Mycobiology

Research Article

Wood Decay Fungi in South Korea: Polypores from Seoul

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Abstract In Seoul, a majority of plant communities have undergone significant changes over the last few decades; however, how wood decay fungi have responded and adapted to the changes in vegetation remains unknown. Through an ongoing investigation of Korean indigenous fungi, ca. 300 specimens with poroid basidiocarp were collected in Seoul during 2008~2012. Morphological examination and molecular analysis using the internal transcribed spacer and nuclear large subunit ribosomal DNA region sequences helped identify 38 species belonging to 28 genera, 10 families, and 5 orders in this area. Among them, three polypores, *Abundisporus pubertatis*, *Coriolopsis strumosa*, and *Perenniporia maackiae* were found to be new to South Korea.

Keywords Basidiomycetes, Phylogeny, Taxonomy

Polypores are a morphological group of basidiomycetous fungi that have tough, leathery poroid basidiocarps, but typically lack a distinct stalk. Traditionally, they have been categorized under the family Polyporaceae, but comprehensive molecular phylogeny has revealed that polypores are polyphyletic in nature, spanning several orders that includes Hymenochaetales, Polyporales, Russulales, and others [1].

With the exception of a few genera, such as *Coltricia*, most polypores along with corticioid fungi are wood decay fungi, causing brown and white rots in conifers and broad-leaved trees [2, 3]. Such wood decay fungi have received much attention due to their ability to degrade lignocellulosic materials. This process not only contributes to nutrient recycling within forest ecosystems, but also has the potential to be used for degrading a wide range of pollutants [4]. The specificity of polypores to wood substrates differs, with preferences towards particular wood species and sizes. Polypores that prefer well-decayed and large logs are more frequently found in old-growth forests [5] and thus are used as indicators of forest health, assisting in forest management in Europe [6].

Although some effort has been directed at understanding the regional diversity of wood decay fungi, including polypores in South Korea [7-12], knowledge about the diversity of such polypores in the mountainous region surrounding a large city such as Seoul is lacking. In Seoul, many plant communities have undergone changes over the last few decades [13]; however, the ecological impact on wood decay fungi due to the changes in vegetation remains unknown. In this study, we focused on the polypore diversity among the wood decay fungi. Previously, 28 species of polypores were reported to exist in Seoul [14-20]. Using the results of our recent survey, we analyzed the diversity of the polypores in Seoul and have provided descriptions of three polypores, *Abundisporus pubertatis*, *Coriolopsis strumosa*, and *Perenniporia maackiae*, which are new to South Korea.

Mycobiology 2014 June, **42**(2): 140-146
http://dx.doi.org/10.5941/MYCO.2014.42.2.140
pISSN 1229-8093 • eISSN 2092-9323

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Received April 2, 2014
Accepted May 26, 2014

MATERIALS AND METHODS

Morphological examination. Basidiocarps collected from Seoul between 2008 and 2012 were used in this study. The collected areas are represented in Fig. 1. Polypore specimens were sorted from the collected materials based on the broad description previously reported by Gilbertson and

