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Morpho-taxonomical notes on some *Rhizophydium* species (Rhizophydiaceae, Rhizophydiales) of North India

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Abstract

In the present study, seven chytrid species from the genus *Rhizophydium*, specifically *Rhizophydium annulatum*, *R. coronum*, *R. condylosum*, *R. elyense*, *R. keratinophilum*, *R. sphaerotheca* and *R. utriculare* were collected from north India and are briefly described. The descriptions are accompanied by photographs illustrating their morphological and taxonomical characteristics. Notably, *R. annulatum*, *R. elyense* and *R. utriculare* represent the first records of these species in the Indian mycobiota.

Keywords

algal parasite; Chytridiomycota; monocentric; morpho-taxonomical characteristics; new record; zoosporic-true fungi

Introduction

Rhizophydium Schenk ex Rabenh. is one of the oldest and most species-rich genera within the family Rhizophydiaceae Letcher (order Rhizophydiales Letcher, class Rhizophydiomycetes Tedersoo et al.) in the phylum Chytridiomycota Doweld of the kingdom Fungi (1-3). This large and complex genus is represented by *Rhizophydium globosum* (A. Braun) Rabenh. as the type species and currently, more than 220 species are recognised under this generic concept (4, 5). Traditionally, *Rhizophydium* was classified within the order Chytridiales Cohn (4, 6). However, molecular phylogenetic studies have placed *Rhizophydium* outside the Chytridiales clade (7). As a result, Rhizophydiales was established to accommodate former members of the genus based on zoospore ultrastructure and molecular phylogenetics data within Chytridiomycota (8-10). *Rhizophydium* species are characterized by a simple thallus development, which can be monocentric or eucarpic and either epibiotic or endobiotic. The endobiotic portion forms a delicate rhizoidal structure, which can be rarely unbranched or branched, while the epibiotic portion consists of the sporangium or resting spore. The sporangium is inoperculate and sessile, or occasionally emerging from an extrametrical stalk, with one or more discharge papillae, pores, or an exit orifice. In some cases, the sporangium wall may deliquesce, either partially or entirely. Zoospores, fully developed within the sporangium, swarm inside before discharge, do not form a mass upon released and are posteriorly uniflagellate, containing a single hyaline refractive lipid globule. The resting spore, which is thick-walled and contains one or more lipid globules or droplets, is formed asexually or sexually. Upon germination, it either produces a sporangium or function as prosporangium (4, 6, 11).

Species of *Rhizophydium* are environmentally diverse and predominantly grow as saprobes on a wide variety of substrates of both plant and animal origin in aquatic (freshwater and marine) and soil ecosystems (4, 12). Members of this cosmopolitan genus are commonly found growing on keratin and pollen, but some species also occur on cellulosic and chitinous materials (4, 6, 11). *Rhizophydium* species are also parasitic on a variety of organisms, especially algae and planktonic microinvertebrates, in both soil and aquatic environments (13). Some of these parasitic species have been successfully isolated and cultured (14). For example, *R. littoreum* Amon [=*Halomyces littoreus* (Amon) Letcher & Powell] was isolated from the siphonaceous marine green macroalga *Codium* (Phylum Chlorophyta) from the coastal region of the eastern USA (15). This species, amenable to laboratory experimentation and observation (16), exhibits a trophic dynamic spectrum ranging from saprotrophy to parasitism (17). It has also been recorded as parasitic on phytoplankton (18, 19) and crab eggs (17). Additionally, *R. graminis* Ledingham is a root parasite of higher plants (mono- and dicotyledonous), including grasses, wheat and certain dicots (20, 21). Another species, *R. fungicola* Zimm. (22), parasitizes the hyphae of the genus *Gloeosporium* Desm. & Mont. (Ascomycota, Fungi). On the other hand, *R. planktonicum* Canter is best known as a phytoplankton parasite of the diatom *Asterionella formosa* Hassall, commonly found in eutrophic lakes (23, 24). While, *R. keratinophilum* Karling is not typically considered a degrader of animal tissue, it has been found growing on the muscle tissues of the *Coregonus albula* Linnaeus (vendace fish) in lakes (25). Recently, a species of *Rhizophydium* sp. has been reported as an obligate parasite of the cyanobacteria *Planktothrix agardhii* (Gomont) Anagn. & Komarek, which causes algal blooms in Sandusky Bay, western Lake Erie basin, in the Laurentian Great Lakes, USA (26). Many other members of the genus are also algal parasites and biotrophic pathogens, capable of causing severe epidemics in freshwater ecosystems (23).

Recently, Chytridiomycota, particularly species within the genus *Rhizophydium*, have been detected in high-throughput sequencing (HTS) surveys conducted worldwide (27, 28). These molecular-based inventories of chytrid ecology in lakes have revealed the presence of both known species and novel clades within the Rhizophydiales. This suggests that *Rhizophydium* may be a significant component of highly diverse aquatic fungal communities (29–31). However, it is surprising that most taxa in this genus lack cultured representatives in the NCBI GenBank database. For those that have been molecularly confirmed, *Rhizophydium* species have been observed on multiple substrates from locations such as Argentina, Australia, Brazil, the USA (27) and Oman (28). Recently, the known range of *Rhizophydium* was expanded to the Arabian Peninsula with the discovery of a new species, '*R. jobii* Hassett' (28). Despite this progress, relationships within the genus remain unclear, highlighting the need for further taxonomic sampling and culture isolations, especially of unsequenced taxa. Expanding this knowledge is crucial for developing more accurate hypotheses about *Rhizophydium* systematics.

To contribute to this effort, we conducted a survey across various regions in northern India, focusing on Chytridiomycota. As a result, several species of the genus *Rhizophydium* were identified from soil and water samples. This study aims to briefly describe these recovered *Rhizophydium* species, accompanied by photographic illustrations to facilitate easy identification based on their morpho-taxonomical characteristics for future mycologists.

