basidiospores measured from *m* basidiomata of *p* collections. Dimensions of basidiospores are given as (*a*)*b* – *c*(*d*), where the range *b* – *c* represents a minimum of 90% of the measured values (5th to 95th percentile), and extreme values (*a* and *d*), whenever present (*a* < 5th percentile, *d* > 95th percentile), are in parentheses. *Q* refers to the length/width ratio of basidiospores; Q_m refers to the average *Q* of basidiospores and is given with a sample standard deviation.

DNA extraction, primers, PCR and sequencing

Total genomic DNA was obtained with Plant Genomic DNA Kit (TIANGEN Company, China) from materials dried with silica gel according to the manufacturer's instructions. The primers used for amplifying the nuclear ribosomal large subunit RNA (28S) were LROR/LR5 (Vilgalys and Hester 1990; James et al. 2006), ITS5/ITS4 (White et al. 1990) for the nuclear rDNA region encompassing the internal transcribed spacers 1 and 2, along with the 5.8S rDNA (ITS), the translation elongation factor 1-α gene (*tef1*) with 983F/1567R (Rehner and Buckley 2005) and the RNA polymerase II second largest subunit gene (*rpb2*) with RPB2-B-F1/RPB2-B-R (Wu et al. 2014). PCR products were checked in 1% (w/v) agarose gels, and positive reactions with a bright single band were purified and directly sequenced using an ABI 3730xl DNA Analyzer (Guangzhou Branch of BGI, China) with the same primers used for PCR amplifications. Assembled sequences were deposited in GenBank (Table 1).

Dataset assembly

For the concatenated multilocus dataset of *Butyriboletus*, 14 sequences (four of 28S, four of ITS, four of *tef1*, and two of *rpb2*) from four collections were newly generated (Table 1) and then combined with selected sequences from previous studies (Table 1). *Rugiboletus extremiorientalis* (Lj.N. Vassiljeva) G. Wu & Zhu L. Yang was chosen as outgroup on the basis of the phylogeny in Wu et al. (2016a). For the concatenated multilocus dataset of *Caloboletus*, *Neoboletus*, and *Sutorius*, 68 sequences (21 of 28S, 16 of ITS, 20 of *tef1*, 11 of *rpb2*) from 23 collections were newly generated and deposited in GenBank (Table 1) and then combined with selected sequences from previous studies (Table 1). *Crocinoboletus laetissimus* (Hongo) N.K. Zeng et al. and *Cr. rufoaureus* (Massee) N.K. Zeng et al. were chosen as outgroup based on the phylogeny in Wu et al. (2016a). For the concatenated multilocus dataset of *Lanmaoa*, eight sequences (three of 28S, two of ITS, and three of *tef1*) from

Table 1. Taxa, vouchers, locations, and GenBank accession numbers of DNA sequences used in this study.

Taxon	Voucher	Locality	28S	ITS	*tef1*	*rpb2*	References
Baorangia pseudocalopus	HKAS63607	Yunnan, SW China	KF112355	–	KF112167	–	Wu et al. 2014
Baorangia pseudocalopus	HKAS75081	Yunnan, SW China	KF112356	–	KF112168	–	Wu et al. 2014
Butyriboletus abieticola	Arora11087	California, USA	KC184413	KC184412	–	–	Arora and Krank 2014
Butyriboletus appendiculatus	Bap1	Germany	AF456837	KJ419923	JQ327025	–	Binder and Bresinsky 2002
Butyriboletus appendiculatus	BR50200893390-25	Meise, Belgium	KT002609	KT002598	KT002633	–	Zhao et al. 2015
Butyriboletus appendiculatus	BR50200892955-50	Zoniënwoud, Belgium	KJ605677	KJ605668	KJ619472	KP055030	Zhao et al. 2014a
Butyriboletus appendiculatus	MB000286	Germany	KT002610	KT002599	KT002634	–	Zhao et al. 2015
Butyriboletus autumniregius	Arora11108	California, USA	KC184424	KC184423	–	–	Arora and Krank 2014
Butyriboletus brunneus	NY00013631	Connecticut, USA	KT002611	KT002600	KT002635	–	Zhao et al. 2015
Butyriboletus fechtneri	AT2003097	–	KF030270	KC584784	–	–	Nuhn et al. 2013
Butyriboletus frostii	JLF2548	New Hampshire, USA	–	KC812303	–	–	Arora and Krank 2014
Butyriboletus frostii	NY815462	Costa Rica	JQ924342	–	KF112164	KF112675	Wu et al. 2014
Butyriboletus hainanensis	N.K. Zeng 1197 (FHMU 2410)	Hainan, southern China	KU961651	KU961653	–	KU961658	Liang et al. 2016
Butyriboletus hainanensis	N.K. Zeng 2418 (FHMU 2437)	Hainan, southern China	KU961652	KU961654	KU961656	KX453856	Liang et al. 2016
Butyriboletus huangnianlaii	N.K. Zeng 3245 (FHMU 2206)	Fujian, SE China	**MH879688**	**MH885350**	**MH879717**	**MH879740**	this study
Butyriboletus huangnianlaii	N.K. Zeng 3246 (FHMU 2207)	Fujian, SE China	**MH879689**	**MH885351**	**MH879718**	**MH879741**	this study
Butyriboletus peckii	3959	Tennessee, USA	JQ326999	–	JQ327026	–	Halling et al. 2012
Butyriboletus persolidus	Arora11110	California, USA	–	KC184444	–	–	Arora and Krank 2014
Butyriboletus primiregius	DBB00606	Dunsmuir, California, USA	KC184451	–	–	–	Arora and Krank 2014
Butyriboletus pseudoregius	BR50201618465-02	Eprave, Belgium	KT002613	KT002602	KT002637	–	Zhao et al. 2015
Butyriboletus pseudoregius	BR50201533559-51	Meise, Belgium	KT002614	KT002603	KT002638	–	Zhao et al. 2015
Butyriboletus pseudospeciosus	HKAS59467	Yunnan, SW China	KF112331	–	KF112176	KF112672	Wu et al. 2014
Butyriboletus pseudospeciosus	HKAS63513	Yunnan, SW China	KT990541	–	KT990743	KT990380	Wu et al. 2016a
Butyriboletus pseudospeciosus	HKAS63596	Yunnan, SW China	KT990542	–	KT990744	KT990381	Wu et al. 2016a
Butyriboletus pseudospeciosus	N.K. Zeng 2127 (FHMU 1391)	Yunnan, SW China	**MH879687**	**MH885349**	**MH879716**	–	this study
Butyriboletus pseudoregius	MG383a	Lazio, Italy	–	KC184458	–	–	Arora and Krank 2014
Butyriboletus pulchriceps	DS4514	Arizona, USA	KF030261	–	KF030409	–	Nuhn et al. 2013
Butyriboletus pulchriceps	R. Chapman 0945	Arizona, USA	KT002615	KT002604	KT002639	–	Zhao et al. 2015
Butyriboletus quercicregius	Arora11100	California, USA	–	KC184461	–	–	Arora and Krank 2014
Butyriboletus regius	MB000287	Germany	KT002616	KT002605	KT002640	–	Zhao et al. 2015
Butyriboletus regius	MG408a	Lazio, Italy	KC584790	KC584789	–	–	Arora and Krank 2014
Butyriboletus regius	PRM:923465	Czech Rep.	KJ419931	KJ419920	–	–	Šutara et al. 2014
Butyriboletus roseoflavus	Arora11054	Yunnan, SW China	KC184435	KC184434	–	–	Arora and Krank 2014
Butyriboletus roseoflavus	HKAS63593	Yunnan, SW China	KJ184559	KJ909517	KJ184571	–	Zhao et al. 2015
Butyriboletus roseoflavus	HKAS54099	Yunnan, SW China	KF739665	KJ909519	KF739779	–	Zhao et al. 2015
Butyriboletus roseoflavus	N.K. Zeng 2123 (FHMU 1387)	Yunnan, SW China	**MH879686**	**MH885348**	**MH879715**	–	this study
Butyriboletus roseopurpureus	E.E. Both3765	New York, USA	KT002617	KT002606	KT002641	–	Zhao et al. 2015
Butyriboletus roseopurpureus	JLF2566	West Virginia, USA	KC184467	KC184466	–	–	Arora and Krank 2014
Butyriboletus roseopurpureus	MB06-059	New York, USA	KF030262	KC184464	KF030410	–	Nuhn et al. 2013
Butyriboletus sanicibus	Arora99211	Yunnan, SW China	KC184470	KC184469	–	–	Arora and Krank 2014
Butyriboletus sp.	MHHNU7456	China	KT990539	–	KT990741	KT990378	Wu et al. 2016a
Butyriboletus sp.	HKAS52525	Yunnan, SW China	KF112337	–	KF112163	KF112671	Wu et al. 2014
Butyriboletus sp.	HKAS57774	Yunnan, SW China	KF112330	–	KF112155	KF112670	Wu et al. 2014

Taxon	Voucher	Locality	28S	ITS	*tef1*	*rpb2*	References
Butyriboletus sp.	HKAS59814	Hunan, central China	KF112336	–	KF112199	KF112699	Wu et al. 2014
Butyriboletus sp.	HKAS63528	Sichuan, SW China	KF112332	–	KF112156	KF112673	Wu et al. 2014
Butyriboletus subappendiculatus	MB000260	Germany	KT002618	KT002607	KT002642	–	Zhao et al. 2015
Butyriboletus subsplendidus	HKAS52661	Yunnan, SW China	KF112339	–	KF112169	KF112676	Wu et al. 2014
Butyriboletus yicibus	Arora9727	Yunnan, SW China	KC184475	KC184474	–	–	Arora and Krank 2014
Butyriboletus yicibus	HKAS57503	Yunnan, SW China	KT002620	KT002608	KT002644	–	Zhao et al. 2015
Butyriboletus yicibus	HKAS68010	Yunnan, SW China	KT002619	KJ909521	KT002643	–	Zhao et al. 2015
Caloboletus calopus	Bc1	Bavaria, Germany	AF456833	DQ679806	JQ327019	–	Zhao et al. 2014a
Caloboletus calopus	BR5020159063805	Montenau, Belgium	KJ184554	KJ605655	KJ184566	–	Zhao et al. 2014a
Caloboletus calopus	112606	California, USA	KF030279	–	–	–	Nuhn et al. 2013
Caloboletus firmus	MB06-060	New York, USA	KF030368	–	KF030408	–	Nuhn et al. 2013
Caloboletus firmus	NY00796115	Cayo, Belize	KJ605678	KJ605656	KJ619464	–	Zhao et al. 2014a
Caloboletus guanyui	N.K. Zeng 3058 (FHMU 2019)	Hainan, southern China	**MH879708**	**MH885365**	**MH879734**	**MH879751**	this study
Caloboletus guanyui	N.K. Zeng 3079 (FHMU 2040)	Hainan, southern China	**MH879709**	**MH885366**	**MH879736**	**MH879752**	this study
Caloboletus guanyui	N.K. Zeng 3257 (FHMU 2218)	Fujian, SE China	**MH879705**	–	**MH879732**	**MH879748**	this study
Caloboletus guanyui	N.K. Zeng 3261 (FHMU 2222)	Fujian, SE China	**MH879706**	–	**MH879733**	**MH879749**	this study
Caloboletus guanyui	N.K. Zeng 3263 (FHMU 2224)	Fujian, SE China	**MH879707**	**MH885364**	**MH879735**	**MH879750**	this study
Caloboletus guanyui	N.K. Zeng 3344 (FHMU 2809)	Hainan, southern China	–	–	**MK061357**	–	this study
Caloboletus inedulis	MB06-044	New York, USA	JQ327013	–	JQ327020	–	Halling et al. 2012
Caloboletus inedulis	HKAS80478	Florida, USA	KJ605671	KJ605657	KJ619465	–	Zhao et al. 2014a
Caloboletus panniformis	HKAS56164	Yunnan, SW China	KJ605674	KJ605667	KJ619466	–	Zhao et al. 2014a
Caloboletus panniformis	HKAS57410	Yunnan, SW China	KJ184555	KJ605659	KJ184567	–	Zhao et al. 2014a
Caloboletus panniformis	HKAS77530	Yunnan, SW China	KJ605670	KJ605661	KJ619470	–	Zhao et al. 2014a
Caloboletus polygonius	K(M)60247	Greece	KU317763	KU317753	–	–	GenBank
Caloboletus radicans	HKAS80856	France	KJ184557	KJ605662	KJ184569	–	Zhao et al. 2014a
Caloboletus sp.	HKAS53353	China	KF112410	–	KF112188	KF112668	Wu et al. 2014
Caloboletus taienus	GDGM44081	Guangdong, southern China	KY800414	KY800420	–	–	Zhang et al. 2017
Caloboletus xiangtoushanensis	GDGM44725	Guangdong, southern China	KY800416	KY800422	–	–	Zhang et al. 2017
Caloboletus xiangtoushanensis	GDGM44833	Guangdong, southern China	KY800415	KY800421	KY800418	–	Zhang et al. 2017
Caloboletus xiangtoushanensis	GDGM45160	Guangdong, southern China	KY800417	KY800423	KY800419	–	Zhang et al. 2017
Caloboletus xiangtoushanensis	N.K. Zeng 1330 (FHMU 883)	Fujian, SE China	**MH879702**	–	–	–	this study
Caloboletus xiangtoushanensis	N.K. Zeng 1331 (FHMU 884)	Fujian, SE China	**MH879703**	**MH885362**	–	–	this study
Caloboletus xiangtoushanensis	N.K. Zeng 1354 (FHMU 906)	Fujian, SE China	**MH879704**	**MH885363**	–	–	this study
Caloboletus yunnanensis	HKAS69214	Yunnan, SW China	KJ184556	KJ605663	KJ184568	–	Zhao et al. 2014a
Caloboletus yunnanensis	HKAS58694	Yunnan, SW China	KJ605672	KJ605664	KJ619470	–	Zhao et al. 2014a
Chalciporus radiatus	N.K. Zeng 1379 (FHMU 930)	Fujian, SE China	**MH879710**	**MH885367**	**MH879738**	–	this study
Chalciporus radiatus	N.K. Zeng 1414 (FHMU 959)	Fujian, SE China	**MH879711**	–	**MH879739**	–	this study
Chalciporus radiatus	N.K. Zeng 1808 (FHMU 2494)	Hainan, southern China	–	–	**MH879737**	–	this study
Costatisporus cyanescens	Henkel9067	Guyana	LC053662	LC054831	–	–	Smith et al. 2015
Crocinoboletus laetissimus	HKAS50232	Yunnan, SW China	KT990567	–	KT990762	–	Wu et al. 2016a

Taxon	Voucher	Locality	28S	ITS	*tef1*	*rpb2*	References
Crocinoboletus rufoaureus	HKAS53424	Hunan, central China	KF112435	–	KF112206	KF112710	Wu et al. 2014
Cyanoboletus brunneoruber	HKAS63504	Yunnan, SW China	KF112368	–	KF112194	–	Wu et al. 2014
Cyanoboletus brunneoruber	HKAS80579-1	Yunnan, SW China	KT990568	–	KT990763	–	Wu et al. 2016a
Cyanoboletus brunneoruber	HKAS80579-2	Yunnan, SW China	KT990569	–	KT990764	–	Wu et al. 2016a
Cyanoboletus hymenoglutinosus	DC14-010	India	KT860060	KT907355	–	–	Li et al. 2016
Cyanoboletus instabilis	HKAS59554	Yunnan, SW China	KF112412	–	KF112186	–	Wu et al. 2014
Cyanoboletus instabilis	FHMU1839	Yunnan, SW China	MG030466	MG030473	MG030478	–	Chai et al. 2018
Cyanoboletus pulverulentus	9606	USA	KF030313	–	KF030418	–	Nuhn et al. 2013
Cyanoboletus pulverulentus	RW109	Belgium	–	–	KT824046	–	Raspe et al. 2016
Cyanoboletus pulverulentus	MG126a	Italy	KT157062	KT157053	–	–	Gelardi et al. 2015
Cyanoboletus pulverulentus	MG456a	Azores Islands, Portugal	KT157063	KT157054	–	–	Gelardi et al. 2015
Cyanoboletus pulverulentus	MG628a	Italy	KT157064	KT157055	KT157073	–	Gelardi et al. 2015
Cyanoboletus sinopulverulentus	HKAS59609	Yunnan, SW China	KF112366	–	KF112193	–	Wu et al. 2014
Cyanoboletus sp.	HKAS76850	Hainan, southern China	KF112343	–	KF112187	–	Wu et al. 2014
Cyanoboletus sp.	HKAS52639	Yunnan, SW China	KF112367	–	KF112195	–	Wu et al. 2014
Cyanoboletus sp.	HKAS52601	Yunnan, SW China	KF112469	–	–	–	Wu et al. 2014
Cyanoboletus sp.	HKAS50292	Yunnan, SW China	KF112470	–	–	–	Wu et al. 2014
Cyanoboletus sp.	HKAS59418	China	KT990570	–	KT990765	–	Wu et al. 2016a
Cyanoboletus sp.	HKAS90208-1	China	KT990571	–	KT990766	–	Wu et al. 2016a
Cyanoboletus sp.	HKAS90208-2	China	–	–	KT990767	–	Wu et al. 2016a
Cyanoboletus sp.	PRM944518	USA	MF373585	–	–	–	Braeuer et al. 2018
Exsudoporus frostii	SAT1221511	Tennessee, USA	KP055021	–	KP055018	KP055027	Zhao et al. 2014b
Exsudoporus frostii	TENN067311	Tennessee, USA	KT002612	KT002601	KT002636	–	Zhao et al. 2015
Lanmaoa angustispora	HKAS74765	Yunnan, SW China	KF112322	–	KF112159	–	Wu et al. 2014
Lanmaoa angustispora	HKAS74752	Yunnan, SW China	KM605139	–	KM605154	–	Wu et al. 2016b
Lanmaoa angustispora	HKAS74759	Yunnan, SW China	KM605140	–	KM605155	–	Wu et al. 2016b
Lanmaoa asiatica	HKAS54094	Yunnan, SW China	KF112353	–	KF112161	–	Wu et al. 2014
Lanmaoa asiatica	HKAS63516	Yunnan, SW China	KT990584	–	KT990780	–	Wu et al. 2016a
Lanmaoa asiatica	HKAS63603	Yunnan, SW China	KM605142	–	KM605153	–	Wu et al. 2016b
Lanmaoa asiatica	FHMU1389	Yunnan, SW China	MG030470	MG030477	MG030481	–	Chai et al. 2018
Lanmaoa asiatica	FHMU1775	Yunnan, SW China	MG030469	–	MG030480	–	Chai et al. 2018
Lanmaoa flavorubra	NY775777	Costa Rica	JQ924339	–	KF112160	–	Wu et al. 2014
Lanmaoa macrocarpa	N.K. Zeng 3021 (FHMU 1982)	Hainan, southern China	**MH879684**	–	**MH879713**	–	this study
Lanmaoa macrocarpa	N.K. Zeng 3251 (FHMU 2212)	Fujian, SE China	**MH879685**	**MH885347**	**MH879714**	–	this study
Lanmaoa pseudosensibilis	DS615-07	USA	KF030257	–	KF030407	–	Nuhn et al. 2013
Lanmaoa rubriceps	FHMU 1756	Hainan, southern China	MG030465	MG030472	–	–	Chai et al. 2018
Lanmaoa rubriceps	FHMU 1757	Hainan, southern China	MG030467	MG030474	–	–	Chai et al. 2018
Lanmaoa rubriceps	FHMU 1763	Hainan, southern China	MG030468	MG030475	MG030479	–	Chai et al. 2018
Lanmaoa rubriceps	FHMU 2801	Hainan, southern China	MG030471	MG030476	–	–	Chai et al. 2018
Lanmaoa rubriceps	N.K. Zeng 3006 (FHMU 1967)	Hainan, southern China	**MH879683**	**MH885346**	**MH879712**	–	this study
Lanmaoa sp.	HKAS52518	Yunnan, SW China	KF112354	–	KF112162	–	Wu et al. 2014
Neoboletus brunneissimus	HKAS52660	Yunnan, SW China	KF112314	–	KF112143	KF112650	Wu et al. 2014
Neoboletus ferrugineus	HKAS77617	Guangdong, southern China	KT990595	–	KT990788	KT990430	Wu et al. 2016a

