Aspicilia stalagmitica (Megasporaceae) – a new lichen species with isidia-like thalline outgrowths

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Summary. Aspicilia stalagmitica Paukov et Davydov from the Altai Mts, a species with isidia-like outgrowths on areoles, is described as new to science. From other species of the genus Aspicilia stalagmitica differs by the following set of characters: short narrow marginal lobes, conidiomata in the isidia-like outgrowths, appressed to almost substipitate apothecia, long picoconidia, and stictic acid as a main secondary metabolite. A phylogenetic analysis of Aspicilia stalagmitica (ITS) showing its relationships within Aspicilia is presented.

Aspicilia stalagmitica (Megasporaceae) – новый вид лишайника с изидиевидными выростами таллома

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Аннотация. Aspicilia stalagmitica Paukov et Davydov – лишайник из северного Китая с изидиевидными выростами на ареолах, описан как новый для науки вид. От других видов рода он отличается следующей совокупностью признаков: короткие и узкие краевые лопасти, изидиевидные выrostы, содержащие конидии, сидячие апотеции, длинные пикноконидии и стиктовая кислота в качестве основного вторичного метаболита. Представлены результаты филогенетического анализа с использованием ITS последовательностей, которые показывают положение вида в пределах рода Aspicilia.

Introduction

Family Megasporaceae (or Aspicilia s. l.) is remarkable in its morphological diversity and comprises taxa of different life forms from those having immersed thalli to dwarf-fruticose and vagrant species (Sohrabi et al., 2013). Saxicolous and some terricolous representatives of the fruticose life form start their ontogenesis from formation of areolate thalli followed by the development of straight or contorted, simple or branched outgrowths up to several millimeters high (Oxner, 1971). A small number of Aspicilia species develop only tiny isidia-like structures which subsequently never form
fruticose thalli (Poelt, 1961). During field work in the northern China in 2005 Evgeny Davydov collected several specimens with such morphology, which were recognized as representatives of a previously undescribed species. Here we describe this species as new to science.

Materials and Methods

Specimens and phenotype studies

The core material for this study was collected by Evgeny Davydov during the expedition to Xinjiang (China) in 2005 and deposited in herbaria LE, ALTB, UFU, and PE. Morphological observations were made using a dissecting microscope. Cross-sections of apothecia and thalli were cut by hand with a razor blade and observed after mounting in water, K, N and iodine solutions. Measurements of spores and conidia are presented as follows: (smallest value recorded) – (X–SE) – (X+SE) – (largest value recorded), where X is the (arithmetic) sample mean, and SE the sample error of mean. The measurements were made with the precision of 0.5 μm.

Secondary products were analyzed by applying standard thin-layer chromatography techniques (TLC, Culberson, Kristinsson, 1970). Solvent A (toluene : 1,4-dioxane : acetic acid, 180 : 45 : 5) and C (toluene : acetic acid, 170 : 30) systems were used for the TLC analysis.

Sequences and phylogenetic reconstructions

To test phylogenetic relations to other species, nuclear internal transcribed spacers and 5.8S rDNA (ITS) sequences of the putative new species and other sequences retrieved from the NCBI database (GenBank) were used for a molecular phylogenetic analysis. Our sampling comprised 14 species of Aspicilia including a putative new species, species of Oxneriaria, Lobothallia and Circinaria, as well as Ochrolechia parella (L.) A. Massal as an outgroup. This selection is based on the studies of Nordin et al. (2007, 2008, 2010), Kondratyuk et al. (2016), Haji Moniri (2017) and a five-gene analysis by Miądlikowska et al. (2014). The information on the samples with the GenBank accession numbers are given in Table.

