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Three new species of *Agaricus* section *Minores* from China

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Abstract

Agaricus subgenus *Minores* section *Minores* has the richest species in the genus *Agaricus* and worldwide distribution. In this paper, the phylogenetic trees generated by Maximum Likelihood and Bayesian analyses for section *Minores* were conducted using ITS, LSU and tef1-α genes sequences from 105 species. The molecular phylogenetic analysis showed there were three new lineages from Chinese specimens within this section, and the following morphological examination supported them as three new species. We named them as *A. parvibrunneus*, *A. pseudominipurpureus* and *A. yanzhiensis* respectively. Descriptions, colour photographs and illustrations of those new species are presented in detail.

Key words – Agaricaceae – Phylogeny – Taxonomy

Introduction

Agaricus L. 1753 (Agaricaceae, Agaricales) is a well-studied genus with many species that are famous because of their high commercial value, such as *A. bisporus* (J.E. Lange) Imbach and *A. subrufescens* Peck.. Regional monographs for *Agaricus* have been published in recent years, such as monographs from Europe (Parra 2008, 2013) and Northern America (Kerrigan 2016). These monographs have given some detailed introductions among *Agaricus* and also well documented *Agaricus* species from those areas (Parra 2008, 2013, Kerrigan 2016). *Agaricus* is a genus with great species diversity, and today more than 500 species are recognized (Zhao et al. 2011, 2016, Chen et al. 2017, He et al. 2017).

Systematics of *Agaricus* drew a great attention of mycologists in the past ten years especially when the molecular data became available. More recently, the comprehensive infrageneric studies segregated this genus into six subgenera and 21 sections (Zhao et al. 2016, Chen et al. 2017). *Agaricus* section *Minores* was raised to subgenus according to its phylogenetic position and divergence time (Zhao et al. 2016). Section *Minores* is the section having the richest species in this genus, and 27 Asian species were introduced from Greater Mekong Subregion and southern China (Chen et al. 2017), latter the monograph of section *Minores* of China reported 19 species (He et al. 2017). Now this section contains about 80 named species and is expected to harbor at least 200 species within this section in the world (Chen et al. 2017, He et al. 2017).

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The morphological characteristics of *A.* sect. *Minores* generally are as follows: basidiomes slender, small or medium sized; annulus simple, thin; odour of almonds or anise; basidiomes turning yellow on touching; the KOH and Schäffer's reactions positive. However, in general, the morphological characteristics used for species distinction are scarce, especially between closely related species. Then in such case, the molecular data becomes essential for an unequivocal identification. Such as for the three species *A. armandomyces* M.Q. He & R.L. Zhao, *A. kerriganii* L.A. Parra, B. Rodr., A. Caball., M. Martín-Calvo & Callac and *A. edmondoi* L.A. Parra, Cappelli & Callac, which cannot be distinguished easily morphologically but require molecular data (He et al. 2017).

During our study of *Agaricus* in China, some new *Minores* members have been introduced in the previous studies, such as *A. gemloides* M.Q. He & R.L. Zhao, *A. coccyginus* M.Q. He & R.L. Zhao, *A. globosporus* M.Q. He & R.L. Zhao and so on (He & Zhao 2015, Li et al. 2016, He et al. 2017). In this study, based on morphological characteristics and multi-locus phylogenetic analyses, we introduce three more new species here from China.

Materials & Methods

Morphologic study

Specimens were collected during rainy seasons (July to September) from China, photographs of fresh specimens were taken immediately *in situ*, basidiomes were wrapped in aluminium foil or put in plastic boxes separately. Morphological characteristics including odour, basidiome size, colour and chemical reaction were recorded when the fruiting body are fresh. Every specimen was dried in an electrical food drier at 65 °C until no more moisture left, kept in a plastic ziplock bag and deposited in Herbarium Mycologicum Academiae Sinicae (HMAS). Anatomical and cytological characteristics including basidiospores, basidia, cystidia and pileipellis were observed under an Olympus CX31 microscope. At least 20 measurements were made. Data were analyzed and recorded as X = the mean of length by width ± SD, Q = the quotient of basidiospore length to width, and Q_m = the mean of Q values ± SD. All the protocols of morphological study followed Largent's methodology (Largent 1986). Macrochemical reactions including KOH reaction and Schäffer's reaction are followed Chen et al. (2015).

DNA extraction and PCR

Genomic DNA of every specimen was extracted by using an E.Z.N.A. Forensic DNA Extraction Kit (D3591-01, Omega Bio-Tek) following the manufacturer's protocol. The primer for internal transcribed spacer (ITS), large ribosomal subunit (LSU), and translation elongation factor (tef1-α) are ITS4/ITS5, LR5/LROR, and 983f/1567r respectively. The PCR programs are followed in He et al. 2017. The PCR products were sent to commercial company for sequencing, and both directions were sequenced to ensure accuracy.

Phylogenetic analyses

Details of newly generated and reference sequences retrieved from GenBank were listed in Table 1. Sequences were checked in BioEdit V.7.0.4 first (Hall 2007). Alignments were made by Muscle (Edgar 2004) for each regions separately, including 109 ITS, 82 LSU and 78 tef1-α, then adjusted by hand and the ambiguous regions were removed. Final multi-locus matrix comprising 746 bp (base pair) LSU, 545 bp tef1-α, and 627 bp ITS. Alignment was submitted to TreeBase (submission ID: 22065). Phylogenetic tree generated by Bayesian Inference (BI) analysis were performed in MrBayes 3.1.2. Two best model for each region were inferred by Mrmodeltest2.2 (Nylander 2004), they are GTR + I + G for ITS and LSU, and SYM + I + G for tef1-α. Ten million generations were run for six Markov chains, and sampled every 100th generation resulting in 100,000 trees. Burn-ins was determined in Tracer v1.6 with effective sample sizes (ESS) higher than 200 (http://tree.bio.ed.ac.uk/software/tracer). Remaining trees were used to calculate Bayesian posterior probabilities (PP). Maximum likelihood (ML) analysis and bootstrap values calculation were

performed in raxmlGUI 1.5b1 with GTRGAMMA model with 1000 replicates (Silvestro & Michalak 2012). Phylogenetic tree was presented in Fig. 1.