Materials and Methods

Isolation and identification

Between 2012 and 2015, water and soil samples were randomly collected from various locations in north India during different seasonal intervals. The samples were carefully transferred in sealable plastic bags and transported to the laboratory within four hours of collection to ensure sample integrity. A subset of these samples was processed using the multiple baiting technique (6, 32). Each subset was baited with keratinous substrates (purified human hair and snakeskin), chitin (shrimp exoskeleton) and cellulose pollen, cellophane, lens paper, bleached corn leaves, sesame seeds to specifically isolate members of the genus *Rhizophydium*. The samples were then incubated at 20°C for two weeks before being examined under a light microscope.

To document thallus morphology and developmental stages on natural substrates for identification purposes, the baited water cultures were periodically monitored under a light microscope. The isolates were analysed to assess the range and variation in thallus development and structural features. These features included sporangial operculation, morphometric attributes such as shape and size, presence of pits on the sporangium wall, discharge apparatus, number of discharge pores/tubes, zoospore discharge mechanism, zoospore flagellation, characteristics of resting spores and rhizoid structure. Taxa identification was carried out using references such as *Aquatic Phycomycetes* (6), *Chytridiomycetarum Iconographia* (11) and other relevant taxonomic literature. The identified isolates were documented with images captured using a Dewinter microscope. The specimens were then deposited in the Collection of the Laboratory of Mycopathology and Microbial Technology, Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi, India.

Results

Description of the species

Rhizophydium annulatum Sparrow, Canad. J. Bot. 55: 1501-1504. 1977.

Morphology: The thallus epibiotic, monocentric, eucarpic and intra-extrametrical. The zoosporangium inoperculate, sessile, hyaline, smooth-walled and double-contoured, spherical in shape, measuring 15-25 µm in diameter. It features a single, short and inconspicuous apical to lateral exit papilla, adorned with 3-50 elongated, slender, flexuous, unbranched hairs up to 40 µm in length. The rhizoidal system extensive and branched, typically arising from a thin, tapering, isodiametric stalk. Zoospores microscopic, spherical, measuring 5-7 µm in diameter, with 3-4 refractive hyaline lipid globules and a single posterior flagellum. They emerge singly upon the deliquescence of the exit papilla. Resting spores were not observed (Fig. 1A-F).

Material examined: Soil samples on lens paper. Ugrasenpur (25°34'5.8" N, 81°10'14.5" E), Prayagraj, U.P. Culture No. 144.

Notes: This saprophytic chytrid is distinctive due to its double-contoured, smooth-walled zoosporangia, typically containing 4-12 zoospores. This marks the first recorded occurrence of *R. annulatum* in India.

Rhizophydium condylosum Karling, Archiv. Mikrobiol. 61: 118-119. 1968.

Morphology: The thallus epibiotic, monocentric, eucarpic and extra-intramatrical. The zoosporangium hyaline, inoperculate, sometimes apophysate and occasionally sessile. It has a smooth, fairly thick wall and predominantly pyriform or obpyriform in shape, though it can also be spherical, ovoid, or almost hemispherical, with a flattened base. The zoosporangium size variable, ranging from 15-35 µm in diameter. It often has small lobes or protrusions, giving it a knobby appearance. At maturity, it develops 2-10 clear, broad condyloid exit papillae for zoospore release. The rhizoidal system arises from 1-5 points at the base of the zoosporangium, delicate and branched. Zoospores small, hyaline, spherical, measuring 3.5-4 µm in diameter, posteriorly uniflagellate and contain a single large refractive lipid globule. They discharged simultaneously from several exit papillae at maturity before swimming away like other *Rhizophydium* species. Resting spores were not observed (Fig. 2A & B).

Material examined: Soil samples on snake skin. Sattal Lake (29°20'39.5" N, 79°31'45.9" E), Nainital, Uttarakhand. Culture No. 177.

Notes: This saprophytic chytrid is notable for its unique, irregular zoosporangium, which develops 2-10 condyloid exit papillae with a knobby appearance at maturity, allowing for the release of zoospores.

Rhizophydium coronum Hanson, Torreya. 44: 31. 1944.

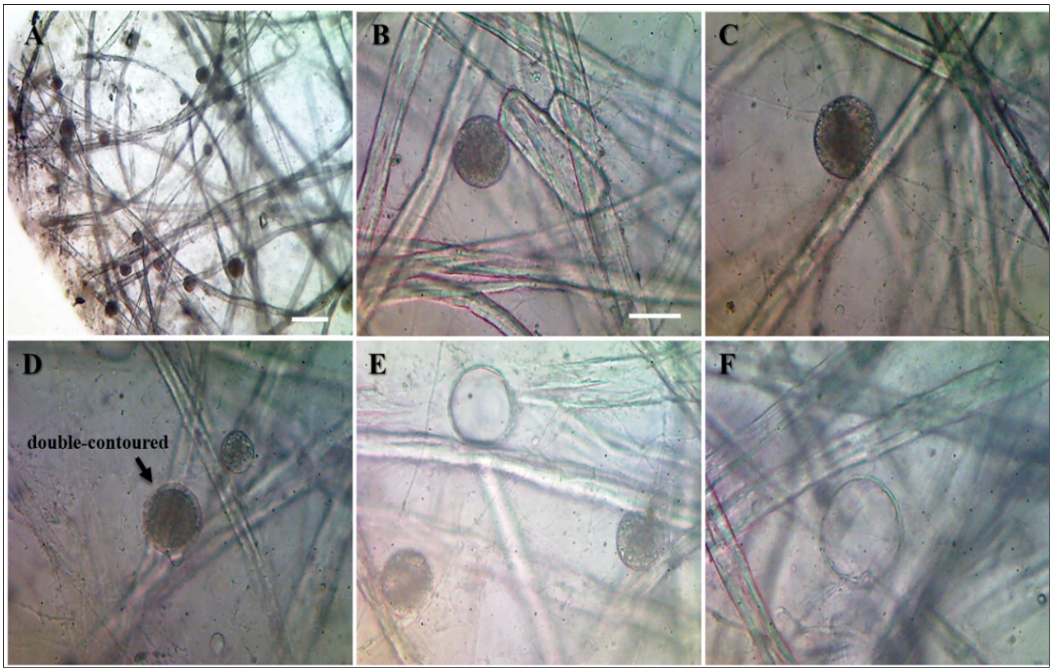

Fig. 1. *Rhizophydium annulatum.* A: Developing thallus on lens paper; B & C: Sessile and spherical sporangium; D: Prominent double-contoured, smooth, colorless wall with a strongly protruding apical discharge papilla; E & F: Discharged sporangium. Bars = 50 µm for A; 20 µm for B–F.

