



# Diversity of fungi on Taiwanese fern plants: review and new discoveries

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**ABSTRACT:** In this review, chances and challenges of investigating fungi on ferns in Taiwan are presented and discussed. Taiwan with a high species number of more than 800 fern species (including lycophytes here) as well as high density of fern plants is an ideal environment for studying the scarcely known fungi that depend as saprotrophs, symbionts and parasites on ferns. In Taiwan only ca. 60 fungi have been recorded on ferns. If we apply the overall estimated average plant-fungus species ratio of ca. five fungi per plant species in a given area, about 90% of fern-associated fungi have not yet been identified in Taiwan. Ca. 30% of fern-associated fungi recorded in Taiwan are rust fungi (Pucciniales, Basidiomycota) and further ca. 10% ascomycetes (Mycosphaerellales), all comprising highly specialized plant parasites. About 3.5% are species of discomycetes (Helotiales, Ascomycota) with most of them being more or less specific saprobic decomposers of dead fern tissues. The illegitimate name *Pseudocercospora christellae* Haldar & J.B. Ray for a parasitic fungus from India is replaced by the new name *Ps. cyclosori*. The new name *Asterocalycella* is proposed for the illegitimate genus *Asterocalyx* (Helotiales, Ascomycota). A new white mutant of *A. mirabilis* saprobic on Cyatheaceae is recorded. DNA sequence analysis suggests excluding this genus from the Sclerotiniaceae. Specimens of further Helotiales (*Lachnum oncospermatum*, *Lachnum* sp. and *Microscypha* sp.) from the same decaying leaf are presented as examples for the specific diversity and its incomplete taxonomic knowledge. The new species *Teratosperma dicranopteridis* found on living *Dicranopteris linearis* illustrates the difficulty to assign higher taxonomic ranks and specific ecological roles to some fungi.

**KEY WORDS:** Ascomycota, Basidiomycota, Biodiversity, Discomycetes, Ferns, Fungi, Taiwan, *Teratosperma dicranopteridis*.

## INTRODUCTION

### Global biodiversity of fungi on ferns

Fungi on ferns were published as early as at the beginning of the 19<sup>th</sup> century (*Sphaeria pteridis* Rebent. 1804; in Fries, 1823). Stevenson (1945) was probably the first who published an overview of fungi parasitic on ferns. The most recent overview of saprobic, parasitic and symbiotic fungi associated with ferns was published by Mehlreter (2010). The relationship between rust fungi and ferns led to the hypothesis of “primitive parasites on primitive hosts” (Oberwinkler, 2012). Molecular analyses, however, indicated that fern rusts were not basal to the rusts on seed plants (Sjamsuridzal *et al.*, 1999). In contrast to the rust fungi which are biotrophs on their host plants, evidence for parasitism by other fungi on ferns is often not clear or is only concluded from field observations. These studies mainly focused on the systematics of sexual and asexual Ascomycota including saprobic as well as presumably parasitic species (e.g. Bubák, 1916; Holm and Holm, 1978; Castañeda Ruiz and Heredia, 2000; Medel and Lorea-Hernández, 2008). Gilbertson and Hemmes (1997) investigated mainly saprobic fungi of different systematic groups on tree ferns. Braun *et al.* (2013) compiled information concerning mainly plant parasitic cercosporoid hyphomycetes on ferns worldwide based on the literature and herbaria. Cercosporoid fungi are considered comparatively host-specific and are identified

to species mainly based on morphological comparison of congeneric species known from members of the same host genus or family. The conspectus of *Mycosphaerella* by Aptroot (2006) contains more than 30 taxa on ferns, although several species on different ferns were morphologically identical with *M. filicum* (Desm.) Starbäck (Aptroot, 2006). The study of fungi on ferns is still in the pioneer stage with biodiversity being recorded and the study of saprobic fungi on fern leaves is expected to result in new discoveries (Mehlreter, 2010).

### Chances and challenges in studying fungi on ferns in Taiwan

#### *Species diversity*

Taiwan has one of the highest density of ferns and is, therefore, particularly suitable for studying the fungi on ferns. Given approximately 800 species of ferns known each for Taiwan (Knapp, 2011; Knapp and Hsu, 2017), Japan (630 species/227,400 km<sup>2</sup>; Iwatsuki, 1992), and Thailand (670 species/514,000 km<sup>2</sup>; Lindsay and Middleton, 2009), the species density is 0.022, 0.002, and 0.001 taxa/km<sup>2</sup>, respectively.