Tabel 1 Taxa information used in the phylogenetic analyses, new taxa are in bold, "T" refers to type

Species	**Collection**	**ITS**	**LSU**	**ef1- α**
Agaricus aridicola	LAPAG589	KT951331	KX084027	KX198081
A. armandomyces T	ZRL2015992	KX684860	KX684882	KX684906
A. arrillagarum	LAPAG810	KF447900	KX083985	KT951592
A. badioniveus	LD2012131	KU975117	-	-
A. boniquamulosus T	ZRL2010106	KX657047	KX656950	KX684951
A. brunneolus	LAPAG938	KU975082	KX083997	KX198062
A. brunneolutosus T	MS514	KU975111	KX084006	-
A. callacii	LAPAG797	KF447899	KX083984	KX198051
A. campbellensis	GAL9420	DQ232644	DQ232657	-
A. campestris T	LAPAG370	JQ903618	KP739803	KR006636
A. candidolutescens T	LD2012129	KT951335	KT951525	KT951616
A. catenatus T	ZRL2012104	KX657023	KX656963	KX684957
A. cerinipileus T	ZRL2012001	KX657021	KX656957	KX684953
A. cf. *kerriganii*	WC912	AY484681	-	-
A. chartaceus	H6271	JF495048	-	-
A. coccyginus	ZRL2014354	KU245981	KX656936	KX684998
A. colpetei	TL2424	JX984565	-	-
A. columellatus	MIN938394	KJ912899	-	-
A. columellatus	SB-2015	KJ912899	-	-
A. comtulus	LAPAG303	KU975078	KX083986	KX198052
A. dilatostipes	ZRL2014450	KX656999	KX656941	KX685003
A. dulcidulus	PRM909627	KF447894	-	KX198064
A. edmondoi	LAPAG412	KT951326	KT951481	KT951590
A. elongatestipes T	ZRL2013271	KX657002	KX656946	KX684975
A. fimbrimarginatus T	LD201250	KU975119	KX084017	KX198076
A. flammicolor	LD201225	KU975115	KX084010	KX198070
A. flavopileatus	MS596	KU975121	KX084022	KX198078
A. friesianus	LAPAG592	KT951316	KX083992	KT951594
A. fulvoaurantiacus T	LD201404	KU975107	KX084002	KX198069
A. gemlii	LAPAG286	KU975079	KX083988	KX198055
A. gemloides T	ZRL2014084	KT633271	KX641405	KX684986
A. globosporus T	ZRL2012656	KX657039	-	KX684968
A. heinemannianus	LAPAG302	KF447906	-	KX198056
A. huijsmanii	LAPAG639	KF447889	KT951444	KT951571
A. jacobi	LAPAG52	KF447895	KX083996	KX198061
A. jingningensis T	ZRL20151562	KX684877	KX684895	KX684917
A. kerriganii T	AH44509	KF447893	KX083999	KX198066
A. laeticulus T	Goossens5272	KX671705	-	-
A. lamelliperditus	MDBF61/96	JX984559	-	-

Table 1 Continued.

Species	Collection	ITS	LSU	ef1- α
A. leucocarpus	LD201226	KU975102	KX083982	KX198049
A. leucocarpus T	LD201215	KU975101	KX084014	KX198074
A. luteofibrillosus	ZRL2012359	KU245978	KX656967	KX684959
A. luteomaculatus	LAPAG331	KF447901	-	KX198053
A. luteopallidus	LD2012113	KU975124	KX084026	KX198080
A. mangaoensis T	ZRL2010056	KX657042	KX656956	KX684946
A. marisae	LAPAG138	KU975083	KX083998	KX198065
A. matrum T	LAPAG817	KF447896	KX083991	KX198058
A. megalosporus	ZRL2012199	KT951367	KT951470	KT951595
*A. microviolaceus*T	ZRL2012718	KX657033	KX656980	KX684971
A. minipurpureus T	ZRL2010058	KX657043	KX656953	KX684947
A. neimengguensis T	ZRL20151845	KX684870	KX684902	KX684924
A. pallens	LAPAG441	KF447898	-	KX198067
A. parvibicolor T	LD2012116	KP715162	KX084016	KX198075
***A. parvibrunneus* T**	**ZRL20161053**	**MG137001**	**MG196345**	**MG196351**
A. patris T	LD201224	KU975118	KX084012	KX198073
A. pseudolutosus	LAPAG454	KT951329	KT951453	KT951602
A. pseudominipurpureus	**ZRL2013320**	**MG136999**	**MG196344**	**MG196349**
***A. pseudominipurpureus* T**	**ZRL2013341**	**MG137000**	**MG196343**	**MG196350**
*A. pseudopallens*T	ZRL20151552	KX684874	KX684891	-
A. pseudopurpurellus T	ZRL2014063	KX656988	KX641404	KX684985
A. purpurellus	LAPAG944	KU975076	KX083994	KX198060
A. purpureofibrillosus T	ZRL3080	JF691542	KX084021	-
A. purpureosquameus T	LE2016047	KX684878	-	-
A. robustulus	ZRL2012357	KT951369	KT951496	KT951610
A. robustulus T	CA847	KU975086	KX084034	KX198039
A. rufifibrillosus T	ZRL20151536	KX684878	KX684893	KX684915
A. rufipileus T	ZRL2014140	KX656991	KX656937	KX684991
A. sodalis T	LD2012159	KP715161	KX084014	KX198074
A. stevensii	FS 06-02-09	KJ877785	-	-
A. viridopurpurascens	Horak68/79	JF514525	-	-
A. wariatodes	TWM1589	JF495052	JF495030	-
A. yanzhiensis	**ZRL20162060**	**MG137002**	**MG196348**	**MG196352**
A. yanzhiensis	**ZRL20162139**	**MG137004**	**MG196347**	**MG196353**
***A. yanzhiensis* T**	**ZRL20162082**	**MG137003**	**MG196346**	**-**
A. sp.	GAL3083	EF460374	EF460399	-
A. sp.	ZD1528	KU975104	KX083987	KX198054
A. sp.	ZRL2014380	KX656998	KX656932	KX685000
A. sp.	CA935	KU975085	KX084036	KX198034
A. sp.	MS386	KU975113	KX084008	KX198044
A. sp.	ZRL2010079	KX657046	KX656951	KX684950
A. sp.	ADK3580	KU975097	-	-

Table 1 Continued.