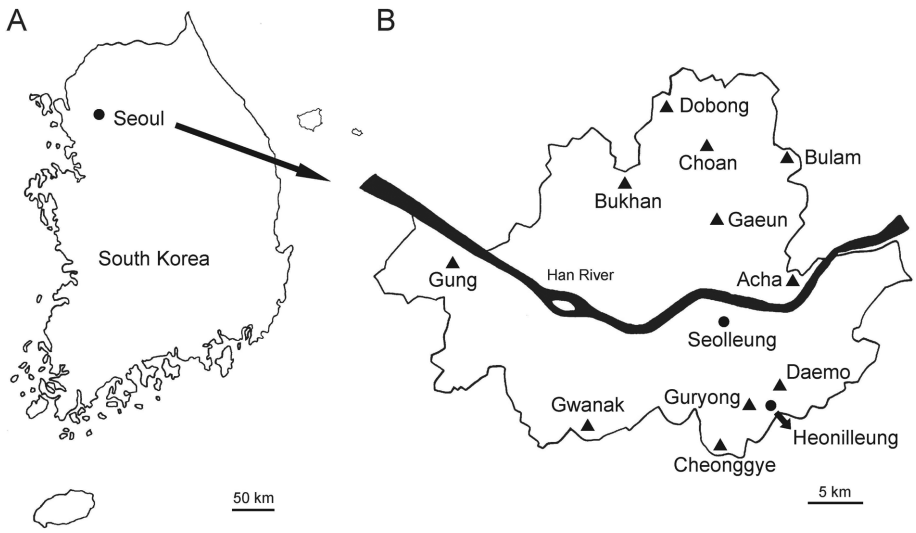

Fig. 1. Collection sites of polypores in Seoul, South Korea. A, Location of Seoul within South Korea; B, Sampling sites of polypores in Seoul. ●, royal tombs; ▲, mountains.

Ryvarden [2, 3]. The polypores were examined according to the descriptions provided by Jang *et al.* [21]. The following abbreviations are used: L = mean spore length, W = mean spore width, and n = the number of spores measured/the number of examined specimens. The study materials were deposited at the National Institute of Biological Resources, Incheon, South Korea (KB) and/or the Korea University Culture Collection, Korea University, Seoul, South Korea (KUC).

Molecular analysis. Genomic DNAs were extracted directly from the fragments of seven basidiocarps (considered as new to South Korea) using Accuprep Genomic DNA extraction kit (Bioneer, Seoul, Korea). Nuclear large subunit ribosomal DNA (nLSU) region and/or internal transcribed spacer (ITS) region were analyzed by performing PCR by the previously described method [19]. DNA sequencing was performed through the Macrogen sequencing service (Seoul, Korea). The sequences obtained in this study were deposited in NCBI GenBank (accession Nos. KF356153~KF356162). Each sequence was compared to the reference sequences in GenBank, using a BLAST search (http://blast.ncbi.nlm.nih.gov/Blast.cgi). For *Abundisporus pubertatis* and *Coriolopsis strumosa*, phylogenetic analyses were performed using the ITS region sequences, as described previously [21]. For *Perenniporia maackiae*, ITS and nLSU region sequences were combined and phylogenetic analysis was performed according to a previously published protocol [22].

RESULTS AND DISCUSSION

Around 300 polypore specimens were sorted from the materials collected in Seoul between 2008 and 2012. Specimens that were immature, too small, or in poor condition were excluded from the analysis, which left approximately 240 specimens for the examination. Our analysis helped identify 38 species of polypores belonging to 28 genera, 10 families, and 5 orders. These are listed in

Table 1. The list of polypores in Seoul, South Korea

Species	Substrate	Location	Specimens collected
Abundisporus pubertatis (Lloyd) Parmasto	Hardwood, *Pinus densiflora*	Mt. Bukhan	2
Antrodia heteromorpha (Fr.) Donk	*Pinus densiflora*	Mt. Bukhan, Mt. Dobong	2
Antrodia malicola (Berk. & M. A. Curtis) Donk		Heonilleung	1
Antrodiella semisupina (Berk. & M. A. Curtis) Ryvarden		Mt. Guryong	1
Bjerkandera adusta (Willd.) P. Karst.	Hardwood	Heonilleung, Mt. Bulam	4
Ceriporia lacerata N. Maek., Suhara & R. Kondo	Hardwood	Mt. Bukhan	1
Cerrena consors (Berk.) K. S. Ko & H. S. Jung	Hardwood	Heonilleung, Mt. Acha, Mt. Cheonggye, Mt. Daemo, Mt. Guryong	8
Coltricia cinnamomea (Jacq.) Murrill	*Pinus densiflora*	Mt. Bukhan	3
Coriolopsis strumosa (Fr.) Ryvarden		Heonilleung, Mt. Bukhan, Mt. Bulam	3

