

LABOULBENIALES (FUNGI, ASCOMYCOTA) OF CHOLEVINE BEETLES (COLEOPTERA, LEIODIDAE) IN BELGIUM AND THE NETHERLANDS

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Summary

This paper presents new records of Laboulbeniales from cholevine hosts (Leiodidae, Cholevinae) in Belgium and the Netherlands. *Corethromyces henrotii* was found on *Choleva cisteloides*, *C. fagniezi*, *C. jeanneli* and *C. oblonga*; it is a first record for the Netherlands. *Diphymyces kaaistoepi* is a newly described species on *Choleva cisteloides* and *C. fagniezi*. Two host insects carried thalli of both *C. henrotii* and *D. kaaistoepi*, apparently without specific growth positions. Descriptions and illustrations are given for both taxa.

Samenvatting

Deze bijdrage geeft nieuwe Belgische en Nederlandse vondsten van Laboulbeniales op kaaskevers (Leiodidae, Cholevinae). *Corethromyces henrotii* werd gevonden op *Choleva cisteloides*, *C. fagniezi* en *C. jeanneli*; het is een eerste melding voor Nederland. *Diphymyces kaaistoepi* is een nieuwe soort op *Choleva cisteloides* en *C. fagniezi*. Twee gastheerspecimens droegen thalli van zowel *C. henrotii* als *D. kaaistoepi*, ogenschijnlijk zonder specifieke groeiplaatsen. Beschrijvingen en illustraties worden gegeven voor beide soorten.

Keywords: *Choleva*, *Corethromyces*, *Diphymyces*, ecology, taxonomy.

Introduction

Laboulbeniales on cholevine beetles (Leiodidae, Cholevinae) are diverse, with species found in six genera: *Asaphomyces* Thaxt., *Columnomyces* R.K. Benj., *Corethromyces* Thaxt., *Diphymyces* I.I. Tav., *Rhachomyces* Thaxt. and *Rodaucea* W. Rossi & Santam. Some of these genera are collected quite often (*Corethromyces*, *Diphymyces*) whereas others have not been reported after description (*Columnomyces*). For example, Haelewaters & Rossi (2017) pointed out that of the 18 species of Laboulbeniales known from American Cholevinae only one (*Asaphomyces cholevae* Thaxt.) has been reported after description. The two genera covered in this report are *Corethromyces* and *Diphymyces*.

The genus *Corethromyces* consists of 84 species (Wijayawardene *et al.* 2017, Haelewaters & Rossi 2017, Rossi & Leonardi 2018). All have (sometimes obliquely) superposed cells II and VI; antheridia that form a series of intercalary cells; and four tiers of perithecial wall cells (Santamaría 2003). However, this latter feature is questionable. Weir & Hughes (2002) mention five tiers of wall cells in at least one species (*C. diochi* Thaxt., Thaxter 1931: Pl. XXXV Fig. 23) and suggest that *Corethromyces* might be restricted or alternatively split into two sub-groups. Most species of *Corethromyces* are associated with Staphylinidae, some are known from Carabidae and Leiodidae, and one species is described from a true bug (Heteroptera, Lygaeidae). In her PhD dissertation, Hughes (2008) reported two thus far

undescribed species of *Corethromyces*, one from Ptiliidae and the other from Byrrhidae.

To date, 24 species of *Diphymyces* (Ascomycota, Laboulbeniales) have been reported (Haelewaters *et al.* 2014, Haelewaters & Rossi 2017, Rossi *et al.* 2018). Species in this genus are characterized by cells II and VI that lie side by side and are separated by a vertical septum; four tiers of perithecial wall cells; and the presence of (sub-)apical outgrowths on the perithecium (Tavares 1985). All species of *Diphymyces* with the exception of three are associated with cholevine hosts. *Diphymyces appendiculatus* (Thaxt.) I.I. Tav. occurs on *Colonellus* (?) sp. (Leiodidae, Coloninae) whereas *D. penicillifer* A. Weir & W. Rossi occurs on rove beetles in the genera *Allodrepa* Steel, 1964, *Nesomalium* Steel, 1964 and *Stenomalium* Bernhauer, 1939 (Staphylinidae, Omaliinae) (reviewed in Haelewaters *et al.* 2014). In addition, an undescribed species of *Diphymyces* was found on Tenebrionidae (Hughes 2008).

