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Taxonomy and phylogeny of *Phanerochaete sensu stricto* (Polyporales, Basidiomycota) with emphasis on Chinese collections and descriptions of nine new species

Xu YL[1] , Cao YF[1], Nakasone KK[2], Chen CC[3] and He SH[1*]

[1]*School of Ecology and Nature Conservation, Beijing Forestry University, Beijing 100083, China*
[2]*Center for Forest Mycology Research, Northern Research Station, U.S. Forest Service, Madison 53726, WI, U.S.A.*
[3]*Department of Plant Pathology, National Chung Hsing University, Taichung 40227, Taiwan, China*

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Abstract

The taxonomy of *Phanerochaete sensu stricto* is studied herein by using both morphological and molecular methods. Phylogenetic analyses are based on a concatenated ITS1-5.8S-ITS2 and nrLSU sequence data of 50 taxa of *Phanerochaete s.s.* around the world. Among these are nine newly described and illustrated species – *P. burdsallii*, *P. cinerea*, *P. hymenochaetoides*, *P. leptocystidiata*, *P. metuloidea*, *P. minor*, *P. sinensis*, *P. subrosea* and *P. yunnanensis*. While *P. burdsallii* is from the U.S.A., the other new species were collected from China. In addition, nine species, *P. bambucicola*, *P. citrinosanguinea*, *P. concrescens*, *P. cumulodentata*, *P. ericina*, *P. incarnata*, *P. livescens*, *P. magnoliae* and *P. taiwaniana* are reported from mainland China for the first time. So far, 28 species of *Phanerochaete s.s.* from mainland China are confirmed by morphology and DNA sequence data. An identification key to all these species is presented. *Phanerochaete fusca* is determined to be a synonym of *P. porostereoides*.

Key words – corticioid fungi – Phanerochaetaceae – phlebioid fungi – white rot

Introduction

Basidiomycetous species are highly diverse and a number of new species have recently been published (Alvarado et al. 2018, Desjardin & Perry 2018, Cui et al. 2019, Hapuarachchi et al. 2019). Many of these species have also been found to produce important secondary metabolites that have huge economic potential (Hapuarachchi et al. 2018a, b, Wu et al. 2019). Among those basidiomycetous species, the large corticioid genus *Phanerochaete* P. Karst. is widely distributed from boreal to tropical forests causing white rots on all kinds of wood and plays an important role in carbon cycling (Burdsall 1985). Morphologically, the genus is characterized by resupinate, membranaceous basidiomata with or without rhizomorphs, a monomitic hyphal system with primarily simple-septate generative hyphae, clavate basidia with four sterigmata, and smooth, thin-walled, inamyloid basidiospores (Eriksson et al. 1978, Burdsall 1985, Bernicchia & Gorjón 2010). Recent molecular studies demonstrate that *Phanerochaete sensu lato* is polyphyletic and distributed across several lineages in the phlebioid clade of the Polyporales and also the Hymenochaetales (de Koker et al. 2003, Greslebin et al. 2004, Wu et al. 2010, Floudas & Hibbett 2015, Miettinen et al. 2016, Justo et al. 2017, Chen et al. 2018). In several studies, *Phanerochaete s.s.* which includes the

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Corresponding Author: Shuang-Hui He – e-mail – shuanghuihe@yahoo.com

type, *P. alnea* (Fr.) P. Karst., formed a strongly supported clade in the Phanerochaetaceae (Floudas & Hibbett 2015, Spirin et al. 2017). After the separation of several small genera based mainly on molecular evidence, the *Phanerochaete s.s.* lineage consists of about one third of the known species of *Phanerochaete s.l.* Recent phylogenetic studies on the other hand revealed morphologically cryptic taxa in *Phanerochaete s.s.* (e.g. Volobuev et al. 2015, Spirin et al. 2017, Phookamsak et al. 2019). The morphological diversity has been relooked into as well. For example, *Phanerochaete krikophora* nom. prov. has been observed to possess primarily clamped septa (Floudas & Hibbett 2015) while *P. inflata* (B.S. Jia & B.K. Cui) Miettinen possesses poroid hymenophore (Miettinen et al. 2016).

The diversity and taxonomy of *Phanerochaete s.l.* in China have been studied for the last 30 years (Wu 1990, 1995, 1998, 2000, 2004, 2007, Xiong & Dai 2009, Wu et al. 2010, 2018a, b, Ghobad-Nejhad et al. 2015, Liu & He 2016, Chen et al. 2018). Early studies focused on the flora of Taiwan Province and often based solely on morphology. About 170 specimens of *Phanerochaete s.s.* were collected by the corresponding author and colleagues during the last decade mostly from mainland China. In this paper, we present data of some of these specimens and contribute to the taxonomy of the Phlebioid clade (Justo et al. 2017) in China.

Materials & Methods

Morphological studies

Voucher specimens are deposited at the herbaria of Beijing Forestry University, Beijing, China (BJFC), Centre for Forest Mycology Research, U.S. Forest Service, Madison, Wisconsin, U.S.A. (CFMR) and National Museum of Natural Science, Taichung, Taiwan, China (TNM). Freehand sections were made from dried basidiomata and mounted in 2% (w/v) potassium hydroxide (KOH), 1% (w/v) phloxine, Melzer’s reagent (IKI) or cotton blue (CB). Microscopic examinations were carried out with a Nikon Eclipse 80i microscope (Nikon Corporation, Japan) at magnifications up to 1000 ×. Drawings were made with the aid of a drawing tube. The following abbreviations are used: IKI– = neither amyloid nor dextrinoid, CB– = acyanophilous, L = mean spore length, W = mean spore width, Q = L/W ratio, n (a/b) = number of spores (a) measured from number of specimens (b). Color codes and names follow Kornerup & Wanscher (1978).

DNA extraction and sequencing

A CTAB plant genomic DNA extraction Kit DN14 (Aidlab Biotechnologies Co., Ltd, Beijing, China) was used to extract total genomic DNA from dried specimens and perform the polymerase chain reaction (PCR), according to the manufacturer's instructions. The ITS1-5.8S-ITS2 region was amplified with the primer pair ITS5/ITS4 (White et al. 1990) by using the following procedure: initial denaturation at 95°C for 4 min, followed by 34 cycles at 94°C for 40 s, 58°C for 45 s and 72°C for 1 min, and final extension at 72°C for 10 min. The nrLSU D1-D2 region was amplified with the primer pair LR0R/LR7 (http://www.biology.duke.edu/fungi/mycolab/primers.htm) by using the following procedure: initial denaturation at 94°C for 1 min, followed by 34 cycles at 94°C for 30 s, 50°C for 1 min and 72°C for 1.5 min, and final extension at 72°C for 10 min. DNA sequencing was performed at Beijing Genomics Institute, and the sequences were deposited in GenBank (Table 1). BioEdit v.7.0.5.3 (Hall 1999) and Geneious v.11.1.15 (Kearse et al. 2012) were used for chromatogram check and contig assembly.

Phylogenetic analyses

The molecular phylogeny was inferred from a concatenated dataset of ITS1-5.8S-ITS2 and nrLSU sequences of 50 *Phanerochaete s.s.* taxa, which were confirmed to belong to *Phanerochaete s.s.* clade by previous studies and our pre-analyses. *Phlebiopsis gigantea* (Fr.) Jülich and *Rhizochaete radicata* (Henn.) Gresl., Nakasone & Rajchenb. were selected as the outgroup (Floudas & Hibbett 2015). The sequences of ITS and nrLSU were aligned separately using MAFFT

v.7 (Katoh et al. 2017, http://mafft.cbrc.jp/alignment/server/) with the G-INS-i iterative refinement algorithm, and optimized manually in BioEdit v.7.0.5.3.. The separate alignments were concatenated using Mesquite v.3.5.1 (Maddison & Maddison 2018). The combined alignments were deposited in TreeBase (http://treebase.org/treebase-web/home.html, submission ID: 26185).

Maximum parsimony (MP), Maximum likelihood (ML) analyses and Bayesian inference (BI) were carried out by using PAUP* v.4.0b10 (Swofford 2002), RAxML v.8.2.10 (Stamatakis 2014) and MrBayes 3.2.6 (Ronquist et al. 2012) respectively. In MP analysis, trees were generated using 100 replicates of random stepwise addition of sequence and tree-bisection reconnection (TBR) branch-swapping algorithm with all characters given equal weight. Branch supports for all parsimony analyses were estimated by performing 1000 bootstrap replicates with a heuristic search of 10 random-addition replicates for each bootstrap replicate. In ML analysis, statistical support values were obtained using rapid bootstrapping with 1000 replicates, with default settings used for other parameters. For BI, the best-fit substitution model was estimated with jModeltest v.2.17 (Darriba et al. 2012). Four Markov chains were run for 2,700,000 generations until the split deviation frequency value was lower than 0.01. Trees were sampled every 100th generation. The first quarter of the trees, which represented the burn-in phase of the analyses, were discarded and the remaining trees were used to calculate posterior probabilities (BPP) in the majority rule consensus tree.

Table 1 Species and sequences used in the phylogenetic analyses. New species are in bold with type specimens mark with *.

Taxa	Voucher	Locality	ITS	nLSU	Literature
Phanerochaete albida	He 4554	China	MT235655	MT248133	This study
P. alnea	OM 8110	Finland	KP135171	–	Floudas & Hibbett 2015
P. alnea	KHL 12054	Norway	EU118653	EU118653	Larsson 2007
P. alnea subsp. lubrica	Spirin 8229	U.S.A.	KU893876	–	Spirin et al. 2017
P. argillacea	Wu 9712-18	China	–	GQ470656	Wu et al. 2010
P. arizonica	RLG-10248-Sp	U.S.A.	KP135170	KP135239	Floudas & Hibbett 2015
P. australis	He 6013	China	MT235656	MT248136	This study
P. australis	HHB-7105-Sp	U.S.A.	KP135081	KP135240	Floudas & Hibbett 2015
P. australosanguinea	20098 Tell	Chile	–	MH233928	Phookamsak et al. 2019
P. australosanguinea	20102 Tell	Chile	–	MH233929	Phookamsak et al. 2019
P. bambucicola	He 3606	China	MT235657	MT248137	This study
P. bambucicola	Wu 0707-2	China	MF399404	MF399395	Wu et al. 2018b
P. brunnea	He 4192	China	MT235658	MT248138	This study
P. brunnea	He 1873	China	KX212220	KX212224	Liu & He 2016
P. burdsallii	**He 2066***	**U.S.A.**	**MT235690**	**MT248177**	**This study**
P. burdsallii	**CFMR: RF9JR**	**U.S.A.**	**KU668973**	–	–
P. burdsallii	**FP-101018-sp**	**U.S.A.**	**AY219348**	–	**de Koker et al. 2003**
P. burtii	HHB-4618-Sp	U.S.A.	KP135117	KP135241	Floudas & Hibbett 2015
P. canobrunnea	He 5726	Sri Lanka	MT235659	MT248139	This study
P. canobrunnea	CHWC 1506-66	China	LC412095	LC412104	Wu et al. 2018a
P. canolutea	Wu 9211-105	China	–	GQ470641	Wu et al. 2010
P. carnosa	He 5172	China	MT235660	MT248140	This study
P. carnosa	HHB-9195	U.S.A.	KP135129	KP135242	Floudas & Hibbett 2015
P. chrysosporium	He 5778	Sri Lanka	MT235661	MT248141	This study

Table 1 Continued.

