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Pseudosperma albobrunneum sp. nov. from coniferous forests of Pakistan

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Abstract—A new species, *Pseudosperma albobrunneum*, is described and illustrated. The specimens are from different areas of Khyber Pakhtunkhwa province, Pakistan. The identification is based on morphological characters, in combination with molecular phylogenetic analysis of sequences of the ITS region of nuclear ribosomal DNA. The species is found distinct morphologically from all closely related taxa, and molecular data confirm its novelty.

Key words—ectomycorrhizal, Himalayan, moist temperate, taxonomy

Introduction

Inocybaceae Jülich (*Basidiomycota*, *Agaricales*) is a highly diversified family of ectomycorrhizal fungi, comprising seven genera and more than 1000 species (Kobayashi 2009; Matheny & al. 2009, 2012, 2019; Kobayashi & Onishi 2010; Kropp & al. 2010; Bougher & Matheny 2011; Bougher & al. 2012; Kokkonen & Vauras 2012; Fan & Bau 2013, 2014; Braaten & al. 2014; Esteve-Raventós & al. 2015; Jabeen & al. 2016; Farooqi & al. 2017; Naseer & al. 2017; Liu & al. 2018; Ullah & al. 2018; Matheny & Kudzma 2019). The family shows more diversification in temperate regions as comparatively fewer species have been reported from tropical rain forests (Matheny & al. 2003; Matheny &

Bougher 2017). The species have demonstrated ectomycorrhizal associations with as many as 23 families of vascular plants, including low woody shrubs in arctic-alpine habitats making these fungi of high interest (Cripps & al. 2010, Matheny & al. 2019).

Among the 28 species representing different genera in *Inocybaceae* reported from Pakistan (Ahmad & al. 1997; Ilyas & al. 2013; Saba & al. 2015, 2020; Jabeen & al. 2016; Farooqi & al. 2017; Naseer & al. 2017, 2019; Liu & al. 2018; Ullah & al. 2018; Jabeen & Khalid 2020), eight represent *Pseudosperma* (Ahmad & al. 1997; Saba & al. 2015, 2020; Liu & al. 2018; Ullah & al. 2018; Jabeen & Khalid 2020).

The many classification systems proposed for the species in *Inocybaceae* include several clades, sections, subgenera, and genera based on morphological features and molecular phylogenetics (Massee 1904, Heim 1931, Kühner & Romagnesi 1953, Kuyper 1986, Singer 1986, Horak 2005, Matheny & Bougher 2006, Matheny & al. 2009, Larsson & al. 2009, Alvarado & al. 2010, Ryberg & al. 2010, Matheny & Kudzma 2019).

One multigene phylogenetic analysis by Matheny & al. (2019) recognized seven genera within *Inocybaceae,* including two new genera [*Nothocybe* Matheny & K.P.D. Latha, *Pseudosperma* Matheny & Esteve-Rav.], two subgenera elevated to generic rank [*Inosperma* (Kühner) Matheny & Esteve-Rav., *Mallocybe* (Kuyper) Matheny & al.], and three previously described genera [*Auritella* Matheny & Bougher, *Tubariomyces* Esteve-Rav. & Matheny, *Inocybe* (Fr.) Fr. sensu stricto].

Pseudosperma comprises species previously placed in *Inocybe* sect. *Rimosae* (Fr.) Quél. and characterized by cheilocystidia, absence of pleurocystidia, hyaline basidia, adnexed to sinuate lamellae, a fibrillose (rarely squamulose) and rimose pileus surface, a cylindrical stipe with a distinctly pruinose, furfuraceous, or somewhat flocculose apex, stipe context not changing color when bruised, odor often spermatic (reminiscent of green corn or honey) but occasionally nil, and smooth elliptic to (occasionally) indistinctly phaseoliform basidiospores (Matheny & al. 2019). *Pseudosperma* is represented by 70 species in Africa, Asia, Australasia, Europe, North America, and northern South America.

During field surveys for ectomycorrhizal fungi associated with *Pinaceae* in different areas of Khyber Pakhtunkhwa province, Pakistan, several collections were identified through both morphological and nrDNA ITS sequence analyses. They showed characters similar to species now classified under *Pseudosperma*. We could not find a published description that fit these

specimens nor published similar ITS sequences and propose these here as a new species

Material & methods

Samples of basidiomata were collected in four different localities in two administrative divisions of Khyber Pakhtunkhwa province, Pakistan.