Table

| Species              | Origin       | Collection number or reference | ITS GenBank Accession number | Reference                             |
|----------------------|--------------|-------------------------------|----------------------------|---------------------------------------|
| Aspicilia abbasiana  | China        | Ismayil et Abbas 20111154     | KM609324                   | Ismayil et al., 2015; Kondratyuk et al., 2016 |
| A. berntii           | Norway       | Nordin 6392                  | EU502747                   | Nordin et al., 2008                  |
| A. blastidiata       | Russia       | Paukov AGP20111009-01        | KX129963                   | Paukov et al., 2015, 2017             |
| A. blastidiata       | Russia       | Paukov AGP20120801-01        | KX159286                   | Paukov et al., 2015, 2017             |
| A. cinerea           | France       | Roux 23869                   | JF703118                   | Roux et al., 2011                    |
| A. cinerea           | France       | Roux 25015                   | JF710311                   | Roux et al., 2011                    |
| A. cuprea            | USA          | Owe-Larsson 9112             | EU057902                   | Nordin et al., 2007                  |
| A. dudinensis        | Sweden       | Nordin 6036                  | EU057906                   | Nordin et al., 2007                  |
| A. epiglypta         | Sweden       | Nordin 6303                  | EU057907                   | Nordin et al., 2007                  |
| A. epiglypta         | Sweden       | Nordin 6305                  | HQ259261                   | Nordin et al., 2011                  |
| A. flaviatiss        | Sweden       | Nordin 6188                  | HQ259264                   | Nordin et al., 2011                  |
| A. goettweigensis    | Austria      | Vondrák 14026                | KX159289                   | Paukov et al., 2017                  |
| A. goettweigensis    | Russia       | Paukov AGP20120513-03        | KX159292                   | Paukov et al., 2017                  |
| A. granulosa         | Sweden       | Nordin 6174                  | HQ259265                   | Nordin et al., 2011                  |
| A. stalagmitica      | China        | Davydov 17620                | MT014019                   | **This paper**                        |
| A. subdepressa       | France       | Roux 24653                   | JF703123                   | Roux et al., 2011                    |
| A. subepiglypta      | Korea        | 100857 KoRL                  | KX249607                   | Kondratyuk et al., 2016              |
| A. subepiglypta      | Korea        | 110495 KoRL                  | KY249608                   | Kondratyuk et al., 2016              |
| A. subradians        | Sweden       | Nordin 5984                  | HQ259267                   | Nordin et al., 2011                  |
| A. subradians        | Finland      | Nordin 6370                  | HQ259268                   | Nordin et al., 2011                  |
| A. verrucigera       | Sweden       | Tibell 22669                 | EU057939                   | Nordin et al., 2007                  |
| Circinaria esculenta | Kazakhstan   | Ivanov s. n. (UFU L-1743)    | MK347507                   | Paukov et al., 2019                  |
Methods used for DNA extraction, amplification and sequencing follow Davydov et Yakovchenko (2017). An ITS 534 bp matrix were aligned using the MAFFT algorithm (Katoh et al., 2005) as implemented on the GUIDANCE web server (Sela et al., 2015). Optimal substitution models were inferred separately for ITS1, 5.8S, and ITS2 using PartitionFinder, version 1.1.1 (Lanfear et al., 2012): the General time reversible parameter with gamma distribution site specific rates (GTR+G) for the ITS1+ITS2 partition, and the Kimura 2-parameter with proportion of invariable sites (K80+I) for the 5.8S partition. Bayesian inference with the Markov chain Monte Carlo (BMC) method (Larget, Shimon, 1999) was performed using MrBayes 3.2.3 (Ronquist et al., 2012). Three parallel Bayesian analyses were run using six chains and every 200th generation was sampled. Convergence of the chains was inferred by calculating the average standard deviation of split frequencies every 100,000 generations using a burn-in fraction of 0.5, and the runs terminated when the standard deviation of split frequencies dropped below 0.001. This was the case after 7.1M generations. The first 50 % of the trees were discarded as burn-in and a 50 % majority rule consensus tree calculated from the remaining trees of three runs with the sumt command implemented in MrBayes 3.2.3. The most likely tree and 1000 rapid bootstrap replicates were calculated using RAxML 8.0.26 (Stamatakis, 2014) byraxmlGUI software version 1.3.1 (Silvestro, Michalak, 2012) applying the GTR+GAMMA model of substitution to the subsets. The tree topologies were taken from RAxML. Bootstrap support values and BMCMC posterior probability were noted onto the best scoring tree (Fig. 1).