Taxa	Voucher	Locality	ITS	nLSU	Literature
P. chrysosporium	HHB-6251-Sp	U.S.A.	KP135094	KP135246	Floudas & Hibbett 2015
P. cinerea	**He 5998***	**China**	**–**	**MT248171**	**This study**
P. cinerea	**He 6003**	**China**	**–**	**MT248172**	**This study**
P. citrinosanguinea	He 4298	China	MT235691	MT248178	This study
P. citrinosanguinea	FP-105385-Sp	U.S.A.	KP135100	KP135234	Floudas & Hibbett 2015
P. concrescens	He 4657	China	MT235662	MT248142	This study
P. concrescens	Spirin 7322	Russia	KP994380	KP994382	Volobuev et al. 2015
P. cumulodentata	He 2995	China	MT235664	MT248144	This study
P. cumulodentata	LE 298935	Russia	KP994359	KP994386	Volobuev et al. 2015
P. cystidiata	He 4224	China	MT235665	MT248145	This study
P. cystidiata	Wu 1708-326	China	LC412097	LC412100	Wu et al. 2018a
P. deflectens	FCUG 2777	Turkey	–	GQ470644	Wu et al. 2010
P. ericina	He 4285	China	MT235666	MT248146	This study
P. ericina	HHB-2288	U.S.A.	KP135167	KP135247	Floudas & Hibbett 2015
P. fusca	Wu 1409-163	China	LC412099	LC412106	Wu et al. 2018a
P. hymenochaetoides	**He 5988***	**China**	**–**	**MT248173**	**This study**
P. incarnata	He 20120728-1	China	MT235669	MT248149	This study
P. incarnata	WEI 16-075	China	MF399406	MF399397	Wu et al. 2018b
P. inflata	Dai 10376	China	JX623929	JX644062	Jia et al. 2014
P. inflata	Cui 7712	China	JX623930	JX644063	Jia et al. 2014
P. krikophora nom. prov.	HHB-5796	U.S.A.	KP135164	KP135268	Floudas & Hibbett 2015
P. laevis	He 20120917-8	China	MT235670	MT248150	This study
P. laevis	HHB-15519	U.S.A.	KP135149	KP135249	Floudas & Hibbett 2015
P. leptocystidiata	**He 5853***	**China**	**MT235685**	**MT248168**	**This study**
P. leptocystidiata	**Dai 10468**	**China**	**MT235684**	**MT248167**	**This study**
P. livescens	He 5010	China	MT235671	MT248151	This study
P. livescens	FD-106	U.S.A.	KP135070	KP135253	Floudas & Hibbett 2015
P. magnoliae	He 3321	China	MT235672	MT248152	This study
P. magnoliae	HHB-9829-Sp	U.S.A.	KP135089	KP135237	Floudas & Hibbett 2015
P. metuloidea	**He 2565***	**China**	**–**	**MT248163**	**This study**
P. metuloidea	**He 2766**	**China**	**MT235682**	**MT248164**	**This study**
P. minor	**He 3988***	**China**	**MT235686**	**MT248170**	**This study**
P. minor	**He 3977**	**China**	**–**	**MT248169**	**This study**
P. parmastoi	He 4570	China	MT235673	MT248153	This study
P. parmastoi	Wu 880313-6	China	–	GQ470654	Wu et al. 2010
P. porostereoides	He 1902	China	KX212217	KX212221	Liu & He 2016
P. porostereoides	He 5365	China	–	MT248154	This study
P. pseudomagnoliae	PP-25	South Africa	KP135091	KP135250	Floudas & Hibbett 2015
P. pseudosanguinea	FD-244	U.S.A.	KP135098	KP135251	Floudas & Hibbett 2015
P. rhodella	FD-18	U.S.A.	KP135187	KP135258	Floudas & Hibbett 2015
P. robusta	Wu 1109-69	China	MF399409	MF399400	Wu et al. 2018b

Table 1 Continued.

Taxa	Voucher	Locality	ITS	nLSU	Literature
P. robusta (*aurantiobadia*)	Ghobad-Nejhad 2288	China	KP127068	KP127069	Ghobad-Nejhad et al. 2015
P. sanguinea	HHB-7524	U.S.A.	KP135101	KP135244	Floudas & Hibbett 2015
P. sanguineocarnosa	FD-359	U.S.A.	KP135122	KP135245	Floudas & Hibbett 2015
P. sinensis	**He 4660***	**China**	**MT235688**	**MT248175**	**This study**
P. sinensis	**GC 1809-56**	**China**	**MT235689**	**MT248176**	**This study**
P. sordida	He 5400	China	MT235676	MT248157	This study
P. sordida	FD-241	U.S.A.	KP135136	KP135252	Floudas & Hibbett 2015
P. stereoides	He 5824	Sri Lanka	MT235677	MT248158	This study
P. stereoides	He 2309	China	KX212219	KX212223	Liu & He 2016
P. subceracea	FP-105974-R	U.S.A.	KP135162	KP135255	Floudas & Hibbett 2015
P. subrosea	**He 2421***	**China**	**MT235687**	**MT248174**	**This study**
P. taiwaniana	He 5269	Vietnam	MT235680	MT248161	This study
P. taiwaniana	Wu 0112-13	China	MF399412	MF399403	Wu et al. 2018b
P. thailandica	2015_07	Thailand	MF467737	–	Sádlíková & Kout 2017
P. velutina	He 3079	China	MT235681	MT248162	This study
P. velutina	Kotiranta 25567	Russia	KP994354	KP994387	Volobuev et al. 2015
P. yunnanensis	**He 2719***	**China**	**MT235683**	**MT248166**	**This study**
P. yunnanensis	**He 2697**	**China**	**–**	**MT248165**	**This study**
Phlebiopsis gigantea	FP-70857-Sp	U.S.A.	KP135390	KP135272	Floudas & Hibbett 2015
Rhizochaete radicata	FD-123	U.S.A.	KP135407	KP135279	Floudas & Hibbett 2015

Results

Phylogenetic analyses

The concatenated dataset contained 72 ITS and 80 nrLSU sequences from 85 samples representing 50 *Phanerochaete s.s.* taxa and the outgroup (Table 1). Thirty ITS and 37 nrLSU sequences were generated for this study. The dataset had an aligned length of 2119 characters, of which 379 are parsimony-informative. MP analysis yielded two equally parsimonious trees (TL = 1568, CI = 0.467, RI = 0.716, RC = 0.335, HI = 0.533). jModelTest suggested GTR+I+G to be the best-fit models of nucleotide evolution for BI. The average standard deviation of split frequencies of BI was 0.009147 at the end of the run. ML and BI analyses resulted in almost identical tree topologies compared to the MP analysis. Only the MP tree is provided in Fig. 1 with the parsimony bootstrap values (≥ 50%, front), likelihood bootstrap values (≥ 50%, middle) and Bayesian posterior probabilities (≥ 0.95, back) labelled along the branches.

In the tree, the nine new species, *P. burdsallii*, *P. cinerea*, *P. hymenochaetoides*, *P. leptocystidiata*, *P. metuloidea*, *P. minor*, *P. sinensis*, *P. subrosea* and *P. yunnanensis* formed distinct lineages respectively. For some species, the sequences generated in this study formed strongly supported lineages with published GenBank sequences.

Phanerochaete burdsallii Y.L. Xu, Nakasone & S.H. He, sp. nov. Fig. 2

MycoBank: MB 835445; Facesoffungi number: FoF 08031

Type – U.S.A., Wisconsin State, Dane County, Madison city, Hoyt park, on fallen angiosperm trunk, 3 September 2014, He 2066 (BJFC 018724, holotype, isotype in CFMR).

Etymology – To honor Harold Hugh Burdsall, Jr. (CFMR, U.S.A.) for his contributions to the taxonomy of *Phanerochaete*.

Fruiting body – Basidiomata annual resupinate, effused, loosely adnate, easily detached from substrate, membranaceous, fragile when dry, first as small patches, later confluent up to 10 µm long, 3 cm wide. Hymenophore smooth, light orange [6A(4–5)], greyish orange [6B(4–6)] to brownish orange [6C(5–8)], turning reddish brown in KOH, uncracked; margin thinning out, fibrillose, with hyphal cords, lighter than hymenophore surface, white (6A1) to light orange [6A(4–5)].

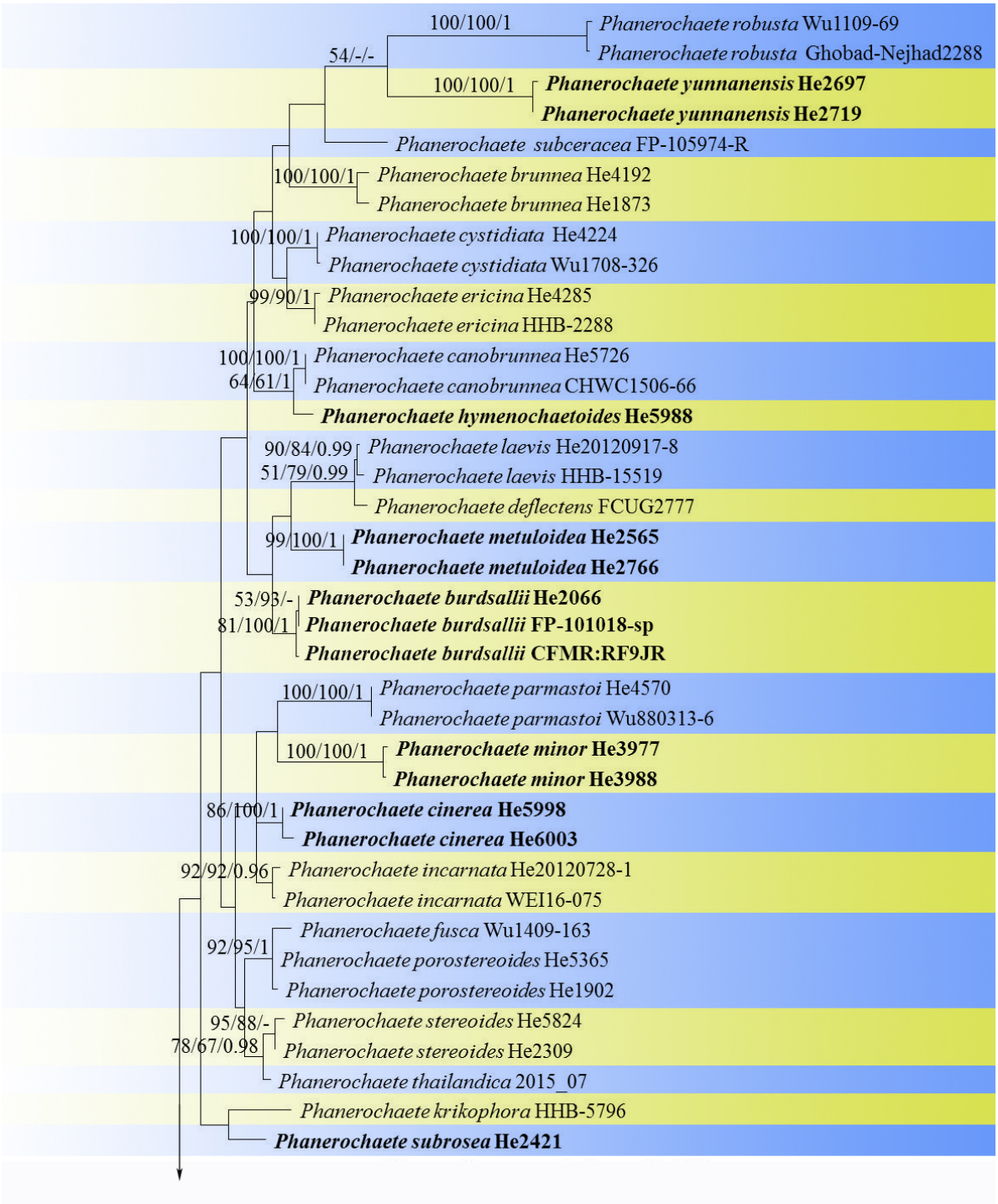

Figure 1 – Phylogenetic tree obtained from maximum parsimony analysis of a concatenated ITS and nrLSU sequence data of *Phanerochaete s.s.* Branches are labelled with parsimony bootstrap values (≥ 50%, front), likelihood bootstrap values (≥ 50%, middle) and Bayesian posterior probabilities (≥ 0.95, back). New species are shown in bold.

