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AGROCYBE HIMALAYENSIS (STROPHARIACEAE), A NEW SPECIES FROM INDIAN HIMALAYA

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A new species, *Agrocybe himalayensis* (Strophariaceae), from Uttarakhand Himalaya, India, is described based on macro- and micro-morphological characters and molecular phylogenetic analyses. This species is characterised by its pale-orange to yellow-brown pileus with distinct umbo, wavy cream margin, crowded pale-salmon to fleshy brown lamellae (often anastomosing), and ellipsoid basidiospores 8.7–11.4 × 6.6–7.8 µm. A phylogenetic tree, line drawings and photographs are provided, as is a table of morphological characters of the new and closely related species.

Keywords. nrITS, phylogeny, Strophariaceae, Uttarakhand.
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Introduction

The genus *Agrocybe* (Strophariaceae) was established by Fayod in 1889, with *A. praecox* (Pers.) Fayod designated as the type species. *Agrocybe* species are versatile and are commonly found across temperate areas in Asia, Europe and North America (Flynn & Miller, 1990). *Agrocybe* is a relatively small genus comprising small to large mushrooms characterised by a rusty-brown to dark-brown spore print and smooth spores, often with a distinct apical pore. The pileus is fleshy, ranging from convex or hemispherical to flattened, and lacks pleated grooves. The lamellae are attached to narrowly adnate. The stipe is typically white, buff or ochre, smooth to fibrous, frequently bearing a ring, and often associated with white basal rhizomorphs. Spores are smooth and commonly possess an apical pore. Cheilocystidia are variable in form, ranging from vesiculose to lageniform or cylindrical. Clamp connections are present. Species of *Agrocybe* occur on a wide range of substrates, including lawns and other grassy areas, humus-rich soils in woodlands, gardens, wood chips and dung.

Singer (1986) carried out an extensive morphological classification of the *Agrocybe* genus, placing it in the Bolbitiaceae family. This classification was based on features such as the pileipellis cell structure, which includes pear-shaped, subspherical sphaerocyte cells; the presence or absence of hymenial cystidia; and brown spore prints. Molecular phylogenetic studies have suggested that the genus should be classified within the family Strophariaceae (Agaricales, Agaricomycetes) (Walther & Weiß (2006), a classification now accepted in the modern taxonomy of the Basidiomycota (Kirk *et al.*, 2008; He *et al.*, 2019; Wijayawardene *et al.*, 2020).

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Earlier reports indicated that only 13 species of *Agrocybe* were documented from India (Abraham, 1991). Owing to the limited and sporadic study and exploration of this genus, there have been very few subsequent updates on its occurrence in the country. Thomas & Manimohan (2003) recorded six species of *Agrocybe* from Kerala, and Kour (2014), two species from Punjab. Its occurrence in agricultural fields, which are often neglected during macrofungal investigations, highlights the importance of conducting surveys in such habitats to better understand fungal diversity and distribution. Since Kour (2014), there have been no further records of the genus from India. Although it is most likely to occur in Uttarakhand, there are no published reports of *Agrocybe* from the area. This may reflect limited taxonomic surveys targeting agaricoid fungi, and the ephemeral nature of basidiomata or their habitat-specific occurrence. This lack of documentation highlights a significant gap in our understanding of the distribution of the genus in the Indian subcontinent.

In the present study, we describe a new species of *Agrocybe* from Uttarakhand State, India, providing detailed macro- and micromorphological characteristics, supplemented with line drawings and a phylogenetic analysis.