Because of the high population and species density of ferns, fungi preferring ferns as substrate are also likely to be found frequently in Taiwan. Among approximately 30 species of *Pseudocercospora* known from ferns worldwide (Braun *et al.*, 2013), six species were described from and are only known from Taiwan (Hsieh and Goh, 1990; Kirschner and Chen, 2007). A



worldwide study on species of the cercosporoid genus *Periconiella* on ferns was published by Braun (2004); two of the species were later recorded from Taiwan (Kirschner and Chen, 2007, 2010). A brief overview about parasitic fungi associated with living ferns with additional new species and records from Taiwan has recently been presented (Kirschner and Liu, 2014). According to our preliminary list (Table 1), more than 60 fungal species have been recorded from ferns in Taiwan, of which about 1/6 was recorded in our own publications (Kirschner and Chen, 2007, 2010; Kirschner and Liu, 2014; Kirschner and Wang, 2015). Fujian Province of mainland China and Taiwan have a particularly high diversity of ferns (Knapp, 2011, 2014; Ye *et al.*, 2007). Further records of mycosphaerellaceous fungi were found on ferns during recent collections in both areas (Kirschner and Wang, 2015).

Studies of fungi on ferns in temperate regions focus mainly on a single species, bracken [*Pteridium aquilinum* (L.) Kuhn], and yielded over 250 fungal records from several countries (Farr and Rossman, 2017; Petrini *et al.*, 1992). The UK may be considered as country in the temperate region with the best record of fungi (Hawksworth 2001) comprising about 60 species alone on this host (Farr and Rossman, 2017). Since this fern species is the most dominant one in temperate regions, records of fungi on other ferns are less frequent there, e.g. ca. 30 species on Dryopteridaceae in the UK (Farr and Rossman, 2017). We may roughly estimate over 100 species of fungi recorded on ferns in the UK due to the long and intensive mycological collection tradition there in spite of the comparatively low diversity of ferns (ca. 100 species, <https://www.fernid.info/>). When extrapolating a conservative average ratio 1:1 of plant to fungal species from UK for the diversity of fern-associated fungi in Taiwan, we may expect ca. 800 species. This estimate, however, is too low when applying other variables. If we, for example, apply the species average ratio of plant and fungal species in a given country or plant group proposed by Hawksworth (2001) of 1:5–6 to the total number of about 800 fern species in Taiwan, we may expect at least 4,000 species of fungi associated with ferns. The number may be somewhat reduced, because some fungi are general saprobes without preference for ferns. Recently, however, Hawksworth and Lücking (2017) updated this estimate to 10 fungal species per plant species so that we may expect altogether 8,000 species of fungi associated with ferns in Taiwan.

The single other tropical/subtropical country where fungal diversity associated with living ferns has been studied recently is Brazil, comprising about 70 fern-associated fungal species (Guatimosim *et al.*, 2016a, b), so that presently Brazil and Taiwan are the two tropical countries whose fern-associated fungi are comparatively better known than in other countries. Ferns are also

species-rich in other tropical Asian countries with many identical or closely related species as in Taiwan, but study of their fungi has been undertaken only rudimentarily (e.g. Razikin *et al.*, 2014).