Taxon	Voucher	Locality	28S	ITS	*tef1*	*rpb2*	References
Neoboletus ferrugineus	HKAS77718	Guangdong, southern China	KT990596	–	KT990789	KT990431	Wu et al. 2016a
Neoboletus flavidus	HKAS58724	Yunnan, SW China	KU974140	–	KU974137	KU974145	Wu et al. 2016a
Neoboletus flavidus	HKAS59443	Yunnan, SW China	KU974139	–	KU974136	KU974144	Wu et al. 2016a
Neoboletus hainanensis	HKAS59469	Yunnan, SW China	KF112359	–	KF112175	KF112669	Wu et al. 2016a
Neoboletus hainanensis	HKAS90209	Hainan, southern China	KT990615	–	KT990809	KT990450	Wu et al. 2016a
Neoboletus hainanensis	HKAS63515	Yunnan, SW China	KT990614	–	KT990808	KT990449	Wu et al. 2016a
Neoboletus hainanensis	HKAS74880	Yunnan, SW China	KT990597	–	KT990790	KT990432	Wu et al. 2016a
Neoboletus hainanensis	N.K. Zeng 2128 (FHMU 1392)	Yunnan, SW China	**MH879690**	–	**MH879719**	–	this study
Neoboletus luridiformis	AT2001087	Berkshire, England	JQ326995	–	JQ327023	–	Halling et al. 2012
Neoboletus magnificus	HKAS54096	Yunnan, SW China	KF112324	–	KF112149	KF112654	Wu et al. 2014
Neoboletus magnificus	HKAS74939	Yunnan, SW China	KF112320	–	KF112148	KF112653	Wu et al. 2014
Neoboletus multipunctatus	HKAS76851	Hainan, southern China	KF112321	–	KF112144	KF112651	Wu et al. 2014
Neoboletus multipunctatus	N.K. Zeng 2498 (FHMU 1620)	Hainan, southern China	**MH879693**	**MH885354**	**MH879722**	–	this study
Neoboletus multipunctatus	N.K. Zeng3324 (FHMU 2808)	Hainan, southern China	**MK061360**	**MK061359**	**MK061358**	–	this study
Neoboletus obscureumbrinus	HKAS63498	Yunnan, SW China	KT990598	–	KT990791	KT990433	Wu et al. 2016a
Neoboletus obscureumbrinus	HKAS89027	Yunnan, SW China	KT990600	–	KT990794	KT990436	Wu et al. 2016a
Neoboletus obscureumbrinus	N.K. Zeng 3091 (FHMU 2052)	Hainan, southern China	**MH879694**	**MH885355**	**MH879723**	**MH879742**	this study
Neoboletus obscureumbrinus	N.K. Zeng 3094 (FHMU 2055)	Hainan, southern China	**MH879695**	**MH885356**	**MH879724**	**MH879743**	this study
Neoboletus obscureumbrinus	N.K. Zeng 3098 (FHMU 2059)	Hainan, southern China	**MH879696**	**MH885357**	**MH879725**	**MH879744**	this study
Neoboletus rubriporus	HKAS83026	Yunnan, SW China	KT990601	–	KT990795	KT990437	Wu et al. 2016a
Neoboletus rubriporus	HKAS89174	Yunnan, SW China	KT990602	–	KT990796	KT990438	Wu et al. 2016a
Neoboletus rubriporus	HKAS89181	Yunnan, SW China	KT990603	–	KT990797	–	Wu et al. 2016a
Neoboletus rubriporus	HKAS90210	Yunnan, SW China	KT990604	–	KT990798	KT990439	Wu et al. 2016a
Neoboletus rubriporus	MHKMU-L.P. Tang 1958	Yunnan, SW China	–	**MH885358**	**MH879726**	–	this study
Neoboletus sanguineoides	HKAS55440	Yunnan, SW China	KF112315	–	KF112145	KF112652	Wu et al. 2014
Neoboletus sanguineoides	HKAS57766	Yunnan, SW China	KT990605	–	KT990799	KT990440	Wu et al. 2016a
Neoboletus sanguineoides	HKAS63530	Sichuan, SW China	KT990607	–	KT990801	–	Wu et al. 2016a
Neoboletus sanguineoides	HKAS80823	Yunnan, SW China	KT990605	–	KT990799	KT990440	Wu et al. 2016a
Neoboletus sanguineus	HKAS80849	Yunnan, SW China	KT990609	–	KT990803	KT990443	Wu et al. 2016a
Neoboletus sanguineus	HKAS90211	Xizang, SW China	KT990610	–	KT990804	KT990444	Wu et al. 2016a
Neoboletus sanguineus	HKAS68587	Yunnan, SW China	KF112329	–	KF112150	KF112657	Wu et al. 2014
Neoboletus sp.	CMU58-ST-0237	–	KX017292	KX017301	–	–	GenBank
Neoboletus sp.	HKAS76851	Hainan, southern China	KF112321	–	KF112144	KF112651	Wu et al. 2014
Neoboletus sp.	HKAS50351	Yunnan, SW China	KF112318	–	–	KF112658	Wu et al. 2014
Neoboletus sp.	HKAS76660	Henan, Central China	KF112328	–	KF112180	KF112731	Wu et al. 2014
Neoboletus thibetanus	HKAS57093	Xizang, China	KF112326	–	–	KF112655	Wu et al. 2014
Neoboletus tomentulosus	HKAS53369	Fujian, SE China	KF112323	–	KF112154	KF112659	Wu et al. 2014
Neoboletus tomentulosus	HKAS77656	Guangdong, southern China	KT990611	–	KT990806	KT990446	Wu et al. 2016a
Neoboletus tomentulosus	N.K. Zeng 1285 (FHMU 841)	Fujian, SE China	**MH879691**	**MH885352**	**MH879720**	–	this study
Neoboletus tomentulosus	N.K. Zeng 1286 (FHMU 842)	Fujian, SE China	**MH879692**	**MH885353**	**MH879721**	–	this study
Neoboletus venenatus	HKAS57489	Yunnan, SW China	KF112325	–	KF112158	KF112665	Wu et al. 2014
Neoboletus venenatus	HKAS63535	Sichuan, SW China	KT990613	–	KT990807	KT990448	Wu et al. 2016a
Rugiboletus brunneiporus	HKAS68586	Xizang, SW China	KF112402	–	KF112197	–	Wu et al. 2014

Taxon	Voucher	Locality	28S	ITS	*tef1*	*rpb2*	References
Rugiboletus brunneiporus	HKAS83009	Xizang, SW China	KM605133	–	KM605146	–	Wu et al. 2016b
Rugiboletus extremiorientalis	HKAS76663	Henan, Central China	KM605135	–	KM605147	KM605170	Wu et al. 2016b
Rugiboletus extremiorientalis	HKAS74754	China	KT990639	–	KT990832	KT990469	Wu et al. 2016a
Rubroboletus latisporus	HKAS63517	Yunnan, SW China	KP055022	–	KP055019	KP055028	Zhao et al. 2014b
Rubroboletus latisporus	HKAS80358	Chongqing, SW China	KP055023	–	KP055020	KP055029	Zhao et al. 2014b
Rubroboletus sinicus	HKAS68620	Yunnan, SW China	KF112319	–	KF112146	KF112661	Zhao et al. 2014b
Sutorius aff. *eximius*	HKAS56291	Yunnan, SW China	KF112400	–	KF112208	KF112803	Wu et al. 2014
Sutorius aff. *eximius*	MHKMU-S.D. Yang 010	Yunnan, SW China	**MH879697**	**MH885359**	**MH879727**	–	this study
Sutorius australiensis	REH9280	Australia	JQ327031	–	JQ327031	–	Arora and Krank 2014
Sutorius australiensis	REH9441	Australia	JQ327006	–	JQ327032	MG212652	Halling et al. 2012
Sutorius eximius	REH9400	USA	JQ327004	–	JQ327029	–	Arora and Krank 2014
Sutorius eximius	HKAS52672	Yunnan, SW China	KF112399	–	KF112207	KF112802	Wu et al. 2014
Sutorius eximius	HKAS50420	Yunnan, SW China	KT990549	–	KT990750	KT990387	Wu et al. 2016a
Sutorius eximius	HKAS59657	China	KT990707	–	KT990887	KT990505	Wu et al. 2016a
Sutorius eximius	8594	Costa Rica	JQ327008	–	JQ327027	–	Halling et al. 2012
Sutorius eximius	995	Costa Rica	JQ327010	–	JQ327030	–	Halling et al. 2012
Sutorius eximius	986	Costa Rica	JQ327009	–	JQ327028	–	Halling et al. 2012
Sutorius eximius	8069	Indonesia	JQ327003	–	–	–	Halling et al. 2012
Sutorius sp.	N.K. Zeng 3297 (FHMU 2258)	Fujian, SE China	**MH879701**	–	**MH879731**	–	this study
Sutorius sp.	ECV3603	Thailand	JQ327000	–	JQ327033	–	Halling et al. 2012
Sutorius sp.	01-528	Zambia	JQ327002	–	–	–	Halling et al. 2012
Sutorius subrufus	N.K. Zeng 3043 (FHMU 2004)	Hainan, southern China	**MH879698**	**MH885360**	**MH879728**	**MH879745**	this study
Sutorius subrufus	N.K. Zeng 3045 (FHMU 2006)	Hainan, southern China	**MH879699**	**MH885361**	**MH879729**	**MH879746**	this study
Sutorius subrufus	N.K. Zeng 3140 (FHMU 2101)	Hainan, southern China	**MH879700**	–	**MH879730**	**MH879747**	this study

three collections were newly generated and deposited in GenBank (Table 1), and then combined with selected sequences from previous studies (Table 1). *Rugiboletus brunneiporus* G. Wu & Zhu L. Yang was chosen as outgroup on the basis of the phylogeny in Wu et al. (2016a). To test for phylogenetic conflict among the different genes in three combined datasets (*Butyriboletus*, *Caloboletus* + *Neoboletus* + *Sutorius*, *Lanmaoa*), the partition homogeneity (PH) or incongruence length difference (ILD) test was performed with 1000 randomized replicates, using heuristic searches with simple addition of sequences in PAUP* 4.0b10 (Swofford 2002). The results of the partition homogeneity test showed that the phylogenetic signals present in the different gene fragments were not in conflict. Then the sequences of different genes in three combined datasets (*Butyriboletus*, *Caloboletus* + *Neoboletus* + *Sutorius*, *Lanmaoa*) were aligned with MAFFT v. 6.8 using algorithm E-INS-i (Katoh et al. 2005) and manually optimized on BioEdit v. 7.0.9 (Hall 1999). The sequences of the different genes were concatenated in three combined datasets (*Butyriboletus*, *Caloboletus* + *Neoboletus* + *Sutorius*, *Lanmaoa*) using Phyutility v. 2.2 for further analyses (Smith and Dunn 2008).

Phylogenetic analyses

The three combined datasets (*Butyriboletus*, *Caloboletus* + *Neoboletus* + *Sutorius*, *Lanmaoa*) were all analyzed by using maximum likelihood (ML) and Bayesian inference (BI). Maximum likelihood tree generation and bootstrap analyses were performed with the program RAxML 7.2.6 (Stamatakis 2006) running 1000 replicates combined with an ML search. Bayesian analysis with MrBayes 3.1 (Huelsenbeck and Ronquist 2005) implementing the Markov Chain Monte Carlo (MCMC) technique and parameters predetermined with MrModeltest 2.3 (Nylander 2004) was performed. The model of evolution used in the Bayesian analysis was determined with MrModeltest 2.3 (Nylander 2004). For the combined dataset of *Butyriboletus*, the best-fit likelihood models of 28S, ITS1+ITS2, 5.8S, *tef1* and *rpb2* were GTR+I+G, HKY+I+G, K80, SYM+I+G and K80+I+G, respectively; for the combined dataset of *Caloboletus*, *Neoboletus*, and *Sutorius*, the best-fit likelihood models of 28S, ITS1+ITS2, 5.8S, *tef1* and *rpb2* were GTR+I+G, HKY+I+G, K80, SYM+I+G and SYM+I+G, respectively; for the combined dataset of *Lanmaoa*, the best-fit likelihood models of 28S, ITS1+ITS2, 5.8S and *tef1* were GTR+I+G, GTR+I, K80 and SYM+G, respectively. Bayesian analysis was run with one cold and three heated chains and sampled every 100 generations; trees sampled from the first 25% of the generations were discarded as burn-in; the average standard deviation of split frequencies was restricted to be below 0.01, and Bayesian posterior probabilities (PP) were then calculated for a majority consensus tree of the retained Bayesian trees.

Results

Molecular data

The four-locus dataset (28S + ITS + *tef1* + *rpb2*) of *Butyriboletus* consisted of 52 taxa and 3116 nucleotide sites (Fig. 1). The aligned dataset was submitted to TreeBASE (http://purl.org/phylo/treebase/phylows/study/TB2:S23508). The molecular phylogenetic analyses showed that the collections numbered as FHMU 2206 and FHMU 2207 respectively grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage within *Butyriboletus* (Fig. 1).

The four-locus dataset (28S + ITS + *tef1* + *rpb2*) with *Caloboletus*, *Neoboletus*, and *Sutorius* consisted of 93 taxa and 3228 nucleotide sites (Fig. 2). The aligned dataset was submitted to TreeBASE (http://purl.org/phylo/treebase/phylows/study/TB2:S23509). The molecular phylogenetic analyses indicated each of the previously described genera, viz. *Neoboletus*, *Sutorius*, *Costatisporus* T.W. Henkel & M.E. Sm., and *Caloboletus*, forms an independent clade with a high statistical support respectively (Fig. 2). In the genus *Neoboletus*, one collection numbered as FHMU 1392 and one previously described *S. hainanensis* (T.H. Li & M. Zang) G. Wu and Zhu L. Yang grouped together with a strong statistical support (BS = 100, PP = 1), forming an independent lineage; two collections numbered as FHMU 841 and FHMU 842 respectively and one previously described

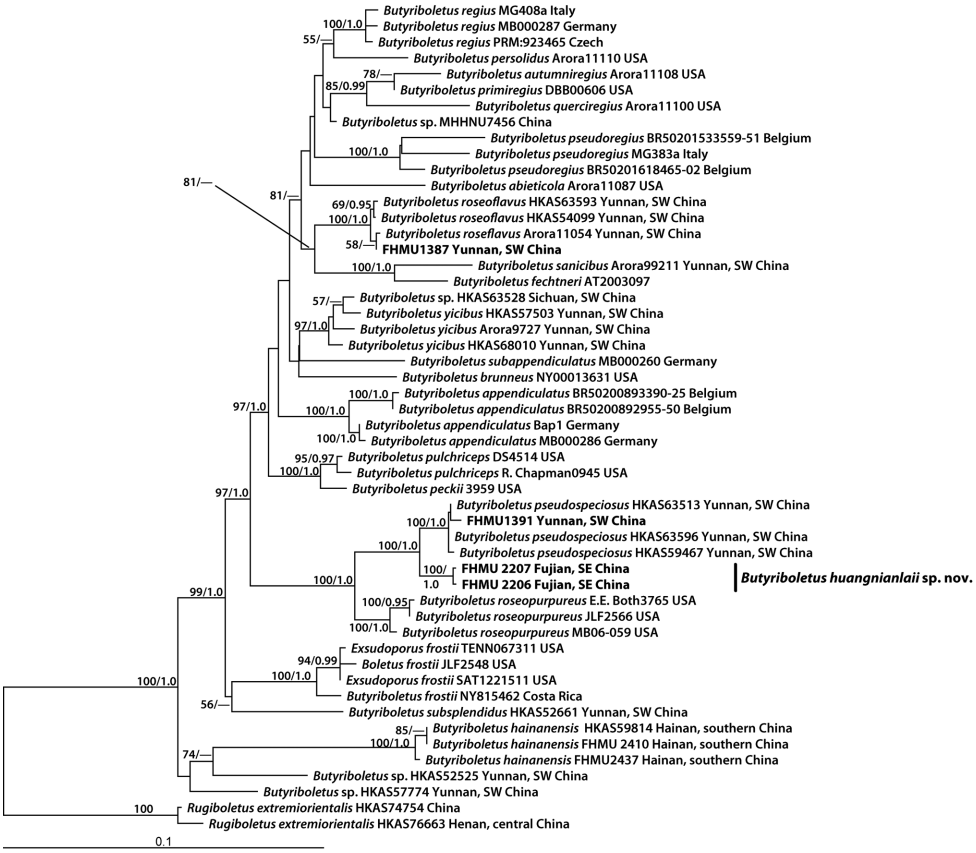

Figure 1. Phylogenetic placement of *Butyriboletus huangnianlaii* inferred from a multilocus (28S, ITS, *tef1*, *rpb2*) dataset using RAxML. BS ≥ 50% and PP ≥ 0.95 are indicated above or below the branches as RAxML BS/PP.