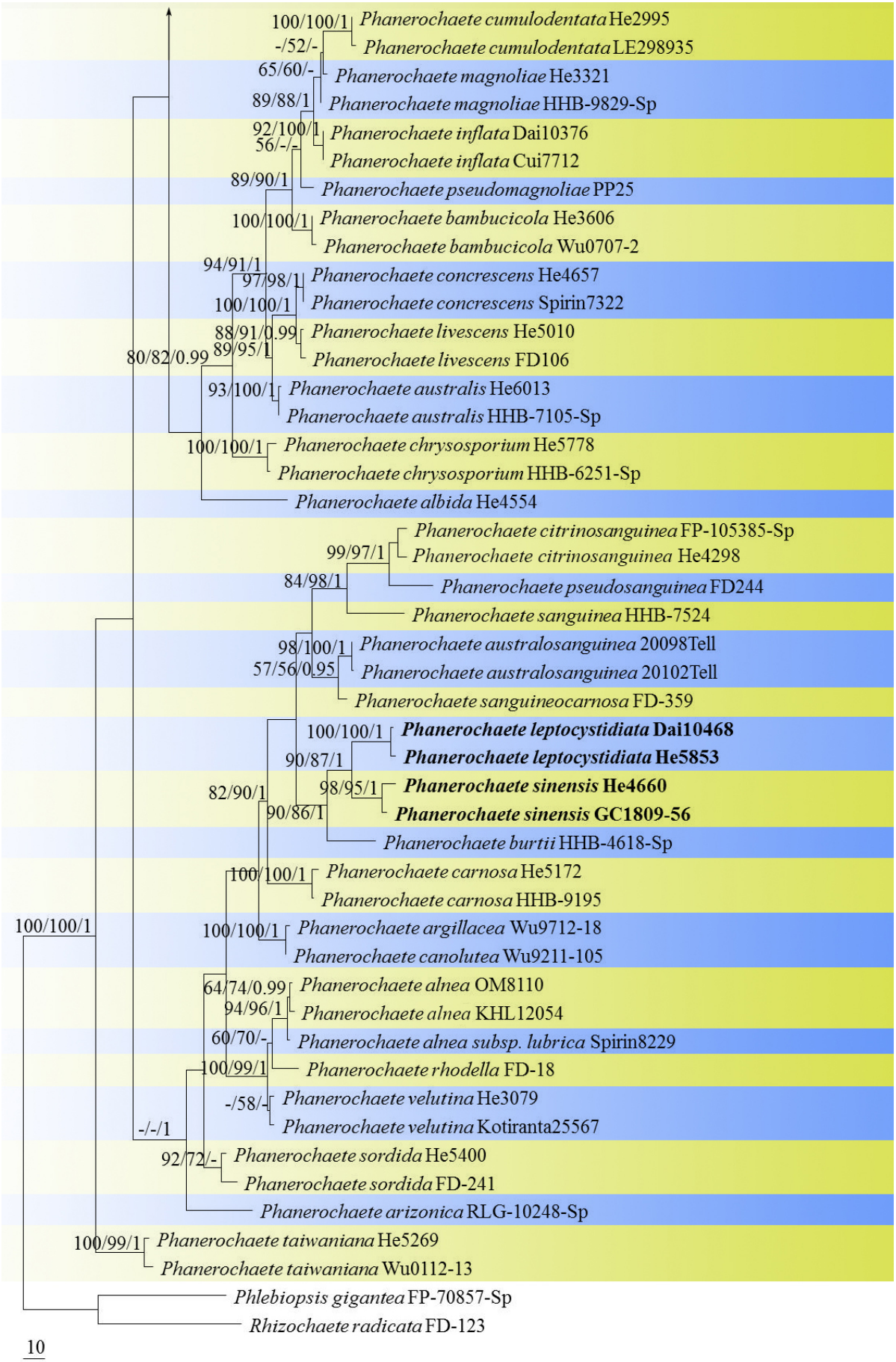

Figure 1 – Continued.

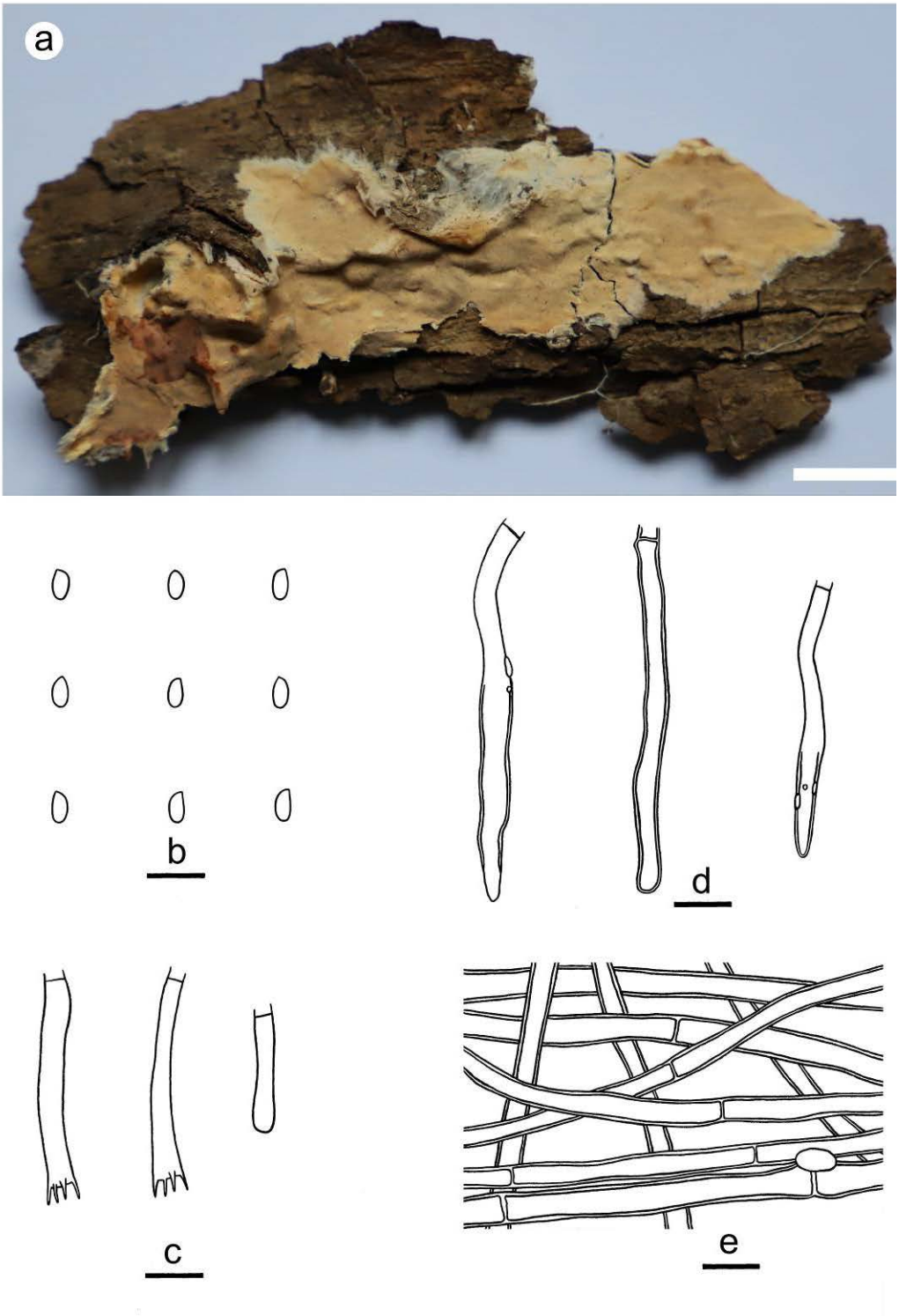

Figure 2 – *Phanerochaete burdsallii* (From the holotype He 2066). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e hyphae from subiculum. Scale bars: a = 1 cm, b–e = 10 µm.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, thick-walled, sparsely encrusted with fine crystals, moderately branched and septate, loosely interwoven, more or less parallel to substrate, 4–7 µm in diam. Cystidia subulate to subcylindrical with tapered or obtuse apex, colorless, thin- to slightly thick-walled, sparsely encrusted with small crystals in the upper part, projecting above the hymenium, with a basal simple septum, 50–90 × 3.5–6 µm. Basidia clavate to cylindrical, colorless, thin-walled, with a basal simple septum and four sterigmata, 22–38

× 4.5–6 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid, colorless, thin-walled, smooth, IKI–, CB–, (5–) 5.3–6 (–6.5) × 2.5–3 (–3.2) µm, L = 5.7 µm, W = 2.8 µm, Q = 2 (n = 30/1).

Additional specimens examined – U.S.A., Wisconsin State, on rotten *Populus* trunk, 2013, D. Richter (CFMR: RF9JR); Minnesota State, Cloquet, on fallen angiosperm trunk, 26 August 1972, FP-101018-sp (CFMR).

Distribution – Wisconsin and Minnesota States, north central U.S.A.

Notes – *Phanerochaete burdsallii* is characterized by its rhizomorphic basidiomata that turns reddish brown in KOH and presence of encrusted cystidia. *Phanerochaete burdsallii* is similar to *P. laevis* (Fr.) J. Erikss. & Ryvarden by sharing encrusted cystidia and same-sized basidiospores, but the latter species differs in having lighter basidiomata and thin-walled subicular hyphae (Burdsall 1985, Bernicchia & Gorjón 2010). In addition, *P. laevis* is widely distributed in Europe and North America, while *P. burdsallii* is known to date only in Wisconsin and Minnesota. *Phanerochaete sordida* (P. Karst.) J. Erikss. & Ryvarden is also similar to *P. burdsallii*, but differs in having thicker basidiomata and more loosely interwoven subicular hyphae that are rigid with thickened walls (Bernicchia & Gorjón 2010). In the phylogenetic tree, three samples of *P. burdsallii* formed a distinct lineage sister to *P. laevis* and *P. metuloidea* (Fig. 1). *Phanerochaete metuloidea* described as new species below resembles *P. burdsallii*, but differs in having softer basidiomata with more heavily encrusted cystidia and larger basidia (40–70 × 5–8.5 µm).

Phanerochaete cinerea Y.L. Xu & S.H. He, sp. nov. Fig. 3

MycoBank: MB 835446; Facesoffungi number: FoF 08032

Type – China, Hainan Province, Changjiang County, Bawangling Nature Reserve, on small diameter bamboo, 4 July 2019, He 5998 (BJFC 030874, holotype).

Etymology – Refers to the grey hymenophore surface.

Fruiting body – Basidiomata annual, resupinate, effused, adnate, detachable from substrate, membranaceous to coriaceous, first as many small patches, later confluent up to 15 µm long, 3 cm wide. Hymenophore smooth, grey (6C1–6D1), brownish grey (6C2–6D2) to greyish brown (6D3), slightly darkening in KOH, uncracked; margin thinning out, velvety, distinct, white (6A1), usually with a dark line near hymenophore when juvenile, becoming indistinct, concolorous or darker with hymenophore surface with age.

Microscopic structures – Hyphal system monomitic; generative hyphae simple-septate. Subicular hyphae yellowish brown, thick-walled to distinctly thick-walled, smooth, moderately branched and septate, tightly interwoven, more or less parallel to substrate, 3–5 µm in diam. Cystidia absent. Hyphida present, yellowish brown, thick-walled, branched. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 20–30 × 4–5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores subcylindrical, colorless, thin-walled, smooth, IKI–, CB–, 4.8–5.6 (–6) × 2–2.5 (–2.8) µm, L = 5.2 µm, W = 2.2 µm, Q = 2.4 (n = 30/1).

Additional specimen examined – China, Hainan Province, Changjiang County, Bawangling Nature Reserve, on small dead bamboo, 4 July 2019, He 6003 (BJFC 030879).

Distribution – Hainan Province, southern tropical China.

Notes – *Phanerochaete cinerea* is characterized by grey basidiomata on small diameter bamboo, absence of cystidia, brown subicular hyphae, and subcylindrical basidiospores. *Phanerochaete stereoides* Sheng H. Wu is similar to *P. cinerea* by sharing grey hymenophore and brown subicular hyphae, but differs in having effuse-reflexed and tough basidiomata and leptocystidia (Wu 1995). *Phanerochaete brunnea* Sheng H. Wu also has brown subicular hyphae and lacks cystidia, but differs from *P. cinerea* in having soft basidiomata and loosely interwoven subicular hyphae and lacking hyphidia (Wu 1990). *Phanerochaete porostereoides* S.L. Liu & S.H. He differs from *P. cinerea* in having brown, tough, coriaceous basidiomata, slightly wider basidiospores (4.7–5.3 × 2.5–3.1 µm) and a distribution in temperate regions (Liu & He 2016). *Phanerochaete thailandica* Kout & Sádlíková differs from *P. cinerea* in having leptocystidia and

larger basidiospores (7–8 × 4–4.5 µm, Sádlíková & Kout 2017). In the phylogenetic tree, two samples of *P. cinerea* formed a distinct lineage from morphologically similar species (Fig. 1).