Results

An ITS sequence was successfully obtained from one specimen of the putative new species, described below as *Aspicilia stalagmitica*. The Bayesian 50 % majority-rule consensus tree had the same topology as the maximum likelihood tree generated by RAxML. The phylogenies are combined in Fig. 1. According to the ITS sequence the new taxon belongs to *Aspicilia* and is the closest relative to the North-American *Aspicilia cuprea* Owe-Larss. et A. Nordin. These two taxa form a clade well-supported by MrBayes (0.97PP), but only weakly by RAxML (62 % BS) and rather long branches lengths. The sister clade contains the type species of the genus, *Aspicilia cinerea* (L.) Körb.
Aspicilia stalagmitica (Megasporaceae) – a new lichen species from Altai

Fig. 1. Maximum likelihood (ML) phylogeny of selected Aspicilia ITS sequences. The reliability of each branch was tested by ML and Bayesian methods. Numbers at tree nodes indicate ML bootstrap percentages (left) and Bayesian inference with the Markov chain Monte Carlo (BMCMC) posterior probabilities (right). Thicker branches indicate when the bootstrap value of ML is ≥ 70 % or the BMCMC posterior probability is ≥ 0.95. Accession numbers are given to serve as operational taxonomic unit (OTU) names (see Table). Originally produced sequence is marked in bold. Ochrolechia parella was used as an outgroup. Branch lengths represent the estimated number of substitutions per site assuming the respective models of substitution. Exception is the branch with a black dot, which was shortened to reduce the overall figure size.

0.06
The species

*Aspicilia stalagmitica* Paukov et Davydov, **sp. nov.**

MycoBank No.: MB 834291

*Aspicilia* with a thin, indistinctly lobate, areolate, grey thallus with isidia-like outgrowths usually containing conidiomata. Lobes short and narrow or absent, areoles angular, apothecia sessile, conidia long, 19–33 μm. Main secondary metabolite stictic acid.

**Type:** “China, Xinjiang, Mongolsky Altai range, SW vicinity of Altai City, granite rocks near the road, 47°47'49''N, 88°04'49''E, elev. 900 m, on rocks. 4 VIII 2005. E. A. Davydov. № 17620” (holo – LE-L15292, iso – ALTB, UFU-L3488) (Fig. 2).

![Image](image_url)

**Fig. 2.** *Aspicilia stalagmitica* (holotype): **A** – thallus; **B** – outer part of the thallus with young projections, **C** – thallus with apothecia; **D** – projections in the central part of the thallus. Scale = 1 mm.

Life habit lichenized. Thallus grey, up to 1.5 mm thick, indistinctly lobate at the periphery and areolate in the central part. Lobes relatively short and narrow, 0.5–1.5 × 0.4–0.5 mm (length × width), moderately convex, inconspicuous in some thalli. Areoles 0.5–1.7 mm, irregular in form, angular, moderately convex, with isidia-like outgrowths. The outgrowths are sphaeric, one, two, rarely more per areola, constricted at the bases, 0.25–0.5 mm, brittle, in the central parts of thalli occasionally cylindric, up to 0.75 mm high, blackish at the tops, commonly containing pycnidia with blackish spot-like or elongated ostioles. Upper cortex paraplectenchymatous, 30–50 μm high, cells 7–10 μm. Medulla I–, K+ yellow, with rare needle-like crystals. Photobiont layer 50–70 μm thick, interrupted by narrow hyphal bands 5–10 μm. Photobiont chlorococcoid, algae 7–20 μm diam. Prothallus absent. Vegetative propagules absent. Apothecia lecanorine, 1 per areole, developing from the outgrowths, appressed, later sessile, constricted at the base, rounded or elliptic in outline, 0.3–0.7 mm diam.; disc initially dot-like, later wide, flat, not pruinose or weakly white pruinose, blackish, surrounded by a projecting thalline margin. Margin 0.10–0.15 mm, lead-grey, darker than the thallus. Exciple of radiating hyphae, poorly recognizable under the hypothecium, widening to 25–30 μm in the uppermost part. Hymenium hyaline, 100–112 μm high, fleetingly bluish in I; paraphyses predominantly submoniliform, rarely moniliform with 2–3 apical cells thickened; epithecium brownish, N+ greenish, 57–62 μm high. Hypothecium hyaline, I+ weakly bluish, 100–120 μm in the central part.
Asci clavate, *Aspicilia*-type; ascospores broadly ellipsoid, hyaline, aseptate (19.0–21.0–21.5–22.0 (–23.0) × (12.0–)13.5–14.0–14.5–16.0) μm (n = 10). Pycnidia common, in isidia-like projections, with punctiform or elongated ostiole; conidia bacilliform, hyaline, curved or straight, aseptate (19.0–)24.5–25.0–25.5(33.0) μm long (n = 56).