S. tomentulosus (M. Zang et al.) G. Wu & Zhu L. Yang grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage; one collection tentatively named *Sutorius* sp. (HKAS 76851) in a previous study (Wu et al. 2016a) and one specimen numbered as FHMU 1620 grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage; three specimens numbered as FHMU 2052, FHMU 2055, FHMU 2059 respectively and one previously described *S. obscureumbrinus* (Hongo) G. Wu & Zhu L. Yang grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage (Fig. 2). In the genus *Sutorius*, the specimens numbered as FHMU 2004, FHMU 2006 and FHMU 2101 respectively grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage (Fig. 2). In the genus *Caloboletus*, the materials numbered as FHMU 883, FHMU 884, FHMU 906 respectively and the holotype of *C. xiangtoushanensis* Ming Zhang et al. grouped together with a high statistical support (BS = 100, PP = 1),

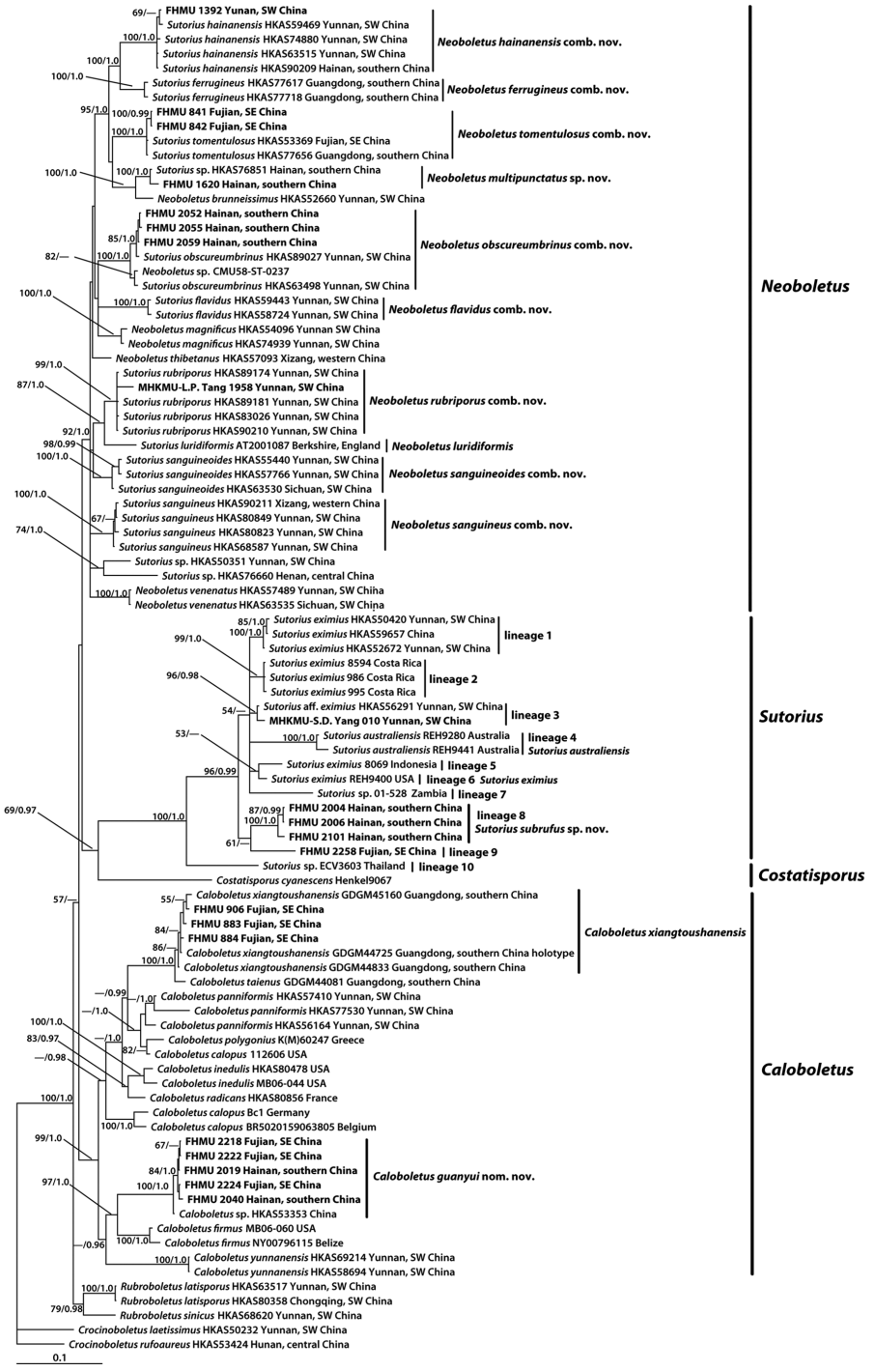

Figure 2. Phylogenetic placement of *Neoboletus multipunctatus*, *Sutorius subrufus* and *Caloboletus guanyui* inferred from a multilocus (28S, ITS, *tef1*, *rpb2*) dataset using RAxML. BS ≥ 50% and PP ≥ 0.95 are indicated above or below the branches as RAxML BS/PP.

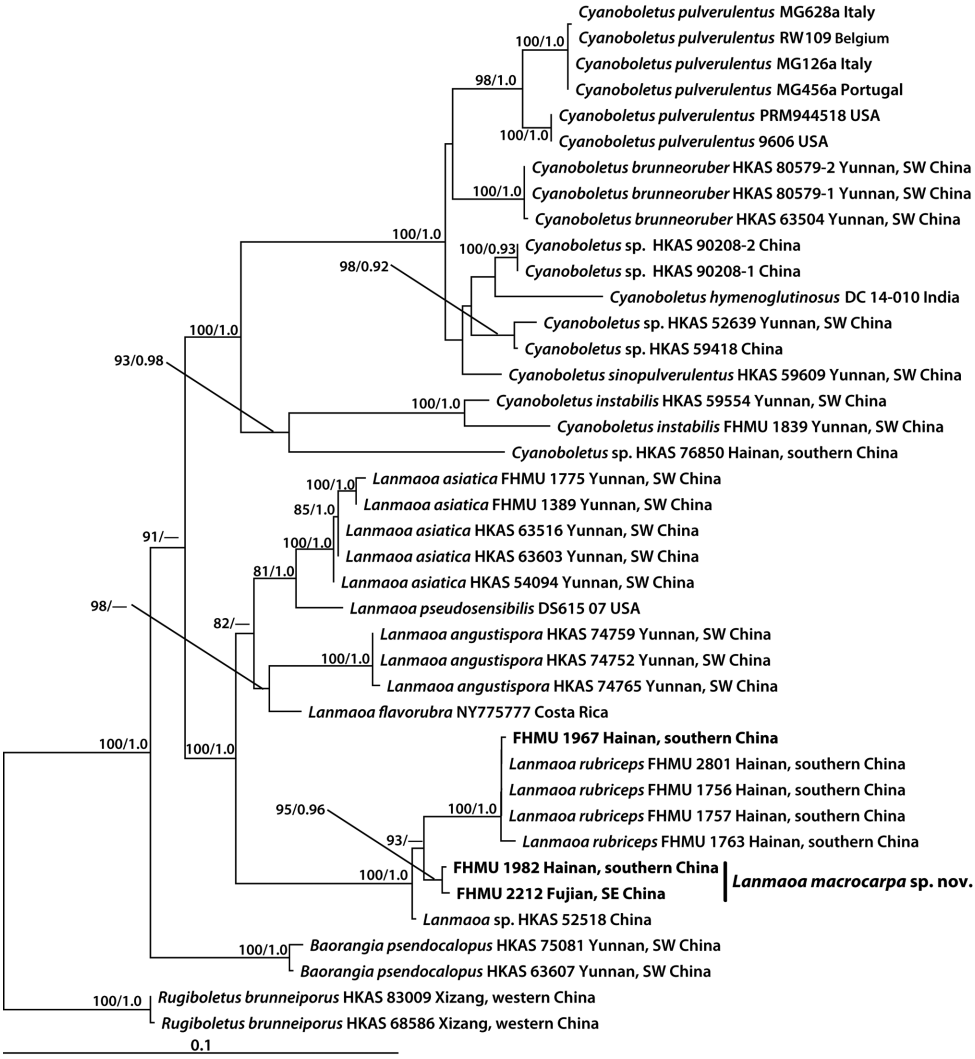

Figure 3. Phylogenetic placement of *Lanmaoa macrocarpa* inferred from a multilocus (28S, ITS, *tef1*) dataset using RAxML. BS ≥ 50% and PP ≥ 0.95 are indicated above or below the branches as RAxML BS/PP.

forming an independent lineage; the collections numbered as FHMU 2019, FHMU 2040, FHMU 2218, FHMU 2222 and FHMU 2224 respectively grouped together with a strong statistical support (BS = 100, PP = 1), forming an independent lineage (Fig. 2).

The three-locus dataset (28S + ITS + *tef1*) of *Lanmaoa* consisted of 40 taxa and 2007 nucleotide sites (Fig. 3). The aligned dataset was submitted to TreeBASE (http://purl.org/phylo/treebase/phylows/study/TB2:S23510). The molecular phylogenetic analyses showed that the collections numbered as FHMU 1982 and FHMU 2212 respectively grouped together with a high statistical support (BS = 100, PP = 1), forming an independent lineage within *Lanmaoa* (Fig. 3).

Taxonomy

Butyriboletus D.Arora & J.L. Frank

Butyriboletus, typified by *But. appendiculatus* (Schaeff.) D. Arora & J.L. Frank, was erected to accommodate the "butter boletes", which are mainly characterized by yellow hymenophore and context staining blue when injured and stipe surface usually covered with reticulations (Arora and Frank 2014; Zhao et al. 2015). Until now, six species, including *But. hainanensis* N.K. Zeng et al., *But. pseudospeciosus* Kuan Zhao & Zhu L.Yang, *But. roseoflavus* (Hai B. Li & Hai L.Wei) D.Arora & J.L. Frank, *But. sanicibus* D. Arora & J.L. Frank, *But. subsplendidus* (W.F. Chiu) Kuan Zhao et al., and *But. yicibus* D. Arora & J.L. Frank have been described from China (Arora and Frank 2014; Liang et al. 2016; Wu et al. 2016a). Herein, we describe another novel species.

1. *Butyriboletus huangnianlaii* N.K. Zeng, H. Chai & Zhi Q. Liang, sp. nov.

MycoBank: MB828521
Figures 4a, b, 7

Typification. CHINA. Fujian Province: Sanming City, Geshikao National Forest Park, elev. 420 m, 16 August 2017, *N.K. Zeng 3246* (FHMU 2207, holotype). GenBank accession numbers: 28S = MH879689, ITS = MH885351, *tef1* = MH879718, *rpb2* = MH879741.

Etymology. Latin, "*huangnianlaii*" is named after Chinese mycologist Nian-Lai Huang, in honor of his contribution to mycology.

Description. *Basidiomata* medium-sized to large. *Pileus* 5–11 cm in diameter, convex to applanate; surface dry, finely tomentose, pale brown (5D1–4D2), brown to reddish brown (5C2–6C2); context 0.6–2.2 cm thick in the center of the pileus, yellowish to yellow, changing blue quickly when injured. *Hymenophore* poroid, adnate or slightly depressed around apex of stipe; pores angular, about 0.5 mm in diameter, yellowish white (30A2) to yellowish brown (4A4), changing blue quickly when injured; tubes 0.4–0.8 cm in length. *Stipe* 4.5–8 × 1.3–2.5 cm, central, subcylindric, solid; surface dry, yellowish (30A2) when young, then brownish red (8D5), reticulate nearly to base; reticulum yellowish (1A2) when young, then brownish red (8D5); context yellowish to yellow, changing blue quickly when injured; basal mycelium white (1A1). *Odor* indistinct.

Basidia 20–31 × 6–9 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 3–4 μm in length. *Basidiospores* [40/2/2] (7–)7.5–10.5(–11) × 3–4 μm, Q=(2.00–)2.14–2.86(–3.14), Q_m=2.51 ± 0.27, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of colorless to yellowish in KOH, 3–10 μm wide, thin- to slightly thick-walled (to 0.5 μm) hyphae. *Cheilocystidia* 32–53 × 7–12 μm, fusiform or subfusiform, thin-walled, yellowish in KOH, no

Figure 4. Basidiomata of boletes. **a, b** *Butyriboletus huangnianlaii* (FHMU 2207, holotype) **c–f** *Caloboletus guanyui* (**c–d** from FHMU 399; **e** from FHMU 2224; f from FHMU 2222) **g–j** *Caloboletus xiangtoushanensis* (**g** from FHMU 883 **h, j** from FHMU 906 **i** from FHMU 884) **k, l** *Chalciporus radiatus* (FHMU 930). Photos by N.K. Zeng.

encrustations. *Pleurocystidia* 40–60 × 8–13 μm, fusiform or subfusiform, thin-walled, yellowish in KOH, no encrustations. *Pileipellis* a trichoderm about 110 μm thick, composed of slightly interwoven, nearly colorless in KOH, 4–6 μm wide, thin-walled hyphae; terminal cells 30–50× 4–8 μm, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 8–12 μm in diameter, thin-walled, colorless in KOH. *Stipitipellis* hymeniform about 120–140 μm thick, composed of thin- to slightly thick-walled (to 0.5 μm) emergent hyphae, colorless to yellowish in KOH, with clavate, subclavate, fusiform or subfusiform terminal cells (15–45 × 4–9 μm) , and occasionally with scattered clavate, 4-spored basidia. *Stipe trama* composed of longitudinally arranged, paral-

lel hyphae 3.5–7 μm wide, cylindrical, thin- to slightly thick-walled (up to 0.5 μm), colorless to yellowish in KOH, parallel hyphae. *Clamp connections* absent in all tissues.

Habitat. Scattered on the ground in forests dominated by *Castanopsis kawakamii* Hay.

Distribution. Southeastern China.

Additional specimens examined. CHINA. Fujian Province: Sanming City, Geshikao National Forest Park, elev. 420 m, 16 August 2017, *N.K. Zeng 3245* (FHMU 2206).

Note. *Butyriboletus huangnianlaii* is characterized by a medium-sized to large basidioma, pileal surface densely covered with pale brown to reddish brown squamules, smaller basidiospores, and its association with fagaceous trees. It is both morphologically similar and phylogenetically related to *But. pseudospeciosus* and *But. roseoflavus* (Fig. 1). However, *But. pseudospeciosus*, originally described from Yunnan Province of southwestern China, has a tomentose pileus without a reddish tinge, surface of pileus and stipe promptly staining blue when bruised, narrower cystidia and longer basidiospores measuring 9–11 × 3.5–4 μm (Wu et al. 2016a); *But. roseoflavus*, originally described from Zhejiang Province of southeastern China, has a pinkish to purplish red or rose-red pileus with tomentose surface, longer basidiospores measuring 9–12 × 3–4 μm, and its association with *Pinus* spp. (Arora and Frank 2014; Li et al. 2014; Wu et al. 2016a).

Caloboletus Vizzini

Caloboletus, typified by *C. calopus* (Pers.) Vizzini, is mainly characterized by yellow tubes, yellow or more rarely orange to red pores changing to blue when injured, bitter taste of the context due to the presence of calopin and cyclocalopin (Hellwig et al. 2002; Vizzini 2014; Zhao et al. 2014a; Wu et al. 2016a; Zhang et al. 2017). Until now, four species, including *C. panniformis* (Taneyama & Har. Takah.) Vizzini, *C. taienus* (W.F. Chiu) Ming Zhang and T.H. Li, *C. xiangtoushanensis* Ming Zhang et al., and *C. yunnanensis* Kuan Zhao & Zhu L. Yang, have been found in China (Zhao et al. 2014a; Wu et al. 2016a; Zhang et al. 2017). We describe two *Caloboletus* species here.

2. *Caloboletus guanyui* N.K. Zeng, H. Chai & S. Jiang, nom. nov.