Khanian is a small village in the northern Kaghan valley in the Mansehra district, Hazara division, in north-east Khyber Pakhtunkhwa province, immediately south of the main Himalayan range with a typically moist temperate climate and dominated by *Cedrus deodara* (Roxb. ex D. Don) G. Don along with *Abies pindrow* (Royle ex D. Don) Royle and *Pinus wallichiana* A.B. Jacks. (Siddiqui & al. 2013).

The Lower Dir district is located in the Hindu Kush range, Malakand division, in northwestern Khyber Pakhtunkhwa province. The area lies in the valley of the Panjkora river, which originates from the Hindu Kush ranges and joins the Swat River near Chakdara. The climate is dry temperate. *Pinus* spp. and *Quercus oblongata* D. Don [= Q. *incana* Roxb., nom. illeg.] are the dominant tree species (Champion & al. 1965). Among *Pinus*, *P. gerardiana* Wall. ex D. Don was the dominant species. Pure *Q. oblongata* forest was found in the mountain heights (H. Bashir, pers. obs.). Kalam and Mashkun, also situated in the Malakand division, are home to the offshoots of the Hindu Kush range (Hamayun & al. 2003), also dominated by *C. deodara* forests with *Pinus* spp. and *Q. oblongata* (Champion & al. 1965). These areas have a typical dry temperate climate (Stucki & Khan 1999).

Basidiomata were collected and photographed in their natural habitat. Morphological data was recorded from the fresh specimens. Color codes follow Munsell color charts (Munsell 1975). Each collection was dried using a fan heater and preserved in sealed bags. Sections from basidiomata were rehydrated in 5% KOH, stained in Congo red, and observed under a Techno MX4300H compound microscope. Microscopical characters were measured using an ocular micrometer, and drawn with the aid of a camera lucida. The abbreviation (n/m/p) represents 'n' number of basidiospores measured, 'm' number of basidiomata, and 'p' number of collections. Basidiospore dimensions were recorded as (a) b–c (d), where (a) and (d) are the extreme values, and the range b–c contains at least 90% of the calculated values; Q indicates the l/w ratio of the spores, and avQ is the average Q of all measured spores. Measurements of hyphae are given as ranges. The collections examined during this study have been deposited in the herbarium, Department of Botany, University of the Punjab, Quaid-e-Azam Campus, Lahore, Pakistan (LAH).

Genomic DNA extraction and PCR amplification of ITS1, 5.8S, and ITS2 was carried out following procedures by White & al. (1990), Gardes & Bruns (1993), and Bruns (1995). The PCR products were purified and sequenced at Macrogen Inc. (Korea). The newly generated sequences were deposited in GenBank. For phylogenetic study, consensus sequences of ITS regions were generated in the BioEdit software version 7.2.5 (Hall 1999). Sequence homology search was investigated using the BLAST algorithm at http://www.ncbi.nlm.nih.gov/. Sequences from the closest

relatives of the Pakistani species were included in the final dataset to reconstruct a phylogeny based on published phylogenies (Larsson & al. 2009, Kropp & al. 2013, Latha & Manimohan 2017, Liu & al. 2018). Sequences from *Auritella* and *Inosperma* were chosen as outgroup (Matheny & al. 2009). GenBank accession numbers are included with each taxon name in the phylogenetic tree. Multiple sequences were aligned using the webPRANK tool at https://www.ebi.ac.uk/goldman-srv/webprank/. Maximum likelihood analysis was performed in MEGA version 6 (Tamura & al. 2013) at 1000 bootstrap pseudoreplicates by finding best-fit substitution model with 1000 bootstrap replicates. The phylogeny was inferred by the Maximum Likelihood method based on the General Time Reversible model. A discrete Gamma distribution was used to model evolutionary rate differences among sites (5 categories (+G, parameter = 0.7529)).

Taxonomy

Pseudosperma albobrunneum Jabeen, Zainab, H. Bashir & Khalid, **sp. nov**.

Figs. 1, 2

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Differs from *Pseudosperma dulcamaroides* and *P. sororium* by the smaller basidiomata, white pileus becoming brownish with age, fibrillose stipe, and smooth, elongate to cylindric, sub-reniform basidiospores.

Type: Pakistan, Khyber Pakhtunkhwa, Hazara division, Mansehra district, Khanian, 2500 m a.s.l., on soil under *Cedrus deodara,* 5 August 2014, Sana Jabeen SJ102 (**Holotype** LAH35047; GenBank MG495392).

Etymology: The specific epithet refers to the white to brown basidiomata.