Table 1. Continued

Species	Substrate	Location	Specimens collected
Daedalea dickinsii Yasuda	*Querqus*	Heonilleung, Mt. Cheonggye, Mt. Daemo	4
Daedaleopsis confragosa (Bolton) J. Schröt.	*Querqus*	Heonilleung, Mt. Bukhan, Mt. Bulam, Mt. Cheonggye, Mt. Dobong, Mt. Gaeun, Mt. Gung, Mt. Guryong	16
Daedaleopsis styracina (Henn. & Shirai) Imazeki	*Querqus*	Mt. Bukhan	1
Fuscoporia gilva (Schwein.) T. Wagner & M. Fisch.	Hardwood	Heonilleung, Mt. Bulam, Mt. Cheonggye, Mt. Choan, Mt. Daemo, Mt. Dobong, Mt. Guryong, Mt. Gwanak	17
Fuscoporia senex (Nees & Mont.) Ghob.-Nejh.		Mt. Choan	1
Ganoderma lucidum (Curtis.) P. Karst.	*Querqus*	Heonilleung, Mt. Bukhan, Mt. Gaeun, Mt. Gwanak	6
Gloeophyllum sepiarium (Wulfen) P. Karst.	Conifer	Mt. Cheonggye	1
Heterobasidion ecrustosum Tokuda, T. Hatt. & Y. C. Dai[a]	*Pinus densiflora*	Heonilleung, Mt. Cheonggye	2
Hyphodontia tropica Sheng H. Wu	*Prunus serrulata* var. *spontanea*, *Querqus*, and other hardwood	Heonilleung, Korea Univ., Mt. Bukhan, Mt. Bulam, Mt. Daemo, Mt. Dobong, Mt. Gaeun, Mt. Gung, Mt. Guryong, Seonjeongneung	23
Irpex lacteus (Fr.) Fr.	Hardwood	Heonilleung, Mt. Acha, Mt. Bukhan, Mt. Bulam, Mt. Daemo, Mt. Dobong, Mt. Gung, Mt. Gwanak	16
Junghuhnia nitida (Pers.) Ryvarden	Hardwood	Mt. Bukhan, Mt. Bulam	2
Lenzites betulina (L.) Fr.	Hardwood	Korea Univ., Mt. Bukhan, Mt. Bulam, Mt. Cheonggye, Mt. Choan, Mt. Daemo, Mt. Guryong	9
Microporus vernicipes (Berk.) Kuntze		Heonilleung	2
Perenniporia fraxinea (Bull.) Ryvarden	*Querqus*, *Robinia pseudoacacia*, and other hardwood	Korea Univ., Mt. Bukhan, Mt. Bulam, Mt. Choan, Mt. Daemo, Mt. Gaeun, Mt. Gung, Mt. Guryong	28
Perenniporia maackiae (Bondartsev & Ljub.) Parmasto	Hardwood	Mt. Bukhan	2
Perenniporia ochroleuca (Berk.) Ryvarden	Hardwood	Mt. Bukhan, Mt. Choan, Mt. Gaeun	3
Porodisculus orientalis J. S. Lee & H. S. Jung	Hardwood	Mt. Acha	1
Postia stiptica (Pers.) Jülich		Mt. Daemo	2
Pycnoporus coccineus (Fr.) Bondartsev & Singer	Hardwood	Mt. Acha, Mt. Bulam, Mt. Gaeun	3
Schizopora flavipora (Berk. & M. A. Curtis ex Cooke) Ryvarden	*Pinus densiflora*	Mt. Acha, Mt. Bukhan, Mt. Daemo, Mt. Dobong, Mt. Gaeun, Mt. Gung, Mt. Guryong, Mt. Gwanak	9
Skeletocutis nivea (Jungh.) Jean Keller	Hardwood	Mt. Bukhan, Mt. Guryong	3
Trametes orientalis (Yasuda) Imazeki	*Querqus*	Mt. Bulam, Mt. Choan, Mt. Daemo, Mt. Gaeun	6
Trametes versicolor (L.) Lloyd	*Pinus densiflora*, *Querqus* and other hardwood	Heonilleung, Mt. Acha, Mt. Bukhan, Mt. Bulam, Mt. Cheonggye, Mt. Choan, Mt. Daemo, Mt. Dobong, Mt. Gaeun, Mt. Gung, Mt. Guryong, Mt. Gwanak, Seonjeongneung	29
Trametopsis cervina (Schwein.) Tomšovský	Hardwood	Heonilleung, Mt. Bukhan, Mt. Dobong	4
Trichaptum abietinum (Dicks.) Ryvarden	*Pinus densiflora*	Mt. Acha, Mt. Bukhan, Mt. Bulam, Mt. Daemo, Mt. Guryong, Mt. Gwanak,	8
Trichaptum biforme (Fr.) Ryvarden	Hardwood	Heonilleung, Korea Univ., Mt. Bukhan, Mt. Dobong, Mt. Guryong, Mt. Bulam	10
Tyromyces chioneus (Fr.) P. Karst.	Hardwood	Mt. Bukhan, Mt. Cheonggye, Mt. Daemo, Mt. Dobong, Mt. Guryong	6
Wrightoporia japonica Núñez & Ryvarden		Mt. Bulam, Mt. Guryong	2
Wrightoporia sp.		Mt. Dobong	1