Species	Collection	ITS	LSU	ef1- α
A. sp.	NTT72	JF514539	-	-
A. sp.	PYP014	KU975091	-	-
A. sp.	CA845	KU975084	KX084033	KX198035
A. sp.	ZRL3056	JF691541	KX084020	-
A. sp.	ADK2751	JF514519	-	-
A. sp.	LD201252	KU975103	-	KX198050
A. sp.	ZRL2011039	KT951351	KT951449	KT951606
A. sp.	Vellinga2360	AF482831	AF482877	-
A. sp.	TL2154	JF495059	-	-
A. sp.	TL2307	JF495058	-	-
A. sp.	ZRL20151437	KX684876	KX684892	KX684914
A. sp.	ZRLWXH3067	KT951387	KT951497	KT951611
A. sp.	CA848	JF727864	KT951445	KT951605
A. sp.	NTS73	KU975099	-	-
A. sp.	NTT33	JF514535	-	-
A. sp.	PS036	KU975087	KX084035	KX198036
A. sp.	ZRL20151119	KX684855	KX684890	KX684913
A. sp.	ZRLLD013	KT951384	KT951516	KT951604
A. sp.	ZRLWXH3402	KX657016	KX656983	KX685006
A. sp.	CA843	JF727866	KX084029	KX198040
A. sp.	ZRL2010002	KX657041	KX656954	KY427449
A. sp.	CA846	JF727865	KT951452	KT951601
A. sp.	PDD68575	AF059224	AF059224	-
A. sp.	GAL5812	EF460364	EF460389	-
A. sp.	MATA774	JF727871	-	-
A. sp.	LAPAM14	KT951312	-	KT951613
A. sp.	ZRLWXH3161	KT951391	KT951526	KT951615
A. sp.	ZRL2012004	KT951355	KT951457	KT951608

Results

Taxonomy

Agaricus parvibrunneus M.Q. He, K.D. Hyde & R.L. Zhao sp. nov. Fig. 2

Fungal Names: FN570507; Faceoffungi Number: FoF03851

Etymology – The epithet ‘‘parvi’’ refers to the small basidiome, “brunneus” refers to the brown fibrils on the cap.

Holotype – China, Beijing, Chaoyang District, Institute of Microbiology, 26 July 2016, collected by Bai Xuming, *ZRL20161053* (HMAS 278316 Holotype).

Original description – *Pileus* 14 – 27 mm in diam., convex when young, plane with age, disc subunbonate, margin straight, exceeding lamellae; Surface dry, with brown fibrillose scales against white background, scales triangular, appressed, denser at disc, scattered towards the margin. *Context* up to 2 mm thick, flesh, white. *Lamellae* 2 – 3 mm broad, free, crowded, pink first, then brown, edge even, intercalated with lamellulae. *Annulus* single, membranous, white, pendant, smooth on both