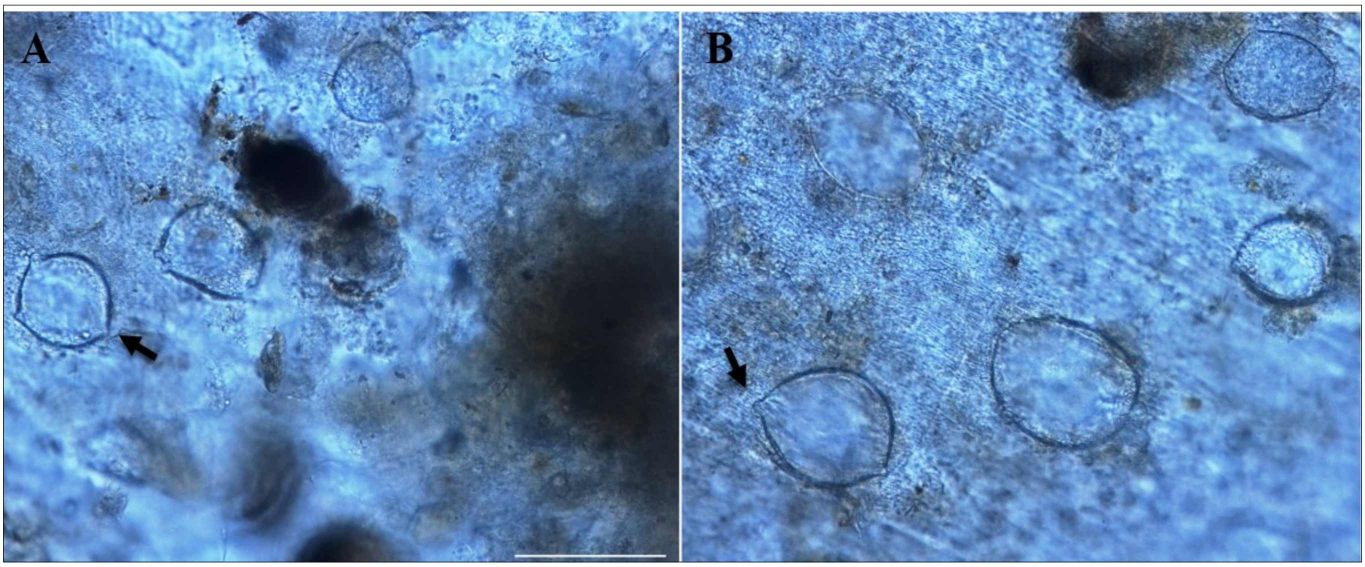

Fig. 2. *Rhizophydium condylosum.* A & B: Discharged sporangium (indicated by arrow) with small lobes or protrusions having a knobby appearance. Bar = 50 µm.

***Morphology**:* The thallus epibiotic, monocentric, eucarpic and extra-intramatrical. The zoosporangium hyaline, inoperculate, non-apophysate and sessile, typically spherical but occasionally ovoid or ellipsoidal, with a variable size of 25-55 µm in diameter. It has a delicate, smooth, colorless gelatinous sheath or concentric halos and laminated walls, 5-12 µm thick. The outer lamina often disintegrates around the upper half of the zoosporangium. At maturity, the zoosporangium usually develops 1-5 clear, broad exit papillae that subspherical or broadly clavate, measuring 6-12 µm long × 3-3.5 µm wide. The concentric halos, originating from the gelatinization of the developing zoosporangium wall, reduced to one after maturity and generally deliquesce before zoospore discharge begins. The rhizoids fairly rigid, well-developed and can be straight or coiled, irregular, sparsely or profusely branched, with blunt ends measuring 2-5 µm in diameter. Rhizoids usually arise from the base of the zoosporangium, with one often predominant and extending up to 450 µm in length. Zoospores small, hyaline and spherical, measuring 3.5-4.5 µm in diameter, with a single large refractive lipid globule (1.5 µm in diameter), filling one-third of the content. Zoospores discharged as a hyaline coherent mass, which remains quiescent for 2-5 min before dispersing and swimming away. Some zoospores continue to swim within the zoosporangium for a short period before emerging singly, encysting on a suitable substrate and enlarging to form the incipient zoosporangium. The resting spore spherical or subspherical, 20-35 µm in diameter, with a thick lamellated wall similar to that of the zoosporangium, faintly golden in color and contains one or more large central globules, encased by a peripheral layer of smaller globules. The resting spore enveloped by one or multiple halo zones, functioning as a prosporangium. Upon germination, it re-establishes a hyaline sporangium, which was again enveloped by a transparent concentric halo (Fig. 3A & B).

***Material examined**:* Water and soil samples on snake skin, lens paper and cellophane. Chandra Prabha Wildlife Sanctuary (24° 55'59.9" N, 83°10'47.6" E), Chandauli, U.P. Culture No. 178.

Notes: This saprophytic chytrid is remarkable for its unique halo or gelatinous sheath (corona) that envelops both the zoosporangium and the resting spore. In other morphological features, it is similar to other *Rhizophydium* species. The concentric halo or corona is reminiscent of *Rhizophydium gelatinosum* Lind and the planktonic parasite *R. difficile* Canter, although these species remain incompletely understood or doubtful (4).

Rhizophydium elyense Sparrow, Trans. Brit. Mycol. Soc. 40: 523-535. 1957. (as *elyensis*).