Materials and methods

Macro- and micromorphology

Fresh basidiomes were collected in the field and photographed with a Nikon D5300 camera (Nikon, Tokyo, Japan). Macromorphological descriptions of fresh specimens in the field were recorded, along with the habitat and associated host. Colour codes were assigned in accordance with Kornerup & Wanscher (1978). Following Largent *et al.* (1977) and Hesler & Smith (1979), chemical spot tests with 10% KOH, $FeSO_4$ and guaiacol were performed on the pileus surface and fresh basidiospores. All the micromorphological details were observed from dried samples, using freehand sections mounted in 10% KOH, 1% phloxine or 1% Congo Red (Largent *et al.*, 1977) and examined using an Olympus BX43 compound microscope (Olympus, Tokyo, Japan). Micromorphological elements were drawn using a camera lucida at a magnification of × 1000. Photomicrographs of the various elements were taken using a digital camera attached to an Olympus BX43 compound microscope. A total of 50 basidiospores from each of the three specimens were observed. Basidiospores measurements are given as minimum–mean–maximum length, minimum–mean–maximum width, and Q (= length-to-width ratio), with Q_m representing the mean Q of all basidiospores. At least 15 measurements were taken for basidia; the basidial length excludes the sterigmata, and the diameter was recorded for the different hyphal arrangements present.

DNA extraction, PCR amplification, and sequencing

A fungal genomic DNA Mini Kit (RGCB, Thiruvanathapuram, India) was used to isolate nuclear genomic DNA from 100 mg of dried fruit bodies of collection number SC/PU/17

and SC/PU/18. The nuclear ribosomal DNA gene's ITS region was amplified using primer pairs ITS1 and ITS4 (White *et al.*, 1990). PCR amplification reactions were performed in a 20 µL reaction volume containing 1 × Phire PCR buffer, 0.2 mM dNTPs, 1 µL of DNA, 0.2 µL of PhireHotstar II DNA polymerase enzyme, 0.1 mg/mL BSA, and 3% DMSO, 0.5 M betaine, and 5 pM forward and reverse primers. PCR amplification was performed in a PCR thermal cycler (Gene Amp PCR System 9700; Applied Biosystems, Waltham, Massachusetts, USA) programmed for 2 min at 96°C, followed by 30 cycles of 30 s at 96°C, 40 s at 50°C, and a final stage of 4 min at 60°C. PCR products were purified using the QIAquick Gel Extraction Kit (Qiagen, Hilden, Germany) and then Sanger-sequenced in an automated DNA sequencer (AB13730xl DNA Analyzer; Applied Biosystems) with the same primers used for amplification. All generated ITS sequences were deposited in GenBank, and accession numbers were obtained.

Phylogenetic analysis

Phylogenetic analysis was conducted utilising the nrITS dataset, which included the newly obtained sequences of collection SC/PU/17 and SC/PU/18, sequences identified through BLAST searches (Altschul *et al.*, 1997) in GenBank (Clark *et al.*, 2016), and previously published phylogenies (Chen *et al.*, 2012; Zhou *et al.*, 2022; Li *et al.*, 2023). For the present study, a dataset consisting of 65 nrITS sequences of *Agrocybe* species, including the newly acquired sequence, was used. The alignment of the nrITS dataset was performed using MAFFT version 7 (Katoh & Standley, 2013). Maximum-likelihood phylogenetic analysis of nrITS sequences was carried out using RaxML GUI software (Edler *et al.*, 2021), with 1000 bootstrap replicates analysed to ascertain nodal support values. Bootstrap support values (> 50%) obtained from the maximum-likelihood analysis are presented above or below the branches at nodes. Species of *Cyclocybe cylindrcea* Corner were utilised as an outgroup for the current phylogenetic analysis (GenBank nos. KM260144 and KM260145).

Results

Phylogenetic inferences

The nrITS dataset was made for investigating the phylogenetic relationships of the proposed new species. In nrITS analysis, *Agrocybe* (GenBank PQ380156, PQ393376) is clustered within a clade formed by a species including *A. putaminum* (Maire) Singer (GenBank OM373535, OR517867, OR562072, MH285875 and KM975434). Within the clade, *Agrocybe* is closest to *A. putaminum* (96.49% identity with 100% query cover), supported by a 100% bootstrap value (**Figure 1**).