MycoBank: MB828522

Figures 4c–f, 8

Boletus quercinus Hongo, Memoirs of Shiga University 17: 92, 1967 (nom. illeg., later homonym)

non *Boletus quercinus* Schrad., Spicilegium Florae Germanicae 1: 157, 1794

non *Boletus quercinus* (Pilát) Hlaváček, Mykologický Sborník 67(3): 87, 1990 (nom. illeg., later homonym)

Etymology. Latin, "*guanyui*" is named for Guan Yu, a historic Chinese hero, said to have a reddish face, and thus sharing the same color of pores of the species when young.

Description. *Basidiomata* medium-sized to large. *Pileus* 5–10 cm in diameter, convex to applanate; surface dry, finely tomentose, dirty white to pale brown; context 0.5–1.8 cm thick in the center of the pileus, white, changing bluish quickly when injured, then back to white. *Hymenophore* poroid, depressed around apex of stipe; pores subround, 0.3–0.5 mm in diameter, reddish to reddish brown when young, then yellow or yellowish brown, changing bluish black when injured; tubes about 0.5–1 cm in length, yellowish, changing bluish quickly when injured. *Stipe* 5.5–9 × 0.7–1.5 cm, central, subcylindric, solid, usually flexuous; surface dry, densely covered with pale brown, brown to reddish brown, minute squamules; context white, sometimes tinged with pale red, unchanging in color when injured; basal mycelium white. *Odor* indistinct.

Basidia 21–30 × 6–8 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 3–4 μm in length. *Basidiospores* [220/12/5] (8.5–)9–11(–12) × 3.5–4.5 μm, Q=(2.00–)2.22–2.67(–2.86), Q_m=2.43 ± 0.17, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of yellowish in KOH, 4–10 μm wide, thin-walled hyphae. *Cheilocystidia* 25–40 × 7–10 μm, fusiform or subfusiform, thin-walled, colorless to yellowish in KOH, no encrustations. *Pleurocystidia* 35–45 × 6–11 μm, fusiform or subfusiform, thin-walled, colorless to yellowish in KOH, no encrustations. *Pileipellis* a trichoderm about 100–200 μm thick, composed of slightly interwoven, nearly colorless in KOH, 5–8 μm wide, thin-walled hyphae; terminal cells 28–35 × 5–10 μm, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 4–8 μm in diameter, slightly thick-walled (to 0.5 μm), colorless to yellowish in KOH. *Stipitipellis* hymeniform about 80–100 μm thick, composed of thin-walled emergent hyphae, yellowish in KOH, with clavate, subclavate, fusiform or subfusiform terminal cells (27–43 × 6–11 μm), and occasionally with scattered clavate, 4-spored basidia. *Stipe trama* composed of longitudinally arranged, parallel hyphae 3–6 μm wide, cylindrical, thin-walled, colorless to yellowish in KOH. *Clamp connections* absent in all tissues.

Habitat. Gregarious on the ground in forests dominated by *Castanopsis kawakamii* Hay. or *Lithocarpus* spp.

Distribution. Southeastern and southern China; Japan (Hongo 1967).

Specimens examined. CHINA. Hainan Province: Ledong County, Yinggeling National Nature Reserve, elev. 650 m, 4 June 2017, *N.K. Zeng 3058* (FHMU 2019); same location, 5 June 2017, *N.K. Zeng 3079* (FHMU 2040). Fujian Province: Zhangping County, Tiantai National Forest Park, elev. 350 m, 28 August 2009, *N.K. Zeng 635* (FHMU 399); Sanming City, Geshikao National Forest Park, elev. 420 m, 16 August 2017, *N.K. Zeng 3257* (FHMU 2218); same location and date, *N.K. Zeng 3261* (FHMU 2222); Yongan City, Tianbaoyan National Nature Reserve, elev. 600 m, 17 August 2017, *N.K. Zeng 3263* (FHMU 2224).

Note. *Caloboletus guanyui* was originally described as *B. quercinus* from Japan (Hongo 1967). Nomenclaturally, the epithet *quercinus* of this species is an illegitimate

name, because Schrader (1794) described a species using the same epithet before Hongo (1967). Therefore, the new epithet *guanyui* is proposed here for this species. Moreover, morphological and molecular evidence indicates the taxon is a member of the genus *Caloboletus* (Fig. 2), and is characterized by a dirty-white to pale-brown pileus, pores reddish to reddish brown when young, then yellow or yellowish brown, changing bluish black when injured, and a stipe densely covered with pale-brown, brown to reddish-brown squamules. Morphologically, *C. taienus* and *C. xiangtoushanensis* also have reddish pores (Bessette et al. 2016; Zhang et al. 2017), however, a dirty-white to pale-brown pileus easily distinguishes *C. guanyui* from the two taxa. Phylogenetically *C. guanyui* is closely related to *C. firmus* (Frost) Vizzini (Fig. 2), however, *C. firmus* has a stipe covered with whitish or reddish reticula, and it is restricted to North and Central America (Bessette et al. 2016).

3. *Caloboletus xiangtoushanensis* Ming Zhang, T.H. Li & X.J. Zhong, Phytotaxa 309: 119, 2017

Figures 4g–j, 9

Description. *Basidiomata* medium-sized to large. *Pileus* 5.5–11 cm in diameter, convex to plane; surface dry, tomentose, yellowish brown, pale brown to brown; context 1–1.5 cm thick in the center of the pileus, yellowish, changing blue quickly when injured. *Hymenophore* poroid, adnate to depressed around apex of stipe; pores subround to angular, 0.5–1 mm in diameter, yellow, sometimes brownish red, changing blue quickly when injured; tubes 0.5–1.4 cm in length, yellowish, changing blue quickly when injured. *Stipe* 5–9 × 0.9–1.6 cm, central, subcylindric, solid, usually flexuous; surface dry, upper part covered with reddish brown, minute squamules, middle and lower part covered with brown minute squamules; context yellowish, changing blue quickly when injured; basal mycelium white. *Odor* indistinct.

Basidia 25–35 × 5–10 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 3–4 μm in length. *Basidiospores* [140/8/3] (9.5–)10–11.5(–13) × 3.5–4.5 μm, Q=(2.11–)2.44–3.00(–3.29), Q_m=2.76 ± 0.21, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of colorless to yellowish in KOH, 4–10 μm wide, thin-walled hyphae. *Cheilocystidia* 25–45 × 7–10 μm, fusiform or subfusiform, thin-walled, colorless in KOH, no encrustations. *Pleurocystidia* 30–50 × 7–12 μm, fusiform or subfusiform, thin-walled, colorless in KOH, no encrustations. *Pileipellis* a trichoderm about 70–100 μm thick, composed of slightly interwoven, colorless or yellowish in KOH, 4–7 μm wide, thin-walled hyphae; terminal cells 35–55 × 4–7 μm, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 3.5–7 μm in diameter, thin-walled, colorless to yellowish in KOH. *Stipitipellis* hymeniform about 60–80 μm thick, composed of thin- to slightly thick-walled (to 0.5 μm) emergent hyphae, colorless to yellowish in KOH, with clavate, subclavate,

fusiform or subfusiform terminal cells (15–46 × 5–8 μm), and occasionally with scattered clavate, four-spored basidia. *Stipe trama* composed of longitudinally arranged, parallel hyphae 3.5–8 μm wide, cylindrical, thin- to slightly thick-walled (to 0.5 μm), yellowish in KOH. *Clamp connections* absent in all tissues.

Habitat. Solitary or gregarious on the ground in forests dominated by fagaceous trees.

Distribution. Southeastern and southern China.

Specimens examined. CHINA. Fujian Province: Zhangping County, Xinqiao Town, Chengkou Village, elev. 350 m, 30 July 2013, *N.K. Zeng 1330* (FHMU 883); same location and date, *N.K. Zeng 1331* (FHMU 884); same location, 1 August 2013, *N.K. Zeng 1354* (FHMU 906).

Notes. Our recent collections and the holotype of *C. xiangtoushanensis*, a species originally described from Guangdong Province of southern China (Zhang et al. 2017), phylogenetically group together with a strong statistical support (Fig. 2), which indicates that these specimens should be recognized as *C. xiangtoushanensis*. It is new to Fujian Province. Morphologically, several features of our collections also match well with the protologue of *C. xiangtoushanensis* (Zhang et al. 2017), but reticulations on the stipe were not observed in our specimens. Moreover, pores of our specimens are sometimes brownish red. In appearance, *C. xiangtoushanensis* is highly similar to Japanese *B. bannaensis* Har. Takah., which needs further confirmation for generic placement (Takahashi 2007). However, *B. bannaensis* has rufescent and faintly cyanescent context, small basidiospores measuring 6.5–9 × 3.5–4 μm, and narrower cystidia (Takahashi 2007). The molecular analyses also indicates that *C. xiangtoushanensis* is closely related to *C. taienus* (W.F. Chiu) Ming Zhang and T.H. Li (Fig. 2), a species originally described from Yunnan Province (Chiu 1948); their morphological differences have been elucidated in a previous study (Zhang et al. 2017).

Chalciporus Bataille

Chalciporus, typified by *Ch. piperatus* (Bull.) Bataille, is an early branching lineage in the Boletaceae (Nuhn et al. 2013; Wu et al. 2014, 2016b) and is characterized by a pinkish-red to reddish-brown hymenophore. Several taxa, including *Ch. citrinoaurantius* Ming Zhang & T.H. Li, *Ch. hainanensis* Ming Zhang & T.H. Li, *Ch. radiatus* Ming Zhang & T.H. Li, and *Ch. rubinelloides* G.Wu & Zhu L. Yang, were recently described from China (Zhang et al. 2015, 2017; Wu et al. 2016b). Here, *Ch. radiatus* is redescribed based on new collections from subtropical and tropical China.

4. *Chalciporus radiatus* Ming Zhang & T.H. Li, Mycoscience 57: 21, 2016

Figures 4k, l, 10

Description. *Basidiomata* small. *Pileus* 2.5–5 cm in diameter, subhemispherical to convex when young, then applanate; surface dry, pale yellowish brown, densely cov-

ered with pale yellowish-brown, yellowish-brown, brown to reddish-brown squamules; margin decurved; context 0.6–1 cm thick in the center of the pileus, yellowish, unchanging in color when injured. *Hymenophore* poroid, slightly decurrent; pores radially strongly elongated, yellow to pale yellowish brown, reddish with age, unchanging in color when injured; tubes 0.2–0.4 cm in length, yellowish, unchanging in color when injured. *Stipe* 2.5–4.5 × 0.5–1 cm, central, subcylindric, solid; surface dry, yellow, covered with yellowish brown, brown to reddish-brown squamules; context yellowish, unchanging in color when injured; annulus absent; basal mycelium yellow. *Odor* indistinct.

Basidia 23–34 × 7–10 μm, clavate, thin-walled, four-spored; sterigmata 5–6 μm in length. *Basidiospores* [101/5/4] 6–7(–8) × 3–4 μm, Q = (1.63–)1.71–2.14(–2.33), Q_m = 1.91 ± 0.15, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid. *Cheilocystidia* 57–75 × 8–10 μm, abundant, subfusiform or fusiform, thin-walled, with pale yellowish-brown to yellowish-brown contents, without encrustations. *Pleurocystidia* 60–76 × 7–9 μm, abundant, fusiform or subfusiform, thin-walled, with pale yellowish-brown to yellowish-brown contents, without encrustations. *Pileipellis* a trichoderm 200–230 μm thick, composed of rather vertically arranged, sometimes slightly interwoven, pale yellowish-brown to yellowish-brown in KOH, thin-walled hyphae 4–10 μm in diameter; terminal cells 25–50 × 6–9 μm, narrowly clavate or subcylindrical, with obtuse apex. *Pileal trama* composed of thin- to slightly thick-walled (up to 0.5μm) hyphae 2–8 μm in diameter. *Stipitipellis* hymeniform composed of thin- walled hyphae with clavate, subclavate, subfusiform or fusiform terminal cells (13–80 × 5–9 μm). *Stipe trama* composed of cylindrical, thin- to slightly thick-walled (to 0.5 μm) parallel hyphae 5–11 μm in diameter. *Clamp connections* absent in all tissues.

Habitat. Solitary, scattered or gregarious on the ground in forests of *Pinus massoniana* Lamb. or *P. latteri* Mason.

Distribution. Central (Zhang et al. 2015), southeastern, and southern China.

Specimens examined. CHINA. Fujian Province: Zhangping County, Xinqiao Town, Chengkou Village, elev. 370 m, 4 August 2013, *N.K. Zeng 1379* (FHMU 930); same location, 17 August 2013, *N.K. Zeng 1414* (FHMU 959); same location, 16 August 2014, *N.K. Zeng 1633* (FHMU 2493). Hainan Province: Dongfang County, Exian Mountain, elev. 633 m, 5 October 2014, *N.K. Zeng 1808* (FHMU 2494).

Notes. Our molecular phylogenetic analyses indicate that the new collections and the holotype of *Ch. radiatus*, a species first described from Hunan Province of central China, group together with a strong statistical support based on a two-locus dataset (28S + *tef1*) (data not shown). This indicates that our specimens should be recognized as *Ch. radiatus* (Zhang et al. 2015). This species is new to Fujian and Hainan Province. Zhang et al. (2015) reported *Ch. radiatus* from under *Cunninghamia lanceolata* (Lamb.) Hook, *Cyclobalanopsis* spp. and *Castanopsis* spp. We found the species associated with *Pinus* spp.

Lanmaoa G.Wu & Zhu L.Yang

Lanmaoa, typified by *L. asiatica* G. Wu & Zhu L. Yang, was erected recently. However, *Lanmaoa* and its closely related genus *Cyanoboletus* share overlapping morphological features and the most important diagnostic feature of *Lanmaoa* defined by Wu et al. (2016a) is not constant (Chai et al. 2018). Here, we treat *Lanmaoa* as an independent genus until the true taxonomic relationship between *Lanmaoa* and *Cyanoboletus* can be studied.

5. *Lanmaoa macrocarpa* N.K. Zeng, H. Chai & S. Jiang, sp. nov.

MycoBank: MB828523
Figures 5a–c, 11

Typification. CHINA. Hainan Province: Qiongzhong County, Yinggeling National Nature Reserve, elev. 750 m, 28 May 2017, *N.K. Zeng 3021* (FHMU 1982, holotype). GenBank accession numbers: 28S = MH879684, *tef1* = MH879713.

Etymology. Latin, "*macrocarpa*", meaning the new species has a large pileus.

Description. *Basidiomata* large. *Pileus* 10–13 cm in diameter, subhemispherical when young, then convex to applanate; surface dry, finely tomentose, brownish red (8B6–9B6); context about 2.5 cm thick in the center of the pileus, yellowish, changing blue quickly when injured. *Hymenophore* poroid, depressed around apex of stipe; pores subround to angular, 1–2 mm in diameter, yellow (3A5), changing blue quickly, then turning brown slowly when injured; tubes about 1.5 cm in length. *Stipe* 8–11 × 1.5–2 cm, central, subcylindric, solid; surface dry, brownish red (9C6), sometimes reticulate at apex; context yellow, changing blue quickly when injured; basal mycelium yellowish (2A4). *Odor* indistinct.

Basidia 18–28 × 6–10 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 3–4 μm in length. *Basidiospores* [40/2/2] (9–)10–12(–13) × 4.5–5 μm, Q=(2.00–)2.10–2.60(–2.67), Q_m=2.39 ± 0.16, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of colorless to yellowish in KOH, 4.5–9 μm wide, thin- to slightly thick-walled (to 0.5 μm) hyphae. *Cheilocystidia* 25–42 × 7–10 μm, ventricose, fusiform or subfusiform, thin-walled, yellowish in KOH, no encrustations. *Pleurocystidia* 25–45 × 7–11 μm, fusiform or subfusiform, thin-walled, yellowish in KOH, no encrustations. *Pileipellis* a trichoderm 120–160 μm thick, composed of rather vertically arranged, nearly colorless in KOH, 4.5–6 μm wide, thin-walled hyphae; terminal cells 21–32 × 4–6 μm long, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 3–10 μm in diameter, thin-walled, nearly colorless in KOH. *Stipitipellis* hymeniform about 100 μm thick, composed of thin- to slightly thick-walled (to 0.5 μm) emergent hyphae, colorless in KOH, with clavate, subclavate, fusiform, or subfusiform terminal cells (22–43 × 3–9 μm), and oc-

Figure 5. Basidiomata of boletes. **a–c** *Lanmaoa macrocarpa* (a from FHMU 2212; **b–c** from FHMU 1982, holotype) **d–f** *Neoboletus hainanensis* (HKAS 90209) **g–l** *Neoboletus multipunctatus* (**g, i–j, l** from FHMU 2808 **h, k** from FHMU 1620, holotype). Photos by N.K. Zeng.

casionally with scattered clavate, 4-spored basidia. *Stipe trama* composed of longitudinally arranged, parallel hyphae 3–8 μm wide, cylindrical, thin- to slightly thick-walled (to 0.5 μm), yellowish in KOH. *Clamp connections* absent in all tissues.

Habitat. Solitary on the ground in forests dominated by *Castanopsis kawakamii* Hay. or *C. fissa* (Champ. ex Benth.) Rehd. et Wils.

Distribution. Southeastern and southern China.

Additional specimens examined. CHINA. Fujian Province: Sanming City, Geshikao National Forest Park, elev. 400 m, 16 August 2017, *N.K. Zeng* 3251 (FHMU 2212).