[a]*Heterobasidion ecrustosum* was also recognized as new to South Korea. The detailed description of this species will be published elsewhere.

Table 1, along with their identified substrates and locations. All the samples were identified up to the species level, with the exception of *Wrightoporia* sp., which could be identified only up to the genus level [19]. Since the field surveys were performed irregularly during a 5-year period and we may not have captured every single species, our survey

suggests that *Trametes versicolor*, *Perenniporia fraxinea*, and *Hyphodontia tropica* are widespread in this region. In addition, 20 species were newly reported in Seoul: *Abundisporus pubertatis*, *Antrodia heteromorpha*, *A. malicola*, *Antrodiella semisupina*, *Ceriporia lacerata*, *Coltricia cinnamomea*, *Coriolopsis strumosa*, *Daedaleopsis confragosa*, *D. styracina*, *Heterobasidion ecrustosum*, *Hyphodontia tropica*, *Junghuhnia nitida*, *Microporus vernicipes*, *Perenniporia maackiae*, *P. ochroleuca*, *Porodisculus orientalis*, *Postia stiptica*, *Pycnoporus coccineus*, *Skeletocutis nivea*, and *Trametes orientalis*.

Although 10 polypores, *Abortiporus biennis* (Bull.) Singer, *Bjerkandera fumosa* (Pers.) P. Karst., *Cerrena unicolor* (Bull.) Murrill, *Daedaleopsis tricolor* (Bull.) Bondartsev & Singer, *Datronia mollis* (Sommerf.) Donk, *Inonotus xeranticus* (Berk.) Imazeki & Aoshima, *Perenniporia subacida* (Peck) Donk, *Pycnoporus cinnabarinus* (Jacq.) P. Karst. *Schizopora paradoxa* (Schrad.) Donk, and *Trichaptum fuscoviolaceum* (Ehrenb.) Ryvarden were also reported previously [14-17], they were not identified in our surveys; therefore, they are not included in Table 1. Further study is required to analyze their distribution in Seoul.

Among the identified species, three polypores were confirmed to be new to South Korea, namely, *Abundisporus pubertatis, Coriolopsis strumosa,* and *Perenniporia maackiae* (Figs. 2~4). They were found in Mt. Bukhan, and *C. strumosa* was additionally found in Heonilleung and Mount Bulam (Fig. 1). Phylogenetic analysis of each species confirmed their species identity (Fig. 5). *A. pubertatis* (KUC20080801-14) was monophyletic with *A. pubertatis* collected from China (Fig. 5A). Concerning *A. pubertatis* (KUC20080726-14),