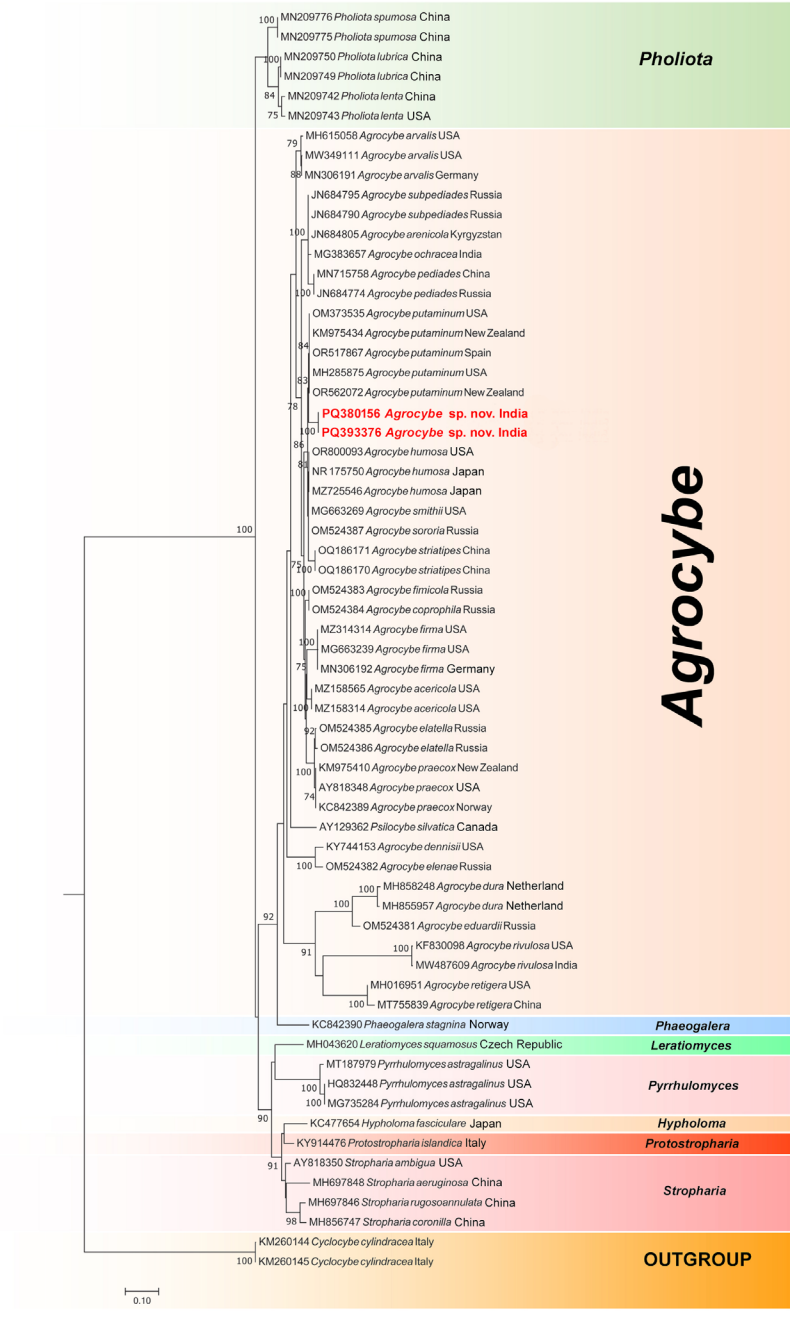

Figure 1. Maximum-likelihood phylogenetic tree inferred from ITS-rDNA sequence data, using the GTR+GAMMA model of nucleotide evolution constructed in RAxML version 2.0.10. Branches are labelled with maximum-likelihood bootstrap support values (≥ 50%). *Agrocybe* sp. nov. is shown as red in the tree.