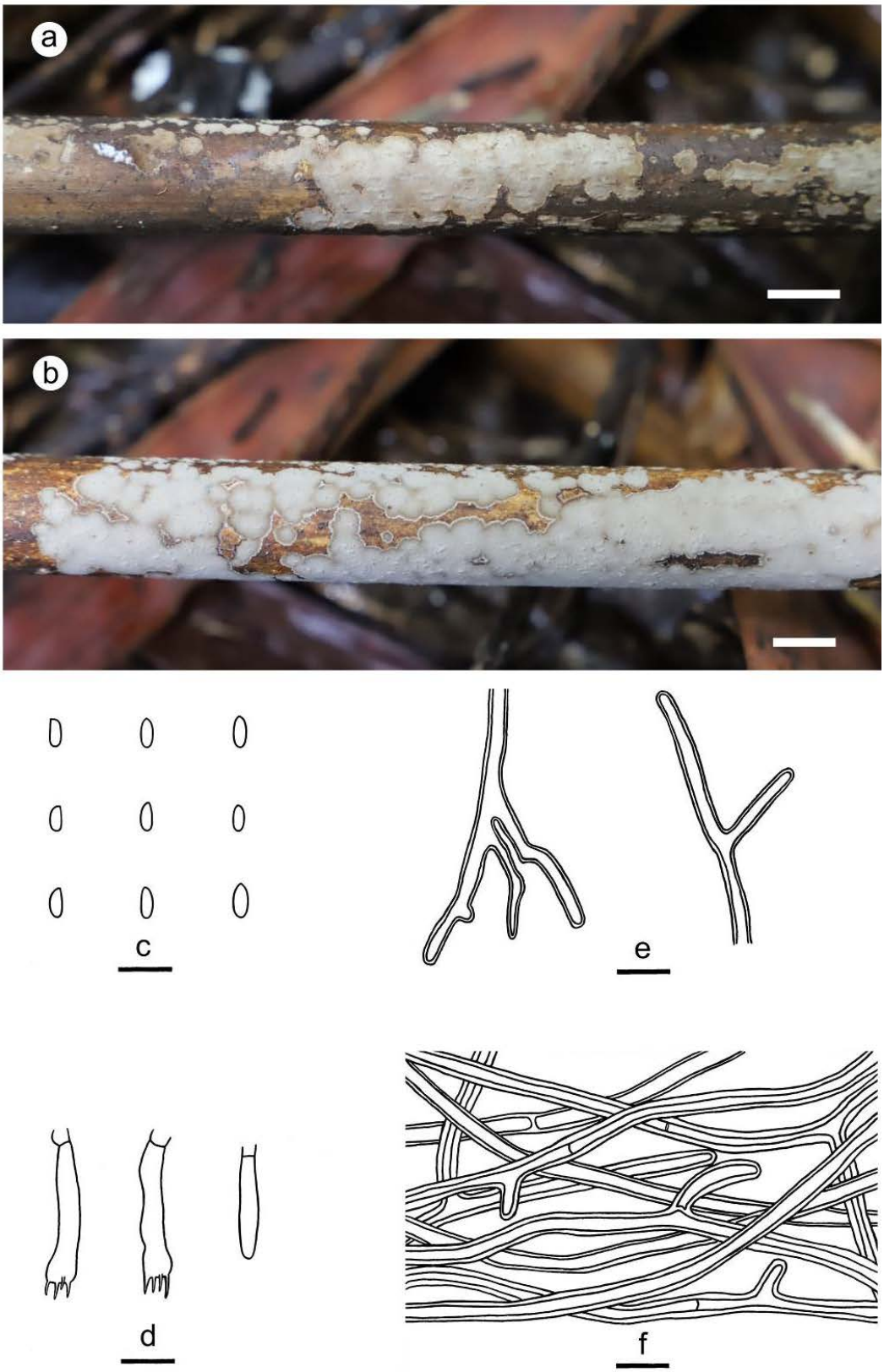

Figure 3 – *Phanerochaete cinerea* (a, c–f: from the holotype He 5998, b: from He 6003). a–b basidiomata. c basidiospores. d basidia and a basidiole. e hyphidia. f hyphae from subiculum. Scale bars: a–b = 1 cm, c–f = 10 µm

Phanerochaete hymenochaetoides Y.L. Xu & S.H. He, sp. nov. Fig. 4

MycoBank: MB 835447; Facesoffungi number: FoF 08033

Type – China, Hainan Province, Lingshui County, Diaoluoshan Nature Reserve, on fallen angiosperm branch, 2 July 2019, He 5988 (BJFC 030864, holotype).

Etymology – Refers to the *Hymenochaete*-like basidiomata.

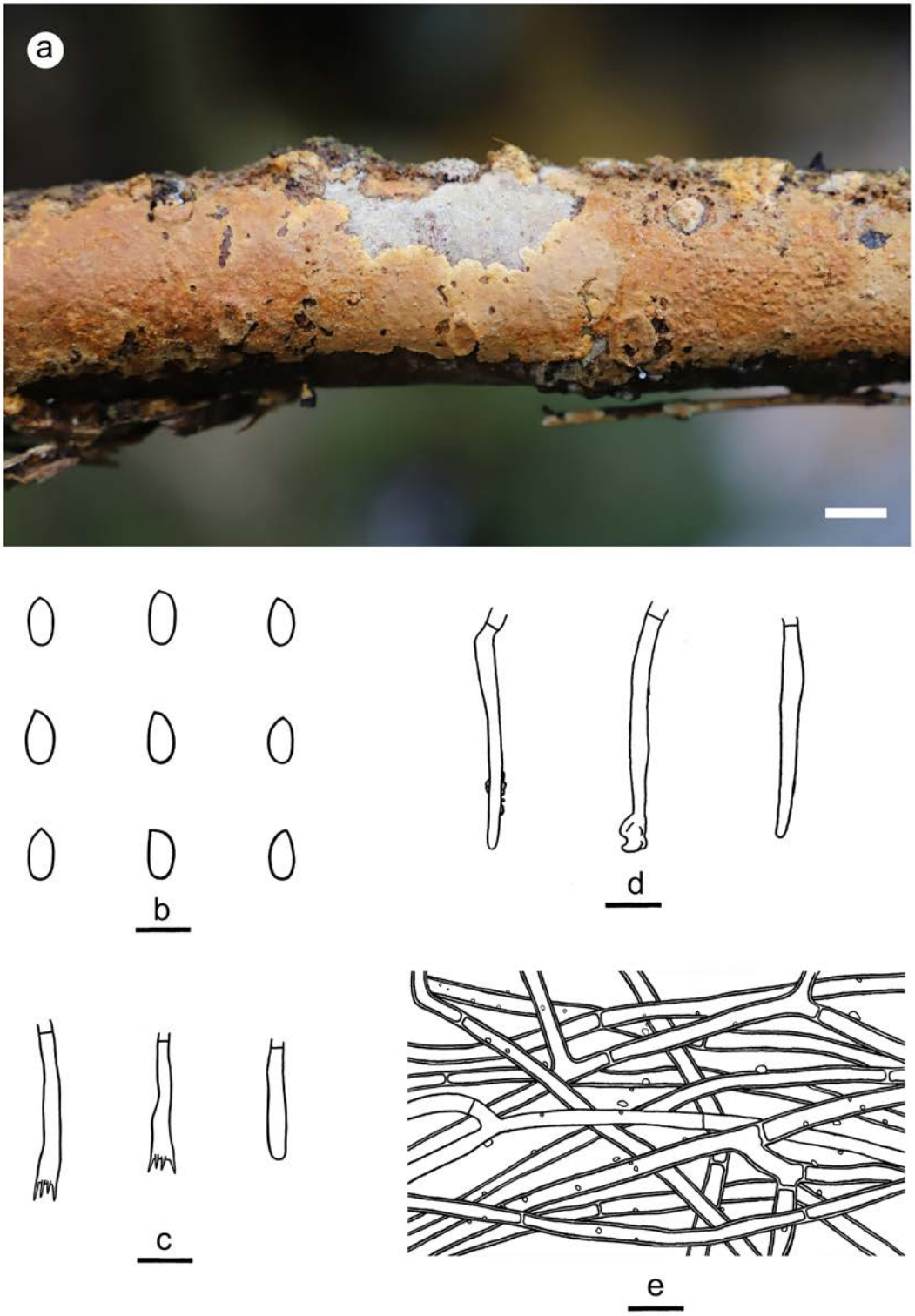

Figure 4 – *Phanerochaete hymenochaetoides* (from the holotype He5988). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e hyphae from subiculum. Scale bars: a = 1 cm, b = 5 µm, c–e = 10 µm.

Fruiting body – Basidiomata annual, resupinate, effused, closely adnate, undetachable from substrate, membranaceous to coriaceous, up to 20 µm long, 3.5 cm wide. Hymenophore smooth, greyish orange [6B(4–6)], brownish orange [6C(4–6)] to light brown [6D(4–6)], turning reddish brown in KOH, uncracked; margin thinning out, lighter or concolorous with hymenophore surface.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with clamp connections. Subicular hyphae colorless to light yellow, thin- to thick-walled, encrusted with yellow resinous granules, frequently branched and septate, interwoven, more or less parallel to substrate, 2–5 µm in diam. Cystidia subulate, tapered toward apex, colorless, thin-walled, encrusted with crystals at apex, projecting above the hymenium, with a basal simple septum, 30–45 × 3–4 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 15–45 × 3.5–5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid, colorless, thin-walled, smooth, IKI–, CB–, 4–5 (–5.2) × 2–2.8 µm, L = 4.3 µm, W = 2.3 µm, Q = 1.9 (n = 30/1).

Distribution – Hainan Province, southern tropical China.

Notes – *Phanerochaete hymenochaetoides* is characterized by the yellow to yellowish brown basidiomata, narrow encrusted subicular hyphae and presence of encrusted cystidia. In the phylogenetic tree, *P. hymenochaetoides* is closely related to *P. canobrunnea* Sheng H. Wu, C.C. Chen & C.L. Wei, but differs in having greyish brown basidiomata, a dimitic hyphal system with brown subicular hyphae, wider generative hyphae (4–9 µm in diam.) and lacking cystidia (Fig. 1, Wu et al. 2018a). *Phanerochaete cystidiata* Sheng H. Wu, C.C. Chen & C.L. Wei is similar to *P. hymenochaetoides* by sharing encrusted cystidia, but differs in having cream to yellow basidiomata with fibrillose margin and slightly larger cystidia (40–60 × 4–5.5 µm; Wu et al. 2018a). *Phanerochaete robusta* Parmasto is similar to *P. hymenochaetoides* by sharing the yellow basidiomata, but differs in having two kinds of cystidia without encrustation, larger basidiospores (5.5–7 × 2.4–2.9 µm) and a boreal distribution (Wu et al. 2018b).

Phanerochaete leptocystidiata Y.L. Xu & S.H. He, sp. nov. Fig. 5

MycoBank: MB 835448; Facesoffungi number: FoF 08034

Type – China, Guangdong Province, Renhua County, Danxiashan Nature Reserve, on fallen angiosperm trunk, 4 June 2019, He 5853 (BJFC 030728, holotype).

Etymology – Refers to the presence of typical leptocystidia.

Fruiting body – Basidiomata annual, resupinate, effused, loosely adnate, easily detached from substrate, pellicular to membranaceous, up to 10 µm long, 8 cm wide. Hymenophore smooth to tuberculate, white (6A1) when fresh, becoming smooth, pale orange (6A3), orange grey (6B2) to greyish orange [6B(3–5)] when dry, slightly darkening in KOH, sparsely cracked with age; margin thinning out, fibrillose, concolorous with hymenophore surface; hyphal cords greyish orange [6B(4–5)] to orange [6B(7–8)], turning reddish brown in KOH.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, slightly thick-walled, encrusted with crystals, rarely branched and septate, loosely interwoven, more or less parallel to substrate, 3–7 µm in diam. Cystidia subulate, tapered toward apex, colorless, thin-walled, smooth or rarely encrusted at apex, projecting above the hymenium, with a basal simple septum, 30–70 × 4–6 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 24–30 × 4.5–6 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid to subcylindrical, colorless, thin-walled, smooth, IKI–, CB–, 5–6 (–6.5) × 2.5–3 µm, L = 5.5 µm, W = 2.7 µm, Q = 2.1 (n = 30/1).

Additional specimens examined – China, Guizhou Province, Xishui County, Xishui Nature Reserve, on fallen angiosperm branch, 6 July 2018, He5426 (BJFC 026487); Jiangxi Province, Fenyi County, Dagangshan Nature Reserve, on fallen angiosperm trunk, 18 September 2008, Dai 10468 (BJFC 004717).

Distribution – Guangdong, Guizhou and Jiangxi Provinces, southern subtropical China.