#### *Ecological groups of fern-associated fungi*

The ecological groups of fungi associated with fern plants can be classified as mycorrhiza fungi, endophytes, plant parasites, and saprobic decomposers. Secondary associations are established by growth of fungi on other organisms occurring on ferns, such as other fungi, insects, spiders etc., including lichenized fungi as particular case. In Taiwan, data about fern mycorrhiza and endophytic fungi are extremely scarce, although they have been studied in other countries (Pressel *et al.*, 2016). As far as we can conclude from other regions, these mycorrhiza and endophytic fungi are usually not specific to ferns (Petrini *et al.*, 1992). Most data, therefore, refer to parasitic (75%) and saprobic fungi (25%). Among the parasitic fungi, about 30% of fungi recorded for ferns (23 species) in Taiwan are obligately biotrophic rust fungi (Pucciniales = Uredinales, Table 1), indicating that the biodiversity of this order might be comparatively well known, whereas in the Mycosphaerellales (Ascomycota), new species and records are continuously published, even on the same host species. For the mycosphaerellaceous fungi and their corresponding cercosporoid asexual morphs (anamorphs) on ferns, mainly only morphological descriptions of the type specimens were available until recently. By extending collections, the range of host species, morphology (particularly with respect to overlooked external and internal hyphae, size range variations and pigmentation), and taxonomy of the known species were revised, and DNA data were provided for the first time. Although internal transcribed spacer (ITS) sequences of the ribosomal RNA genes of different species of cercosporoid fungi are often 100% identical, our sequences obtained from fern-associated fungi differed at least for 2 bp from all other available sequences in GenBank. DNA data were particularly helpful in showing that newly detected asexual and sexual fungi on the same host fern were not conspecific. For example, the newly recorded sexual fungus *Mycosphaerella gleicheniae* T.S. Ramakr. & K. Ramakr. and the anamorph *Zasmidium dicranopteridis* R. Kirschner occurring on the same host *Dicranopteris linearis* (Burm. f.) Underw., differed by internal growth associated with leaf spots in the former and external growth without symptoms in the latter (Kirschner and Liu, 2014). Other plant pathogenic fungi (five species, Table 1) recorded on ferns in Taiwan represent single findings. *Irenina selaginellae* Sawada & W. Yamam. belongs to the Meliolales, a species-rich group of obligate biotrophic plant pathogens mainly confined to angiosperms in the tropics. *Ophioidiaporthe cyatheae*



**Table 1.** Preliminary list of fungi on ferns in Taiwan. Several names of fungi updated with Index Fungorum (anamorph names of rusts given in brackets), those of ferns with Tropicos. Biology: L = lichen, P = pathogen, S = saprob.