Only a few reports are known of Laboulbeniales from Cholevinae in Europe. *Asaphomyces tubanticus* (Middelh. & Boelens ex Middelh.) Scheloske (sometimes treated synonymous with *A. cholevae*, described from North America), *Corethromyces henrotii* Balazuc ex Balazuc and *Diphymyces niger* (T. Majewski) I.I. Tav. are known in several European countries (Santamaría *et al.* 1991). *Diphymyces urbasoli* Santam. is only known from the type locality in Spain (Santamaría 1993, 2003). Three more

species are known from Balkan countries: *Diphymyces cornutus* W. Rossi in Bulgaria (Rossi *et al.* 2018), *D. pavicevicii* W. Rossi & Santam. in Serbia (Rossi & Santamaría 2010) and *D. spelaei* W. Rossi in Albania (Rossi 2006). In Belgium and the Netherlands, *A. tubanticus* has been reported, from *Catops* spp. (Middelhoek 1949, Rammeloo 1986, De Kesel & Rammeloo 1992). In Belgium, De Kesel & Rammeloo (1992) and De Kesel (1997) mentioned a mixed infection with two species of *Corethromyces* on *Choleva cisteloides* (Frölich, 1799): *Corethromyces henrotii* and a provisionally named new taxon ("*C. cholevae*"). After the discovery of infected Dutch material from nature reserve De Kaaistoep, we are now able to formally describe this new taxon in the genus *Diphymyces*.

Materials and methods

Collection of host insects in the Netherlands happened with the help of a pitfall trap in dead crayfish (P. van Wielink & H. Spijkers unpubl.). Signal crayfish (*Pacifastacus leniusculus*) were killed in boiling water and dumped in an open cave. New dead crayfish were added twice a week. The pitfall was constructed in the same cave, separated from the dead crayfish by gauze and Plexiglas and protected from rainfall by a Plexiglas screen on top. Insects were sampled weekly with spiritus/coolant as killing and preservative agent.

Long-term preservation of insects from Belgium and the Netherlands was in formalin or 70-96% ethanol. Insects were screened for Laboulbeniales infection under 50× magnification. Thalli were removed at the foot and mounted in Amann solution (Benjamin 1971) using a Minuten Pin (BioQuip #1208SA, Rancho Dominguez, California) inserted onto a wooden rod. Hoyer's medium (30 g Arabic gum, 200 g chloral hydrate, 16 mL glycerol, 50 mL ddH₂O) was used to arrange and dry-fix the thalli on the microscope slide. Drawings and measurements were made using an Olympus BX51 light microscope with drawing tube, digital camera and AnalySIS (Soft Imaging System GmbH).

Insect hosts from nature reserve De Kaaistoep are preserved at the Brabant Museum of Nature, Tilburg (NNKN). Microscope slides of Laboulbeniales from these hosts are deposited at the Farlow herbarium, Harvard University (FH) and the Brabant Museum of Nature Herbarium (NMBT). Both Belgian hosts and microscope slides are deposited at the Herbarium of Meise Botanic Garden, Belgium (BR).

Results

1. *Corethromyces henrotii* Balazuc ex Balazuc

[Nouvelle Revue d'Entomologie 1: 252 (1971) (*nomen nudum*)]; Bulletin mensuel de la Société Linnéenne de Lyon 42: 283 (1973).