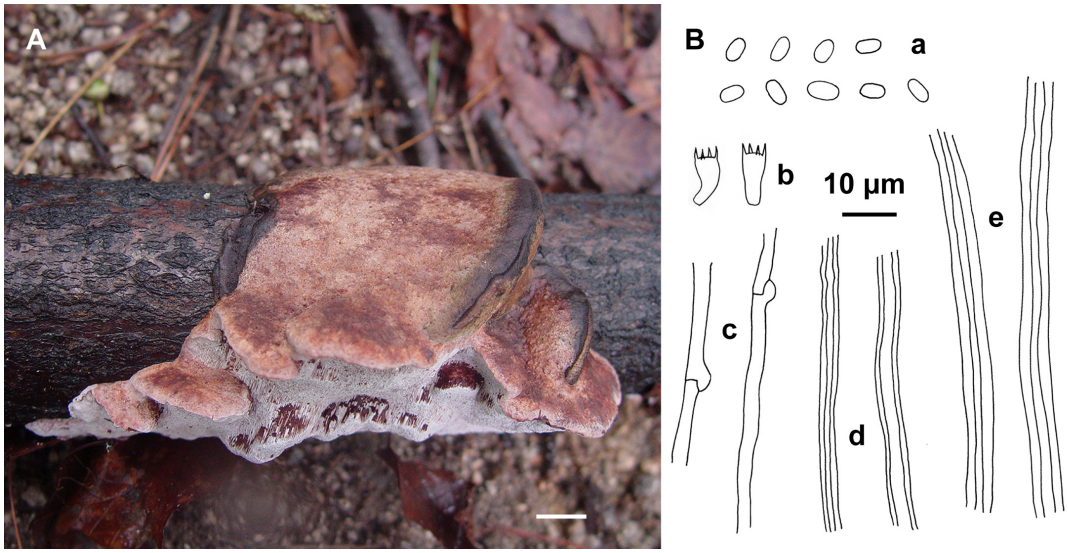

Fig. 2. Image and microscopic features of *Abundisporus pubertatis* (KUC20080726-14). A, Basidiocarp; B, Microscopic features (scale bars: A = 1 cm, B = 10 μm). a, basidiospores; b, basidia; c, generative hyphae from trama; d, skeletal hyphae from trama; e, skeletal hyphae from context.

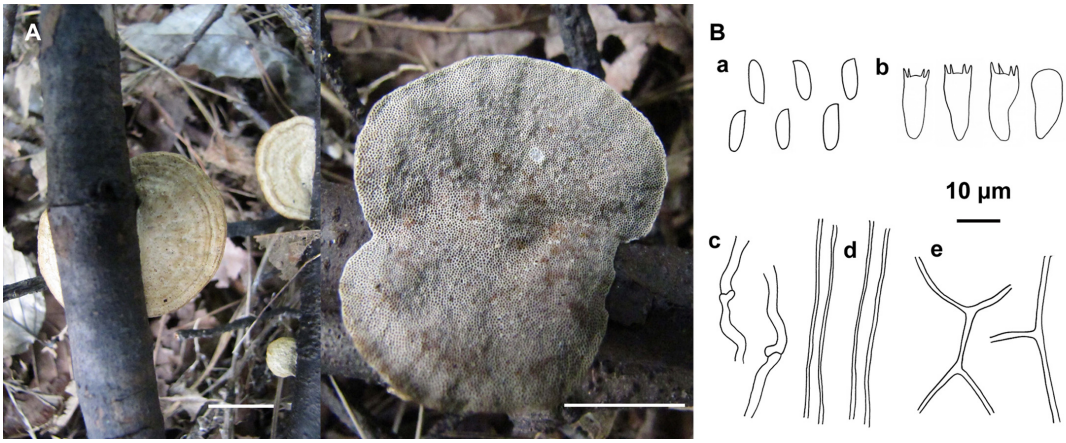

Fig. 3. Image and microscopic features of *Coriolopsis strumosa* (KUC20110916-07). A, Basidiocarp; B, Microscopic features (scale bars: A = 1 cm, B = 10 μm). a, basidiospores; b, basidia; c, generative hyphae from trama; d, skeletal hyphae from trama; e, binding hyphae from trama.