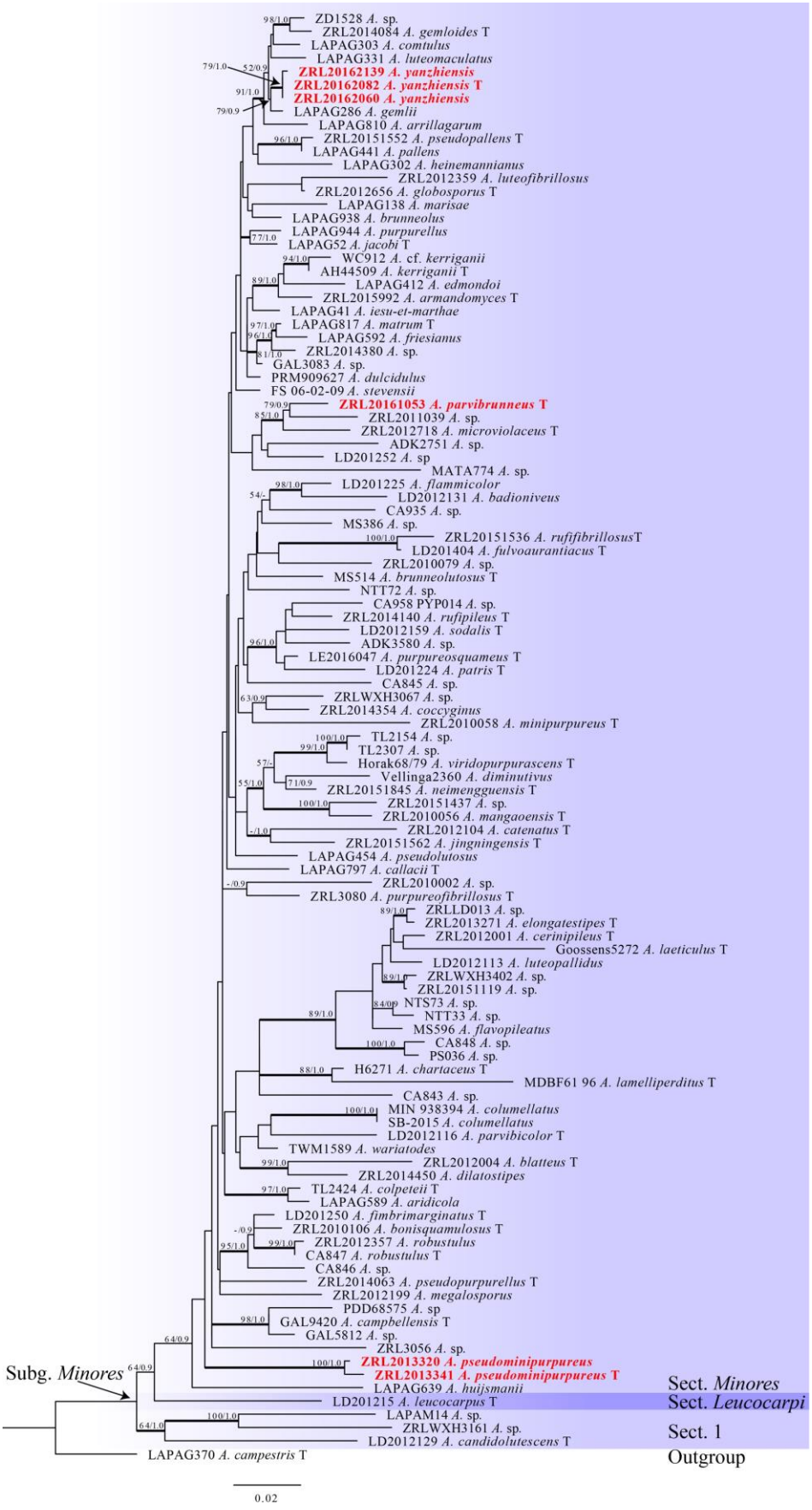

Figure 1 – Maximum likelihood (ML) tree of *Agaricus* subg. *Minores* based on LSU, tef1-α and ITS sequences with the outgroup *A. campestris* L. The bootstrap values and Bayesian posterior probabilities more than 50%/0.9 (BS/PP) are indicated at the nodes. The branches in bold mean the related PP > 0.95, "T" refers to sequences from type specimen.

sides. *Stipe* 21 – 32 × 3 – 7 mm, white, hollow, cylindrical, sometimes with a subbulbous base, surface dry, smooth. Odour of almonds. Basidiome strongly yellow when rubbed.

KOH reaction – positive yellow. Schäffer's reaction: positive, reddish orange on dry specimen.

Basidiospores 5.0 – 5.8 × 3.7 – 4.1 μm, [x = 5.3 ± 0.2 × 3.9 ± 0.2, Q = 1.3 – 1.5, Q_m = 1.4 ± 0.1, n = 20], ellipsoid, smooth, thick-walled, brown. *Basidia* 13.3 – 24.7 × 6.2 – 7.5 μm, clavate, hyaline, 4-spored, smooth. *Cheilocystidia* 14.2 – 30.0 × 6.7 – 15.5 μm, single, hyaline, smooth, pyriform most, also can be clavate, septa at base, some with yellow pigment inside. *Pleurocystidia* absent. *Pileipellis* a cutis composed of hyphae of 5.0 – 6.6 μm in diam., smooth, cylindrical, hyaline or light brown.

Habitat – solitary on grassland in garden.

Notes – In the phylogenetic analyses, *A. parvibrunneus* clustered with *ZRL2011039/A.* sp. and *A. microviolaceus* M.Q. He & R.L. Zhao with the BS/PP=79/0.9 value in section *Minores*. The molecular data shows *ZRL2011039* is closely related to *A. parvibrunneus*. Due to the immature basidiome of *ZRL2011039*, it was considered as *A.* sp. in this study. So *A. microviolaceus* is the only known species phylogenetically close to *A. parvibrunneus*.

Compared in morphology, *A. microviolaceus* and *A. parvibrunneus* both have small basidiomes, but *A. parvibrunneus* can be easily distinguished by brown pileus, while *A. microviolaceus* is purple. Many species in section *Minores* have small basidiomes (pileus diameter less than 30 mm), such as *A. blatteus* M.Q. He & R.L. Zhao, *A. minipurpureus* M.Q. He & R.L. Zhao, *A. purpureofibrillosus* Linda J. Chen, R.L. Zhao & K.D. Hyde, and *A. callacii* L.A. Parra, R. Iglesias, Fdez. -Vic. & Oyarzabal. But they all have pinkish and purple fibrils, the pileus color tends to be red while it is brown in *A. parvibrunneus*. Moreover, *A. parvibrunneus* has larger basidiospores than those of *A. blatteus* (4.5 ± 0.2 × 3.3 ± 0.2 μm) and *A. purpureofibrillosus* (4.9 ± 0.12 × 2.9 ± 0.14 μm), or smaller than those of *A. callacii* (6.2 × 4.9 μm) (Parra 2013, Chen et al. 2017, He et al. 2017). *Agaricus minipurpureus* has the same sized basidiospores, but its cheilocystidia are clavate while they are pyriform in *A. parvibrunneus*. Based on phylogenetic analyses and morphological characteristics, *A. parvibrunneus* is introduced here as a new species, and this new species is characterized by its small basidiomes, brown pileus and pyriform cheilocystidia.

Agaricus pseudominipurpureus M.Q. He, K.D. Hyde & R.L. Zhao sp. nov. Fig. 3

Fungal Names: FN570508; Faceoffungi Number: FoF03852

Etymology – refers to the similarity of this new species to *A. minipurpureus* in morphology.

Holotype – China, Yunnan Province, Dehong County, Tongbiguan natural reserve, 24°61′ N, 97°64′ E, altitude 1341m, 20 July 2013, collected by Zhao Ruilin, *ZRL2013341* (HMAS 278354 Holotype).

Original description – *Pileus* 14 – 26 mm in diam., parabolic first, then convex, finally plane with age, disc unbonate, margin straight, slightly exceeding lamellae, uplifted when mature; Surface dry, with plenty of appressed, purple, reddish brown fibrils against white background, denser at disc, scattered towards the margin. *Context* up to 2 mm thick, flesh, white. *Lamellae* 2 – 3 mm broad, free, crowded, pink firstly, then brown, edge even, intercalated with lamellulae. *Annulus* single, membranous, white, pendant, upper surface smooth, lower surface fibrillose. *Stipe* 24 – 43 × 2 – 3 mm, white, hollow, cylindrical, surface dry, surface below the annulus fibrillose. Odour of almonds. Basidiome strongly yellow when rubbed then orange brown immediately.