Pileus 1–1.8 cm in diam., conical with a prominent umbo; surface dry, rimose, fibrillose, white (10Y8/4) to brownish (7.5YR6/10); umbo yellowish (5Y8/6) becoming brownish (7.5YR6/10) at maturity; margin incurved when young. Lamellae adnexed, moderately close, up to 2 mm deep, golden brown (10YR5/6), with fimbriate edge. Stipe 5.5 × 0.4 cm, central, cylindrical, narrower towards the apex and wider towards the base; surface dry, pruinose towards apex, fibrillose; white (10Y8/4) when young, becoming grayish brown (5R4/1) to brown (7.5YR6/10) upon maturity, context off-white (5Y9/2). Odor spermatic.

Basidiospores [100/5/5] (12.7–)13.2–14.4(–16.4) × (5.3–)6.1–6.9(–8.2) µm, avl × avw = 13.8 × 6.5 µm, Q = (1.90–)1.94–2.20(–2.50), avQ = 2.00, elongate to cylindric, constricted in the center in side view, sub-reniform, smooth, guttulate, brown in 5% KOH. Basidia (38.1–)40.3–42.2(–43.7) ×

Figure. 1. *Pseudosperma albobrunneum*. A. LAH35288; B. LAH35047 (holotype). Scale bars = 0.5 cm. Photos by Abdul Nasir Khalid and Sana Jabeen.


A
B

(9.2–)9.5–11.8(–12.1) µm, 2–4-spored, clavate, guttulate, hyaline in 5% KOH; clamp connections observed at the base. Cheilocystidia (20.2–)25.4–27.4 (–30.3) × 4.4–6.5 µm, avl × avw = 26.4 × 5.5 µm, clavate, connected with basal cell, hyaline in 5% KOH; clamp connections at base common. Pleurocystidia absent. Caulocystidia at the extreme apex of the stipe, (43.1–)45.2–50.3 (–56.11) × (7.6–)9.4–10.9(–11.2) µm, avl × avw = 47.7 × 10.1 µm, clavate, hyaline in 5% KOH; clamp connections observed at the base. Pileipellis hyphae 4.6–7.7 µm wide, avw = 6.1 µm, septate, filamentous, branched, hyaline in 5% KOH; clamp connections frequent. Stipitipellis hyphae (6.1–)8.3–11.04 (–11.69) µm wide, avw = 9.7 µm, septate, filamentous, rarely branched; terminal cells clavate; clamp connections observed.

Additional specimens examined: **PAKISTAN**. **Khyber Pakhtunkhwa**, **Malakand division**, Lower Dir district, near Darosh, 1840 m a.s.l., on soil under *Pinus wallichiana*, 4 September 2015, Hira Bashir & Abdul Nasir Khalid D15 (LAH35288; GenBank MG495393); Swat district, Kalam, 2400 m a.s.l., on soil under *C. deodara*, 4 September 2013, Sana Jabeen SJ146 (LAH35045; GenBank MG495395); Swat district, Mashkun, 2500 m a.s.l., on soil under *C. deodara*, 5 September 2013, Aamna Ishaq SJ147 (LAH35046; GenBank MG495396); SJ110 (LAH35289; GenBank MG495394).