Morphology: The thallus epibiotic, monocentric, eucarpic and intra-extrametrical. The zoosporangium inoperculate, sessile, hyaline, non-apophysate, smooth and thin-walled. Initially spherical, it becomes distinctly and irregularly polygonal at maturity, measuring 15-36 µm in diameter. At maturity, the zoosporangium typically develops 2-5 clear discharge papillae or pores. The rhizoidal system well-developed, either straight or coiled, irregular and sparsely or profusely branched. It composed of a main axis arising from the base of the zoosporangium, with fine, delicate and moderately branched rhizoids. The zoospores microscopic and spherical, measuring 3.5-4.5 µm in diameter, with a large eccentric refractive lipid globule and a single posterior flagellum. Zoospores passively and slowly released in a small globular mass, surrounded by a layer of hyaline or slimy matrix, through 2-5 scarcely visible discharge pores. They remain quiescent for a few minutes before separating and swimming away, occasionally becoming amoeboid. The remaining zoospores become active within the sporangium and emerge individually. Resting spores were not observed (Fig. 4A-C).

***Material examined**:* Soil samples on snake skin, onion epidermis and corn straw. Mussorie Range (30°28'29.7" N, 78° 2'11.9" E), Mussorie, Uttarakhand. Culture No. 226.

Notes: The morphological characteristics of the specimens match the original description of the species (33). The saprophytic chytrid species is commonly found on keratinous substrates. This is the first report of *R. elyense* from India.

Rhizophydium keratinophilum Karling, Amer. J. Bot. 33: 753. 1944.

***Morphology**:* The thallus epibiotic, monocentric, eucarpic and intra-extramatrical. The zoosporangium inoperculate, hyaline, non-apophysate, sessile, either solitary or gregarious, unsmooth, thin-walled, predominantly spherical but may also be oval or slightly oblong, measuring 7-50 µm in diameter. Typically, the zoosporangium 1-5 prominent, broad and conspicuous discharge papillae. The outer surface of the wall ornamented with a few to numerous short, simple spines, which may be single, bifurcate, or dichotomously branched, measuring 2-5 µm in length. These spines give the zoosporangium a prickled appearance and they may occasionally extend into long, fine, simple or branched hairs, up to 10-30 µm in height, often resulting in a hirsute appearance. Rhizoids well-developed,

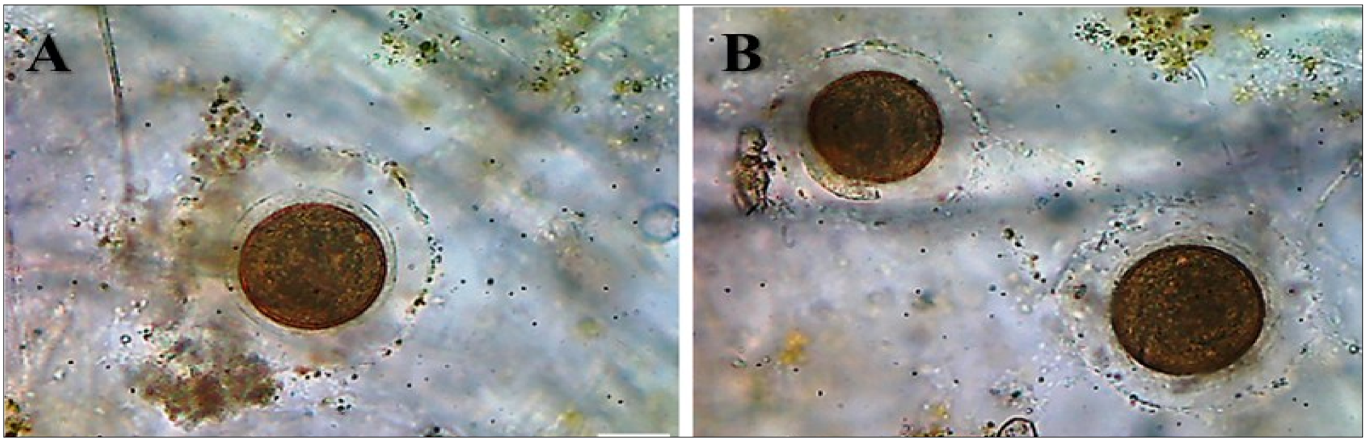

Fig. 3. *Rhizophydium coronum.* A & B: Thin gelatinous coronum encircling the zoosporangia. Bar = 50 µm.

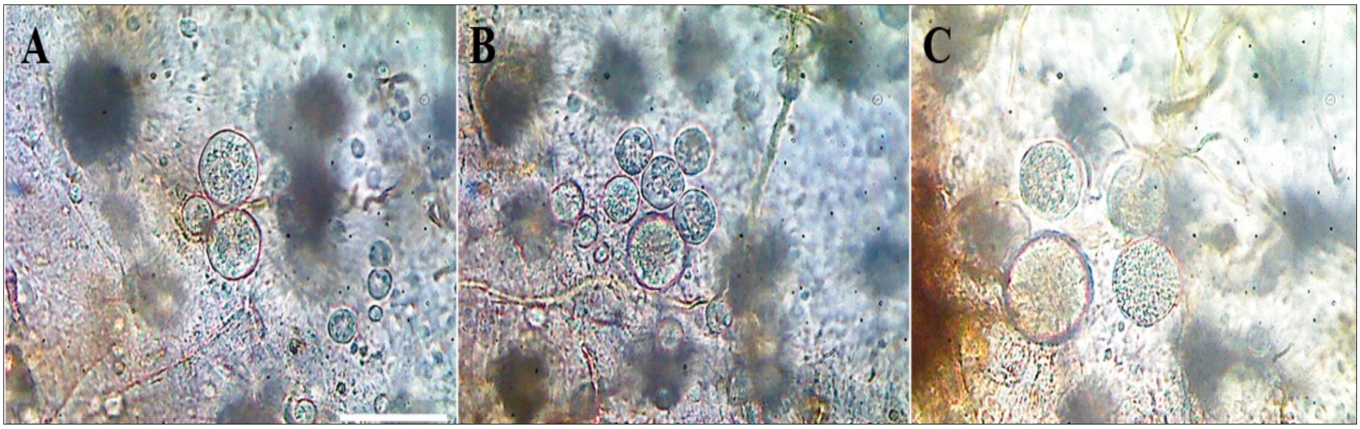

Fig. 4. *Rhizophydium elyensis.* A–C: Zoosporangium on snake skin with hyaline refractive bodies. Bar = 50 µm.