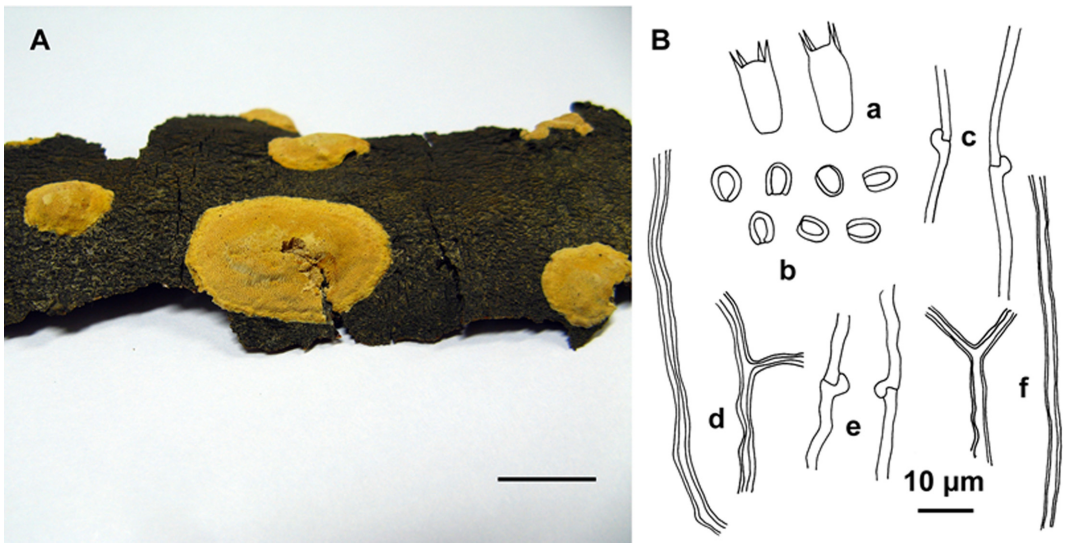

Fig. 4. Image and microscopic features of *Perenniporia maackiae*. A, Basidiocarp (KUC20080801-45); B, Microscopic features (a, b, c, d, f, KUC20080801-33; e, KUC20080801-45) (scale bars: A = 1 cm, B = 10 μm). a, basidia; b, basidiospores; c, generative hyphae from trama; d, skeletal hyphae from trama; e, generative hyphae from context; f, skeletal hyphae from context.