KOH reaction – positive yellow. Schäffer's reaction: positive, reddish orange on dry specimen.

Basidiospores 4.3 – 5 × 3.1 – 3.6 μm, [x = 4.6 ± 0.2 × 3.3 ± 0.1, Q = 1.3 – 1.5, Q_m = 1.4 ± 0.1, n = 20], ellipsoid, smooth, thick-walled, brown. *Basidia* 11 – 15.2 × 5 – 6.6 μm, clavate, hyaline, 4-spored, smooth. *Cheilocystidia* absent. *Pleurocystidia* absent. *Pileipellis* a cutis composed of hyphae of 6.5 – 10.5 μm in diam., smooth, cylindrical, hyaline or light brown.

Habitat – solitary on soil in forest.

Other specimens examined cChina, Yunnan Province, Dehong County, Tongbiguan natural reserve, 24°61′ N, 97°65′ E, altitude 1341m, 20 July 2013, collected by Zhao Ruilin, *ZRL2013320* (HMAS 278427).

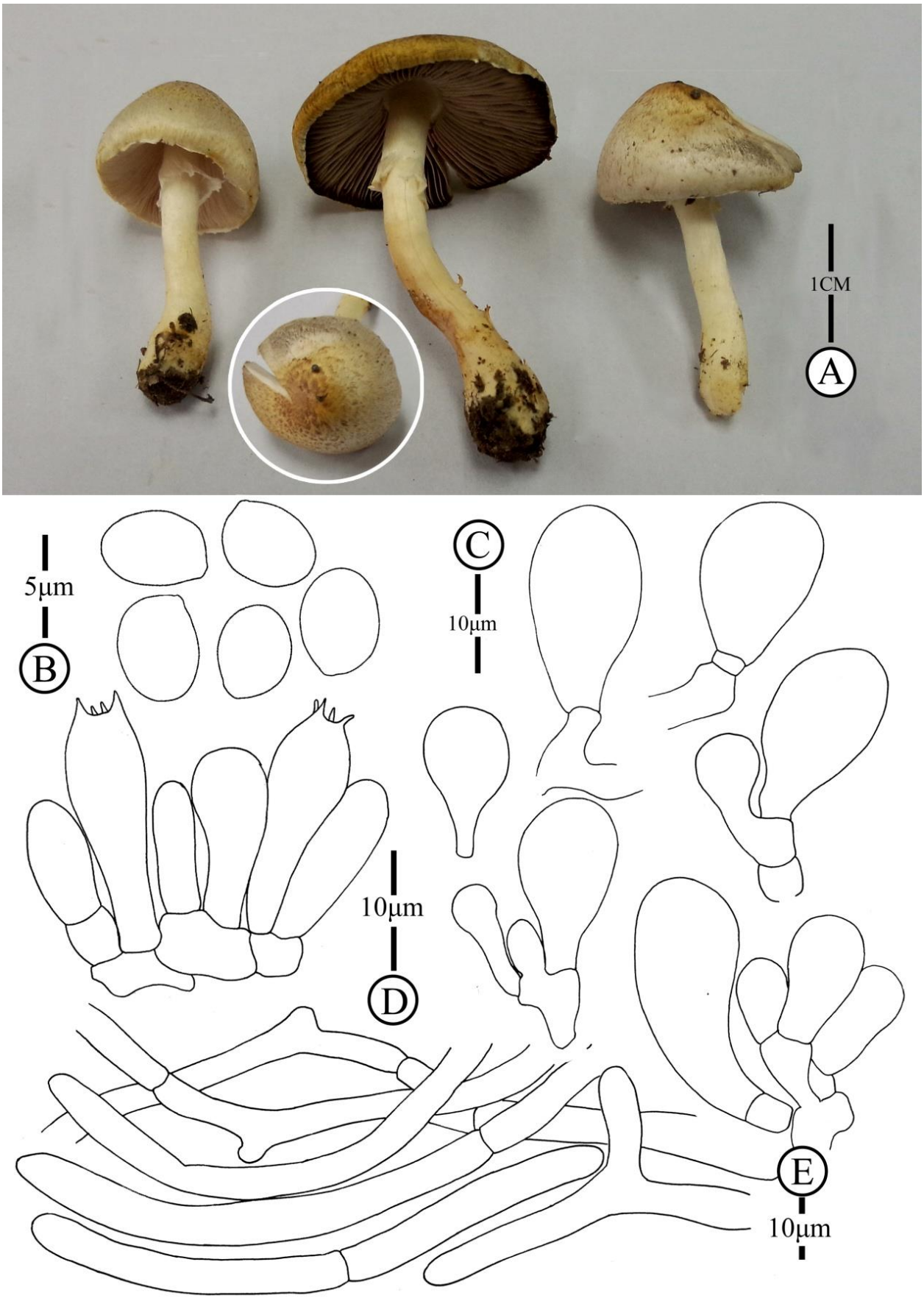

Figure 2 Morphology of *Agaricus parvibrunneus*, A basidiomes. B basidiospores. C cheilocystidia. D basidia. E pileipellis hyphae.

Notes – According to phylogenetic study, the two specimens (*ZRL2013320* and *ZRL2013341*) clustered at the base position of section *Minores* with fully support (BS/PP = 100/1.0 value), which is representing *A. pseudominipurpureus.* In the tree *A. pseudominipurpureus* has a distinct position. But there are many morphologically similar species, such as *A. microviolaceus*, *A. blatteus*, *A. minipurpureus*, *A. purpureofibrillosus* and *A. pseudopurpurellus*. They all have small basidiomes (pileus diameter < 30 mm), and a pileus covered by purple fibrils (He et al. 2017). In addition, microscopically, the new species differs from all of them by the absence of cheilocystidia. *Agaricus pseudopurpurellus* is similar to this new species because both have small basidiomes, the same basidiospores in shape and size, and absent cheilocystidia. However, in their ITS sequence, those two species are different at 38 positions. The molecular phylogenetic tree also clearly showed they are different species. Based on phylogenetic and morphological characteristics, *A. pseudominipurpureus* is introduced here as a new species, and it is characterized by its small basidiomes, absence of cheilocystidia and distinct phylogenetic position in section *Minores*.