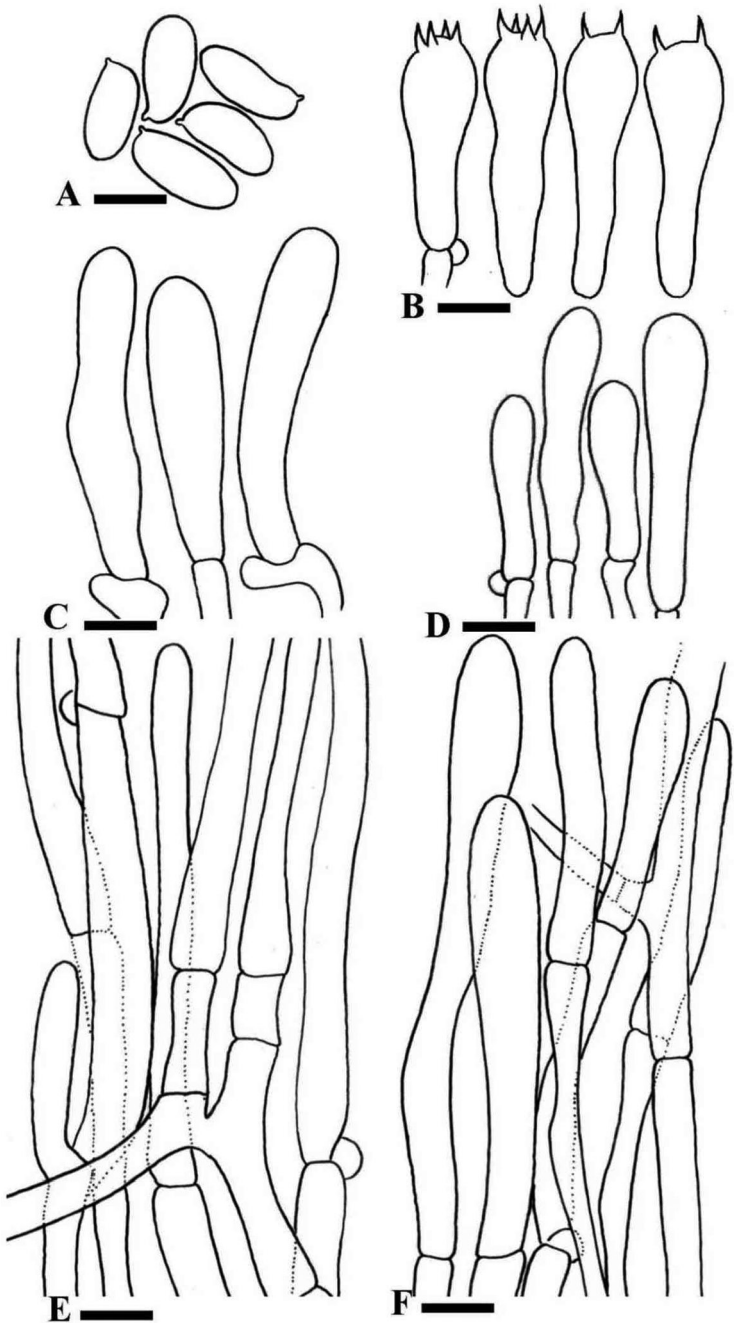
Habitat & distribution—Himalayan moist *Pinaceae*-dominated forests (including *Pinus roxburghii* Sarg., *P. wallichiana,* and few *Cedrus deodara*) and dry oak-dominated temperate forests (including *Quercus oblongata*). Currently known only from Pakistan's Khyber Pakhtunkhwa province.

Ecology & distribution—1840–2500 m asl in dry and moist temperate coniferous forests, Pakistan.

Molecular phylogenetic analysis

A BLAST search of NCBI comparing the ITS consensus sequence of 658 base pairs from the type specimen of *Pseudosperma albobrunneum* (LAH35045) was closely similar to HQ604626 & KP783443 sequences named as *I. sororia* (*P. sororium* (Kauffman) Matheny & Esteve-Rav. in Index Fungorum) from USA and Russia. The ITS dataset involved 100 nucleotide sequences including these two and others closely related from the BLAST along with sequences generated during this study and those from published literature as well as those chosen as outgroup. Of the total 1642 positions in the final dataset, 771 were conserved, 465 were variable, 342 were parsimony informative, and 114 were present as singletons.

Figure. 2. *Pseudosperma albobrunneum* (holotype, LAH35047). A. Basidiospores; B. Basidia; C. Caulocystidia; D. Cheilocystidia, E. Pileipellis; F. Stipitipellis. Scale bars = 10 µm. Drawings by Sana Jabeen.


A
B
C
D
E
F

In the phylogenetic tree (Fig. 3), two major clades were recovered within *Pseudosperma* labeled as clade A and clade B. The *P. albobrunneum s*equences generated during this study formed their own lineage in clade A clustered with *P. sororium* (HQ604626 & KP783443) but separated from them with 94% boot strap support. The second set of *P. sororium* sequences (HQ604607, HQ604610, HQ604617, HQ604618) found in clade B does not show remarkable genetic similarity with our *P. albobrunneum* sequences.

Discussion

Pseudosperma albobrunneum is characterized by its whitish to brownish basidiomata, a very prominent long-lasting umbo, a comparatively long and slender stipe, and smooth and elongate to cylindric, sub-reniform basidiospores.

The new Pakistani species resembles the European *P. dulcamaroides* (Kühner) Matheny & Esteve-Rav., which also has brown basidiomata but with a short stipe compared with its cap diameter and with a non-umbonate pileus that becomes convex to flat at maturity (Larsson & al. 2009).