moderately extensive and profusely branched. They arise from a single main axis at the base of the zoosporangium, measuring up to 5 µm in diameter. The rhizoids were blunt-ended and can extend up to 120 µm in length. Zoospores relatively small, spherical, measuring 2.5-3 µm in diameter, with a minute, single, spherical hyaline refractive lipid globule (0.3-0.5 µm in diameter) and a posteriorly directed flagellum. Zoospores discharge as a dense, coherent mass that remains quiescent for a few minutes before separating and swimming away. The remaining zoospores swarm inside the sporangium for a short period before emerging singly. These zoospores germinate and develop into sporangia or resting spores. Resting spores spherical or oval, 7-14 µm in diameter, with prominently short, tapering pegs or warts on their thick walls, and light brown in color. The contents coarsely granular and evenly distributed. Resting spores function as prosporangia, forming a superficial sporangium upon germination (Fig. 5A-I).

Material examined: Soil and water samples collected from keratinized tissues (human hair, snake skin, feathers). Sattal Lake (29°20’39.5” N, 79°31’45.9” E), Nainital, Uttarakhand. Culture No. 315.

Notes: This saprophytic species is keratinophilic and occurs exclusively on keratinized substrates. It is morphologically distinct from other members of the *Rhizophydium* genus but bears some resemblance to *R. chaetiferum* Sparrow [=*Alphamyces chaetifer* (Sparrow) Letcher] due to the presence of long hairs and its hirsute appearance (34).

Rhizophydium sphaerotheca Zopf, Abh. Naturf. Ges. Halle. 17: 92. 1887.

Morphology: The thallus epi-endobiotic, monocentric, eucarpic and intra-extrametrical. The zoosporangium inoperculate, hyaline, non-apophysate, sessile, occurring singly or in groups. It has smooth, colourless walls that distinctly double-contoured. The zoosporangium typically spherical, subspherical, or subglobose, measuring 10-30 µm in diameter and generally multiporous, with protruding

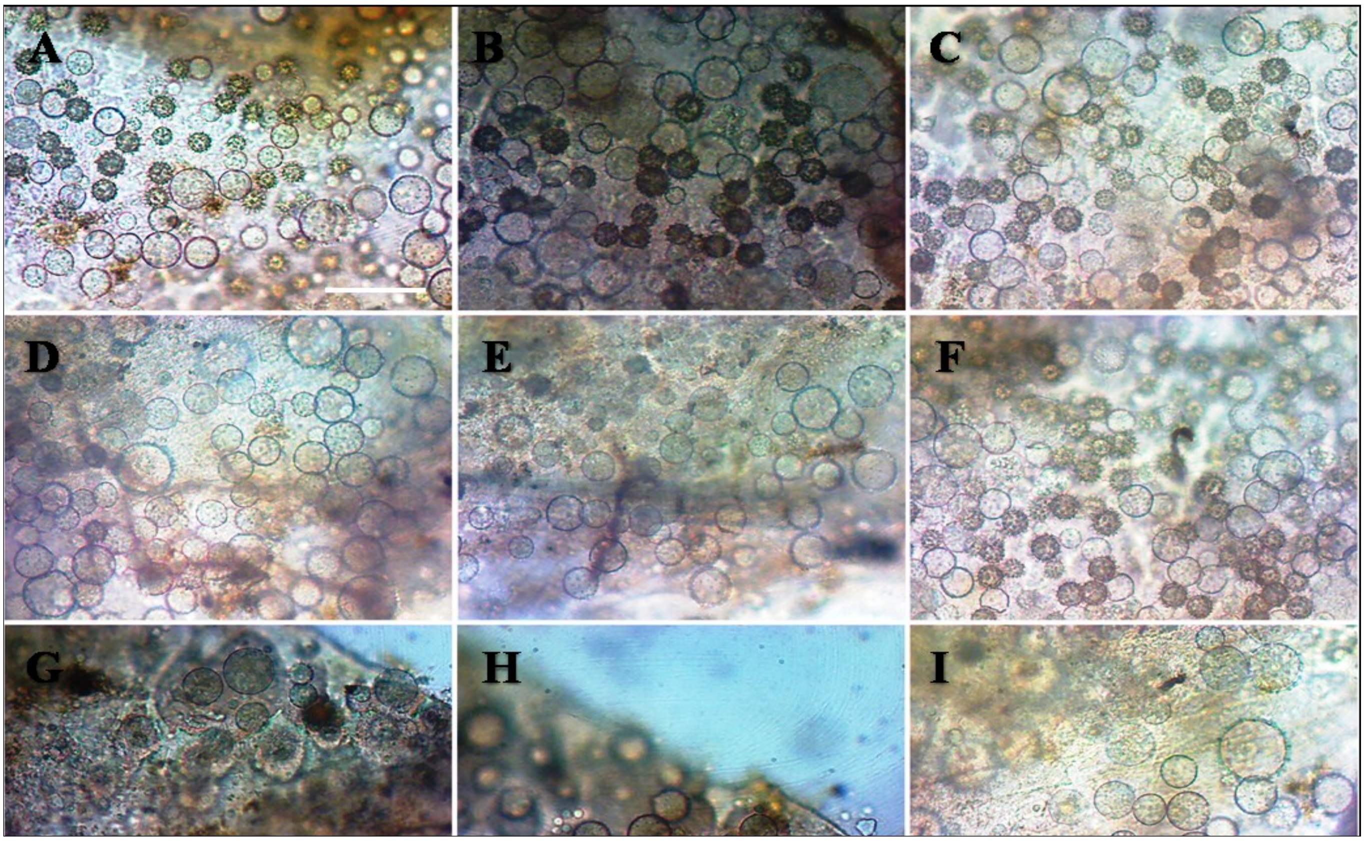

Fig. 5. *Rhizophydium keratinophilum.* A–I: Zoosporangia on snake skin; the outer surface of sporangia wall ornamented with few to numerous, short, simple, single, bifurcate and/or dichotomously branched spines or wart, providing a marked prickled appearance. Bar = 50 µm.