Fungal species	Host species	Host family	Bio- Reference logy
<i>Asterocalyx mirabilis</i> Höhn.	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon, <i>Sphaeropteris lepifera</i> (J. Sm. ex Hook.) R.M. Tryon <i>Angiopteris lygodiifolia</i> Rosenst.	Cyatheaceae, Marattiaceae	S Wu 2002
<i>Byssoloma subdiscordans</i> (Nyl.) P. James	<i>Polystichum</i> sp.	Dryopteridaceae	L Aptroot & Sparrus 2003
<i>Cercospora cyclosori</i> Goh & W.H. Hsieh	<i>Cyclosorus</i> × <i>acuminatoides</i> (W.C. Shieh & J.L. Tsai) Y.H. Chang	Thelypteridaceae	P Hsieh & Goh 1990
<i>Clonostachys rosea</i> f. <i>rosea</i> (Link) Schroers, Samuels, Seifert & W. Gams	<i>Sphaeropteris lepifera</i> (J. Sm. ex Hook.) R.M. Tryon	Cyatheaceae	S Guu <i>et al.</i> 2010
<i>Dictyosporium heptasporum</i> (Garov.) Damon	<i>Angiopteris lygodiifolia</i> Rosenst.	Marattiaceae	S Matsushima 1980
<i>Fellhanera bouteillei</i> (Desm.) Vězda	<i>Polystichum</i> sp.	Dryopteridaceae	L Aptroot & Sparrus 2003
<i>Hyalopsora cryptogrammes</i> Dietel ( <i>Uredo c.</i> (Dietel) Hirats. f.)	<i>Onychium japonicum</i> (Thunb.) Kunze	Pteridaceae	P Farr & Rossman 2017
<i>Hyalopsora hakodatensis</i> Hirats. f.	<i>Diplazium mettenianum</i> (Miq.) C. Chr.	Athyriaceae	P Sawada 1959
<i>Hyalopsora polypodii</i> (Pers.) Magnus	<i>Cryptogramma brunoniana</i> Wall. ex Hook. & Grev. <i>Diplazium wichurae</i> (Mett.) Diels <i>Phegopteris decursive-pinnata</i> (H.C. Hall) Fée	Pteridaceae, Athyriaceae, Thelypteridaceae	P Farr & Rossman 2017
<i>Hyalopsora taiwaniana</i> Hirats. f. ( <i>Uredo cystopteridis</i> Hirats. f.)	<i>Cystopteris moupinensis</i> Franch. (= <i>C. sphaerocarpa</i> Hayata)	Cystopteridaceae	P Farr & Rossman 2017
<i>Hydropisphaera suffulta</i> (Berk. & M.A. Curtis) Rossman & Samuels	<i>Sphaeropteris lepifera</i> (J. Sm. ex Hook.) R.M. Tryon	Cyatheaceae	S Guu <i>et al.</i> 2010
<i>Irenina selaginellae</i> Sawada & W. Yamam.	<i>Selaginella doederleinii</i> Hieron.	Selaginellaceae	P Farr & Rossman 2017
<i>Lachnum flavidulum</i> (Rehm) J.H. Haines	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon, other Cyatheaceae	Cyatheaceae	S Wu <i>et al.</i> 1998
<i>Lachnum nudipes</i> (Fuckel) Nannf.	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon	Cyatheaceae	S Liou & Chen 1977
<i>Lachnum oncospermatum</i> (Berk. & Broome) M.L. Wu & J.H. Haines	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon <i>Histiopteris incisa</i> (Thunb.) J. Sm.	Cyatheaceae, Dennstaedtiaceae	S Wu <i>et al.</i> 1998
<i>Lachnum pteridophyllum</i> (Rodway) Spooner	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon <i>Histiopteris incisa</i> (Thunb.) J. Sm.	Cyatheaceae, Dennstaedtiaceae	S Wu <i>et al.</i> 1998
<i>Macrophoma neottopteridis</i> Sawada	<i>Asplenium nidus</i> L. (= <i>Neottopteris nidus</i> (L.) J. Sm. ex Hook.)	Aspleniaceae	P Sawada 1959
<i>Microthyrium dryopteridis</i> Sawada	<i>Dryopteris</i> sp.	Dryopteridaceae	S? Sawada 1944
<i>Milesia hashioekae</i> Hirats. f.	<i>Dryopsis lachoogensis</i> (Bedd.) B.K. Nayar & Kaur (= <i>Dryopsis clarkei</i> (Baker) Holttum & P.J. Edwards, <i>Dryopteris clarkei</i> (Baker) Kuntze) <i>Goniophlebium amoenum</i> (Wall. ex Mett.) Vudd. var. <i>arisanense</i> (Hayata) Rödl-Linder (= <i>Polypodium amoenum</i> Wall. ex Mett.)	Dryopteridaceae, Polypodiaceae	P Farr & Rossman 2017
<i>Milesia tenuis</i> Faull (= <i>Uredo tenuis</i> (Faull) Hirats. f.)	<i>Nephrolepis cordifolia</i> (L.) C. Presl (= <i>Nephrolepis auriculata</i> (L.) Trimen)	Nephrolepidaceae	P Farr & Rossman 2017
<i>Milesina arisanense</i> Hirats. (= <i>Uredo arisanensis</i> (Hirats.) Hirats. f.)	<i>Arachniodes amabilis</i> (Blume) Tindale (= <i>Polystichum amabile</i> (Blume) J. Sm.) <i>Athyrium delavayi</i> Christ. var. <i>subrigescens</i> Hayata (= <i>Athyrium subrigescens</i> (Hayata) Hayata ex H. Itô, <i>Athyrium elegans</i> Tagawa)	Dryopteridaceae, Athyriaceae	P Farr & Rossman 2017
<i>Milesina coniogrammes</i> Hirats. f. ( <i>Milesia c.</i> , = <i>Uredo c.</i> )	<i>Coniogramme fraxinea</i> , (D. Don) Fée ex Diels, <i>C. japonica</i> (Thunb.) Diels, <i>Pteris cretica</i> L., <i>P. multifida</i> Poir.	Pteridaceae	P Farr & Rossman 2017
<i>Milesina coniogrammicola</i> Hirats. f.	<i>Coniogramme intermedia</i> Hieron., <i>Pteris cretica</i> L.	Pteridaceae	P Farr & Rossman 2017
<i>Milesina coreana</i> Hirats. f. ( <i>Uredo coreana</i> (Hirats. f.) Hirats. F.)	<i>Dryopteris varia</i> (L.) Kuntze (= <i>Dryopteris yabei</i> Hayata), <i>Polystichum</i> sp.	Dryopteridaceae	P Farr & Rossman 2017
<i>Milesina erythrosora</i> (Faull) Hirats. f.	<i>Arachniodes quadripinnata</i> (Hayata) Seriz. (= <i>Dryopteris quadripinnata</i> Hayata, <i>Leptorumohra quadripinnata</i> (Hayata) H. Itô)	Dryopteridaceae	P Farr & Rossman 2017
<i>Milesina exigua</i> Faull	<i>Hypolepis punctata</i> (Thunb.) Mett. <i>Microlepis strigosa</i> (Thunb.) C. Presl <i>Dryopteris apiciflora</i> (Wall. ex Mett.) Kuntze (= <i>Ctenitis apiciflora</i> (Wall. ex Mett.) Ching), <i>Polystichum hancockii</i> (Hance) Diels	Dennstaedtiaceae, Dryopteridaceae	P Farr & Rossman 2017