Agaricus yanzhiensis M.Q. He, K.D. Hyde & R.L. Zhao sp. nov. Fig. 4

Fungal Names: FN570506; Faceoffungi Number: FoF 03850

Etymology – The epithet ‘‘yanzhiensis’’ refers to the type location, Yanzhi Mountain of Qilianshan National Natural Reserve in China.

Holotype – China, Gansu Province, Shandan County, Yanzhishan Forest Park, 38°78′ N, 101°08′ E, altitude 1765m, 31 August 2016, collected by Dai Rong-chun, *ZRL20162082* (HMAS 281083 Holotype).

Original description – *Pileus* 21 – 75 mm in diam., parabolic first, then convex, finally plane with age, disc can be subunbonate when mature, margin straight, also can be uplifted when mature, slightly exceeding lamellae, sometimes with little appendiculate remains of universal veil; Surface dry, covered by appressed, brown or reddish brown fibrils, background white, denser at disc, scattered towards the margin. *Context* up to 5 mm thick, flesh, white. *Lamellae* 5 mm broad, free, crowded, white first, then pink or reddish brown, brown finally, edge even, intercalated with lamellulae. *Annulus* single, membranous, white, pendant, upper surface smooth, lower surface fibrillose, sometimes with brown pigment on the edge, connect stipe with white silky fibrils. *Stipe* 29 – 65 × 6 – 8 (12 – 18 at base) mm, white, hollow, cylindrical, some with bulbous base, surface dry, surface below the annulus fibrillose. Odour of almonds. Basidiome strongly yellow when rubbed.

KOH reaction – positive yellow. Schäffer’s reaction: positive, reddish orange on dry specimen. *Basidiospores* 5.0 – 5.8 × 3.7 – 4.1 μm, [x = 5.3 ± 0.2 × 3.9 ± 0.2, Q = 1.3 – 1.5, Q_m = 1.4 ± 0.1, n = 20], ellipsoid, smooth, thick-walled, brown. *Basidia* 13.3 – 24.7 × 6.2 – 7.5 μm, clavate, hyaline, 4-spored, smooth. *Cheilocystidia* single, smooth, hyaline, pyriform, septa at base. *Pleurocystidia* absent. *Pileipellis* a cutis composed of hyphae of 6.5 – 10.5 μm in diam., smooth, cylindrical, hyaline or light brown, slightly constrict at septa.

Habitat – Gregarious on soil in forest.

Other specimens examined – China, Gansu Province, Shandan County, Yanzhishan Forest Park, 38°78′ N, 101°08′ E, altitude 1765 m, 31 August 2016, collected by Zhao Rui-lin, *ZRL20162060* (HMAS 280994). China, Gansu Province, Sunan County, Dayekou, 38°83′ N, 99°61′ E, altitude 2294m, 01 September 2016, collected by Bai Xu-Ming, *ZRL20162139* (HMAS 281085).

Notes – Our phylogenetic analyses indicated that *A. yanzhiensis* is a member of section *Minores* (Fig. 1). Three specimens (*ZRL20162060*, *ZRL20162082* and *ZRL20162139*) clustered together representing *A. yanzhiensis* with the statistic support of BS/PP=79/1.0 value, then *A. yanzhiensis* clades with ZD1528/*A.* sp., *A. gemloides*, *A. comtulus* Fr., *A. luteomaculatus* F.H. Møller and *A. gemlii* L.A. Parra, Arrillaga, M.Á. Ribes & Callac with the support of BS/PP=52/0.9 value.

In the morphological study, the phylogenetically closest species is *A. gemlii* which have six different positions in ITS, one position in LSU and eight positions in tef1-α sequences. *Agaricus gemlii* can be separated from this new species by its reddish purple fibrils on the pileus while *A. yanzhiensis* is reddish brown. Furthermore, the habitat of *A. gemlii* is damp Atlantic wood while this new species is continental cold forest which dominated by *Picea crassifolia*. There are some more species that