discharge papillae 2-5 µm wide. Smaller zoosporangia usually with a single papilla. The rhizoidal system well-developed, with a short, coarse main axis at the base, from which fine, delicate and highly branched rhizoids extend. Zoospores spherical or ellipsoidal, relatively small, measuring 2-4 µm in diameter and contain a large eccentric hyaline refractive lipid globule (1-1.3 µm diameter) relative to the size of zoospore. They have a single long posterior flagellum. Zoospores ooze from the sporangium through relatively large, circular and occasionally slightly protruding discharge pores, formed by the deliquescence of the papillae. Zoospores exhibit both amoeboid movement and random free swimming. Upon reaching an appropriate substrate, the zoospores encyst and enlarge to form the incipient zoosporangium. Resting spore was not observed Fig. 6A & B.

Material examined: Water samples collected from onion skin. Sattal Lake (29°20’39.5” N, 79°31’45.9” E), Nainital, Uttarakhand. Culture No. 141.

Notes : This saprophytic chytrid species closely resembles *Rhizophydium poliinis-pini* (Braun) Zopf [*Globomyces pollinis-pini* (A. Braun) Letcher] in morphological features, with the exception of the number and position of the discharge pores. In *R. poliinis-pini*, the zoosporangium typically has a single exit pore (uniporous) at maturity.

Rhizophydium utriculare Uebelm. ex Letcher, Arch. Mikrobiol. 25: 314. 1956.

Morphology: The thallus epibiotic, monocentric, eucarpic and intra-extrametrical. The zoosporangium inoperculate, sessile, hyaline, colourless, non-apophysate, smooth and thin-walled, primarily sac- or pear-shaped, with some appearing narrowly obpyriform or clavate, through rarely spherical. The zoosporangium measures 25-35 µm in length and 20-30 µm in diameter at the apex, tapering at the base to 5-8 µm in diameter, multiporus, typically developing 3-8 large, clear and prominent discharge papillae/pores at maturity. The rhizoidal system thin, delicate, and sparsely branched, arising from a single axis. Zoospores globose or spherical, measuring 2.5-3 µm in diameter, with a minute hyaline refractive lipid globule, 1-1.5 µm in width, and a long posterior flagellum. The zoospores discharged passively and slowly through the pores in a small globular mass, formed by the deliquescence of the prominent papillae. Spores liberated either simultaneously or successively and remain quiescent for a few minutes before becoming active and swimming away. Resting spores were not observed (Fig. 7A-I).

Material examined: Soil and water samples collected from snake skin and bleached corn leaves. Sattal Lake (29° 20’39.5” N, 79°31’45.9” E), Nainital, Uttarakhand. Culture No. 218.

Notes: This chytrid closely resembles *R. angulosum*, though the angular appearance in latter species is attributed to the zoosporangial shape rather than the presence of papillae. This is the first record of *R. utriculare* from India.

Discussion

Despite a long history of research on Chytridiomycota in India, only 27 species of the genus *Rhizophydium* have been reported (35, 36; Table 1). Among these, 7 species were represented in the present study, continuing our previous work as part of an ongoing taxonomic study of chytrid fungi in North India (46, 47). We supported these identifications based on morpho-taxonomical features, including photographs that illustrate the development of these chytrids on their preferred baits in water culture. This comparison aids in aligning our findings with type descriptions and distinguishing them from similar species. The taxonomic placement of an unidentified *Rhizophydium* often requires molecular characterisation due to the morphological similarities within the genus. With this in mind, the detailed descriptions provided in this study are crucial for accurately identifying all reported *Rhizophydium* species. Notably, *R. annulatum*, *R. elyense* and *R. utriculare* serve as new records for the Indian mycobiota.

The last comprehensive monographic treatment of chytrids in India was published over 30 years ago (36), highlighting the need for updated summaries of chytrid genera. For more than 150 years, the classification of chytrids has primarily relied on thallus morphological features. However, recent advances in ultrastructural and molecular analysis have revolutionized our understanding of chytrid systematics (48, 49). Despite these advancements, having readily accessible summaries of established taxa based on morphological traits remain essential for modern systematic decisions.

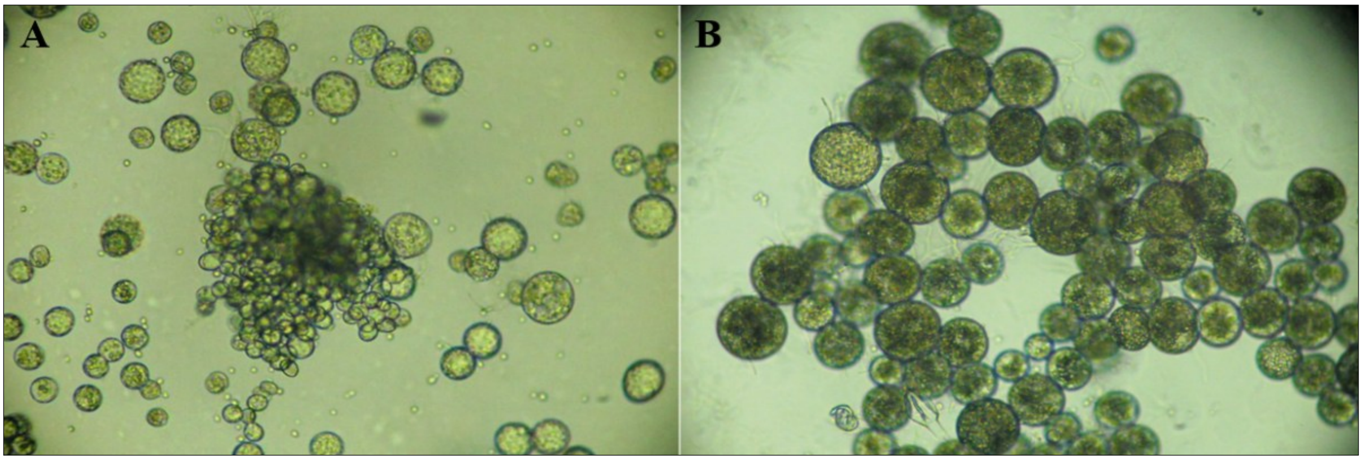

Fig. 6. *Rhizophydium sphaerotheca.* A & B: Zoosporangia of *R. sphaerotheca.* Bar = 50 µm.