Table 1. Continued

Fungal species	Host species	Host family	Bio-logy	Reference
<i>Milesina formosana</i> Hirats. f. & Hashioka	<i>Diplazium kawakamii</i> Hayata	Athyriaceae	P	Sawada 1959
<i>Milesina hiratsukae</i> Morim. ( <i>Uredo hiratsukae</i> (Morim.) S. Uchida)	<i>Plagiogyria euphlebia</i> (Kunze) Mett.	Plagiogyriaceae	P	Farr & Rossman 2017
<i>Milesina miyabei</i> Kamei	<i>Dryopsis lachoogensis</i> (Bedd.) B.K. Nayar & Kaur (= <i>Dryopsis clarkei</i> (Baker) Holttum & P.J. Edwards, <i>Dryopteris clarkei</i> (Baker) Kuntze), <i>Dryopteris wallichiana</i> (Spreng.) Hyl. (= <i>Dryopteris paleacea</i> (T. Moore) Hand.-Mazz.)	Dryopteridaceae	P	Farr & Rossman 2017
<i>Milesina morrisonensis</i> Hirats. f. (= <i>Uredo morrisonensis</i> (Hirats. f.) Hirats. f.)	<i>Dryopteris wallichiana</i> (Spreng.) Hyl. (= <i>Dryopteris paleacea</i> (T. Moore) Hand.-Mazz.)	Dryopteridaceae	P	Farr & Rossman 2017
<i>Milesina nitakensis</i> Hirats. f. ( <i>Uredo n.</i> (Hirats. f.) Hirats. f.)	<i>Dryopteris peranema</i> Li Bing Zhang (= <i>Peranema cyatheoides</i> D. Don)	Dryopteridaceae	P	Farr & Rossman 2017
<i>Milesina philippinensis</i> Syd.	<i>Nephrolepis cordifolia</i> (L.) C. Presl	Nephrolepidaceae	P	Hsu <i>et al.</i> 2002
<i>Milesina polypodii-superficialis</i> Hirats. f. (= <i>Uredo polypodii-superficialis</i> (Hirats. f.) Hirats. f.)	<i>Lepidomicrosorium buergerianum</i> (Miq.) Ching & K.H. Shing (= <i>Microsorium buergerianum</i> (Miq.) Ching), <i>Lepidomicrosorium superficiale</i> (Blume) L. Wang	Polypodiaceae	P	Farr & Rossman 2017
<i>Mixia osmundae</i> (Nishida) C.L. Kramer	<i>Osmunda japonica</i> Thunb.	Osmundaceae	P	Farr & Rossman 2017
<i>Monilochaetes laeensis</i> (Matsush.) Réblová, W. Gams & Seifert	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon	Cyatheaceae	S	Matsushima 1987
<i>Mycocentrospora fusarioides</i> Matsush.	<i>Alsophila spinulosa</i> (Wall. ex Hook.) Tryon	Cyatheaceae	S	Matsushima 1987
<i>Mycosphaerella gleicheniae</i> T.S. Ramakr. & K. Ramakr.	<i>Dicranopteris linearis</i> (Burm. f.) Underw.	Gleicheniaceae	P	Kirschner & Liu 2014
<i>Ophiodiaporthe cyatheae</i> Y.M. Ju <i>et al.</i>	<i>Sphaeropteris lepifera</i> (J. Sm. ex Hook.) R.M. Tryon	Cyatheaceae	P	Fu <i>et al.</i> 2013
<i>Orbilina cf. auricolor</i> (A. Bloxam) Sacc.	<i>Angiopteris lygodiifolia</i> Rosenst.	Marattiaceae	S	Wu 1998
<i>Passalora lygodii</i> (Sawada ex Goh & W.H. Hsieh) R. Kirschner	<i>Lygodium japonicum</i> (Thunb.) Sw. (= <i>L. microstachyum</i> Desv.)	Schizaeaceae	P	Hsieh & Goh 1990, Kirschner & Wang 2015
<i>Periconiella lygodii</i> Arch. Singh, Bhalla & S.K. Singh ex U. Braun	<i>Lygodium japonicum</i> (Thunb.) Sw.	Schizaeaceae	P	Kirschner & Chen 2010