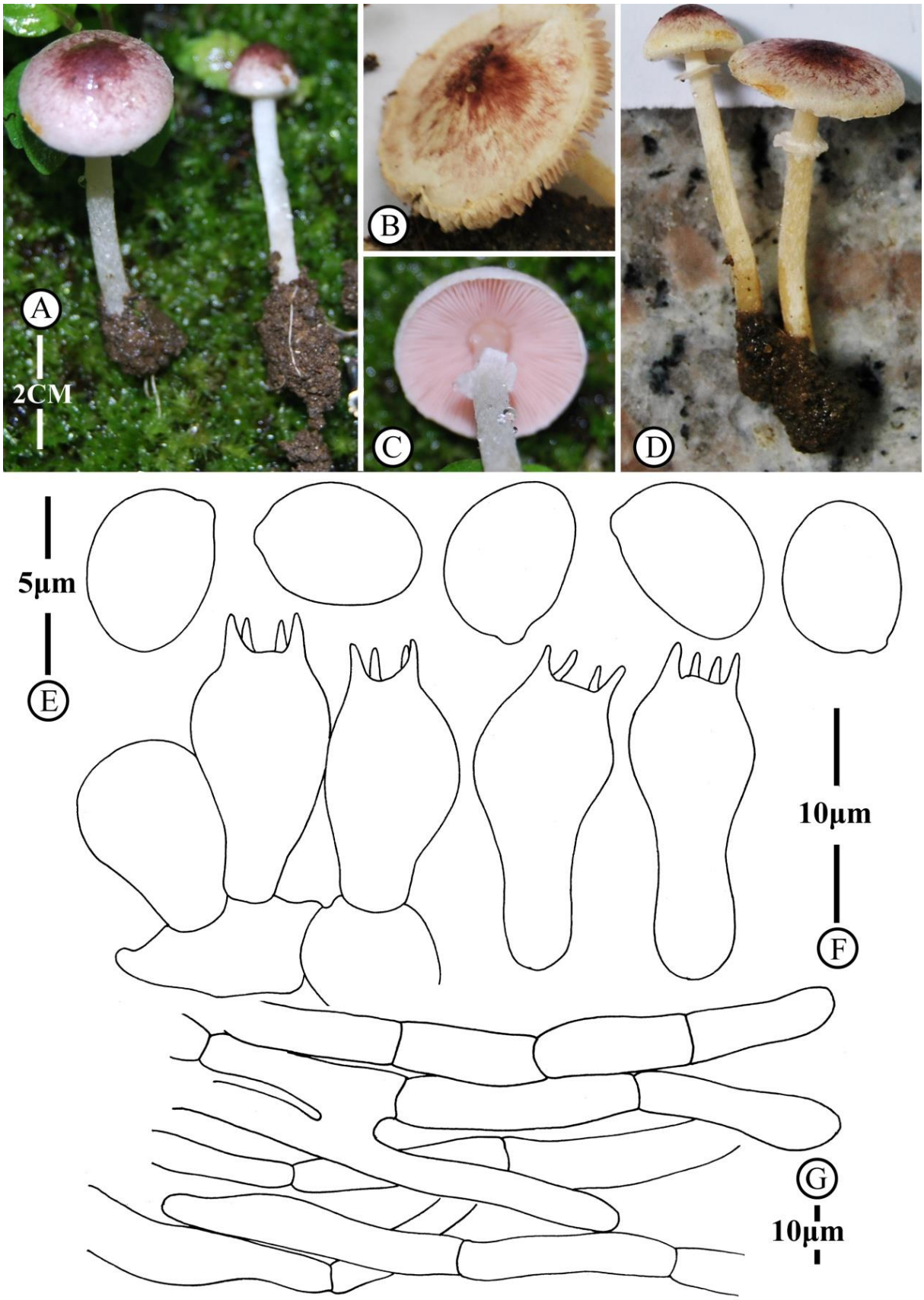

Figure 3 – Morphology of *Agaricus pseudominipurpureus*, A–D basidiomes in the field. E basidiospores. F basidia. G pileipellis hyphae.

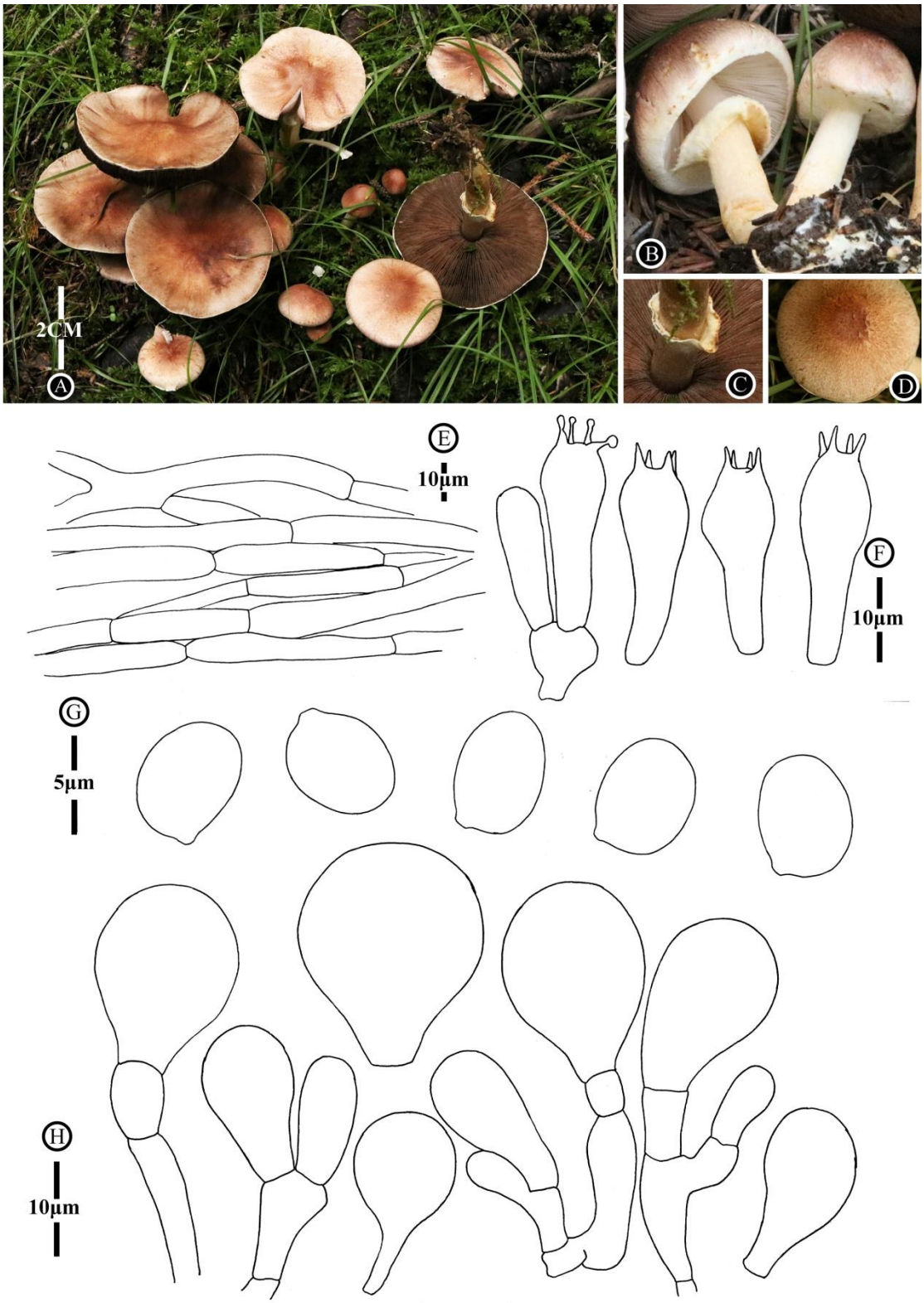

Figure 4 – Morphology of *Agaricus yanzhiensis*, A–D basidiomes in the field. E pileipellis hyphae. F basidia. G. basidiospores. H Cheilocystidia.