Illustrations: Balazuc 1971 (Fig. 9); Rossi 1975 (Fig. 2);

Huldén 1983 (Fig. 27a-c, infection pattern in Fig. 109); De Kesel & Rammeloo 1992 (Fig. 3a); De Kesel 1997 (Pl. 61a-b); Santamaría 1995 (Figs. 14-15); Rossi & Máca 2006 (Figs. 3-4). **Fig. 1f-g.**

Description

Thallus 260-280 µm long; almost entirely hyaline to faintly yellowish. Receptaculum three-celled, 60-80 µm long. Cell I 15-20 µm long, small, obtriangular, colored darker above the foot. Cell II larger than cell I, isodiametric or longer than broad, sometimes inflated; carrying cells III and VI apically. Cell III slightly longer than broad, hyaline or exceptionally pigmented dark brown. Primary appendage up to 110-170 µm long, composed of a relatively large basal cell, carrying apically a number of fertile and sterile branches. Fertile branches finest, branched once or twice, with intercalary antheridia. Sterile branches up to 85-110 µm long, repeatedly branched, comprising cells that are more elongate and robust compared to those of the fertile branches. Cell VI 70-110 µm long, cylindrical, occasionally somewhat inflated. Basal cells of perithecium 30-40 µm long, longer than broad. Perithecium 119-130 × 38-43 µm, elongated, subsymmetrical, broadest below the middle; preapical region with a darkened spot on the posterior side; ending in a blunt apex, consisting of unequal and rounded lips.

Known distribution and hosts

Only found on hosts in the genus *Choleva* Latreille, 1796. It has been observed on *C. cisteloides* Frölich, 1799 in Belgium (De Kesel & Rammeloo 1992, De Kesel 1997) and Spain (Santamaría 1995, 2003); *C. oblonga* Latreille, 1807 in France (Balazuc 1973) and the Czech Republic (Rossi & Máca 2006); on *C. septentrionis* Jeannel, 1923 in Finland (Huldén 1983); and on *C. sturmi* Brisout, 1863 in Italy (Rossi 1975).

Studied material:

BELGIUM, Prov. West Flanders, Oostduinkerke, on *Choleva cisteloides*, in wet dune valley, 03.iii.1974, leg. E. Deconinck & R. Bosmans, slide JR5056 (thalli removed from elytral tips), mixed infection with *Diphymyces kaaistoepi*; Prov. Namur, Jemeppe-sur-Sambre, Spy (Onoz), on *C. cisteloides*, 28.vi.1942, leg. A. Collart, slide L12 (thalli removed from elytral tips). THE NETHERLANDS, Prov. North Brabant, Tilburg, nature reserve De Kaaistoep, on female *Choleva fagniezi* Jeannel, 1922, pitfall in dead crayfish, 51°32'25"N 05°00'37"E, 01-08.vii.2015, leg. H. Spijkers & P. van Wielink, slides D. Haelew. 1058a (6 thalli from anterior third of right elytron), D. Haelew. 1058b (12 thalli from pronotum), D. Haelew. 1058d (1 thallus from anterior third of right elytron), D. Haelew. 1058e (8 thalli from pronotum & elytra), D. Haelew. 1058f (2 thalli from pronotum & elytra), double infection with *D. kaaistoepi*; same data, on male *Choleva jeanneli*