Note. *Lanmaoa macrocarpa* is characterized by its large basidioma, brownish red pileus and stipe, thickness of hymenophore 3/5 times that of pileal context, and its

association with *Castanopsis* spp. It is both morphologically similar and phylogenetically related to Chinese *L. rubriceps* N.K. Zeng & Hui Chai (Chai et al. 2018) and one collection tentatively named "*Lanmaoa* sp. HKAS 52518" (Fig. 3). However, *L. rubriceps* has a red to crimson, orange-red pileus, pores stuffed when young, sometimes tinged with reddish when old, and smaller basidiospores measuring 8–11 × 4–5 μm (Chai et al. 2018); careful examinations showed that *Lanmaoa* sp. HKAS 52518 has a smaller basidioma, a reddish to red or blackish-red pileus, and surface of stipe turning blue when injured.

Neoboletus Gelardi, Simonini & Vizzini

Neoboletus, typified by *N. luridiformis* (Rostk.) Gelardi et al., is characterized by stipitate-pileate or sequestrate; when basidiomata stipitate-pileate, pores brown, dark brown to reddish brown when young, becoming yellow when old (Fig. 6c, d, f), tubes always yellow (Figs 5f, l, 6e, h), hymenophore and context staining blue, and stipe usually covered with punctuations (Vizzini 2014; Wu et al. 2016a). The monophyly of *Neoboletus* has been assessed, and many species of the genus were described (Wu et al. 2014, 2016b). Astonishingly, the same authors recombined *Neoboletus* species in the genus *Sutorius* after a short time (Wu et al. 2016a). As a matter of fact, the stipe ornamentation pattern, spore print color, and colors of pores and tubes are fully different between the two genera (Halling et al. 2012; Vizzini 2014; Gelardi 2017). Furthermore, with more sequences added, our molecular data infers that *Neoboletus* forms an independent clade with strong support, and the genus *Sutorius* is sister to *Costatisporus* T.W. Henkel & M.E. Sm. (Smith et al. 2015) (Fig. 2). Thus, we recognize *Neoboletus* as an independent genus.

6. *Neoboletus hainanensis* (T.H. Li & M. Zang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.

MycoBank: MB828527
Figure 5d–f

Boletus hainanensis T.H. Li & M. Zang, Mycotaxon 80: 482, 2001
Sutorius hainanensis (T.H. Li & M. Zang) G. Wu & Zhu L. Yang, Fungal Diversity 81: 135, 2016

Habitat. Solitary on the ground in forests dominated by fagaceous trees including *Lithocarpus* spp.

Distribution. Southern and southwestern China.

Note. *Boletus hainanensis* T.H. Li & M. Zang was first described from Hainan Province of southern China (Zang et al. 2001). It was later also reported from Yunnan Province of southwestern China (Wu et al. 2016a) and was transferred to the genus

Sutorius. It is called the "Black bolete" in Yunnan Province, and largely traded in local mushroom markets (Wang et al. 2004).

Specimens examined. CHINA. Hainan Province: Changjiang County, Bawangling National Nature Reserve, elev. 650 m, 20 August 2009, *N.K. Zeng 523* (HKAS 90209). Yunnan Province: Kunming City, bought from market, 11 July 2015, *N.K. Zeng 2128* (FHMU 1392).

7. *Neoboletus multipunctatus* N.K. Zeng, H. Chai & S. Jiang, sp. nov.

MycoBank: MB828528
Figures 5g–l, 12

Typification. CHINA. Hainan Province: Qiongzhong County, Yinggeling National Nature Reserve, elev. 800 m, 3 August 2015, *N.K. Zeng* 2498 (FHMU 1620, holotype). GenBank accession numbers: 28S = MH879693, ITS = MH885354, *tef1* = MH879722.

Etymology. Latin, "*multipunctatus*", referring to the many punctuations on the stipe.

Description. *Basidiomata* medium-sized. *Pileus* 5.7–7 cm in diameter, convex to applanate; surface dry, finely tomentose, brown (4D7), dark brown (5C7) to blackish brown (5D5); context 1–1.5 cm thick in the center of the pileus, yellowish (1A5), changing blue quickly when injured. *Hymenophore* poroid, depressed around apex of stipe; pores subround, 0.3–0.4 mm in diameter, brown (7B5) to reddish brown (6C8), changing bluish black quickly when injured; tubes 0.5–0.7 cm in length, yellowish (1A5), changing blue quickly when injured. *Stipe* 7–7.4 × 1–1.3 cm, central, subcylindric, solid, usually flexuous; surface dry, covered with reddish-brown (7B5) squamules; context yellow (1A3), changing blue (21B3) quickly when injured; basal mycelium yellow (1A3). *Odor* indistinct.

Basidia 27–37 × 6–10 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 5–6 μm in length. *Basidiospores* [80/4/3] 8.5–11(–12) × 4–5 μm, Q=(1.80–)1.90–2.50(–2.75), Q_m=2.22 ± 0.22, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of colorless to yellowish in KOH, 4–8 μm wide, thin-walled hyphae. *Cheilocystidia* 27–34 × 5–7 μm, fusiform or subfusiform, thin-walled, fawn to tawny in KOH, no encrustations. *Pleurocystidia* 38–61 × 6–8 μm, fusiform or subfusiform, thin-walled, colorless to tawny in KOH, no encrustations. *Pileipellis* a trichoderm about 120 μm thick, composed of vertically arranged, nearly colorless to yellowish in KOH, 3–5 μm wide, thin-walled hyphae; terminal cells 21–70 × 3–5 μm, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 3–8 μm in diameter, thin-walled, colorless to yellowish in KOH. *Stipitipellis* hymeniform about 100 μm thick, composed of thin-walled emergent hyphae, colorless to yellowish in KOH, with clavate, subclavate, fusiform or subfusiform

terminal cells (25–44 × 3–9 μm), and occasionally with scattered clavate, 4-spored basidia. *Stipe trama* composed of longitudinally arranged, parallel hyphae 4–9 μm wide, cylindrical, thin to slightly thick-walled (to 0.5 μm), colorless in KOH. *Clamp connections* absent in all tissues.

Habitat. Solitary on the ground in forests dominated by fagaceous trees including *Lithocarpus* spp.

Distribution. Southern China.

Additional specimens examined. CHINA. Hainan Province: Changjiang County, Bawangling National Nature Reserve, elev. 600 m, 22 August 2009, *N.K. Zeng 559* (HKAS 76851); Ledong County, Yinggeling National Nature Reserve, elev. 620 m, 6 May 2018, *N.K. Zeng 3324* (FHMU 2808).

Note. *Neoboletus multipunctatus* is characterized by a brown, dark brown to blackish brown pileus, brown to reddish-brown pores changing bluish black when injured, stipe surface densely covered with brown to reddish-brown punctuations, smaller basidiospores, and its association with fagaceous trees. It is both morphologically similar and phylogenetically related to *N. brunneissimus* (W.F. Chiu) Gelardi et al. (Fig. 2), a species originally described from Yunnan Province of southwestern China. However, *N. brunneissimus* has larger basidiospores measuring 10–14 × 4.5–5 μm, and it occurs in temperature regions in addition to subtropical belts (Wu et al. 2016a). *Neoboletus multipunctatus* is also similar to *N. hainanensis* and *N. sinensis* (T.H. Li & M. Zang) Gelardi et al. morphologically. However, both pileal and stipe surface of *N. hainanensis* stain blue when injured, with white basal mycelium on the stipe, relatively larger basidiospores measuring 9.5–13.5 × 4–5 μm, and a trichodermium to ixotrichodermium pileipellis (Zang et al. 2001; Wu et al. 2016a). *Neoboletus sinensis*, a species also described from Hainan Province, has a cherry red stipe with reticulations, larger basidiospores measuring 13–19 × 5–6.5 μm, and wider cystidia (Zang et al. 2001; Vizzini 2014).

8. *Neoboletus obscureumbrinus* (Hongo) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.

MycoBank: MB828529
Figure 6a–e

Boletus obscureumbrinus Hongo, Mem. Fac. Lib. Arts. Educ. Shiga Univ. Nat. Sci., 18: 4, 1968
Sutorius obscureumbrinus (Hongo) G. Wu & Zhu L. Yang, Fungal Diversity 81: 138, 2016

Habitat. Solitary or gregarious on the ground in forests dominated by fagaceous trees including *Lithocarpus* spp.

Distribution. Southern and southwestern China; Japan (Hongo 1968).

Note. *Boletus obscureumbrinus* Hongo was originally described from Japan (Hongo 1968) and later reported from Guangdong Province of southern China and Yunnan Province of southwestern China (Wu et al. 2016a). It was transferred to the genus

Sutorius by Wu et al. (2016a); in the present study, we place the species in *Neoboletus* according to the evidence referred to above (Fig. 2). It is new to Hainan Province. The fruit body of this species is eaten by the Li people who live in the region (our own investigations).

Specimens examined. CHINA. Hainan Province: Ledong County, Yinggeling National Nature Reserve, elev. 620 m, 5 June 2017, *N.K. Zeng 3091*, *3094, 3098* (FHMU 2052, 2055, 2059); same location, 6 May 2018, *N.K. Zeng 3310, 3353* (FHMU 2271, 2814).

9. *Neoboletus tomentulosus* (M. Zang, W.P. Liu & M.R. Hu) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.
MycoBank: MB828530
Figure 6f–h

Boletus tomentulosus M. Zang, W.P. Liu & M.R. Hu, Acta Botanica Yunnanica 13: 150, 1991
Sutorius tomentulosus (M. Zang, W.P. Liu & M.R. Hu) G. Wu & Zhu L. Yang, Fungal Diversity 81: 142, 2016

Habitat. Solitary or gregarious on the ground in forests dominated by *Castanopsis kawakamii* Hay.

Distribution. Southeastern China.

Note. *Boletus tomentulosus* M. Zang et al. was first described from Fujian Province of southeastern China (Zang et al. 1991) and later reported from Guangdong Province of southern China (Wu et al. 2016a). Although the description of the protologue was brief (Zang et al. 1991), it has been well studied by Wu et al. (2016a). Our new collections were encountered near the type locality and augments our understanding of the species and the genus *Neoboletus*.

Specimens examined. CHINA. Fujian Province: Zhangping County, Xinqiao Town, Chengkou Village, elev. 350 m, 27 July 2013, *N.K. Zeng 1285, 1286* (FHMU 841, 842).

Sutorius Halling, Nuhn & N.A. Fechner

Sutorius, typified by *S. eximius* (Peck) Halling et al., is mainly characterized by pores and tissues that are tinged with reddish at all growth stages, tissues not stained blue, a reddish-brown spore print, and transversely scissurate scales on stipe surface (Smith and Thiers 1971; Halling et al. 2012). Until now, only two taxa, *S. australiensis* (Bougher & Thiers) Halling and N.A. Fechner, and *S. eximius* (Peck) Halling et al., were described, excluding those in Wu et al (2016a). Herein, we describe another species new to science.

Figure 6. Basidiomata of boletes. **a–e** *Neoboletus obscureumbrinus* (**a, e** from FHMU 2271 **b, d** from FHMU 2055 **c** from FHMU 2814) **f–h** *Neoboletus tomentulosus* (**h–i** from FHMU 842, **j** from FHMU 841) **i–k** *Sutorius subrufus* (FHMU 2004, holotype) **l** *Tylopilus virescens* (FHMU 1004). Photos by N.K. Zeng.

10. *Sutorius subrufus* N.K. Zeng, H. Chai & S. Jiang, sp. nov.

MycoBank: MB828531
Figures 6i–k, 13

Typification. CHINA. Hainan Province: Qiongzhong County, Yinggeling National Nature Reserve, elev. 850 m, 29 May 2017, *N.K. Zeng 3043* (FHMU 2004, holotype).

GenBank accession numbers: 28S = MH879698, ITS = MH885360, *tef1* = MH879728, *rpb2* = MH879745.

Etymology. Latin, "*subrufus*" refers to the stipe surface and context of the species turning reddish when injured.

Description. *Basidiomata* medium to large. *Pileus* 5–10 cm in diameter, subhemispherical to convex when young, then applanate; surface dry, finely tomentose, brown to pale reddish brown (10C2–11C3); context about 1.6 cm thick in the center of the pileus, white (6A1), changing reddish (9C3) when injured. *Hymenophore* poroid, adnate or slightly depressed around apex of stipe; pores angular, about 0.3 mm in diameter, pale brown (8C3), brown (7E2) to pale reddish brown (10C2), mostly unchanging in color when injured, but sometimes changing reddish; tubes about 1 cm in length, pale brown (8D3), unchanging in color when injured, but sometimes changing reddish. *Stipe* 6–10 × 1–2.2 cm, central, subcylindric, solid; surface dry, gray-white, but brownish yellow at base, covered with pale reddish-brown (7B2) to blackish-brown squamules, usually changing reddish when injured; context white (1D1–2), changing reddish (9C3) when injured; annulus absent; basal mycelium white (1A1). *Odor* indistinct.

Basidia 18–30 × 6–9 μm, clavate, thin-walled, colorless to yellowish in KOH; four-spored, sterigmata 2–3 μm in length. *Basidiospores* [200/24/3] (8–)9–12(–13.5) × 3.5–4.5 μm, Q=(2.25–)2.50–3.00(–3.29), Q_m=2.79 ± 0.21, subfusoid and inequilateral in side view with a weak or distinct suprahilar depression, elliptic-fusiform to subfusiform in ventral view, slightly thick-walled (to 0.5 μm), olive-brown to yellowish brown in KOH, smooth. *Hymenophoral trama* boletoid; composed of colorless to yellowish in KOH, 5–10 μm wide, thin- to slightly thick-walled (up to 0.5 μm) hyphae. *Cheilocystidia* 28–45 × 7–10 μm, ventricose, fusiform or subfusiform, thin-walled, colorless to yellowish in KOH, no encrustations. *Pleurocystidia* 35–50 × 7–10 μm, fusiform or subfusiform, thin-walled, colorless to yellowish in KOH, no encrustations. *Pileipellis* a trichoderm about 100–150 μm thick, composed of rather vertically arranged, yellowish in KOH, 3.5–6 μm wide, thin-walled hyphae; terminal cells 30–43 × 3.5–6 μm, clavate or subclavate, with obtuse apex. *Pileal trama* made up of hyphae 4.5–10 μm in diameter, thin-walled, nearly colorless in KOH. *Stipitipellis* hymeniform about 60–80 μm thick, composed of thin-walled emergent hyphae, colorless in KOH, with clavate, subclavate terminal cells (22–28 × 4–9 μm), and occasionally with scattered clavate, four-spored basidia. *Stipe trama* composed of longitudinally arranged, parallel hyphae 4–8 μm wide, cylindrical, thin- to slightly thick-walled (to 0.5 μm), fawn to tawny in KOH, parallel hyphae. *Clamp connections* absent in all tissues.

Habitat. Scattered, gregarious or caespitose on the ground in forests dominated by fagaceous trees, including *Lithocarpus* spp.

Distribution. Southern China.

Additional specimens examined. CHINA. Hainan Province: Qiongzhong County, Yinggeling National Nature Reserve, elev. 860 m, 29 May 2017, *N.K. Zeng 3045* (FHMU 2006); Ledong County, Yinggeling National Nature Reserve, elev. 650 m, 27 July 2017, *N.K. Zeng* 3140 (FHMU 2101).

Note. *Sutorius subrufus* is characterized by a brown to pale reddish-brown pileus, stipe surface and context turning reddish when injured, relatively smaller basidi-

ospores, and it is restricted in tropical China. It is both morphologically similar and phylogenetically related to *S. eximius* (Peck) Halling et al. and *S. australiensis* (Bougher & Thiers) Halling and N.A. Fechner. However, stipe surface and context of *S. eximius* does not change when injured. Moreover, *S. eximius* has larger basidiospores, and a distribution in North and Central America (Singer 1947; Smith and Thiers 1971; Halling et al. 2012); *S. australiensis* has relatively larger basidiospores, a distribution in Australia, and is associated with Myrtaceae and Casuarinaceae (Halling et al. 2012).

Tylopilus P. Karst.

Tylopilus, typified by *T. felleus* (Bull.) P. Karst., is characterized by the pallid, pinkish, vinaceous and pinkish-brown hymenophore, white to pallid context without color change, but some species becoming rufescent or sea-green when injured, and the bitter taste of the context (Baroni and Both 1998; Henkel 1999; Fulgenzi et al. 2007; Osmundson and Halling 2010; Wu et al. 2016a; Magnago et al. 2017; Liang et al. 2018). In China, although lots of species of the genus have been previously discovered (Li et al. 2002; Fu et al. 2006; Gelardi et al. 2015; Wu et al. 2016a; Liang et al. 2018), still there are a large number of undescribed taxa in this region.

11. *Tylopilus virescens* (Har. Takah. & Taneyama) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.

MycoBank: MB828532
Figure 6l

Boletus virescens Har. Takah. & Taneyama, The fungal flora in southwestern Japan, agarics and boletes 1: 45, 2016
Tylopilus callainus N.K. Zeng, Zhi Q. Liang & M.S. Su, Phytotaxa 343 (3): 271, 2018

Habitat. Solitary or gregarious on the ground in forests dominated by fagaceous trees including *Lithocarpus* spp. or *Castanopsis kawakamii* Hay.

Distribution. Southeastern and southern China; Japan (Terashima et al. 2016).

Note. *Tylopilus callainus* N.K. Zeng et al. was described from the south of China (Liang et al. 2018). This taxon was previously thought to be different from *B. virescens* Har. Takah. & Taneyama, a species described from Japan (Terashima et al. 2016). After a careful re-evaluation of specimens, we now know that the two taxa are conspecific, and *T. callainus* is synonymized with *B. virescens*. Clarifying the taxonomic relationship between the two taxa also indicated that the *B. virescens* is a member of *Tylopilus*, and thus the new combination is proposed. Illustrations and a full description have been provided by Liang et al. (2018).