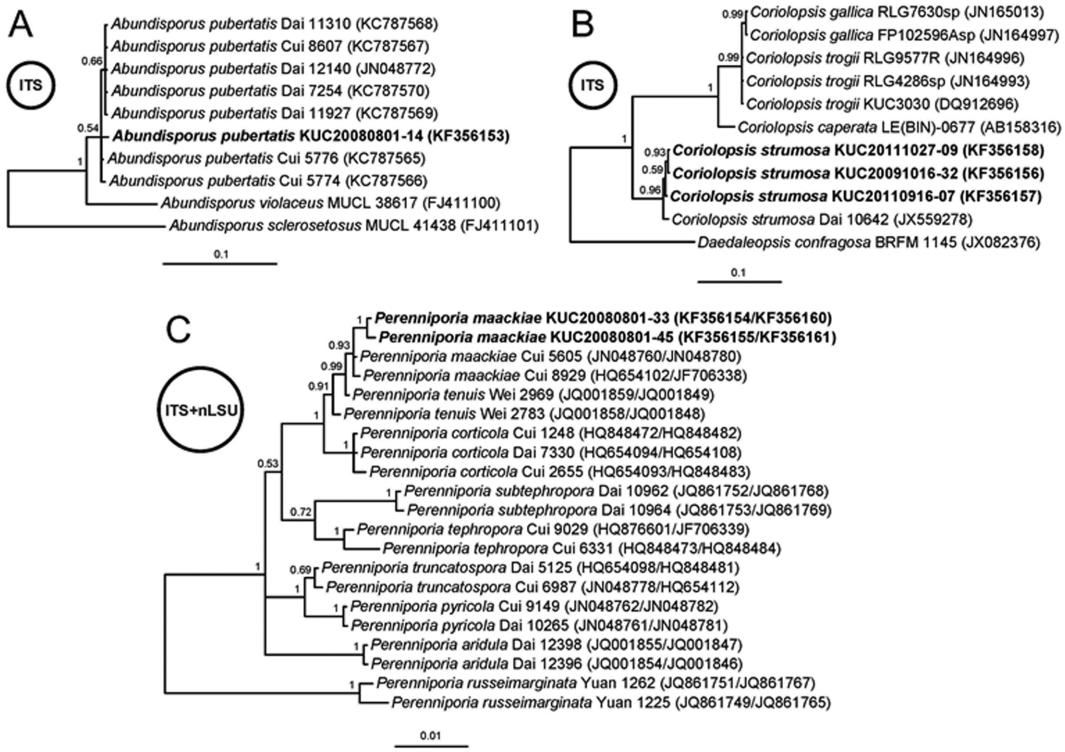

Fig. 5. Bayesian analysis of the three polypores, *Abundisporus pubertatis*, *Coriolopsis strumosa*, and *Perenniporia maackiae*. A, The dataset is composed of 10 taxa and 493 characters to which the HKY + I model was applied; B, The dataset is composed of 11 taxa and 555 characters to which the HKY + I model was applied; C, The dataset is composed of 21 taxa and 1,907 characters (551 characters of internal transcribed spacer [ITS] and 1,356 characters of nuclear large subunit ribosomal DNA [nLSU]). HKY + I + G model was applied for ITS, and HKY + I model was used for nLSU. Posterior probability values above 0.5 are shown on the branches. Specimens found in this study are in bold. GenBank accession Nos. are in parentheses.

while the ITS sequence was not successfully amplified, the identity of the polypore could be confirmed using the nLSU sequence. Three specimens of *C. strumosa* (KUC20091016-32, KUC20110916-07, and KUC20111027-09) clustered with *C. strumosa* from China, with high support (0.96 posterior probability value [p.p.]) (Fig. 5B), and two specimens of *P.*

maackiae (KUC20080801-33 and KUC20080801-45) grouped with *P. maackiae* from China, with high support (0.93 p.p) (Fig. 5C). The detailed descriptions of these three species are presented below.

Taxonomy.

Abundisporus pubertatis (Lloyd) Parmasto, Karstenia 40: 133 (2000).

Basidiocarps sessile to effused-reflexed, broadly attached, triquetrous, up to 8 cm long, 5.5 cm thick at the base. Pileus surface reddish brown (5YR5/3 to 4/3) to dark reddish brown (5YR3/2-3), with a very dark grey (5YR3/1) margin up to 1 cm when dry. Margin round. Pores angular to round, 5~7 per mm, pink (5YR7/3) to reddish brown (5YR5/3), dissepiments entire. Tubes reddish brown (5YR4/3), 5 mm long. Context corky, concolorous with the tubes. Hyphal system dimitic; generative hyphae with clamp connections, hyaline, thin-walled, 2~4.5 µm wide; skeletal hyphae hyaline to pale olivaceous brown, thick-walled, 2.5~5 µm wide. Cystidia and other sterile elements absent. Basidia clavate, 4-sterigmate, 10~13 × 3~4.5 µm. Basidiospores ellipsoid, pale brown, 3.9~5.3 × 2.2~3 µm, L = 4.48 µm, W = 2.58 µm (n = 61/2).

Specimens examined: Korea, Seoul, Mt. Bukhan, 37°37'46" N, 127°04'47" E, on the branch of a hardwood tree, 26 Jul 2008, Jae-Jin Kim, KUC20080726-14 (KB, NIBRFG0000107238; GenBank accession No. KF356159); on the branch of *Pinus densiflora*, 1 Aug 2008, Jae-Jin Kim, KUC20080801-14 (KB, NIBRFG0000107332; GenBank accession No. KF356153).

Note: *Abundisporus pubertatis* is characterized by its reddish brown basidiocarp and small pores (5~7 per mm). *Abundisporus fuscopurpureus* (Pers.) Ryvarden, which was reported by Lee and Jung [23], with its slightly larger pores (4~5 per mm) and slightly smaller basidiospores (3~4 × 2~2.5 µm) is different from *A. pubertatis*.

Coriolopsis strumosa (Fr.) Ryvarden, Kew Bull. 31: 95 (1976).