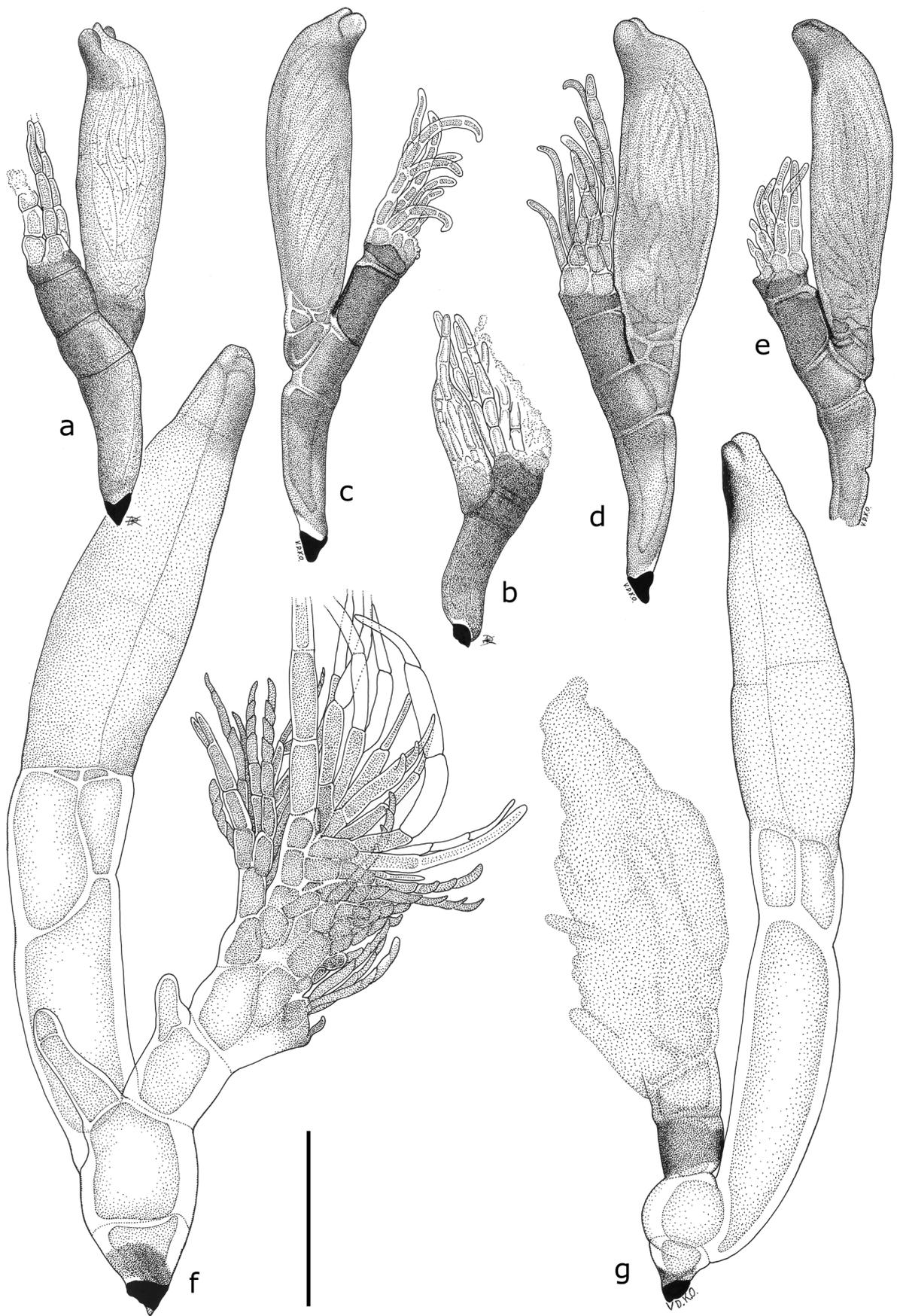


Fig 1. Laboulbeniales from *Choleva* spp. **a-e.** *Diphymyces kaaistoepi* sp. nov., with **a.** mature thallus (D. Haelew. 1058f, holotype, from shoulder of right elytron of *C. fagniezi*), **b.** thallus with young perithecium and trichogyne (D. Haelew. 1058f), **c-e.** mature thalli (JR5056, on *C. cisteloides*). **f-g.** *Corethromyces henrotii*, with **f.** mature thallus (JR5056, on elytron of *C. cisteloides*), **g.** older thallus with pigmented cell III (L12, on elytron of *C. cisteloides*). Scale bar = 50µm.