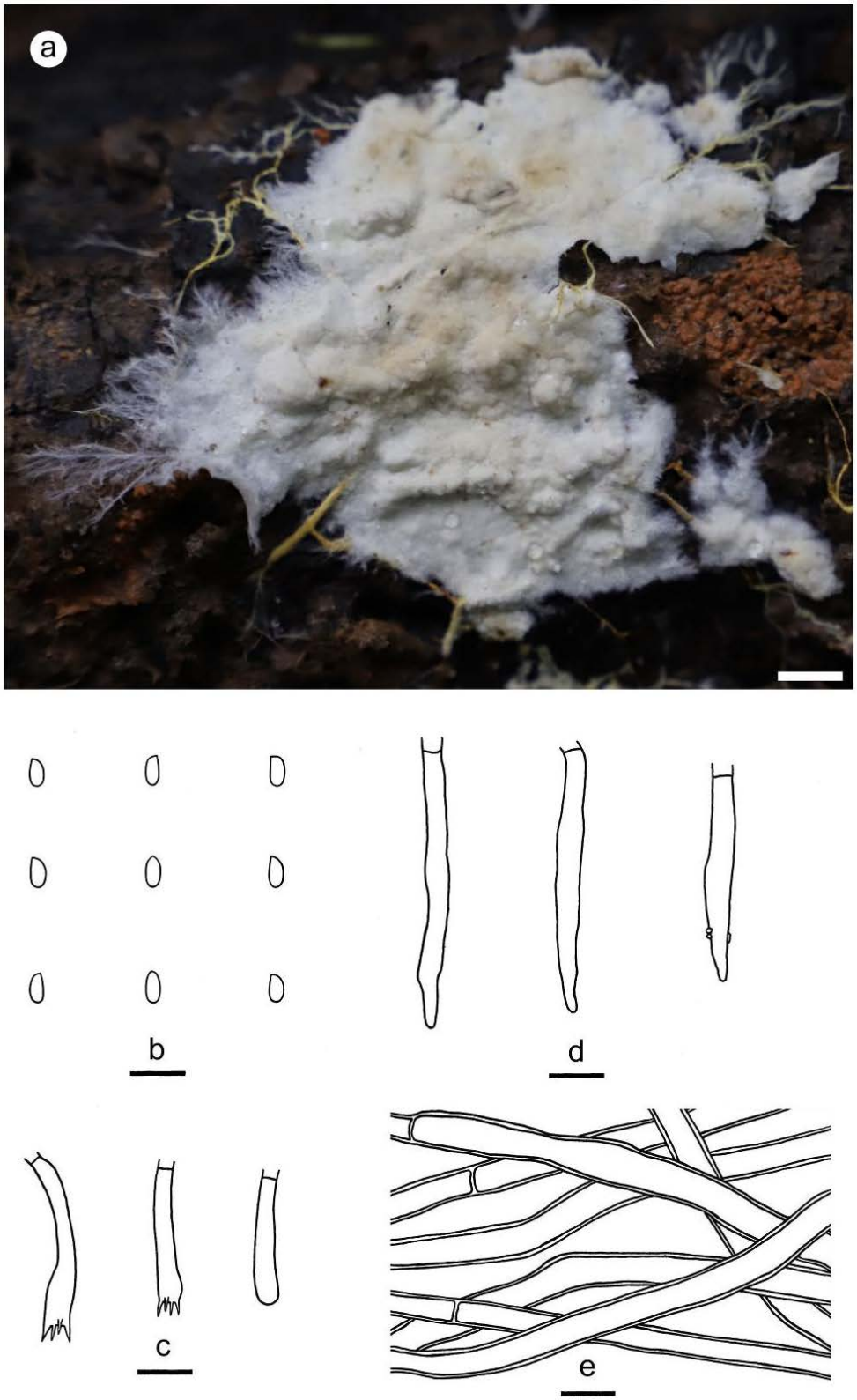

Figure 5 – *Phanerochaete leptocystidiata* (from the holotype He 5853). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e hyphae from subiculum. Scale bars: a = 1 cm, b–e =10 µm.

Notes – *Phanerochaete leptocystidiata* is characterized by the white to greyish orange pellicular basidiomata with hyphal cords and leptocystidia. In the phylogenetic tree, *P. leptocystidiata*, *P. sinensis* and *P. burtii* (Romell ex Burt) Parmasto formed a strongly supported clade (Fig. 1). Morphologically, the three species are very similar to each other by sharing

pellicular basidiomata with hyphal cords and leptocystidia. *Phanerochaete sinensis* differs from *P. leptocystidiata* by having slightly shorter cystidia (35–50 µm), slightly smaller basidiospores (4–5 × 2–2.5 µm) and a temperate distribution. *Phanerochaete burtii* differs from *P. leptocystidiata* by slightly shorter cystidia (25–55 µm), slightly narrower basidiospores (2–2.5 µm) and a distribution in U.S.A., Jamaica, Argentina, Brazil and Australia (Burdsall 1985, Hjortstam 2000). The *P. burtii* group is also morphologically similar to and phylogenetically close to *P. sanguinea* (Fr.) Pouzar group and *P. carnosa* (Burt) Parmasto. However, species of *P. sanguinea* group have orange to red basidiomata that usually stain the substrate with same color, whilst *P. carnosa* has an ochraceous hymenophore that turns dark green in KOH (Burdsall 1985, Xiong & Dai 2009, Floudas & Hibbett 2015).

Phanerochaete metuloidea Y.L. Xu & S.H. He, sp. nov. Fig. 6

MycoBank: MB 835449; *Facesoffungi number*: FoF 08035

Type – China, Yunnan Province, Jingdong County, Ailaoshan Nature Reserve, on fallen angiosperm branch, 24 August 2015, He 2565 (BJFC 021018, holotype).

Etymology – Refers to the presence of numerous lamprocystidia.

Fruiting body – Basidiomata annual, resupinate, widely effused, loosely adnate, easily detached from substrate, membranaceous to coriaceous, fragile after dried, up to 20 cm long, 6 cm wide. Hymenophore smooth, greyish orange [6B(3–4)], brownish orange [6C(3–4)] to light brown [6D(4–5)], turning reddish brown in KOH, uncracked or sparsely cracked with age; margin thinning out, byssoid when juvenile, becoming indistinct with age, concolorous with hymenophore surface.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, slightly thick-walled, moderately branched and septate, tightly interwoven, more or less parallel to substrate, 3–7 µm in diam. Cystidia (lamprocystidia) subulate to subfusiform, colorless, thick-walled, encrusted with crystals in the upper part, with a basal simple septum, occasionally with one or two secondary septa, projecting above the hymenium, 40–80 × 5–8 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 40–70 × 5–8.5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid, colorless, thin-walled, smooth, IKI–, CB–, (4.5–) 5–6 × 2.5–3 µm, L = 5.5 µm, W = 2.8 µm, Q = 2 (n = 30/1).

Additional specimens examined – China, Fujian Province, Wuyishan County, Wuyishan Nature Reserve, on dead angiosperm branch, 17 August 2016, He 4463 (BJFC 023904); Jiangxi Province, Lianping County, Jiulianshan Nature Reserve, on fallen angiosperm trunk, 13 August 2016, He 4322 (BJFC 023764); Yunnan Province, Jingdong County, Ailaoshan Nature Reserve, on fallen angiosperm branch, 25 August 2015, He 2619 (BJFC 021065); Yongde County, Daxueshan Nature Reserve, on *Quercus* stump, 27 August 2015, He 2664 (BJFC 021104) & He2675 (BJFC 021114), 28 August 2015, He 2766 (BJFC 021204); Yongping County, Baotaishan Forest Park, on base of living *Quercus*, 27 November 2015, He 3235 (BJFC 021630); on *Quercus* stump, 27 November 2015, He 3272 (BJFC 021667); Kunming, Panlong District, Yeyahu Park, on fallen angiosperm branch, 28 July 2014, He20140728-1 (BJFC 019238) & He 20140728-14 (BJFC 019247); on living *Quercus* tree, 22 August 2015, He 2523 (BJFC 020976); Luquan County, Zhuanlong Town, on dead angiosperm branch, 4 December 2015, He3508a (BJFC 021905); Zhejiang Province, Kaihua County, Gutianshan Nature Reserve, on fallen angiosperm trunk, 12 August 2013, He 1799 (BJFC 016266) & He 1806 (BJFC 016273).

Distribution – Southern China, mainly on *Quercus*.

Notes – *Phanerochaete metuloidea* is characterized by the presence of thick-walled lamprocystidia and long basidia. In macro-morphology, *P. metuloidea* is similar to *P. laevis*, *P. sordida* and *P. burdsallii*, but differs in having soft texture basidiomata, obviously thick-walled cystidia, and much longer basidia. In the phylogenetic tree, two samples of *P. metuloidea* formed a lineage sister to *P. laevis* and *P. burdsallii*, but distant from *P. sordida* (Fig. 1). *Phanerochaete livescens* (P. Karst.) Volobuev & Spirin is similar to *P. metuloidea* by sharing thick-walled

lamprocystidia, but differs in having ceraceous, ochraceous basidiomata, smaller basidia (16.4–27.2 × 3.9–5.0 µm) and a northern temperate distribution (Volobuev et al. 2015). *Phanerochaete australis* Jülich differs from *P. metuloidea* in having shorter but wider cystidia (38–56 × 7–10.8 µm) and shorter basidia (20–25.8 × 4.3–5 µm, Xiong & Dai 2009).

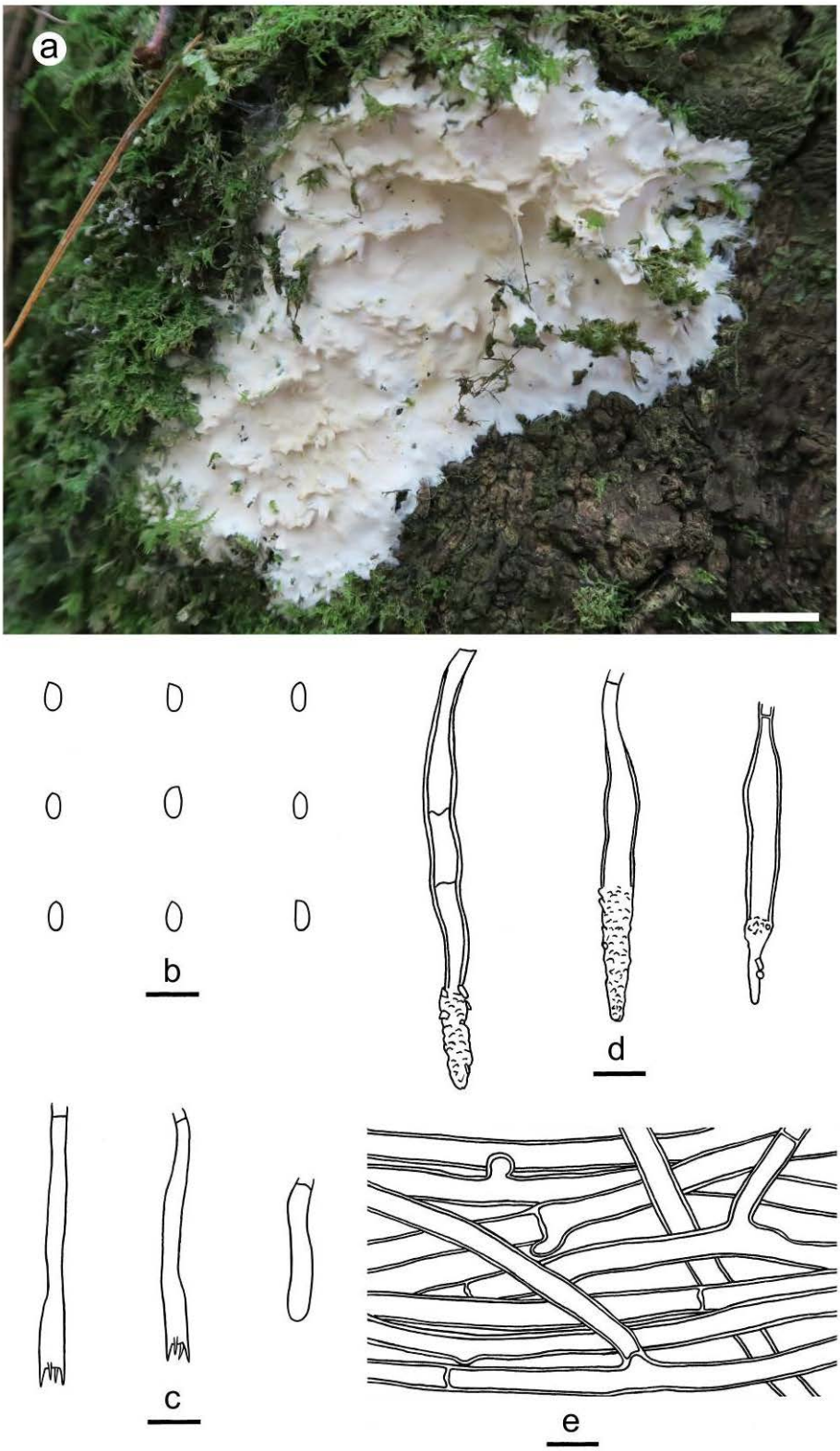

Figure 6 – *Phanerochaete metuloidea* (a from He 3235, b–e from the holotype He 2565). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e hyphae from subiculum. Scale bars: a = 1 cm, b–e = 10 µm.