Table 1. List of the *Rhizophydium* species reported from India

Chytridiomycota	Type of sample	Substrates	Nutrition	Collection sites	Reference
Rhizophydium apiculatum Karling	Water	Protozoa	Parasitic	Varanasi (U.P.)	(37)
R. blyttiomycerum S.N.Dasgupta and R.John	Water	Sporangium of *Blyttiomyces spinosus* and zygospore of *Spirogyra* sp.	Parasitic	Lucknow (U.P.)	(38)
R. carpophilum (Zopf) A.Fisch.	Water	Sporangia of *Olpidioupsis achlyae*	Parasitic	Varanasi (U.P.)	(39)
R. collapsum Karling	Water, organic matter, soil	Pollen of *Pinus sylvestris*, filamentous algae and angiospermic leaf	Saprophytic, parasitic	Ramanathapuram (T.N.), Varanasi (U.P.)	(40)
R. conchiforme S.N.Dasgupta and R.John	Water	*Spirogyra* sp.	Parasitic	Lucknow (U.P.)	(38)
R. condylosum Karling	Water	Snake skin	Saprophytic	Varanasi (U.P.)	(41)
R. constantineani Saccardo [=*Rhizophydium constantineanui* Sacc. & D.Sacc.]	Water	*Closterium* sp.	Parasitic	Lucknow (U.P.)	(38)
R. coronum A.M.Hanson	Water	Snake skin	Saprophytic	Jabalpur (M.P.)	(42)
R. difficile Canter	Water	Decaying leaves	Saprophytic	Varanasi (U.P.)	(43)
R. persicum Kiran and Dayal ex Letcher (= *R. dubium* Kiran and Dayal)	Water	Decomposing leaves of *Eichhornia* sp.	Saprophytic	Varanasi (U.P.)	(40)
R. globosum (A.Braun) Rabenh.	Water	Filamentous algae	Parasitic	Varanasi (U.P.)	(40)
R. gonapodyanum S.N.Dasgupta and R.John	Water	Sporangium of *Gonapodya polymorpha*	Parasitic	Lucknow (U.P.)	(38)
R. keratinophilum Karling	Water, soil	Human hair, sporangium of *Blyttiomyces spinosus*, zygospore of *Spirogyra* and *Chara*	Saprophytic, parasitic	Ramanathapuram (T.N.), Lucknow, Varanasi (U.P.)	(38, 40)
R. lagenaria S.N.Dasgupta and R.John	Water	Sporangium of *Blastocladia* sp.	Parasitic	Lucknow (U.P.)	(38)
R. mammillatum (A.Braun) A.Fisch.	Water	Oospore of *Oedogonium* sp.	Parasitic	Lucknow (U.P.)	(38)
R. minutum G.F.Atk.	Water	*Spirogyra* sp.	Parasitic	Patna (Bihar)	(44)
R. ovatum Couch	Water	Monocot stem	Parasitic	Varanasi (U.P.)	(40)
R. poculiforme S.N.Dasgupta and R.John	Water	*Closterium* sp.	Parasitic	Lucknow (U.P.)	(38)
R. racemosus A.Gaertn.	Water	Decomposing leaf	Saprophytic	Varanasi (U.P.)	(40)
R. reflexum S.N.Dasgupta and R.John	Water	Sporangium of *Blastocladia* sp.	Parasitic	Lucknow (U.P.)	(38)
R. rhizinum S.N.Dasgupta and R.John	Water	Sporangium of *Blastocladia* sp.	Parasitic	Lucknow (U.P.)	(38)
R. sphaerotheca Zopf	Soil	Pollen of *Pinus sylvestris*	Saprophytic	Ramanathapuram (T.N.)	(45)
R. spinosum S.N.Dasgupta and R.John	Water	Sporangium of *Blastocladia* sp.	Parasitic	Lucknow (U.P.)	(38)
R. stellatum S.N.Dasgupta and R.John	Water	Sporangium of *Gonapodya polymorpha*	Parasitic	Lucknow (U.P.)	(38)
R. tubulatum S.N.Dasgupta and R.John	Water	*Closterium* sp.	Parasitic	Lucknow (U.P.)	(38)
R. urceolatum S.N.Dasgupta and R.John	Water	*Blastocladia* sp.	Parasitic	Lucknow (U.P.)	(38)
R. verrucosum Cejp	Water	Decaying leaves	Saprophytic	Varanasi (U.P.)	(43)