Chemistry. Thallus K+ yellow, C−; medulla K+ yellow, C−; stictic acid complex by TLC, norstictic acid as a minor substance in all specimens.

Etymology. The name refers to the vertical outgrowths on areoles which resemble stalagmites.

Ecology. *Aspicilia stalagmitica* was found in arid conditions on exposed siliceous rocks (granite and schistose) in steppe communities at elevations 880–1600 m a. s. l. The following species co-occurred with *Aspicilia stalagmitica*: *Acarospora bohlinii* H. Magn., *A. irregularis* H. Magn., *Aspicilia cinerea* (L.) Körb., *Candelariella vitellina* (Ehrh.) Müll. Arg., *Candelariella maculata* (H. Magn.) Q. Ren, *Protoparmeliopsis garovaglii* (Körb.) Arup et al., *Immersaria cupreoatra* (Nyl.) Calat. et Rambold, *Lecanora argopholis* (Ach.) Ach., *Rusavskia dasanensis* S. Y. Kondr. et al., and *Xanthoparmelia delisei* (Duby) O. Blanco et al.

Distribution. The species is known from three localities in the Xinjiang autonomous region of China. Paratypes: China, Xinjiang, Mongolsky Altai range, “left bank of the Kran River, Altai City, S slope of Mt., on rocks, elev. 880 m. 47°49'52''N, 88°08'08''E. 31 VII 2005. E. A. Davydov. № 18943” (ALTB, UFU); “valley of Irtysh River at 10 km E settlement Kektogoy, steppe slope, on rocks, elev. 1300–1600 m. 47°13'40''N, 89°55'18''E. 7 VIII 2005. E. A. Davydov. № 17618, 17619” (ALTB, UFU).

Discussion

*Aspicilia stalagmitica* is a peculiar species which can be easily distinguished from other *Aspicilia* s. l. by its isidia-like outgrowths, which contain conidiomata. Along with this character the species has long pycnonidia, up to 33 μm, and contains the stictic acid complex. All the found specimens contain vertical outgrowths but the combination of long conidia and stictic acid may be a separate character which segregates this species from all known taxa within the genus.

According to the ITS phylogeny the closest species to *Aspicilia stalagmitica* is *A. cuprea*, which is known from the USA, California. It differs from the former by its similarity to *Aspiciliella cupreoglauc*a (B. de Lesd.) Zakeri et al. (Zakeri et al., 2019), i. e. its brown thallus, immersed apothecia, and large spores (20–31 × 11–17 μm) (Owe-Larsson et al., 2007). The conidium length is a character, which segregates both *Aspicilia cuprea* and *A. stalagmitica* from the *Aspicilia cinerea*-group. Only *Aspicilia dudinensis* (H. Magn.) Oxner from this group has a conidium length that considerably overlaps with *Aspicilia stalagmitica* and *A. cuprea* (Nordin et al., 2008; Paukov et al., 2017), but never reaches 30 μm. Other similar species with conidia exceeding this range belong to *Oxneriaria* (*Oxneriaria rivulicola* (H. Magn.) S. Y. Kondr. et L. Lőkös, and *O. super tegens* (Arnold) S.Y. Kondr. et L. Lőkös), but lack secondary metabolites.

Compared to species with isidia-like projections, *Aspicilia stalagmitica* is most similar to *Oxneriaria mashiginensis* (Zahlbr.) S.Y. Kondr. et L. Lőkös, which, however, differs by its darker thallus, smaller spores (14–18 × 9–11 μm) and shorter conidia (12.5–19.0 μm), and by containing substictic acid. Further, the outgrowths usually disintegrate into soredia and do not contain conidiomata (Nordin et al., 2008).

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