Phanerochaete minor Y.L. Xu & S.H. He, sp. nov. Fig. 7

MycoBank: MB 835450; *Facesoffungi number*: FoF 08027

Type – China, Hainan Province, Baoting County, Qixianling Forest Park, on rotten monocots culm, 11 June 2016, He 3988 (BJFC 022490, holotype).

Etymology – Refers to the small cystidia and basidiospores.

Fruiting body – Basidiomata annual, resupinate, effused, loosely adnate, easily detached from substrate, membranaceous, up to 15 cm long, 2 cm wide. Hymenophore smooth, light orange [6A(4–5)] to greyish orange [6B(3–6)], unchanged in KOH, uncracked or sparsely and minutely cracked with age; margin thinning out, fimbriate or indistinct, concolorous with hymenophore surface.

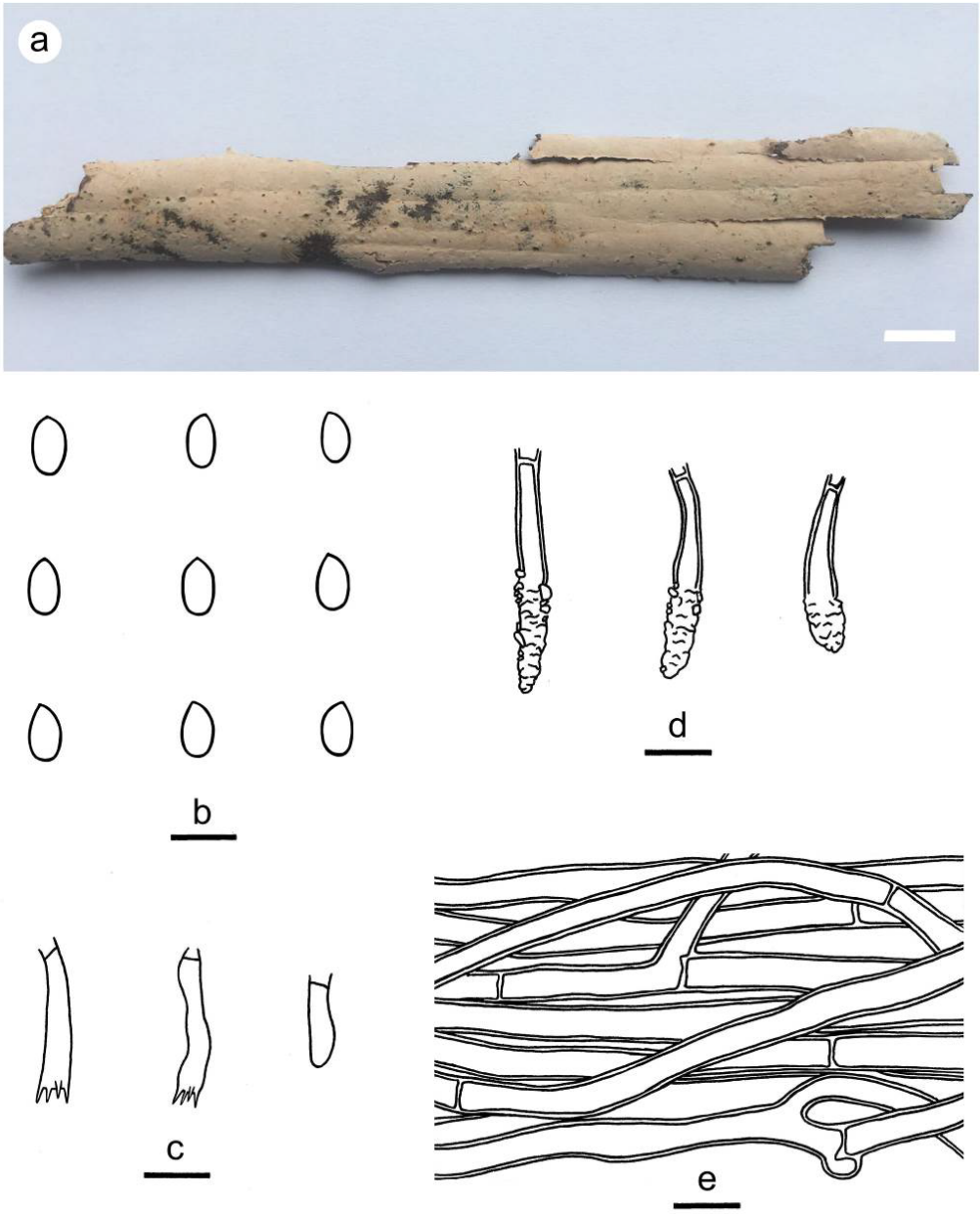

Figure 7 – *Phanerochaete minor* (from the holotype He 3988). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e hyphae from subiculum. Scale bars: a = 1 cm, b = 5 µm, c–e = 10 µm.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, slightly thick-

walled, moderately branched and septate, tightly interwoven, more or less parallel to substrate, 3–5 µm in diam. Cystidia (lamprocystidia) subcylindrical to subclavate, colorless, thick-walled, encrusted with crystals in the upper part, with a basal simple septum, occasionally with a secondary septum, projecting above the hymenium, 19–37 × 3–7 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 15–21 × 3–5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid, colorless, thin-walled, smooth, IKI–, CB–, (3.5–) 4–4.6 (–4.8) × 2–2.5 (–2.8) µm, L = 4.2 µm, W = 2.2 µm, Q = 1.9 (n = 30/1).

Additional specimen examined – China, Hainan Province, Wuzhishan County, Wuzhishan Nature Reserve, on rotten monocots culms, 11 June 2016, He 3977 (BJFC 022479).

Distribution – Hainan Province, southern tropical China.

Notes – *Phanerochaete minor* is characterized by the light orange basidiomata on monocots, short lamprocystidia, and small basidiospores. In the phylogenetic tree, two samples of *P. minor* formed a lineage sister to *P. cystidiata*, which differs in having cream to light yellow basidiomata and longer thin-walled cystidia (40–60 µm, Wu et al. 2018a). A similar species, *Phanerochaete flavidogrisea* Sheng H. Wu has yellowish grey hymenophore, small basidiospores (3–3.8 × 2–2.8 µm), and lacks cystidia (Wu 1998). *Phanerochaete eburnea* Sheng H. Wu is similar to *P. minor* by sharing encrusted cystidia and small basidiospores, but differs in having ivory-colored hymenophore, longer cystidia (30–60 µm) and subglobose basidiospores (3.7–4.7 × 2.8–3.2 µm, Wu 1998).

Phanerochaete sinensis Y.L. Xu, C.C. Chen & S.H. He, sp. nov. Fig. 8

MycoBank: MB 835451; Facesoffungi number: FoF 08028

Type – China, Liaoning Province, Zhuanghe County, Xianrendong Forest Park, on fallen angiosperm branch, 5 August 2017, He 4660 (BJFC 024179, holotype).

Etymology – Refers to the distribution in China.

Fruiting body – Basidiomata annual, resupinate, effused, loosely adnate, easily detached from substrate, pellicular to membranaceous, up to 10 cm long, 4 cm wide. Hymenophore smooth, white (6A1), light orange (6A4) to greyish orange [6B(3–4)], slightly darkening in KOH, uncracked or sparsely cracked when dried; margin thinning out, fibrillose or indeterminate, concolorous with hymenophore surface; hyphal cords white (6A1) to orange [6B(7–8)], turning reddish brown in KOH.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, slightly thick-walled, frequently branched and septate, loosely interwoven, more or less parallel to substrate, 3–7 µm in diam. Cystidia (leptocystidia) subcylindrical, slightly tapering toward apex, colorless, thin-walled, smooth, with a basal simple septum, projecting above the hymenium, 35–50 × 4–6 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 17–22 × 4–5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid to subcylindrical, colorless, thin-walled, smooth, IKI–, CB–, 4–5 (–5.5) × 2–2.5 µm, L = 4.9 µm, W = 2.2 µm, Q = 2.2 (n = 30/1).

Additional specimens examined – China, Yunnan Province, Pingbian County, Daweishan Forest Park, on fallen angiosperm trunk, 11 November 2019, He 6189 (BJFC); Taiwan Province, Nantou County, Jenai Township, Aowanda National Forest Recreation Area, pine tree zone, 121°11' E, 23°56' N, alt. 1300 m, on fallen gymnosperm branch, 12 September 2018, GC 1809-56 (TNM).

Distribution – Liaoning, Yunnan and Taiwan Provinces of China.

Notes – *Phanerochaete sinensis* is characterized by the pellicular basidiomata with hyphal cords, presence of leptocystidia and subcylindrical basidiospores. It belongs to the *P. burtii* group, and morphologically almost indistinguishable from *P. burtii*, which, however, has longer basidia (25–35 µm) and a distribution outside China. For other comparisons with similar species, see the discussions under *P. leptocystidiata* above.

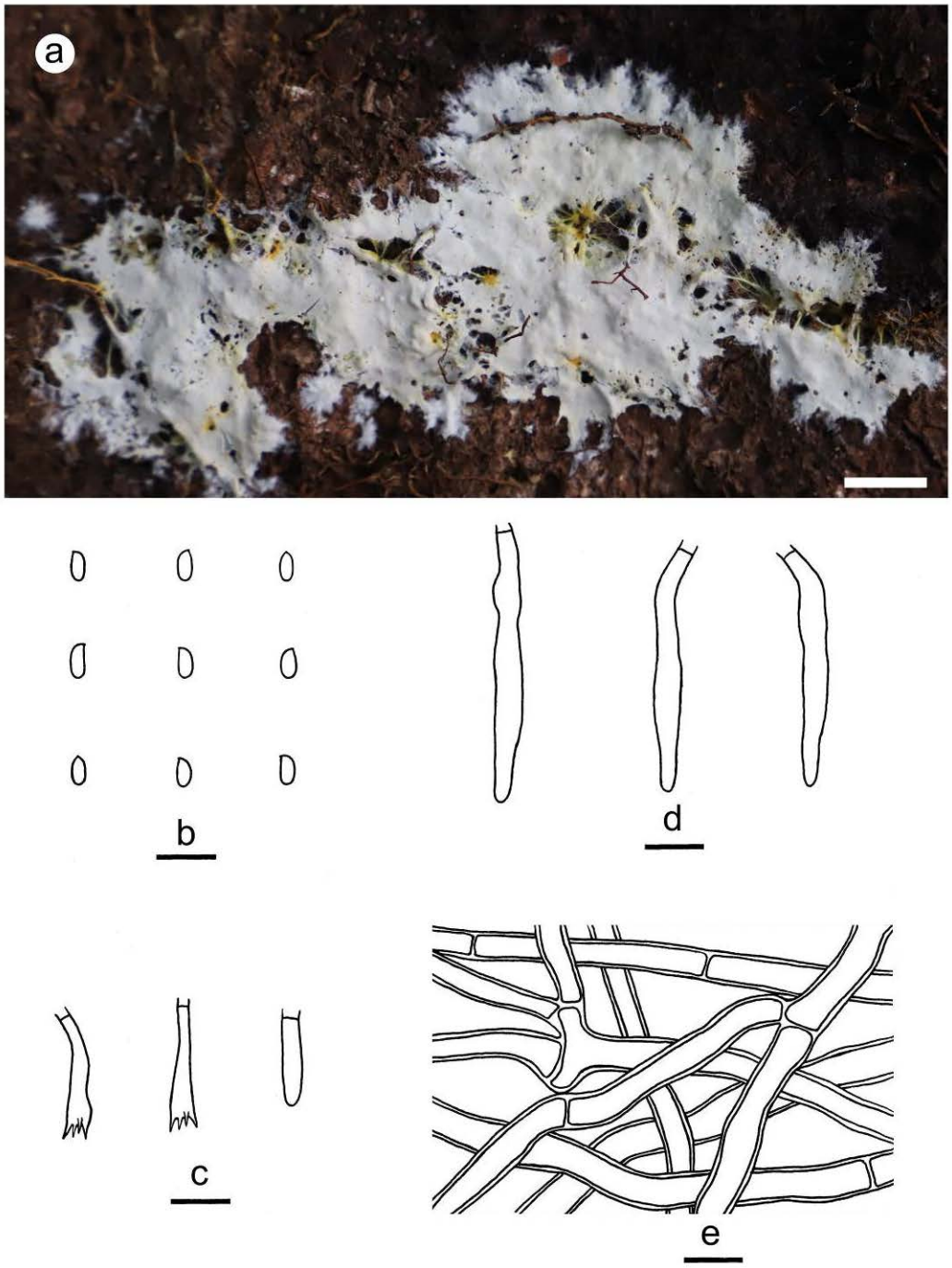

Figure 8 – *Phanerochaete sinensis* (a from He 6189, b–e from the holotype He 4660). a basidiomata; b. basidiospores; c. basidia and a basidiole; d. cystidia; e. hyphae from subiculum. Scale bars: a = 1 cm, b–e = 10 µm

Phanerochaete subrosea Y.L. Xu & S.H. He, sp. nov. Fig. 9

MycoBank: MB 835452; Facesoffungi number: FoF 08029

Type – China, Ningxia Autonomous Region, Jingyuan County, Liupanshan Forest Park, on fallen angiosperm branch, 4 August 2015, He 2421 (BJFC 020874, holotype).