resemble this new species, such as *A. comtulus*, *A. brunneolus* (J.E. Lange) Pilát, and *A. brunneolutosus* Linda J. Chen, Karun. & K.D. Hyde. In the field they all have middle-sized basidiomes, and brown or reddish brown pileus (Parra 2013), however *A. yanzhiensis* can be distinguished under the microscope by its larger basidiospores when compared with *A. comtulus* (4.8 × 3.4 μm) and *A. brunneolutosus* (4.3 × 2.9 μm) (Parra 2013). *Agaricus yanzhiensis* differs from *A. brunneolus* by having triangular shaped fibrils scales on the pileus while those of *A. brunneolus* does

not. In addition, the breadth of lamellae of *A. brunneolus* (up to 9 mm) is nearly double than those of *A. yanzhiensis*. Based on phylogenetic analyses and morphological characteristics, we introduce *A. yanzhiensis* new to science and this species is characterized by its brown to reddish brown pileus, cheilocystidia pyriform, and often with long narrow stipe, occasionally with one septa at the base.

Discussion

Members of subgenera *Minores* and *Minoriopsis* can be preliminarily separated from other subgenera of *Agaricus* in the field, because of their relatively small basidiomes, their yellow discoloration when bruised, their simple annulus and their odor of almonds. In addition, species of subgenus *Minoriopsis* are only known from the Americas. In subgenera *Minores,* morphological characteristics can be overlapped among species, so the molecular phylogeny analysis is necessary for the identification on species level. Among those three new species we proposed here, *A. pseudominipurpureus* is the example which is hard to distinguish from other known species through morphology, but can be distinguished by molecular data. Presently numerous species of *Agaricus* section *Minores* were introduced worldwide. The recent published species in section *Minores* are *A. purpureosquameus* and *A. rufifibrillosus*. Compare with these three new species in this paper morphologically, *A. purpureosquameus* has small basidiomes, purple pileus and is originally from Thailand. *Agaricus rufifibrillosus* is originally from east part of China, and it resembles *A. yanzhiensis* by its medium sized basidiomes, and reddish brown pileus. But under microscope, they can be differed by cheilocystidia which of *A. yanzhiensis* is pyriform, while *A. rufifibrillosus* is absent. Up to now, there are 24 species of this section published from China in last three years (He & Zhao 2015, Li et al. 2016, He et al. 2017, Hyde et al. 2017). Now section *Minores* has 83 named species including those three new species and 44 of which can be found in China, such as those species which is originally from Thailand: *A. patris* L.J. Chen, Callac, K.D. Hyde & R.L. Zhao and *A. megalosporus* J. Chen, R.L. Zhao, Karunarathna & K. D. Hyde (Chen et al. 2012, He et al. 2017).

Supplementary note – In the papers "He, M.Q., Chen, J., Zhou, J.L., Cheewangkoon, R., Hyde, K.D. & Zhao, R.L. (2017). Tropic origins, a dispersal model for saprotrophic mushrooms in *Agaricus* section *Minores* with descriptions of sixteen new species, Scientific Reports 7(5122): 1–31", "Hyde, K.D. & al. (2017). Fungal diversity notes 603–708: taxonomic and phylogenetic notes on genera and species, Fungal Diversity 87:1–235" and "Hyde, K.D., He, M.Q., Zhao, R.L., Perera, R.H., Jayawardena, R.S. & Camporesi, E. (2017). Nomenclatural novelties. Index Fungorum 347: 1", the authors of six names propose corrections for the epithets of these names, which were incorrectly published due to typographical errors in those papers, as follows:

Agaricus bonussquamulosus M.Q. He & R.L. Zhao, Sci Rep. 7(5122): 9; Fig. 5. Fungal Names: FN570359 is to be corrected to *Agaricus bonisquamulosus* M.Q. He & R.L. Zhao.

Agaricus minorpurpureus M.Q. He & R.L. Zhao, Sci Rep. 7(5122): 12; Fig. 8. Fungal Names: FN570349 is to be corrected to *Agaricus minipurpureus* M.Q. He & R.L. Zhao.

Agaricus cerinupileus M.Q. He & R.L. Zhao, Sci Rep. 7(5122): 11; Fig. 7. Fungal Names: FN570358 is to be corrected to *Agaricus cerinipileus* M.Q. He & R.L. Zhao.

*Agaricus rufuspileu*s M.Q. He & R.L. Zhao, Sci Rep. 7(5122): 22; Fig. 18. Fungal Names: FN570347 is to be corrected to *Agaricus rufipileus* M.Q. He & R.L. Zhao.

Agaricus rufusfibrillosus M.Q. He & R.L. Zhao, Fungal Divers. 87(1): 188; Fig. 136. Index Fungorum number: IF553825 is to be corrected to *Agaricus rufifibrillosus* M.Q. He & R.L. Zhao.

Agaricus purpurlesquameus M.Q. He & R.L. Zhao, Index Fungorum 347:1. Index Fungorum number: IF552301 is to be corrected to *Agaricus purpureosquameus* M.Q. He & R.L. Zhao. Note to

the readers: This name was previously published in Fungal Divers. 87(1): 185; Fig. 135 but it was invalidly published because two specimens were designated as holotype (Art. 9.1). The name was later validly published in Index Fungorum 347:1.

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