Britten, 1922, pitfall in dead crayfish, 11-18.v.2016, leg. H. Spijkers & P. van Wielink, slides D. Haelew. 1410a (5 thalli from pronotum), D. Haelew. 1410d (3 thalli from left profemur); Prov. North Holland, National Park Zuid-Kennemerland, on male *Choleva oblonga* Latreille, 1708, pitfall trap series 29, 52°23'52.57"N 04°34'55.50"E, 14.iv.2018, leg. M. Boeken, slides D. Haelew. 1516a (2 thalli from tip of right elytron), D. Haelew. 1516c (10 thalli from sternites).

Remarks

As noted for other species of Laboulbeniales (e.g. Thaxter 1931, Rossi 1991, Weir 1998), pigmentation is not a constant characteristic in *C. henrotii*. For example, cell III is pigmented only in some thalli (Fig. 1g) and the lowest tier of perithecial wall cells is pigmented conspicuously only in our Dutch material from De Kaaistoep. Rossi & Máca (2006: Fig. 3) mention the presence of a second perithecium, which is initiated on cell III. We have also observed this in a single thallus from De Kaaistoep and in three thalli from Zuid-Kennemerland. Likewise, in one thallus from *C. cisteloides*, primordial perithecia seem to develop from cells II and III, respectively (Fig. 1f).

Thalli removed from *C. fagniezi* (D. Haelew. 1058) are remarkably larger than those from *C. cisteloides* from Belgium and Spain (Santamaría 1995). We provide these measurements separately, drawing attention to differences between populations growing on different host species. Total length from foot to perithecial tip 377-386 µm, length of cell I 20-22 µm, cell III 24-25 × 19-21 µm, length of cell VI 123-125 µm, basal cells of perithecium 51-55 µm, perithecium (without basal cells) 144-151 × 36-38 µm. More material needs to be collected to verify whether these differences are consistent, potentially host-related, and whether they represent *within-species* variation or are indicative of speciation events. It may be noted that *C. fagniezi* is significantly different from *C. cisteloides* in measurements. A limited biometric study of 13 specimens (*C. cisteloides*: 3 ♀♀ & *C. fagniezi*: 7 ♀♀, 3 ♂♂; pers. comm. M. Perreau) resulted in the observation that *C. fagniezi*, the host carrying thalli that are consistently larger than those from *C. cisteloides*, is also 10% larger. At the same time, these two host species do not belong to the same species group (Jeannel 1923, 1936) and thus may be phylogenetically not closely related.

2. *Diphymyces kaaistoepi* Haelew. & De Kesel, sp. nov.

Illustrations: De Kesel 1997 (Pl. 60a-c, ut *Corethromyces cholevae* nom. provis).

MycoBank: MB 827523.

Fig. 1a-e.

Diagnosis

Differs from other species of *Diphymyces* by its slender cell I, flattened cell VI and perithecial apex

without projections, bent posteriorly and with two large lips.

Etymology

Referring to De Kaaistoep, a Dutch nature reserve soon celebrating its 25th anniversary of sustained All-Taxa Biodiversity Inventory efforts.

Type material

THE NETHERLANDS, Prov. North Brabant, Tilburg, nature reserve De Kaaistoep, on female *Choleva fagniezi*, pitfall in dead crayfish, 51°32'25"N 05°00'37"E, 01-08.vii.2015, leg. H. Spijkers & P. van Wielink, slide D. Haelew. 1058f (HOLOTYPE, 6 thalli from shoulder of right elytron), double infection with *C. henrotii*.