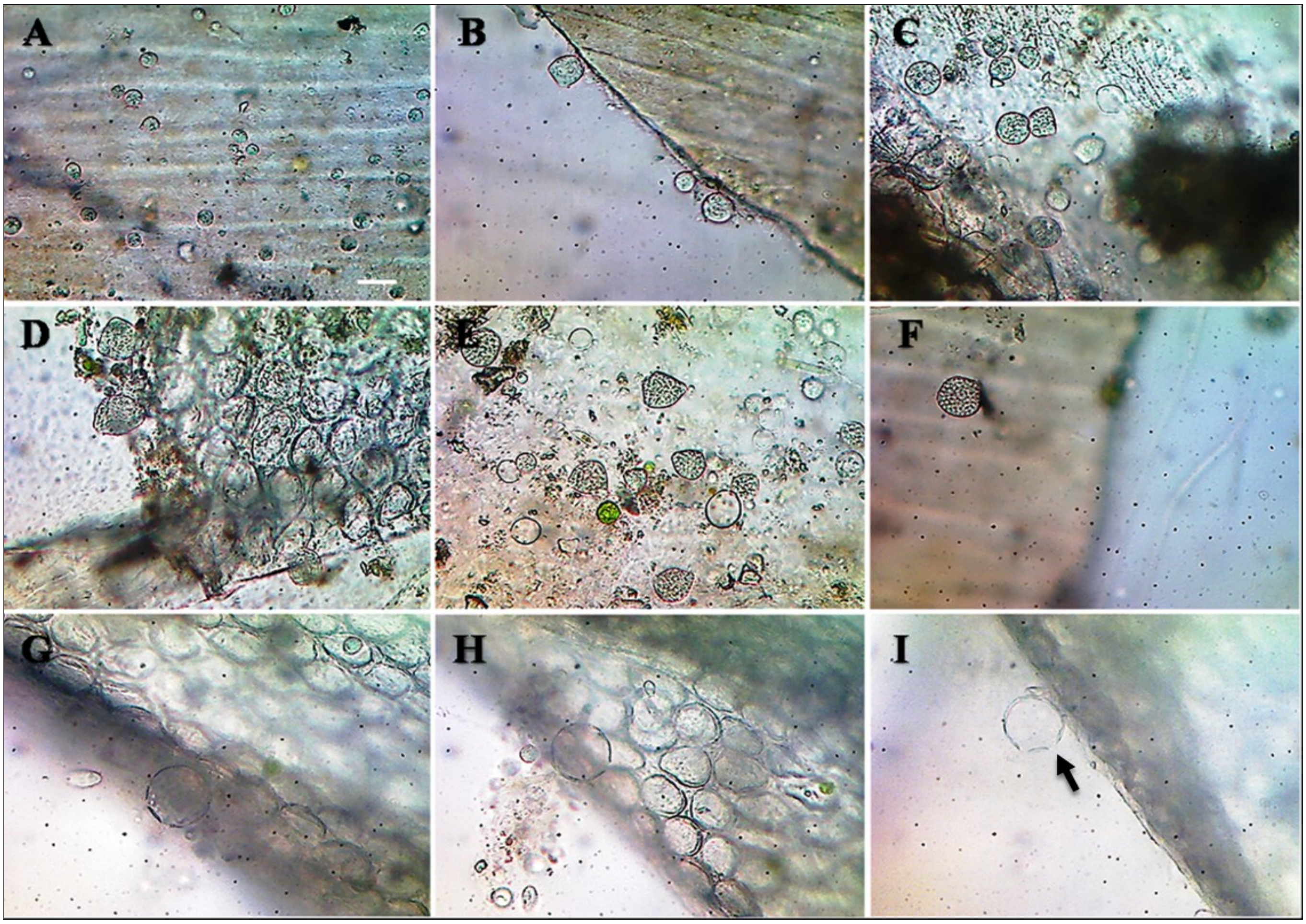

Fig. 7. *Rhizophydium utriculare.* A–F: Development of thin-walled predominantly sac- or pear-shaped or narrowly obpyriform or clavate sporangia; G-I: Discharged sporangium. Bar = 20 µm.

Recent studies on parasitic *Rhizophydium* species have gained attention due to their potential to control harmful algal blooms (26, 50). One of the most prevalent chytrid parasites, *Rhizophydium fusus* (Zopf) A.Fisch., has been documented parasitizing 10 diatom host species (51). Among various chytrid-diatom interactions, the relationship between *R. planktonicum* (chytrid parasite) and *Asterionella formosa* (the diatom host) has been the subject of extensive research, with over 24 publications documenting this specific phenomenon (51). Excluding *A. formosa*, *R. fragilariae* Canter has been reported to parasitize the diatom *Fragilaria crotonensis* Kitton on 11 occasions. Additionally, at least 5 or more diatom hosts have been infected or parasitized by eight different chytrids. Numerous studies have also indicated that *Rhizophydium* can serve as a bioindicator for harmful algal blooms. Recently, *Rhizophydium* sp. JEL317 was identified as an indicator fungal species, laying the groundwork for early-stage prevention of algal blooms during *Eriocheir sinensis* culture (52).

Despite the growing understanding of the importance of chytrids, the alarming rise in global temperature due to climate change poses significant threats to the distribution and diversity of these organisms. Therefore, it is imperative to record and quantify the abundance of chytrid fungi in various underexplored ecosystems worldwide and to isolate them for conservation, enabling future biochemical, genetic and molecular studies. In India, the occurrence and distribution of many chytrid fungal species remain inadequately documented, particularly in eastern India. Furthermore, most Indian chytrid species are defined solely by morphological characteristics, with type material often missing and no molecular annotations provided (47). Many previously described chytrid taxa are awaiting rediscovery and subsequent nucleotide assignment, leading to substantial gaps in our understanding of chytrid biogeography, ecology, habitat and substrate requirements. Contributing factors include narrow ecological niches (substratum), time-consuming sampling, unstable taxonomy and challenges in species identification. More intensive surveys of underexplored ecosystems in India, particularly those near freshwater sources, are likely to yield new chytrid fungal species and possibly endemic lineages identified through phylogenetic methods. The identification of these species will reflect the current status of the ecosystem and inform future conservation measures. Therefore, we present here a new record and addition to the mycoflora of India.

Conclusion

The present study has led to the discovery of numerous rare, noteworthy and newly reported *Rhizophydium* species in India. Notably, *R. annulatum*, *R. elyense* and *R. utriculare* are mentioned for the first time in India, contributing new records to the chytrid inventory of the country. Given the challenges in assessing variations in taxonomic features based solely on descriptions, we have included microphotographs to illustrate the morpho-taxonomical characteristics of all reported *Rhizophydium* species, facilitating easier identification of the taxa discussed. Additionally, we address issues related to morphological variability in diagnostic characters that are primarily used for identifying chytrid taxa. Our findings suggest that local chytrid inventories can reveal novel taxa and potentially prompt revisions of current taxonomy. Furthermore, a more thorough understanding of the mechanisms driving the diversity and distribution of chytrids is essential for making informed decisions regarding the conservation and management of various habitats.

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Authors' contributions

MKD conceptualized, conceived, designed, carried out all the experiments and wrote the manuscript. RSU reviewed, edited, enriched the literature and supervised the study.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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