Species description

Agrocybe himalayensis Choudhary, Uniyal & Y.P.Sharma, **sp. nov.**

Agrocybe himalayensis differs from its closely allied species *A. putaminum* by its large basidiomata (80 mm vs 60 mm in *A. putaminum*), velvety to smooth pale-orange to yellow-brown pileus (vs glabrous, wrinkled, yellow brown), distinct umbo (vs slight umbo), margin not clearly demarcated, wavy, cream (vs inflexed to deflexed – sometimes wrinkled and reflexed, and light brown). It also differs in its crowded, pale-salmon to fleshy brown lamellae often anastomosing (vs well spaced, pale yellow decurrent and toothed), stipe without any velar remnants (vs strongly fibrillose to dark-brown granulose-flocculose), presence of large basidiospores 8.7–11.4 × 6.6–7.8 µm (vs 11.7–13.8 × 7.5–8.5 µm) and with pleurocystidia 26–45.5 × 11.4–18 µm (vs 38.9–56.9 × 13–27 µm) and cheilocystidia 24.5–32.6 × 7.9–14.3 µm (vs 44–63 × 11–14 µm). – Type: India, Uttarakhand, Garhwal, Chamoli district, Devsathali, 2051 m, 30°09'27.80"N 79°15'21.26"E, 26 vi 2023, *S. Choudhary, P. Uniyal & Y.P. Sharma* 2139 (holotype CAL). MycoBank 860484. GenBank accession nos. nrITS: PQ380156; PQ363376. **Figures** 2, 3.

Pileus 25–80 mm, initially convex to plano-convex, slightly umbonate, pale orange (5A4) to yellow brown (5B4), dry, initially velvety, then glabrous, smooth, umbo dark yellow brown (5B6), margins wavy pale cream white (5A3). *Lamellae*, crowded, adnexed to adnate, segments formed with lamellulae, anastomising, first pale salmon (6A4), then fleshy brown (6D4). *Stipe* 42–90 × 6.0–13 mm, pale orange (5A3) at apex to brown (5D8) at base, cylindrical, uniform, stuffed, fistulose, strongly fibrillose, absence of veil, long striations turning dark brown (5D9) towards the base with white cottony rhizomorphs with buried sclerotium at the base. *Context* firm, salmon (6A4) to fleshy brown (6D4), darkening when cut. *Odour* indistinct.

Basidiospores: 60/2/3; (8.7–10.0–11.4) × (6.6–7.3–7.8) µm; *Q* = 1.16–1.61; ellipsoid to oblong; adaxial side slightly less convex than abaxial; surface smooth; wall moderately thick (up to 0.8 µm); apical germ pore (up to 1.2 µm); yellow brown in ammonia. *Basidia*: 24.8–39.0 × 6.3–9.5 µm; narrowly clavate; 4-spored. *Cheilocystidia*: 24.5–32.6 × 7.9–14.3 µm; lageniform to narrowly utriform, rarely clavate; contents sometimes yellow brown, refractive; thin-walled. *Pleurocystidia*: 26–45.5 × 11.4–18.0 µm; narrowly to broadly utriform or clavate; apex sometimes with crystals; contents yellowish brown, refractive; wall thin. *Pileipellis*: structure irregular hymeniderm, transition to epithelium; elements erect, irregularly clavate (not measured); pigment pale yellow to brown; encrusted or parietal. *Pileocystidia*: 24.5–45.3 × 8.3–11.5 µm, pedicellate-clavate. *Stipitipellis* thick-walled, up to 10 µm wide hyphae. *Caulocystidia* present same as pileocystidia in shape 29.7–39.5 × 9.5–13 µm, lageniform to clavate.

Distribution. India, Uttarakhand, Chamoli district.