Specimens examined. CHINA. Fujian Province: Zhangping County, Xinqiao Town, Chengkou Village, elev. 350 m, 22 August 2013, *N.K. Zeng 1360, 1459* (FHMU

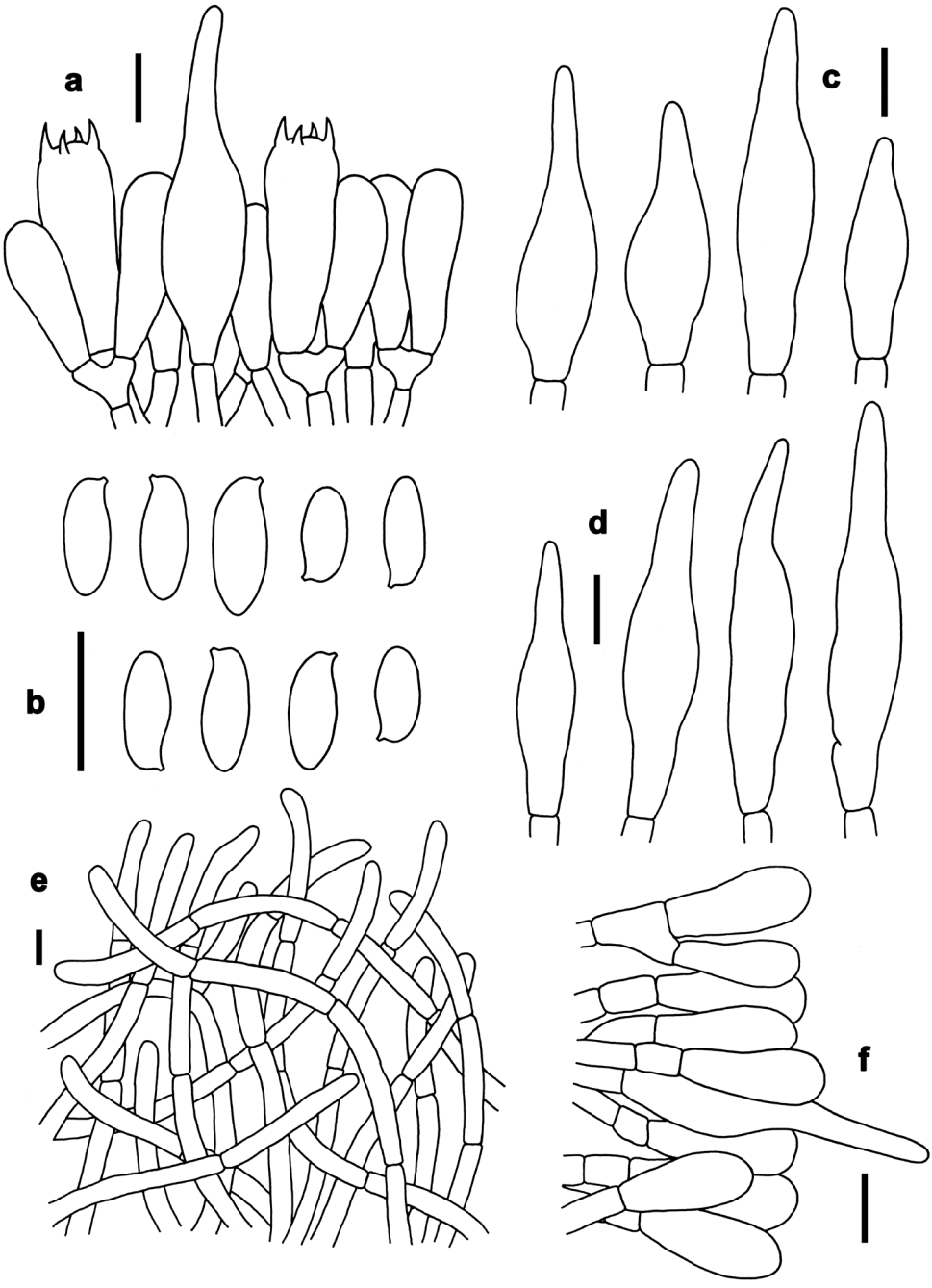

Figure 7. Microscopic features of *Butyriboletus huangnianlaii* (FHMU 2207, holotype). **a** Basidia and pleurocystidium **b** Basidiospores **c** Cheilocystidia **d** Pleurocystidia **e** Pileipellis **f** Stipitipellis. Scale bars: 10 μm.

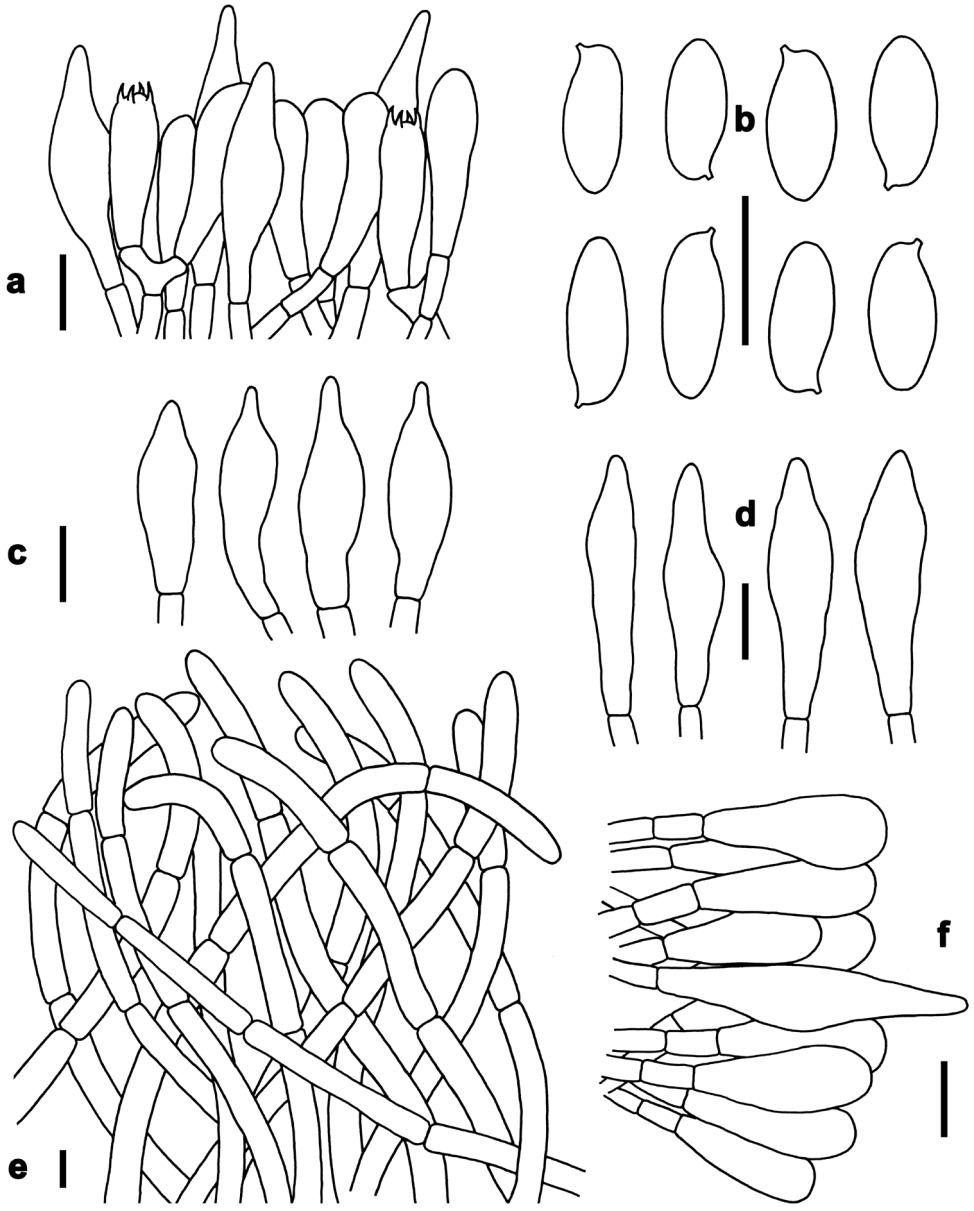

Figure 8. Microscopic features of *Caloboletus guanyui* (FHMU 2040). **a** Basidia and pleurocystidia **b** Basidiospores **c** Cheilocystidia **d** Pleurocystidia **e** Pileipellis **f** Stipitipellis. Scale bars: 10 μm.

2812, 1001); same location, 23 August 2013, *N.K. Zeng 1460* (FHMU 2813); same location, 24 August 2013, *N.K. Zeng 1464* (FHMU 1004). Hainan Province: Baisha County, Yinggeling National Nature Reserve, elev. 550 m, 1 August 2015, *N.K. Zeng 2436* (FHMU 1562); same location, 26 May 2017, *N.K. Zeng 2982* (FHMU 1943);

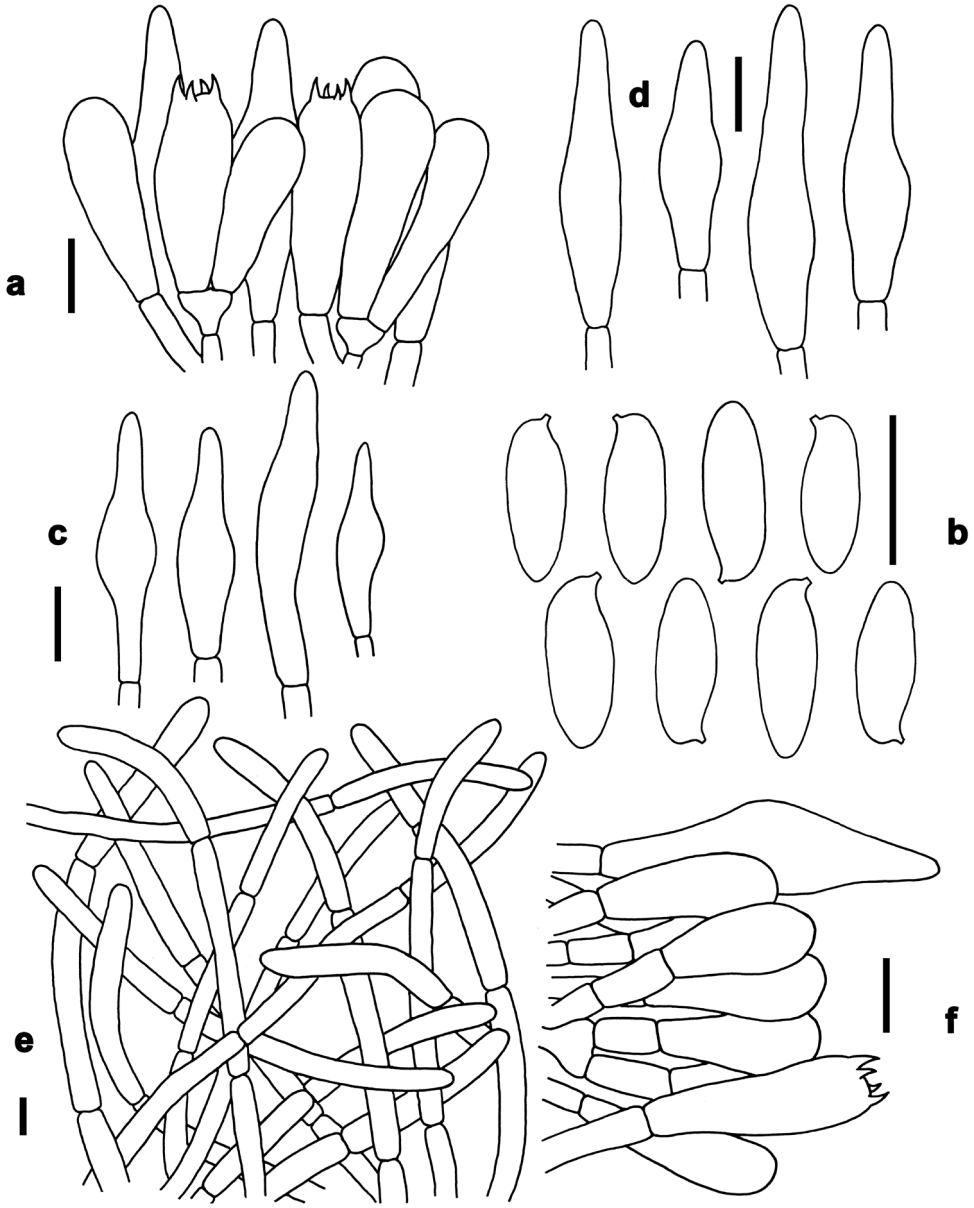

Figure 9. Microscopic features of *Caloboletus xiangtoushanensis* (FHMU 883). **a** Basidia and pleurocystidia **b** Basidiospores **c** Cheilocystidia **d** Pleurocystidia **e** Pileipellis **f** Stipitipellis. Scale bars: 10 μm.

same location, 27 May 2017, *N.K. Zeng 3001* (FHMU 1962); Ledong County, Jianfengling National Nature Reserve, elev. 850 m, 27 June 2018, *N.K. Zeng 3426, 3431* (FHMU 2810, 2811).

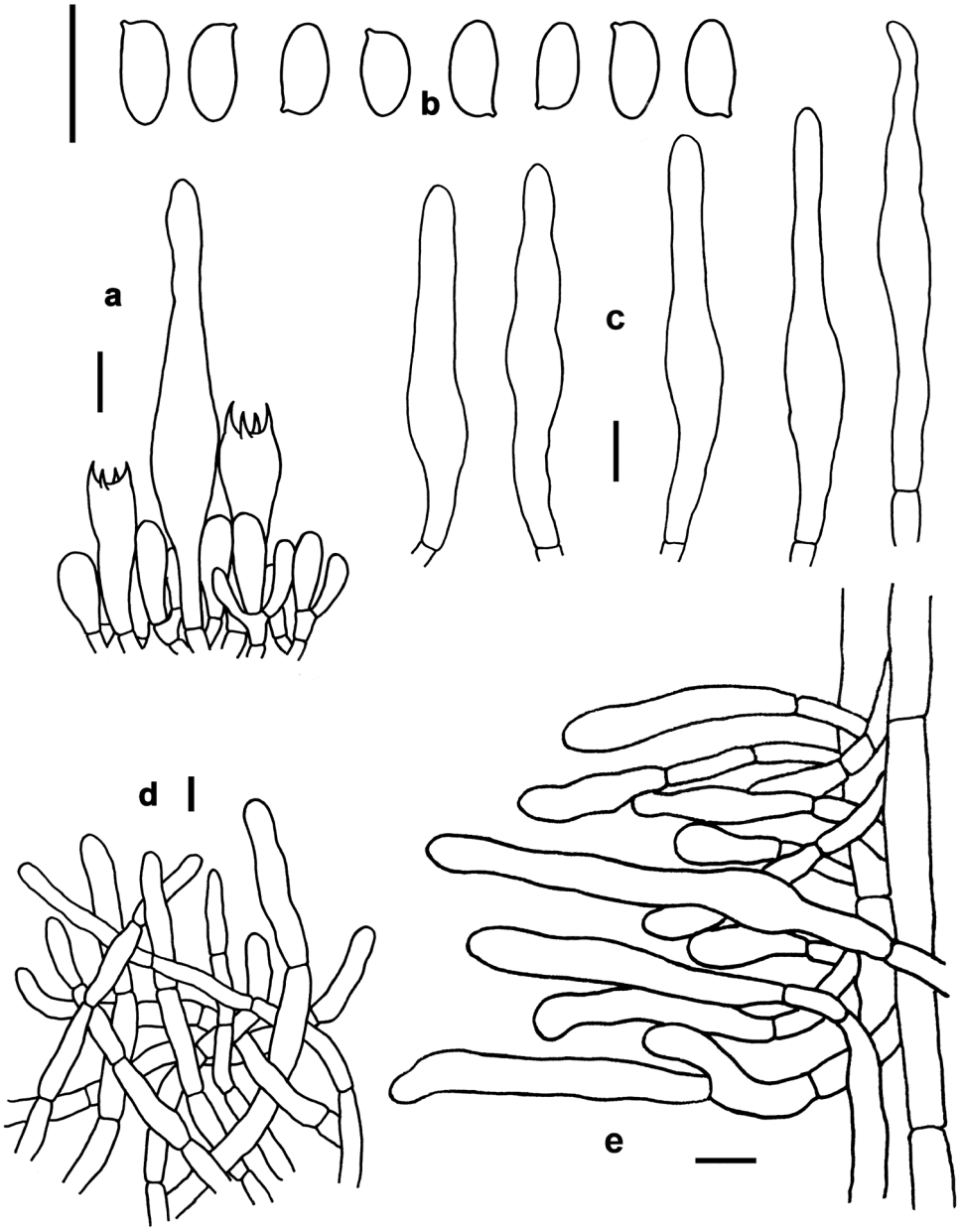

Figure 10. Microscopic features of *Chalciporus radiatus* (FHMU 930). **a** Basidia and pleurocystidium **b** Basidiospores **c** Cheilocystidia **d** Pileipellis **e** Stipitipellis. Scale bars: 10 μm.