Etymology – Refers to the light pink to red basidiomata.

Fruiting body – Basidiomata annual, resupinate, effused, loosely adnate, easily detached from substrate, membranaceous, fragile after dried, up to 20 cm long, 3.5 cm wide. Hymenophore smooth, pale red (8A3), pastel red [8A(4–5)] to greyish red [8B(4–5)], turning purple in KOH,

uncracked; margin thinning out, fimbriate or indistinct, lighter or concolorous with hymenphore surface; hyphal cords concolorous with hymenophore, turning purple in KOH.

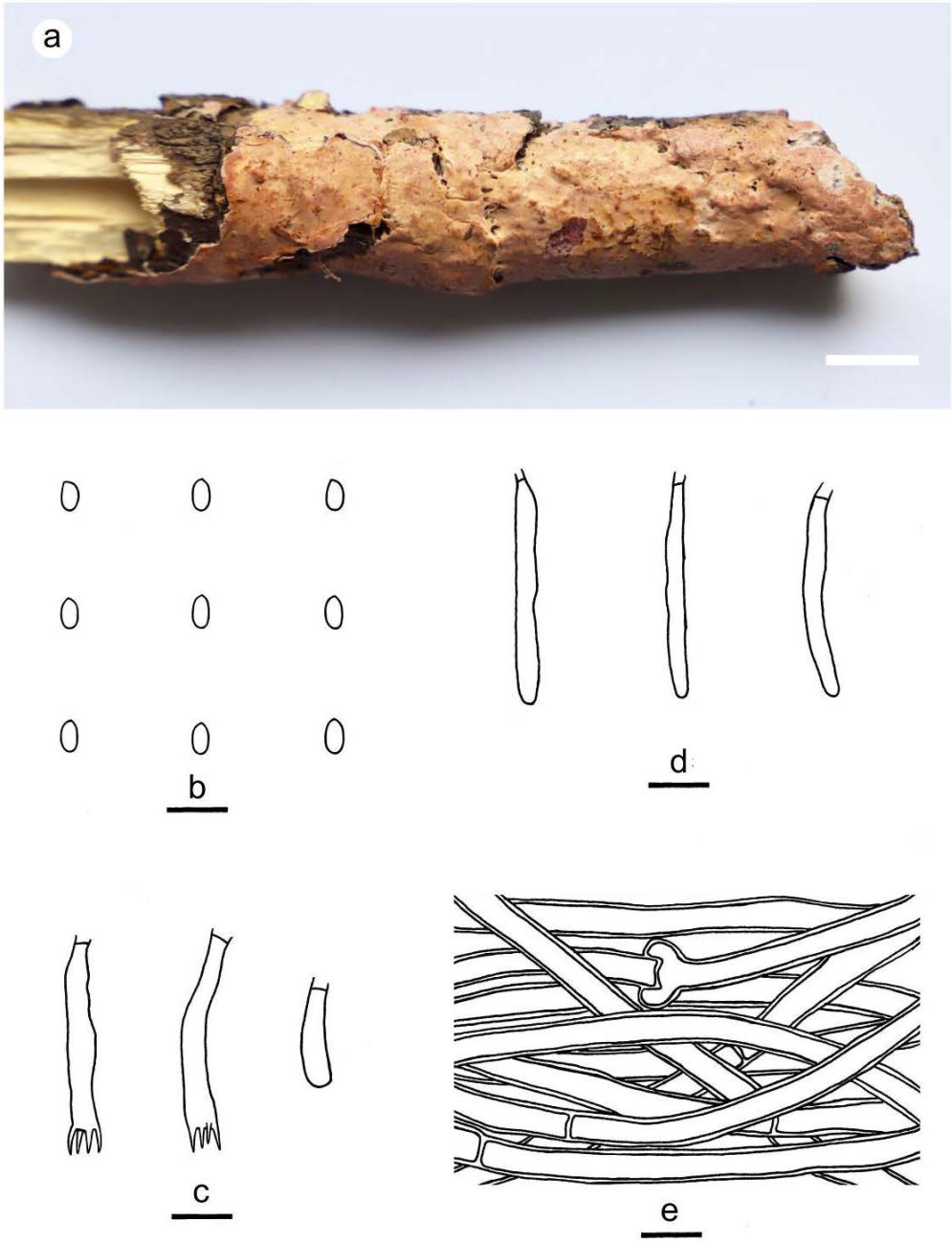

Figure 9 – *Phanerochaete subrosea* (from the holotype He 2421). a basidiomata. b basidiospores. c basidia and a basidiole. d cystidia. e. hyphae from subiculum. Scale bars: a = 1 cm, b–e = 10 µm

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, slightly thick-walled, moderately branched and septate, tightly interwoven, more or less parallel to substrate, 3–5 µm in diam. Cystidia (leptocystidia) subcylindrical, colorless, thin-walled, smooth, with a basal simple septum, projecting above the hymenium, 33–55 × 3–5 µm. Basidia clavate, colorless, thin-walled, with a basal simple septum and four sterigmata, 24–36 × 4.5–5.5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid, colorless, thin-walled, smooth, IKI–, CB–, 5–6 (–6.5) × 2.5–3 µm, L = 5.3 µm, W = 2.8 µm, Q = 1.9 (n = 30/1).

Distribution – Ningxia Autonomous Region, northwest China.

Notes – *Phanerochaete subrosea* is characterized by the light pink to red basidiomata turning purple in KOH and subcylindrical leptocystidia. Morphologically, the *P. sanguinea* group resembles *P. subrosea* by sharing the more or less red basidiomata with hyphal cords and presence of leptocystidia, but differs in turning black in KOH and staining the substrate with reddish orange color (Burdsall 1985, Bernicchia & Gorjón 2010, Floudas & Hibbett 2015). *Phanerochaete carnosa* is also similar to *P. subrosea*, but differs in having basidiomata turning green in KOH, subulate cystidia and slightly smaller basidiospores (Burdsall 1985). In the phylogenetic tree, *P. subrosea* is not closely related to the *P. sanguinea* group and *P. carnosa*, but forms a lineage with a sequence of *P. krikophora* (HHB-5796). However, this lineage received low support values from all analyses, and the latter name was not officially published and represented a species with clamp connections (Fig. 1, Floudas & Hibbett 2015). *Phanerochaete subrosea* resembles species of *Rhizochaete* Gresl., Nakasone & Rajchenb. by sharing the membranaceous basidiomata and hyphal cords turning purple in KOH, but they are not phylogenetically closely related (Greslebin et al. 2004).

Phanerochaete yunnanensis Y.L. Xu & S.H. He, sp. nov. Fig. 10

MycoBank: MB 835478; Facesoffungi number: FoF 08030

Type – China, Yunnan Province, Yongde County, Daxueshan Nature Reserve, on dead liana, 27 August 2015, He 2719 (BJFC 021157, holotype).

Etymology – Refers to the type locality in Yunnan Province, southwest China.

Fruiting body – Basidiomata annual, resupinate, effused, closely adnate, membranaceous to coriaceous, up to 20 cm long, 2.5 cm wide. Hymenophore grandinioid with small dense granules, pale orange (6A3), light orange [6A(4–5)] to greyish orange [6B(3–6)], unchanged in KOH, uncracked at first then densely cracked with age; margin thinning out, distinct, white, byssoid, becoming thick and indistinct with age.

Microscopic structures – Hyphal system monomitic; generative hyphae mostly simple-septate, occasionally with single or double clamp connections. Subicular hyphae colorless, thick-walled, moderately branched and septate, interwoven, more or less parallel to substrate, 3–5 µm in diam. Cystidia absent. Encrusted hyphae present, cylindrical, projecting above the hymenium, more or less grouped together. Basidia clavate to subcylindrical, colorless, thin-walled, with a basal simple septum and four sterigmata, 15–35 × 3.5–5 µm; basidioles numerous, similar to basidia but smaller. Basidiospores ellipsoid to subcylindrical, colorless, thin-walled, smooth, IKI–, CB–, 4.5–6 × 2–3 µm, L = 5.6 µm, W = 2.5 µm, Q = 2.2 (n = 30/1).

Additional specimens examined – China, Yunnan Province, Yongde County, Daxueshan Nature Reserve, on dead *Quercus* branch, 27 August 2015, He 2697 (BJFC 021136); 28 August 2015, He 2741 (BJFC 021179); Wenshan County, Laojunshan Nature Reserve, on dead angiosperm branch, 13 November 2019, He 6233.

Distribution – Yunnan Province, southwest China.

Notes – *Phanerochaete yunnanensis* is characterized by the light yellow grandinioid basidiomata, encrusted hyphae in hymenium, and absence of cystidia. *Phanerochaete granulata* Sheng H. Wu from Taiwan is similar to *P. yunnanensis* by sharing grandinioid basidiomata and absence of cystidia, but differs in lacking encrusted hyphae in hymenium and slightly shorter basidiospores (3.7–4.5 µm, Wu 2007). In addition, the ITS DNA sequences of type specimens of the two species are largely different (data not shown). *Phanerochaete reflexa* Sheng H. Wu is similar to *P. yunnanensis* by having uneven hymenophore and lacking cystidia, but differs in having tuberculate hymenophore with a reflexed margin (Wu 1998). *Phanerochaete subquercina* (Henn.) Hjortstam is similar to *P. yunnanensis* by sharing the odontioid hymenophore and absence of cystidia, but differs in having longer aculei and thin-walled hyphae, and lacks the encrusted hyphae in hymenium (Bernicchia & Gorjón 2010). *Phanerochaete aculeata* Hallenb. also has odontioid hymenophore, but differs from *P. yunnanensis* in having encrusted cystidia (Bernicchia & Gorjón 2010). In the phylogenetic tree, *P. yunnanensis* formed a sister lineage to *P. robusta*, but the latter can be easily distinguished by having smooth hymenophore and two kinds of cystidia (Wu

et al. 2018b). Morphologically, *P. yunnanensis* resembles *Hyphodermella corrugata* (Fr.) J. Erikss. & Ryvarden, which also has grandinioid hymenophore and encrusted hyphae in hymenium, and lacks cystidia. However, they are not phylogenetically closely related.