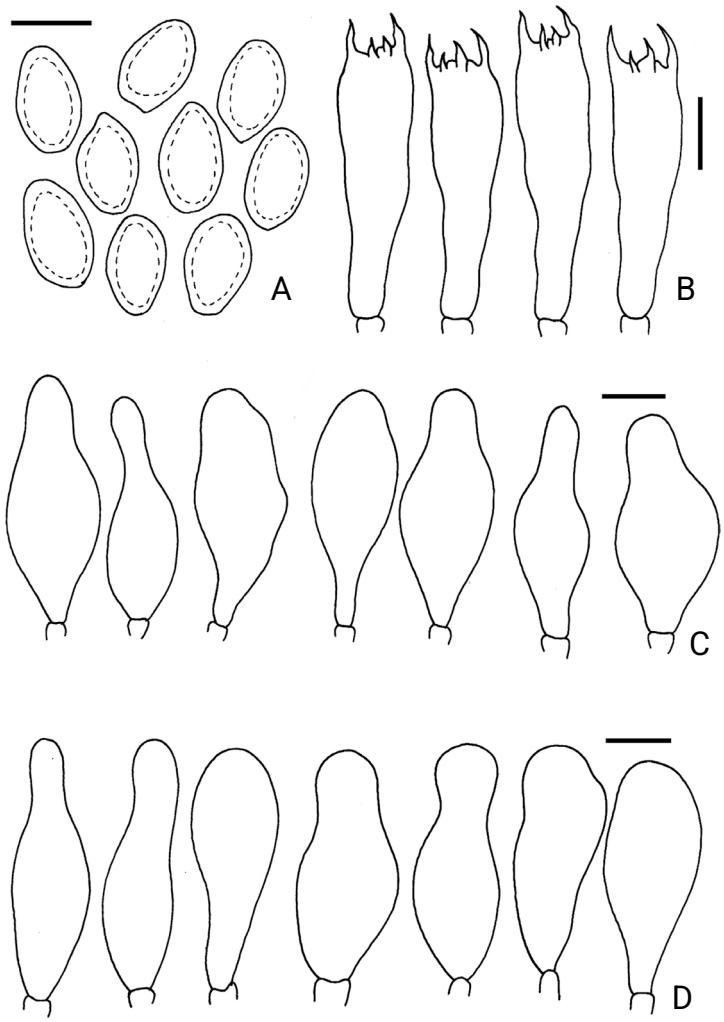

Figure 2. *Agrocybe himalayensis* Choudhary, Uniyal & Y.P.Sharma, sp. nov. A, Basidiospores; B, basidia; C, pleurocystidia; D, cheilocystidia. Scale bars: 10 µm. Drawn by Shikha Choudhary from the holotype, *S. Choudhary, P. Uniyal & Y.P. Sharma* 2139.

Habitat and ecology. Gregarious in the soil of agricultural potato fields.

Etymology. The specific epithet refers to the Himalayan Mountain range, where the type specimen was collected.

Notes. In the phylogenetic analysis (**Figure 1**), *Agrocybe himalayensis* and *A. putaminum* formed a distinct lineage separated from other *Agrocybe* species. However, *Agrocybe putaminum* can be easily distinguished by the morphological characters highlighted in the new species diagnosis (see also Vellinga, 2008; Halama, 2016).

Figure 3. Macro- and micromorphological images of *Agrocybe himalayensis* Choudhary, Uniyal & Y.P.Sharma, sp. nov. A and B, Fresh basidiomata in the field and basecamp; C, basidiospores; D, basidia; E–G, pleurocystidia; H, cheilocystidia; I, pileocystidia. Scale bars: A, 10 mm; C–I, 10 µm. All images of the holotype, *S. Choudhary, P. Uniyal & Y.P. Sharma* 2139, taken by Priyanka Uniyal and Shikha Choudhary.

Agrocybe himalayensis is also similar to *A. striatipes* R.L.Zhao & J.XinLi but can be easily distinguished by its yellowish ochraceous-brown pileus, stipe deeply striate-sulcate with somewhat fibril, relatively larger pleurocystidia and cheilocystidia, and smaller basidiospores (8.1–10 × 5.2–6.9 µm). Similarly, *Agrocybe smithii* Watling & H.E.Bigelow can be easily distinguished from *A. himalayensis* by its fresh cap with olive shades, and bigger basidiospores (11–13.5 × 6.5–8 µm) (Li *et al.*, 2023). Another morphologically similar species is *Agrocybe broadwayi* (Murrill) Dennis, which differs from *A. himalayensis* by its bigger basidiospores (12–15 × 8–9 µm) and margin of pileus usually striated, occasionally covered with small concolorous squamules (Niveiro *et al.*, 2020). *Agrocybe arvalis* (Fr.) Heim & Romagnesi differs from the new species by its smaller basidiomata (up to 40 mm), a broadly umbonate pileus with a slight depression at maturity, and the presence of ventricose pleurocystidia with a multidiverticulate apex bearing digitate projections, along with vesiculiform elements in the pileipellis (Sánchez & Casas, 2016). Similarly, *Agrocybe pediades* (Fr.) Fayod, a closely related species, can be distinguished from *A. himalayensis* by its smaller basidiomata (up to 35 mm), a pileus with a slight central depression and white powdery remnants toward the margins, and a stipe covered with velar remnants; microscopically, it lacks pleurocystidia (Niveiro *et al.*, 2020). A comparison of morphology between closely related species is presented in the **Table**.