Description

Thallus slender, 139-172 µm long; receptacle, basal cell of appendage, cell VI and perithecial basal cells as well as posterior preostolar area pigmented dark brown. Receptaculum three-celled, 70-90 µm long. Cell I 38-50 µm long, slender, obtriangular, up to times as long as broad. Cell II almost isodiametric, carrying apically cell III and laterally cell VI. Cell III as broad as cell II, variable in length, up to two times as long as broad. Primary appendage 50-70 µm long, basal cell flattened, giving rise apically to a number of branchlets, each branchlet 40-60 µm long, with one or two ramifications. Antheridia not observed. Cell VI 6-10 µm long, flattened, broadly triangular to trapezoidal in shape, broadest at its anterior side. Perithecium 83-93 × 23-32 µm, oblong, asymmetrical, broadest in the middle or above the middle; apex oriented posteriorly, consisting of two large lips, one conspicuously rounded, the other carrying a minute tooth. Ascospores 30-35 × 2.5-3 µm, bicellular.

Additional material

BELGIUM, Prov. West Flanders, Oostduinkerke, on *Choleva cisteloides*, in wet dune valley, 03.iii.1974, leg. E. Deconinck & R. Bosmans, slide JR5056 (PARATYPE), double infection with *C. henrotii*.

Discussion

Diphymyces kaaistoepi can be easily separated from those species in the same genus that have perithecia with projections or protrusions at the apex: *D. anthracinus* Haelew. & W. Rossi, *D. appendiculatus*, *D. bidentatus* (Thaxt.) I.I. Tav., *D. cornutus*, *D. giachinoi* W. Rossi & Santam., *D. newtonii* Haelew. & W. Rossi, *D. niger*, *D. perreai* Haelew. & W. Rossi, *D. pusillus* W. Rossi & Santam., *D. sabahensis* Haelew. & Pfister, *D. spelaei* and *D. urbanoli* (Thaxter 1931, Santamaría 1993, Rossi 2006, Rossi & Santamaría 2010, Haelewaters *et al.* 2014, Haelewaters & Rossi 2017, Rossi *et al.* 2018).

It can be distinguished from the other species based on the combination of its receptacular and perithecial features. For example, it is different from *D. arnaudii* W. Rossi & Santam., *D. blackwelliae* Haelew. & W. Rossi, *D. costaricensis* Haelew. & W. Rossi, *D. depressus*

M.B. Hughes, A. Weir & C. Judd, *D. obesus* Haelew. & W. Rossi, *D. pavicevicii*, *D. penicillifer* A. Weir & W. Rossi and *D. silphidarum* (Thaxt.) I.I. Tav. in its cell I (slender) and perithecial apex (bent posteriorly, two large lips) (Weir & Rossi 1997, Hughes *et al.* 2004, Rossi & Santamaría 2010, Haelewaters & Rossi 2017).

Two other species are different in that they carry multiple perithecia: *Diphymyces lescheni* M.B. Hughes, A. Weir & C. Judd (2 perithecia in 9 of 12 observed mature thalli) and *D. polycarpus* Haelew. & W. Rossi (2 perithecia in one thallus, 3 in the other) (Hughes *et al.* 2004, Haelewaters & Rossi 2017). *Diphymyces dichromus* Haelew. & W. Rossi is consistently distinctly bicolored and is highly variable in length (Haelewaters & Rossi 2017). Finally, *D. curvatus* (Thaxt.) I.I. Tav. is strongly curved and has a rather stout habitus (Thaxter 1931).

Diphymyces kaaistoepi seems most closely allied with *D. spelaei*, described from hosts in the genus *Anthroherpon* Reitter, 1889 (Leiodidae, Cholevinae, Leptodirini) collected in Albania (Rossi 2006). However, as described above, *D. spelaei* differs in having a single finger-like projection. Also, in two of the illustrated thalli of *D. spelaei* (Rossi 2006: Figs. 2-3), removed from the head and metafemur, the perithecium curves towards anterior, whereas in *D. kaaistoepi* the perithecium itself is straight but its apex is oriented posteriorly.