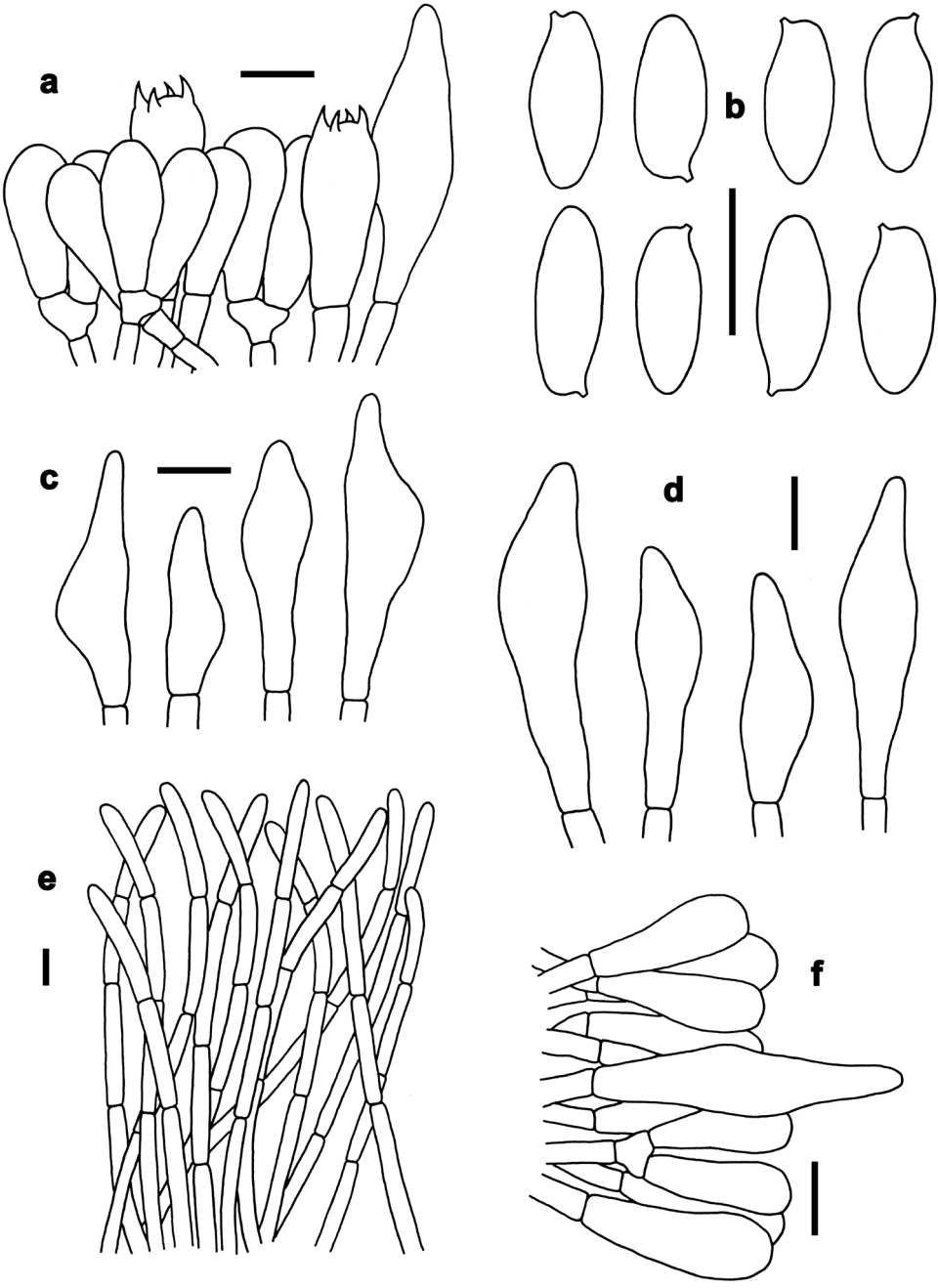

Figure 11. Microscopic features of *Lanmaoa macrocarpa* (**a–e** from FHMU 1982, holotype **f** from FHMU 2212). **a** Basidia and pleurocystidium **b** Basidiospores **c** Cheilocystidia **d** Pleurocystidia **e** Pileipellis **f** Stipitipellis. Scale bars: 10 μm.

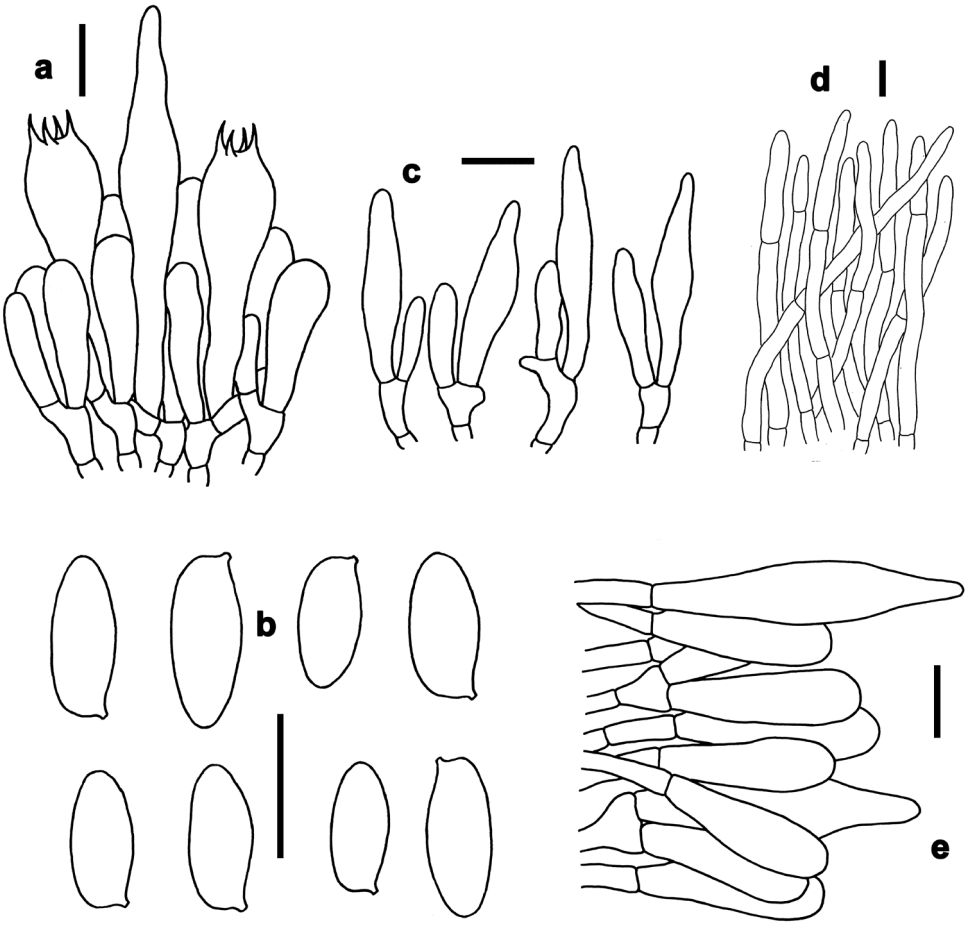

Figure 12. Microscopic features of *Neoboletus multipunctatus* (FHMU 1620, holotype). **a** Basidia and pleurocystidium **b** Basidiospores **c** Cheilocystidia **d** Pileipellis **e** Stipitipellis. Scale bars: 10 μm.

New combinations

According to the analytical results presented here, the following new combinations are proposed:

Neoboletus ferrugineus **(G. Wu, F. Li & Zhu L. Yang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.**
MycoBank: MB828533

Sutorius ferrugineus G. Wu, Fang Li & Zhu L. Yang, Fungal Diversity 81: 134, 2016

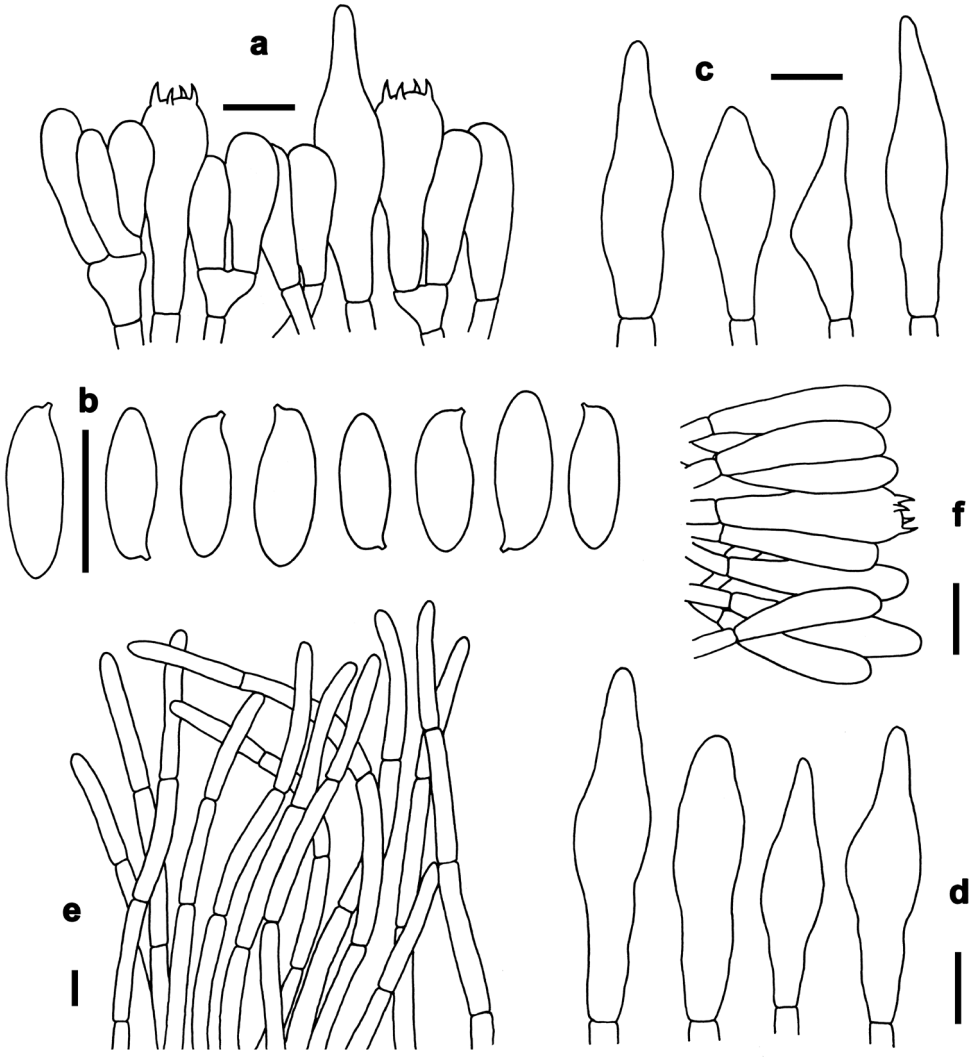

Figure 13. Microscopic features of *Sutorius subrufus* (FHMU 2004, holotype). **a** Basidia and pleurocystidium **b** Basidiospores **c** Cheilocystidia **d** Pleurocystidia **e** Pileipellis **f** Stipitipellis. Scale bars: 10 μm.

Neoboletus flavidus **(G. Wu & Zhu L. Yang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.**
MycoBank: MB828534

Sutorius flavidus G. Wu & Zhu L. Yang, Fungal Diversity 81: 135, 2016

Neoboletus rubriporus **(G. Wu & Zhu L. Yang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.**
MycoBank: MB828535

Sutorius rubriporus G. Wu & Zhu L. Yang, Fungal Diversity 81: 139, 2016

Neoboletus sanguineoides **(G. Wu & Zhu L. Yang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.**
MycoBank: MB828536

Sutorius sanguineoides G. Wu & Zhu L. Yang, Fungal Diversity 81: 140, 2016

Neoboletus sanguineus **(G. Wu & Zhu L. Yang) N.K. Zeng, H. Chai & Zhi Q. Liang, comb. nov.**
MycoBank: MB828537

Sutorius sanguineus G. Wu & Zhu L. Yang, Fungal Diversity 81: 141, 2016

Discussion

Molecular phylogenetic analyses have been used widely to define the genera of boletes, and as a result, many genera were erected or merged (Zeng et al. 2012, 2014b; Nuhn et al. 2013; Wu et al. 2014, 2016a, b). Recently, the genus *Neoboletus* was synonymized with *Sutorius* solely based on the evidence of molecular data (Wu et al. 2016a). Our molecular phylogenetic analyses based on a four-locus dataset (28S + ITS + *tef1* + *rpb2*) with sequences from taxa of *Neoboletus*, *Sutorius*, *Costatisporus*, and *Caloboletus* (Fig. 2) indicate those species that morphologically match the concept of genus *Neoboletus* do not belong in *Sutorius*; instead, they form an independent clade with strong support (Fig. 2). At the same time, the morphological features including the stipe ornamentation pattern, spore print color, and color change of tissues are different between the two genera and has been noted in previous studies (Halling et al. 2012; Gelardi 2017). It is noteworthy that the color of tubes of *Neoboletus* is always yellow (Figs 5f, l, 6e, h), and in this genus the pores usually become yellow when old (Fig. 6d, f), whereas the color of tubes and pores of *Sutorius* are always tinged with reddish at different growth stages (Fig. 6i–k).

The present study further shows that the most important diagnostic feature of the genus *Lanmaoa*, viz. "short hymenophoral tubes (thickness of hymenophore 1/3–1/5 times that of pileal context at the position halfway to the pileus center) and a slow color change when injured" defined by Wu et al. (2016b) is not constant (Chai et al. 2018), for the thickness of hymenophore is about 3/5 times that of pileal context in our newly described *L. macrocarpa*. Additionally, context and hymenophore of our new species turn quickly and strongly when injured (Fig. 5c).

According to current molecular data, 10 lineages (lineages 1–10) of *Sutorius* were found (Fig. 2). Lineages 4 and 6 were identified as *S. australiensis* and *S. eximius* respectively in a previous study (Halling et al. 2012). Lineages 1, 2, 3, 5, 7 and 9 may have not diverged enough (Fig. 2) and are treated here as a series of closely related taxa or disjunct populations of previously described entities; these will be assessed in the future with more DNA sequences and more collections. As to lineages 8 and 10, they should be treated as independent taxa due to their high degree divergence. Moreover, morphological and ecological features (described above) of specimens (FHMU 2004, FHMU 2006, FHMU 2101) in lineage 8 from Hainan Province are also different from the described taxa of *Sutorius*, and thus, the new taxon *S. subrufus* was proposed. Lineage 10 was not described due to the paucity of the materials (Halling et al. 2012).

Subtropical and tropical China is believed to be a biodiversity hotspot. Mycologists have paid much attention to boletes of the region in the past decade, and many taxa have been discovered (Bi et al. 1997; Zeng and Yang 2011; Zeng et al. 2012, 2013, 2014a, b, 2015a, b, 2016, 2017, 2018; Zang 2013; Liang et al.2016, 2017, 2018; Chai et al. 2018; Xue et al. 2018). Among of them, many have been found to be as North American or European species (Bi et al. 1997; Zang 2013), and recent studies have shown that species shared between subtropical/tropical China and North America/Europe are rare but that there are many common species between Japan and subtropical/tropical China (Zeng et al. 2013, 2016, 2017). Our study now reveals that the geographic distributions of the Japanese *C. guanyui*, *N. obscureumbrinus*, and *T. virescens* extend into subtropical or tropical China.

Acknowledgments

We are grateful to the forest rangers (Hainan Yinggeling National Nature Reserve) for their kind help during the field investigations. Special thanks are due to three reviewers for their valuable suggestions and comments which improved our manuscript. The study was supported by the National Natural Science Foundation of China (Nos. 31560005, 31760008, 31360008, 31400024).

References

Arora D, Frank JL (2014) Clarifying the butter boletes: a new genus, *Butyriboletus*, is established to accommodate Boletus sect. *Appendiculati*, and six new species are described. Mycologia 106: 464–480. https://doi.org/10.3852/13-052

Baroni TJ, Both EE (1998) *Tylopilus violatinctus*, a new species of *Tylopilus* for North America, with comments on other violaceous colored *Tylopilus* taxa. Bulletin of the Buffalo Society of Natural Sciences 36: 261–264.

Bessette AE, Roody WC, Bessette AR (2016) Boletes of Eastern North America. Syracuse University Press, Syracuse, New York, 536 pp.

Bi ZS, Li TH, Zhang WM, Song B (1997) A Preliminary Agaric Flora of Hainan Province. Guangdong Higher Education Publishing, Guangzhou, 388 pp.

Binder M, Bresinsky A (2002) *Retiboletus*, a new genus for a species-complex in the Boletaceae producing retipolides. Feddes Repertorium 113: 1–2, 30–40. https://doi.org/10.1002/1522-239X(200205)113:1/2<30::AID-FEDR30>3.0.CO;2-D

Braeuer S, Goessler W, Kameník J, Konvalinková T, Zigová A, Borovička J (2018) Arsenic hyperaccumulation and speciation in the edible ink stain bolete (*Cyanoboletus pulverulentus*). Food Chemistry 242: 225–231. https://doi.org/10.1016/j.foodchem.2017.09.038

Chai H, Liang ZQ, Jiang S, Fu XL, Zeng NK (2018) *Lanmaoa rubriceps*, a new bolete from tropical China. Phytotaxa 347: 71–80. https://doi.org/10.11646/phytotaxa.347.1.4

Chen ZH, Yang ZL, Tolgor B, Li TH (2016) Poisonous Mushrooms: Recognition and Poisoning Treatment. Science Press, Beijing, 308 pp.

Chiu WF (1948) The boletes of Yunnan. Mycologia 40: 199–231. https://doi.org/10.2307/3755085

Fu SZ, Wang QB, Yao YJ (2006) *Tylopilus microsporus*, a new species from Southwest China. Mycotaxon 96: 41–46.

Fulgenzi TD, Henkel TW, Halling RE (2007) *Tylopilus orsonianus* sp. nov. and *Tylopilus eximius* from Guyana. Mycologia 99: 622–627. https://doi.org/10.1080/15572536.2007.11832556

Gelardi M (2017) Contribution to the knowledge of Chinese boletes. II: *Aureoboletus thibetanus* s. l., *Neoboletus brunneissimus*, *Pulveroboletus macrosporus* and *Retiboletus kauffmanii* (Part I). Rivista Micologica Romana 102(3): 13–30.