Additional specimen examined. India. Uttarakhand: district Chamoli, Deval, Lohajung, Dedna trek, Bedni-bugyal, 30°09'53.60"N, 79°38'04.12"E, elevation 2485 m, 2 viii 2023, *Choudhary* et al., SC/PU/18 (HBJU/M/183, paratype).

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Table. Comparison of *Agrocybe himalayensis* Choudhary, Uniyal & Y.P.Sharma, sp. nov., and closely related species

Character	*A. himalayensis*	*A. arvalis*	*A. broadwayi*	*A. pediades*	*A. putaminum*	*A. smithii*	*A. striatipes*
Pileus size (diameter)	25–80 mm	To 40 mm	55 mm	To 35 mm	60 mm	To 60 mm	18–45 mm
Pileus shape	Convex to plano-convex, slightly umbonate	Broadly umbonate with slight depression at maturity	Convex to plano-convex	Convex, slightly depressed at centre	Conical to plano-convex	Plano-convex becoming nearly flat with age	Convex
Pileus colour and surface	Pale orange to yellow brown, dry, velvety	Ochraceous-brown to becoming paler with age	Occasionally covered with small concolorous squamules	White powdery remnants near margin	Yellow brown with glabrous and wrinkled surface	Fresh cap with olive shades	Yellowish ochraceous-brown
Lamellae	Crowded, adnexed to adnate, anastomosing	Adnate to subfree	Narrow, crowded, annexed to subfree	Adnate to subdistant	Narrowly adnate to decurrent, crowded	Adnexed to narrowly adnate	Adnate to subdecuurent
Stipe characters	Cylindrical, fibrillose, long dark striations, rhizomorphs and buried sclerotium present, veil absent	Slender, fibrous, subconcolorous with stipe, covered with fine whitish pruina	Concolorous with pileus, upper portion pruinose, with pale chestnut squamules towards the base, hollow, fragile, cylindrical	Covered with velar remnants	Tapering to subclavate, strongly fibrillose to granulose	Cylindrical, fibrous, surface pale brown to whitish toward apex	Deeply striate-sulcate, somewhat fibrillose
Basidiospores	8.7–11.4 × 6.6–7.8 µm	10–11.5 × 4.9–5.7 µm	12–16 × 8–9 µm	11–15 × 7–10.5 µm	11.7–13.8 × 7.5–8.5 µm	11–13.5 × 6.5–8 µm	8.1–10 × 5.2–6.9 µm
Cheilocystidia	24.5–32.6 × 7.9–14.3 µm; lageniformtonarrowly utriform	37–51 × 8–17 µm; fusiform to lageniform	33–43 × 18–30 µm; ventricose	16–35 × 5–8 µm; lageniform	44–63 × 11–14µm;lageniform to narrowly utriform	Not specified	38.5–46.5 × 20–27.9 µm; ventricose
Pleurocystidia	26–45.5 × 11.4–18.0 µm; utriform to clavate	Ventricose with multidiverticulate apex and digitate projections	46–77 × 18–30 µm; ventricose	Very rare	38.9–56.9 × 13–27 µm; narrowly urtiform to clavate	Not specified	34–47.2 × 24.7–28 µm; ventricose
Pileipellis	Irregular hymeniderm transitioning to epithelium	Hymeniform with vesiculiform elements present	Hymeniform with vesiculiform elements present	Hymeniform with clavate cells	Hymeniderm to epithelium of clavate elements	Composed of inflated elements with cystidioid terminal cells	Hymeniform, composed of clavate hyphae
Reference	Present study	Sánchez & Casas (2016)	Niveiro *et al.* (2020)	Niveiro *et al.* (2020)	Halama (2016)	Li *et al.* (2023)	Li *et al.* (2023)

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