Pseudosperma sororium (Kauffman) Matheny & Esteve-Rav. showed morphological characters more or less similar to *P. albobrunneum* as described by Kauffman (1924), but its yellow pileus and basidiospores that are ellipsoid or elongate-ellipsoid and not truly sub-reniform, sub-inequilateral, obtuse at both ends distinguish *P. sororium* from *P. albobrunneum*. Furthermore, *P. sororium* has a very strong green corn odor.

In the absence of type studies, modern descriptions of *P. dulcamaroides* (Larsson & al. 2009) and *P. sororium* (as *Inocybe,* Stuntz 1978) also support *P. albobrunneum* as morphologically distinct.

Pseudosperma breviterincarnatum (D.E. Stuntz ex Kropp & al.) Matheny & Esteve-Rav. from conifer and quaking aspen forests of the western USA differs by its pinkish lamellae and brownish pileus as well as a pinkish to brownish stipe (Kropp & al. 2013).

Pseudosperma flavorimosum Jabeen & Khalid from Pakistan morphologically resembles *P. albobrunneum* but can be distinguished by its basidiospores that are elliptical, amygdaliform with broad apex and narrow base (Jabeen & Khalid 2020). In the phylogenic tree (Fig. 3), *P. albobrunneum* forms a separate clade, supporting its novelty.

Acknowledgements

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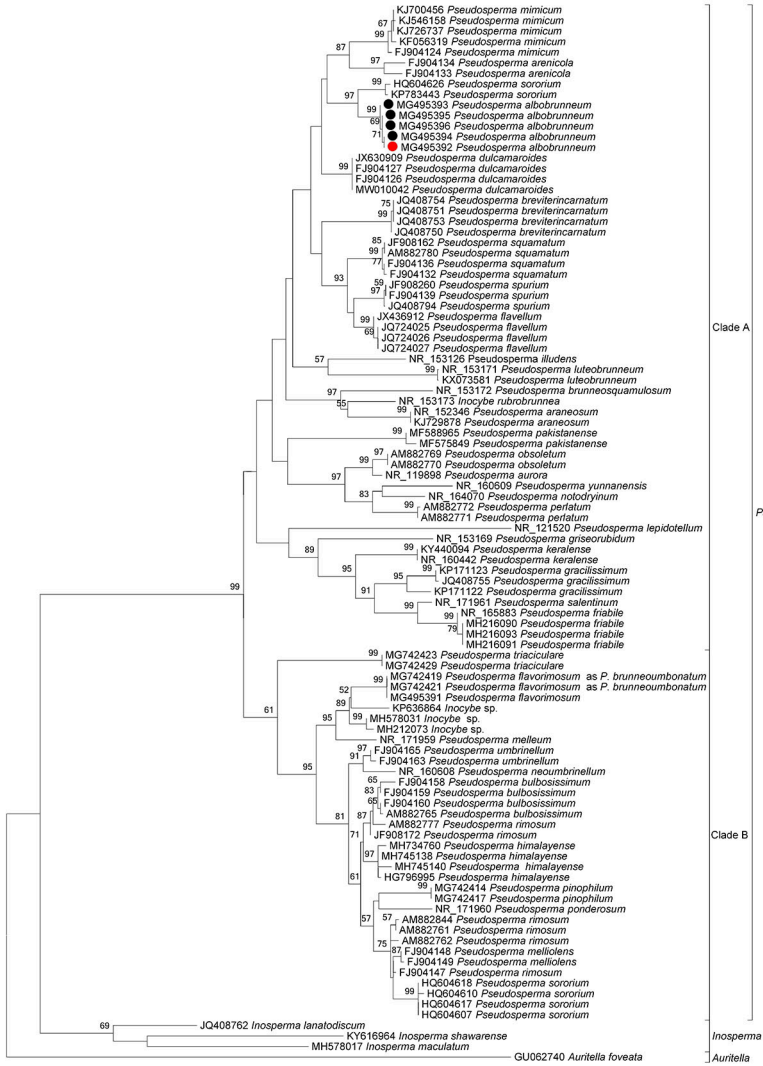

FIGURE. 3. Molecular phylogenetic analysis of *Pseudosperma albobrunneum* based on ITS sequences. Sequences generated during this study are marked with bullets; a red bullet indicates the holotype sequence.

Chang-Lin Zhao (Southwest Forestry University, Kunming, Yunnan, P.R. China), Dr. Tine Grebenc (Department of Forest Physiology and Genetics, Slovenian Forestry Institute, Ljubljana, Slovenia), and Dr. Else C. Vellinga (University of California, Berkeley, USA) for presubmission reviews of the manuscript.

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