Basidiocarps annual, solitary to imbricate, dimidiate, applanate to flabelliform, up to 6.5 cm long and 4 cm wide, up to 1 cm thick at the base, coriaceous, margin thin and sharp. Pileus surface very pale brown (10YR7/3-4) to light yellowish brown (10YR6/4), glabrous, numerous concentric, slightly sulcate zones and some radial striae present, sometimes finely warted. Margin thin, undulating. Pore surface somewhat darker than the pileus surface, pores round, 5~6 per mm, entire. Tubes concolorous with the pore surface, 1~2 mm long. Context concolorous with the tubes, black in KOH. Hyphal system trimitic; generative hyphae hyaline, thin-walled, 1.5~3 µm wide; skeletal hyphae abundant, hyaline to yellowish brown, thick-walled, 2.5~5.5 µm wide; binding hyphae difficult to find, hyaline, 1~2.5 µm wide. Cystidia and other sterile elements absent. Basidia clavate, 4-sterigmate, 13~18 × 5~7.5 µm. Basidiospores cylindrical, (8.3~) 9~11 (~13) × 3~4 µm, L = 9.76 µm, W = 3.41 µm (n = 60/2).

Specimens examined: Korea, Mt. Bukhan, on a wood branch, 16 Oct 2009, Jaejung Lee, KUC20091016-32 (KB, NIBRFG0000113536; GenBank accession No. KF356156); Heonilleung, 37°21'51" N, 127°04'55" E, on a wood branch, 16 Sep 2011, Yeongseon Jang, KUC20110916-07 (KB, NIBRFG0000115756; GenBank accession No. KF356157); Mt. Bulam, 37°39'19" N, 127°04'49" E, on the wood log, 27 Oct 2011, Yeongseon Jang, KUC20111027-09 (KB, NIBRFG0000116096; GenBank accession Nos. KF356158, KF356162).

Note: This species is easily recognized by its brownish basidiocarp with radial striae in the field. *Coriolopsis gallica* (Fr.) Ryvarden was reported as *Trametes hispida* Bagl. in Jung [15], but there was no description. According to Gilbertson and Ryvarden [2], *C. gallica*, with its larger and angular pores (1~3 per mm) and slightly larger basidiospores (10~16 × 3~5 µm), is different from *C. strumosa*.

Perenniporia maackiae (Bondartsev & Ljub.) Parmasto, Ann. Bot. Fenn. 32: 223 (1995).

Basidiocarps resupinate, corky when dry, margin sterile, up to 1 mm wide. Pores angular to round 6~8 per mm, yellow (10YR8/6-8), dissepiments thick, entire. Context very pale brown (10YR 8/3), corky, up to 1 mm thick, tubes concolorous with pore surface, tubes corky, up to 1 mm long. Hyphal system dimitic, generative hyphae hyaline, thin-walled, 2~3 µm wide, skeletal hyphae thick-walled, frequently branched, 1.5~3 µm wide. Cystidia and other sterile elements absent. Basidia broadly clavate, 4-sterigmate, 14~18 × 6~7 µm. Basidiospores broadly ellipsoid to subglobose, thick-walled, more or less truncate, smooth, variably dextrinoid, (4.7~) 5.1~6.7 (~7) × 3.5~5 (~5.3) µm, L = 5.66 µm, W = 4.29 µm (n = 60/2).

Specimens examined: Korea, Seoul, Mt. Bukhan, 37°37'46" N, 127°04'47" E, on a branch of a hardwood tree, 1 Aug 2008, Jae-Jin Kim, KUC20080801-33 (KB, NIBRFG0000107345; GenBank accession Nos. KF356154, KF356160); on a wood branch, 1 Aug 2008, Jae-Jin Kim, KUC20080801-45 (GenBank accession Nos. KF356155, KF356161).

Note: This species is easily recognized owing to its yellow, fully resupinate basidiocarp with small pores in the field. *Perenniporia truncatospora* (Lloyd) Ryvarden was reported as *Truncospora truncatospora* (Lloyd) S. Ito in Jung [15], but no description was provided. According to Dai *et al.* [24], *P. truncatospora* is different from *P. maackiae* by slightly larger and inamyloid basidiospores [(5~) 5.3~7.5 (~8) × (3.8~) 4~5 (~5.5) µm].

ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2013R1A1A2A10011390). Support for this study was also provided by the Indigenous Species Survey and Investigation

project from the National Institute of Biological Resources (NIBR) under the Ministry of Environment, Republic of Korea.

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