Gelardi M, Simonini G, Ercole E, Davoli P, Vizzini A (2015) *Cupreoboletus* (Boletaceae, Boletineae), a new monotypic genus segregated from *Boletus* sect. *Luridi* to reassign the Mediterranean species *B. poikilochromus.* Mycologia 107: 1254–1269. https://doi.org/10.3852/15-070

Hall TA (1999) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symposium Series 41: 95–98.

Halling RE, Nuhn M, Fechner NA, Osmundson TW, Soytong K, Arora D, Hibbett DS, Binder M (2012) *Sutorius*: a new genus for *Boletus eximius*. Mycologia 104: 951–961. https://doi.org/10.3852/11-376

Hellwig V, Dasenbrock J, Gräf C, Kahner L, Schumann S, Steglich W (2002) Calopins and cyclocalopins-bitter principles from *Boletus calopus* and related mushrooms. European Journal of Organic Chemistry 17: 2895–2904. https://doi.org/10.1002/1099-0690(200209)2002:17<2895::AID-EJOC2895>3.0.CO;2-S

Henkel TW (1999) New taxa and distribution records for *Tylopilus* from *Dicymbe* forests of Guyana. Mycologia 91: 655–665. https://doi.org/10.2307/3761252

Hongo T (1967) Notulae mycologicae (6). Memoirs of Shiga University Press 17: 89–95.

Hongo T (1968) Notulae mycologicae (7). Memoirs of Shiga University Press 18: 34–39.

Huelsenbeck JP, Ronquist F (2005) Bayesian analysis of molecular evolution using MrBayes. In: Nielsen R (Ed.) Statistical Methods in Molecular Evolution. Springer, New York, 183–226. https://doi.org/10.1007/0-387-27733-1_7

James TY, Kauff F, Schoch C, Matheny PB, Hofstetter V, Cox C, Celio G, Gueidan C, Fraker E, Miadlikowska J, Lumbsch HT, Rauhut A, Reeb V, Arnold AE, Amtoft A, Stajich JE, Hosaka

K, Sung GH, Johnson D, O'Rourke B, Crockett M, Binder M, Curtis JM, Slot JC, Wang Z, Wilson AW, Schüßler A, Longcore JE, O'Donnell K, Mozley-Standridge S, Porter D, Letcher PM, Powell MJ, Taylor JW, White MM, Griffith GW, Davies DR., Humber RA, Morton JB, Sugiyama J, Rossman AY., Rogers JD, Pfister DH, Hewitt D, Hansen K, Hambleton S, Shoemaker RA, Kohlmeyer J, Volkmann-Kohlmeyer B, Spotts RA, Serdani M, Crous PW, Hughes KW, Matsuura K, Langer E, Langer G, Untereiner WA, Lücking R, Büdel B, Geiser DM, Aptroot A, Diederich P, Schmitt I, Schultz M, Yahr R, Hibbett D, Lutzoni F, McLaughlin D, Spatafora J, Vilgalys R (2006) Reconstructing the early evolution of the fungi using a six gene phylogeny. Nature 443: 818–822. https://doi.org/10.1038/nature05110

Katoh K, Kuma K, Toh H, Miyata T (2005) MAFFT version 5: improvement in accuracy of multiple sequence alignment. Nucleic Acids Research 33: 511. https://doi.org/10.1093/nar/gki198

Kornerup A, Wanscher JH (1981) Taschenlexikon der Farben. 3. Aufl. Muster-Schmidt Verlag, Göttingen, 242 pp.

Li GJ, Hyde KD, Zhao RL, Hongsanan S, Abdel-Aziz FA, Abdel-Wahab MA, Alvarado P, Alves-Silva G, Ammirati JF, Ariyawansa HA, Baghela A, Bahkali AH, Beug M, Bhat DJ, Bojantchev D, Boonpratuang T, Bulgakov TS, Camporesi E, Boro MC, Ceska O, Chakraborty D, Chen JJ, Chethana KWT, Chomnunti P, Consiglio G, Cui BK., Dai DQ, Dai YC, Daranagama DA, Das K, Dayarathne MC, De CE, De ORJV, Souza CAF, Souza JI, Dentinger BTM, Dissanayake AJ, Doilom M, Drechsler-Santos ER, Ghobad-Nejhad M, Gilmore SP, Góes-Neto A, Gorczak M, Haitjema CH, Hapuarachchi KK, Hashimoto A, He MQ, Henske JK, Hirayama K, Iribarren MJ, Jayasiri SC, Jayawardena RS, Jeon SJ, Jerônimo GH, Jesus AL, Jones EBG, Kang JC, Karunarathna SC, Kirk PM, Konta S, Kuhnert E, Langer E, Lee HS, Lee HB, Li WJ, Li XH, Liimatainen K, Lima DX, Lin CG, Liu JK, Liu XZ, Liu ZY, Luangsaard JJ, Lücking R, Lumbsch HT, Lumyong S, Leaño EM, Marano AV, Matsumura M, McKenzie EHC, Mongkolsamrit S, Mortimer PE, Nguyen TTT, Niskanen T, Norphanphoun C, O'Malley MA, Parnmen S, Pawłowska J, Perera RH, Phookamsak R, Phukhamsakda C, Pires-Zottarelli CLA, Raspé O, Reck MA, Rocha SCO, Santiago AL, Senanayake IC, Setti L, Shang QJ, Singh SK, Sir EB, Solomon KV, Song J, Srikitikulchai P, Stadler M, Suetrong S, Takahashi H, Takahashi T, Tanaka K, Tang LP, Thambugala KM, Thanakitpipattana D, Theodorou MK, Thongbai B, Thummarukcharoen T, Tian Q, Tibpromma S,Verbeken A, Vizzini A, Vlasák J, Voigt K, Wanasinghe DN, Wang Y, Weerakoon G, Wen HA, Wen TC, Wijayawardene NN, Wongkanoun S,Wrzosek M, Xiao YP, Xu JC, Yan JY, Yang J, Da YS, Hu Y, Zhang JF, Zhao J, Zhou LW, Peršoh D, Phillips AJL, Maharachchikumbura SSN (2016) Fungal diversity notes 253–366: taxonomic and phylogenetic contributions to fungal taxa. Fungal Diversity 78: 1–237. http://doi.org/10.1007/s13225-016-0366-9

Li HB, Wei HL, Peng HZ, Ding HM, Wang LL, He L, Fu LZ (2014) *Boletus roseoflavus*, a new species of *Boletus* in section *Appendiculati* from China. Mycological Progress 13: 21–31. https://doi.org/10.1007/s11557-013-0888-4

Li TH, Song B, Shen YH (2002) A new species of *Tylopilus* from Guangdong. Mycosystema 21: 3–5.

Liang ZQ, An DY, Jiang S, Su MZ, Zeng NK (2016) *Butyriboletus hainanensis* (Boletaceae, Boletales), a new species from tropical China. Phytotaxa 267: 256–262. https://doi.org/10.11646/phytotaxa.267.4.2

Liang ZQ, Chai H, Jiang S, Ye ZK, Zeng NK (2017) The genus *Xanthoconium* (Boletaceae, Boletales) in tropical China. Phytotaxa 295: 246–254. https://doi.org/10.11646/phytotaxa.295.3.5

Liang ZQ, Su MS, Jiang S, Hong D, Zeng NK (2018) *Tylopilus callainus*, a new species with a sea-green color change of hymenophore and context from the south of China. Phytotaxa 343: 269–276. https://doi.org/10.11646/phytotaxa.343.3.7

Magnago AC, Reck MA, Dentinger BTM, Moncalvo JM, Neves MA, Silveira RMBD (2017) Two new *Tylopilus* species (Boletaceae) from Northeastern Atlantic Forest, Brazil. Phytotaxa 316: 250–260. https://doi.org/10.11646/phytotaxa.316.3.4

Nuhn ME, Binder M, Taylor AF, Halling RE, Hibbett DS (2013) Phylogenetic overview of the Boletineae. Fungal Biology 117: 479–511. https://doi.org/10.1016/j.funbio.2013.04.008

Nylander JAA (2004) MrModeltest 2.3. Program distributed by the author. Evolutionary Biology Center, Uppsala University.

Osmundson TW, Halling RE (2010) *Tylopilus oradivensis* sp. nov.: a newly described member of the *Tylopilus balloui* complex from Costa Rica. Mycotaxon 113: 475–483. https://doi.org/10.5248/113.475

Raspé O, Vadthanarat S, De Kesel A, Degreef J, Hyde KD, Lumyong S (2016) *Pulveroboletus fragrans*, a new Boletaceae species from Northern Thailand, with a remarkable aromatic odor. Mycological Progress 15: 38. https://doi.org/10.1007/s11557-016-1179-7

Rehner SA, Buckley E (2005) A *Beauveria* phylogeny inferred from nuclear ITS and EF1-a sequences: evidence for cryptic diversification and links to *Cordyceps* teleomorphs. Mycologia 97: 84–98. https://doi.org/10.1080/15572536.2006.11832842

Roman MD, Claveria V, Miguel AMD (2005) A revision of the descriptions of ectomycorrhizas published since 1961. Mycological Research 109: 1063–1104. https://doi.org/10.1017/S0953756205003564

Schrader HA (1794) Spicilegium Florae Germanicae: 1–194.

Singer R (1947) The Boletoideae of Florida with notes on extralimital species III. American Midland Naturalist 37: 1–135. https://doi.org/10.2307/2421647

Smith ME, Amses KR, Elliott TF, Obase K,Aime MC, Henkel TW (2015) New sequestrate fungi from Guyana: *Jimtrappea guyanensis* gen. sp. nov., *Castellanea pakaraimophila* gen. sp. nov. and *Costatisporus cyanescens* gen. sp. nov. (Boletaceae, Boletales). IMA Fungus 6: 297–317. https://doi.org/10.5598/imafungus.2015.06.02.03

Smith SA, Dunn CW (2008) Phyutility: a phyloinformatics tool for trees, alignments and-molecular data. Bioinformation 24: 715–716. https://doi.org/10.1093/bioinformatics/btm619

Smith AH, Thiers HD (1971) The Boletes of Michigan. University of Michigan Press, Ann Arbor, 428 pp.

Stamatakis A (2006) RAxML-VI-HPC: maximum likelihood-based phylogenetic analyses with thousands of taxa and mixed models. Bioinformatics 22: 2688–2690. https://doi.org/10.1093/bioinformatics/btl446

Šutara J, Janda V, Kříž M, Graca M, Kolařík M (2014) Contribution to the study of genus *Boletus*, section *Appendiculati*: *Boletus roseogriseus* sp. nov. and neotypification of *Boletus fuscoroseus* Smotl. Czech Mycology 66: 1–37. https://doi.org/10.1037/10663-011

Swofford DL (2002) PAUP*: phylogenetic analysis using parsimony (*and other methods), version 4.0b10. Sinauer Associates Publishing, 2000.

Takahashi H (2007) Five new species of the Boletaceae from Japan. Mycoscience 48: 90–99. https://doi.org/10.1007/S10267-006-0332-6P

Terashima Y, Takahashi H, Taneyama Y (2016) The Fungal Flora in Southwestern Japan: Agarics and Boletes. Tokai University Press, Tokyo, 303 pp.

Vilgalys R, Hester M (1990) Rapid genetic identification and mapping of enzymatically amplified ribosomal DNA from several *Cryptococcus* species. Journal of Bacteriology 172: 4238–4246. https://doi.org/10.1128/jb.172.8.4238-4246.1990

Vizzini A (2014) *Neoboletus* Gelardi, Simonini & Vizzini, gen. nov. Index Fungorum 192: 1.

Wang XH, Liu PG, Yu FQ (2004) Color atlas of wild commercial mushrooms in Yunnan. Yunnan Science and Technology Press, Kunming, 136 pp.

White TJ, Bruns T, Lee S, Taylor JW (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenies. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (Eds) PCR Protocols: A Guide to Methods and Applications. Academic Press, New York, 315–322. https://doi.org/10.1016/B978-0-12-372180-8.50042-1

Wu G, Feng B, Xu JP, Zhu XT, Li YC, Zeng NK, Hosen MI, Yang ZL (2014) Molecular phylogenetic analyses redefine seven major clades and reveal 22 new generic clades in the fungal family *Boletaceae.* Fungal Diversity 69: 93–115. https://doi.org/10.1007/s13225-014-0283-8

Wu G, Li YC, Zhu XT, Zhao K, Han LH, Cui YY, Li F, Xu JP, Yang ZL (2016a) One hundred noteworthy boletes from China. Fungal Diversity 81: 25–188. https://doi.org/10.1007/s13225-016-0375-8

Wu G, Zhao K, Li YC, Zeng NK, Feng B, Halling R, Yang ZL (2016b) Four new genera of the fungal family Boletaceae. Fungal Diversity 81: 1–24. https://doi.org/10.1007/s13225-015-0322-0

Wu XL, Mao XL, Tolgor B, Song B, Li TH, Zhao YX, Chen SL, Zeng NK, Huang SZ, Wen TC, Deng CY (2013) Medicinal Fungi of China. Science Press, Beijing, 923 pp.

Xue R, Chai H, Wang Y, Hong D, Su MS, Liang ZQ, Zeng NK (2018) Species clarification of the locally famous mushroom *Suillus placidus* from the south of China with description of *S. huapi* sp. nov. Phytotaxa 371: 251–259. https://doi.org/10.11646/phytotaxa.371.4.2

Zang M (2013) Flora fungorum sinicorum. Vol. 44. Boletaceae I. Science Press, Beijing, 152 pp.

Zang M, Hu MR, Liu WP (1991) Two new taxa of Boletaceae from Fujian. Acta Botanica Yunnanica 13: 149–152.

Zang M, Li TH, Petersen RH (2001) Five new species of Boletaceae from China. Mycotaxon 80: 481–487.

Zeng NK, Cai Q, Yang ZL (2012) *Corneroboletus*, a new genus to accommodate the Southeast Asian *Boletus indecorus*. Mycologia 104: 1420–1432. https://doi.org/10.3852/11-326

Zeng NK, Chai H, Jiang S, Xue R, Wang Y, Hong D, Liang ZQ (2018) *Retiboletus nigrogriseus* and *Tengioboletus fujianensis*, two new boletes from the south of China. Phytotaxa 367: 45–54. https://doi.org/10.11646/phytotaxa.367.1.5

Zeng NK, Liang ZQ, Tang LP, Li YC, Yang ZL (2017) The genus *Pulveroboletus* (Boletaceae, Boletales) in China. Mycologia 109: 422–442. https://doi.org/10.1080/00275514.2017.1331689

Zeng NK, Liang ZQ, Wu G, Li YC, Yang ZL, Liang ZQ (2016) The genus *Retiboletus* in China. Mycologia 108: 363–380. https://doi.org/10.3852/15-072

Zeng NK, Liang ZQ, Yang ZL (2014a) *Boletus orientialbus*, a new species with white basidioma from subtropical China. Mycoscience 55: 159–163. https://doi.org/10.1016/j.myc.2013.07.004

Zeng NK, Su MS, Liang ZQ, Yang ZL (2015a) A geographical extension of the North American genus *Bothia* (Boletaceae, Boletales) to East Asia with a new species *B. fujianensis* from China. Mycological Progress 14: 1015. https://doi.org/10.1007/s11557-014-1015-x

Zeng NK, Tang LP, Li YC, Tolgor B, Zhu XT, Zhao Q, Yang ZL (2013) The genus *Phylloporus* (Boletaceae, Boletales) from China: morphological and multilocus DNA sequence analyses. Fungal Diversity 58: 73–101. https://doi.org/10.1007/s13225-012-0184-7

Zeng NK, Wu G, Li YC, Liang ZQ, Yang ZL (2014b) *Crocinoboletus*, a new genus of Boletaceae (Boletales) with unusual boletocrocin polyene pigments. Phytotaxa 175: 133–140. https://doi.org/10.11646/phytotaxa.175.3.2

Zeng NK, Yang ZL (2011) Notes on two species of *Boletellus* (Boletaceae, Boletales) from China. Mycotaxon 115: 413–423. https://doi.org/10.5248/115.413

Zeng NK, Zhang M, Liang ZQ (2015b) A new species and a new combination in the genus *Aureoboletus* (Boletales, Boletaceae) from southern China. Phytotaxa 222: 129–137. https://doi.org/10.11646/phytotaxa.222.2.5

Zhang M, Li TH, Gelardi M, Song B, Zhong XJ (2017) A new species and a new combination of *Caloboletus* from China. Phytotaxa 309: 118–126. https://doi.org/10.11646/phytotaxa.309.2.2

Zhang M, Li TH, Song B (2017) Two new species of *Chalciporus* (Boletaceae) from southern China revealed by morphological characters and molecular data. Phytotaxa 327: 47–56. https://doi.org/10.11646/phytotaxa.327.1.2

Zhang M, Wang CQ, Li TH, Song B (2015) A new species of *Chalciporus* (Boletaceae, Boletales) with strongly radially arranged pores. Mycoscience 57: 20–25. https://doi.org/10.1016/j.myc.2015.07.004

Zhao K, Wu G, Feng B, Yang ZL (2014a) Molecular phylogeny of *Caloboletus* (Boletaceae) and a new species in East Asia. Mycological Progress 13: 1127–1136. https://doi.org/10.1007/s11557-014-1001-3

Zhao K, Wu G, Halling RE, Yang ZL (2015) Three new combinations of *Butyriboletus* (Boletaceae). Phytotaxa 234: 51–62. https://doi.org/10.11646/phytotaxa.234.1.3

Zhao K, Wu G, Yang ZL (2014b) A new genus, *Rubroboletus*, to accommodate *Boletus sinicus* and its allies. Phytotaxa 188: 61–77. https://doi.org/10.11646/phytotaxa.188.2.1