Ecology

Cholevinae are detritus feeders. They feed on decaying organic material of all kinds of origin: plant litter, fungi, dung, carrion (carcasses), organic matter in vertebrate nests (Chandler & Peck 1992). Species in the genus *Choleva* are typically associated with narrow channels, tunnels and nests of small mammals (Růžička & Vávra 1993, Kočárek 2003). This hypogean lifestyle may be linked to the damage that is often observed on the appendage system of *Diphymyces* thalli (Thaxter 1918, 1931, Haelewaters *et al.* 2014). Also, thalli of *Columnomyces* spp. and *Laboulbenia clivinalis* Thaxt. are regularly damaged, which likewise may be linked to the habitat specialization observed for their hosts (Benjamin 1955, De Kesel 1995, M. Perreau & D. Haelewaters unpubl.). *Columnomyces* occurs on cholevine hosts in the genera *Proptomaphagus* Szymczakowski, 1969 and *Ptomaphagus* Hellwig, 1795, whereas *Laboulbenia clivinalis* Thaxt. occurs on *Clivina fossor* (Linnaeus, 1758). All of these hosts have an underground lifestyle, at least partly.

Corethromyces versus *Diphymyces*

The two genera *Corethromyces* and *Diphymyces* are distinguished mainly by the position of cell II and cell VI. In *Corethromyces*, cells II and VI are superposed, thus separated by a horizontal septum. In *Diphymyces*, they lie next to each other, separated by a vertical septum. However, the relative placement of these cells is prone to some variation (morphological plasticity). The result is that, sometimes, septum II-VI is obliquely positioned and, consequently, cell VI does not touch cell I. This makes it difficult to assign certain thalli to either genus. It is a question whether the establishment of the genus *Diphymyces* and transfer of some species from *Corethromyces* to this genus (Tavares 1985) was a good decision.

Hughes *et al.* (2004) noted that *Diphymyces leschenii* is highly similar to *Asaphomyces tubanticus*. Also, *Asaphomyces* and *Euphoriomyces* Thaxt. bear close resemblance and might even be synonymous (sensu Thaxter 1931). Thaxter (1931) wrote about *Asaphomyces* that “[i]t is not, however, symmetrically developed on either side, the perithecium or their primordia, being superposed in a unilateral series [...]” However, perithecia in *Euphoriomyces* are not always produced bilaterally, as described by Hughes (2008).

These four genera, although potentially closely related or even synonymous, are classified in three different subtribes following Tavares (1985) (Table 1). *Asaphomyces* is placed within subtribe Asaphomycetinae, tribe Teratomyceteae. The other three genera are placed in the tribe Laboulbenieae. *Corethromyces* and *Diphymyces* are part of subtribe Stigmatomycetinae, but *Euphoriomyces* is placed under subtribe Euphoriomycetinae. This classification was based on perithecial development, perithecial wall structure and the nature of antheridia, but several higher taxa from this system turn out to be polyphyletic following ribosomal DNA-based phylogenies (SSU: Goldmann & Weir 2018, SSU+LSU: Haelewaters *et al.* 2018).

In other words, after more than 30 years we are becoming less confident in the tribes and subtribes as described by Tavares (1985). We would not be surprised if the classification of *Asaphomyces*, *Corethromyces*, *Diphymyces* and *Euphoriomyces* were to change radically based on molecular data. However, currently no sequences exist for *Asaphomyces*, *Diphymyces* or *Euphoriomyces*. Only two SSU sequences are available for *Corethromyces* (Weir & Hughes 2002). Continued studies with molecular phylogenetic methods are necessary to solve this taxonomic puzzle.

Genus	Family	Tribe	Subtribe
<i>Asaphomyces</i>	Laboulbeniaceae	Teratomyceteae	Asaphomycetinae
<i>Corethromyces</i>	Laboulbeniaceae	Laboulbenieae	Stigmatomycetinae
<i>Diphymyces</i>	Laboulbeniaceae	Laboulbenieae	Stigmatomycetinae
<i>Euphoriomyces</i>	Laboulbeniaceae	Laboulbenieae	Euphoriomycetinae

Table 1. Affiliations of the 4 genera (Tavares 1985).

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