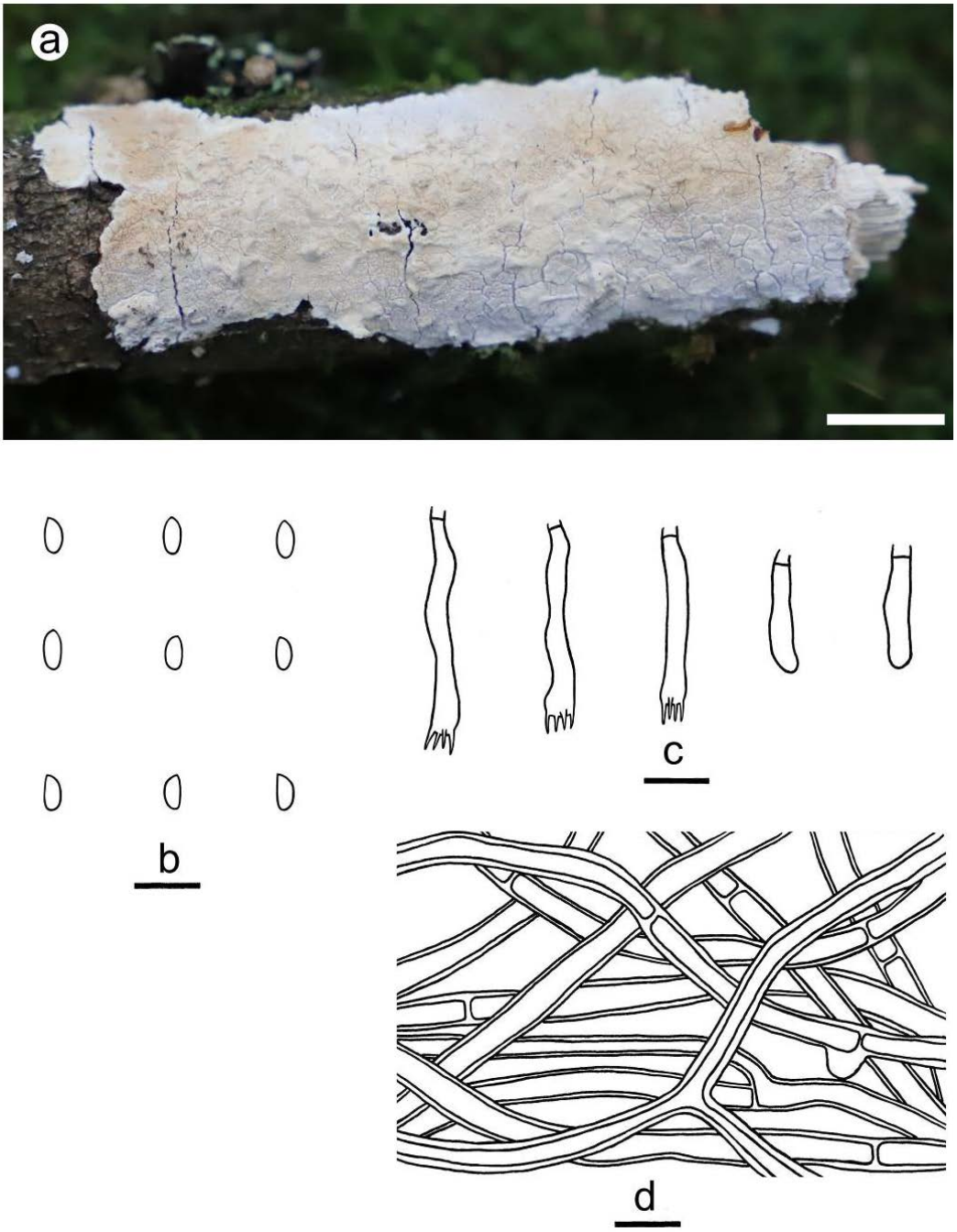

Figure 10 – *Phanerochaete yunnanensis* (a from He 6233; b–d from the holotype He 2719). a basidiomata. b basidiospores. c basidia and basidioles. d hyphae from subiculum. Scale bars: a = 1 cm, b–d = 10 µm.

Discussion

At present, species of *Phanerochaete s.s.* show a great diversity with a broad range of morphological characters, for example, basidiomata may be smooth, grandinioid to poroid with different color reactions in KOH, subicular hyphae are colorless or brown, cystidia are absent or if present then smooth or heavily encrusted etc. So far, there does not seem to be any specific

morphological characters that can be used to delimit or subdivide the genus. In addition, no distinct subclades with strong support values can be recognized in the *Phanerochaete* clade.

Phanerochaete albida Sheng H. Wu from Taiwan, China was sequenced for the first time. The Chinese samples of *P. australis*, *P. carnosa*, *P. citrinosanguinea* Floudas & Hibbett, *P. concrescens* Spirin & Volobuev, *P. cumulodentata* (Nikol.) Parmasto, *P. ericina* (Bourdot) J. Erikss. & Ryvarden, *P. laevis*, *P. livescens*, *P. magnoliae* (Berk. & M.A. Curtis) Burds., *P. sordida* and *P. velutina* (DC.) P. Karst. formed strongly supported lineages with samples from other countries. *Phanerochaete canobrunnea* and *P. stereoides* originally described from Taiwan, China, were also collected in Sri Lanka by us. Surprisingly, the specimen from Sri Lanka (He 5778) formed a well-supported lineage with the temperate species *P. chrysosporium* Burds. (HHB-6251-sp). The species *P. taiwaniana* Sheng H. Wu was also found in Vietnam. The sequences of *P. argillacea* Sheng H. Wu and *P. canolutea* Sheng H. Wu, but not from type materials, clustered together with strong support values. It is probable that the two sequences represent the same species but this requires further study.

Phanerochaete fusca Sheng H. Wu, C.C. Chen & C.L. Wei and *P. porostereoides* have brown hymenophores and subicular hyphae; they formed a strongly supported lineage in our analyses. The ITS similarity (within 563 base pairs) of type specimens of the two species is 99.3 %. Moreover, the type localities of the two species are very close. According to Wu et al. (2018a), *P. fusca* differs from *P. porostereoides* in possessing cystidia and larger basidiospores (5.7–7.3 × 3–3.5 μm vs. 4.7–5.3 × 2.5–3.1 μm). However, Liu & He (2016) observed hyphal ends that are similar to cystidia in *P. porostereoides*. Because the basidiospores are rare in the two specimens of *P. porostereoides* studied herein, only a narrow range of basidiospore sizes was obtained. The evidence presented here shows that *P. fusca* is a later synonym of *P. porostereoides*.

Xiong & Dai (2009) recorded 19 names of *Phanerochaete s.l.* in China, among which eight species, *P. affinis* (Burt) Parmasto (= *P. laevis*), *P. australis*, *P. burtii*, *P. carnosa*, *P. sanguinea*, *P. sordida*, *P. stereoides* and *P. velutina*, belong to *Phanerochaete s.s.* (Floudas & Hibbett 2015, Liu & He 2016). Except for *P. burtii* and *P. sanguinea*, the other six species in China were confirmed by our analyses. However, based on the descriptions and illustrations in Dai & Xiong (2012), it is possible that *P. burtii* sensu Xiong & Dai (2009) may represent *P. leptocystidia* or *P. sinensis*, since they are very similar in morphology. The occurrence of *P. sanguinea* in China needs further studies.

Ghobad-Nejhad et al. (2015) reported the new species, *P. aurantiobadia* Ghobad-Nejhad, S.L. Liu & E. Langer from northeast China that was later treated as a synonym of *P. robusta* by Spirin et al. (2017) and Wu et al. (2018b). Liu & He (2016) described a new species, *P. porostereoides* and recorded *P. brunnea* in mainland China. Miettinen et al. (2016) proposed the new combination of *P. inflata* (B.S. Jia & B.K. Cui) Miettinen, which has typical poroid hymenophore and was originally described from China as *Ceriporia*.

In addition to the nine new species described above, we also report the occurrence of nine more *Phanerochaete* species – *P. bambucicola* Sheng H. Wu, *P. citrinosanguinea*, *P. concrescens*, *P. cumulodentata*, *P. ericina*, *P. incarnata* Sheng H. Wu, *P. livescens*, *P. magnoliae* and *P. taiwaniana* in mainland China for the first time. A total of 28 species of *Phanerochaete s.s.* is now known from mainland China.

Corticioid fungi is a large group of wood-inhabiting fungi with simpler fruiting body and fewer distinguishing morphological features when compared with polypores and mushrooms, but its species and phylogenetic diversity is even higher and less intensively studied (Bernicchia & Gorjón 2010, Larsson et al. 2004, Binder et al. 2005). A large amount of corticioid taxa have not been discovered and described worldwide especially in the subtropical-tropical areas. As shown in this study and earlier ones (Volobuev et al. 2015, Chen et al. 2018, Ordynets et al. 2018), DNA sequence data are very useful in exploring cryptic taxa and diversity of corticioid fungi. Thus, in order to understand the diversity, phylogeny and evolution of the fungi, future taxonomic and phylogenetic work should focus more on the corticioid group by using both molecular and morphological characters.

Key to 28 *Phanerochaete s.s.* species in mainland China

1. Hymenophore poroid ..... *P. inflata*
1. Hymenophore non-poroid 2
2. Hymenophore grandinioid ..... *P. yunnanensis*
2. Hymenophore smooth to raduloid 3
3. Hymenophore at first smooth, odontioid to raduloid when mature 4
3. Hymenophore smooth to more or less tuberculate 5
4. Distributed in northern China ..... *P. cumulodentata*
4. Distributed in southern China ..... *P. magnoliae*
5. Basidiomata with hyphal cords 6
5. Basidiomata without hyphal cords 10
6. Hymenophore and hyphal cords purple in KOH ..... *P. subrosea*
6. Hymenophore and hyphal cords not purple in KOH 7
7. Hyphal cords reddish brown ..... *P. citrinosanguinea*
7. Hyphal cords cream to yellow 8
8. Cystidia obviously encrusted with crytals ..... *P. laevis*
8. Cystidia smooth or sparsely encrusted 9
9. Cystidia 30–70 × 4–6 µm; basidiospores 5–6 × 2.5–3 µm ..... *P. leptocystidiata*
9. Cystidia 35–50 × 4–6 µm; basidiospores 4–5 × 2–2.5 µm ..... *P. sinensis*
10. Subicular hyphae brown 11
10. Subicular hyphae colorless to pale yellow 14
11. Hymenophore brown ..... *P. porostereoides*
11. Hymenophore gray to grayish brown 12
12. Cystidia present ..... *P. stereoides*
12. Cystidia absent 13
13. Subicular hyphae loosely interwoven, clamps present; hyphidia absent ..... *P. brunnea*
13. Subicular hyphae tightly interwoven; clamps absent, hyphidia present ..... *P. cinerea*
14. Cystidia obviously encrusted 15
14. Cystidia smooth or sparsely encrusted 26
15. Cystidia encrusted with yellow resinous granules 16
15. Cystidia encrusted with white crystals 17
16. Hymenophore brown; quasi-binding hyphae present ..... *P. ericina*
16. Hymenophore lilac pink; quasi-binding hyphae absent ..... *P. incarnata*
17. On Monocotyledons ..... *P. minor*
17. On Dicotyledons 18
18. Cystidia up to 150 µm long ..... *P. velutina*
18. Cystidia up to 80 µm long 19
19. Cytidia up to 13 µm wide 20
19. Cytidia up to 9 µm wide 21
20. Cystidia only apically encrusted; widely distributed in north and south ..... *P. concrescens*
20. Cystidia encrusted in up to one third of the length; distributed only in south ..... *P. australis*
21. Hymenophore yellow to buff 22
21. Hymenophore white to cream 24
22. Basidiomata ceraceous; basidiospores > 5.5 µm long ..... *P. livescens*
22. Basidiomata membranaceous, basidiospores < 5.5 µm long 23
23. Hymenophore yellow to yellowish brown; margin determinate ..... *P. hymenochaetoides*
23. Hymenophore cream to light yellow; margin fibrillose ..... *P. cystidiata*
24. Cystidia thick-walled; basidia up to 70 µm long, 8.5 µm wide ..... *P. metuloidea*
24. Cystidia thin- to slightly thick-walled; basidia up to 50 µm long, 6 µm wide 25
25. Subicular hyphae thin to slightly thick-walled; cystidia subulate ..... *P. laevis*
25. Subicular hyphae thick-walled; cystida tapering but with obtuse apex ..... *P. sordida*

26. Cystidia two kinds ..... *P. robusta*
26. Cystidia one kind 27
27. Basidiospores < 6.5 µm long ..... *P. carnosa*
27. Basidiospores > 6.5 µm long 28
28. Basidiospores 7–8.5 × 3–4.2 µm; on bamboo ..... *P. bambucicola*
28. Basidiospores 6.5–7.2 × 3.3–4 µm; on wood ..... *P. taiwaniana*

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