<i>Periconiella rachidicola</i> U. Braun	<i>Angiopteris lygodiifolia</i> Rosenst.	Marattiaceae	S?	Kirschner & Chen 2007
<i>Pseudocercospora angiopteridis</i> Goh & W.H. Hsieh	<i>Angiopteris lygodiifolia</i> Rosenst.	Marattiaceae	P	Hsieh & Goh 1990
<i>Pseudocercospora athyrii</i> Goh & W.H. Hsieh	<i>Deparia japonica</i> (Thunb.) M. Kato [this species record not confirmed for Taiwan, might be <i>D. petersenii</i> (Kunze) M. Kato], <i>D. longipes</i> (Ching) Shinohara	Athyriaceae	P	Hsieh & Goh 1990, Kirschner & Liu 2014
<i>Pseudocercospora cyatheae</i> C. Nakash. & S. Inaba	<i>Sphaeropteris lepifera</i> (J. Sm. ex Hook.) R.M. Tryon	Cyatheaceae	P	Kirschner & Liu 2014
<i>Pseudocercospora microlepieae</i> R. Kirschner	<i>Microlepiea speluncae</i> (L.) T. Moore, <i>Microlepiea trichocarpa</i> Hayata	Dennstaedtiaceae	P	Kirschner & Wang 2015
<i>Pseudocercospora nephrolepidis</i> R. Kirschner	<i>Nephrolepis cordifolia</i> (L.) C. Presl (= <i>Nephrolepis auriculata</i> (L.) Trimen)	Nephrolepidaceae	P	Kirschner & Chen 2007
<i>Pseudocercospora pteridicola</i> U. Braun & Y.L. Guo	<i>Pteris alata</i> Lam. (= <i>Pteris semipinnata</i> L.)	Pteridaceae	P	Kirschner & Wang 2015
<i>Pseudocercospora pteridophytophila</i> Goh & W.H. Hsieh	<i>Cyclosorus parasiticus</i> (L.) Farw.	Thelypteridaceae	P	Hsieh & Goh 1990, Kirschner & Liu 2014
<i>Pseudocercospora rumohrae</i> Goh & W.H. Hsieh	<i>Arachniodes amabilis</i> (Blume) Tindale (= <i>Rumohra amabilis</i> (Blume) Ching)	Dryopteridaceae	P	Hsieh & Goh 1990
<i>Pseudocercospora tectariae</i> R. Kirschner	<i>Tectaria harlandii</i> (Hook.) C.M. Kuo	Tectariaceae	P	Kirschner & Wang 2015
<i>Pseudocercospora thelypteridis</i> Goh & W.H. Hsieh	<i>Metathelypteris laxa</i> (Franch. & Saw.) Ching (= <i>Thelypteris laxa</i> (Franch. & Saw.) Ching)	Thelypteridaceae	P	Hsieh & Goh 1990
<i>Pseudocercospora plagiogyriae</i> Sawada ex Goh & W.H. Hsieh	<i>Plagiogyria euphlebia</i> (Kunze) Mett.	Plagiogyriaceae	P	Hsieh & Goh 1990
<i>Rhizoctonia solani</i> J.G. Kühn	<i>Marsilea minuta</i> L. (= <i>Marsilea crenata</i> C. Presl)	Marsileaceae	P	Sawada 1919



Table 1. Continued

Fungal species	Host species	Host family	Bio-logy	Reference
<i>Rhynchosporium dryopteridis</i> Sawada	<i>Dryopteris</i> sp.	Dryopteridaceae	P	Sawada 1944
<i>Simplicillium lanosoniveum</i> (J.F.H. Beyma) Zare & W. Gams	<i>Salvinia auriculata</i> , <i>Salvinia molesta</i> D.S. Mitch	Salviniaceae	P	Chen <i>et al.</i> 2008
<i>Uredinopsis athyrii</i> Kamei	<i>Athyrium</i> sp.	Athyriaceae	P	Sawada 1959
<i>Uredinopsis hashiokae</i> Hirats. f.	<i>Pteridium aquilinum</i> (L.) Kuhn	Dennstaedtiaceae	P	Farr & Rossman 2017
<i>Uredinopsis macrosperma</i> (Cooke) Magnus	<i>Pteridium aquilinum</i> (L.) Kuhn (= <i>P. aquilinum</i> (L.) Kuhn var. <i>japonicum</i> Nakai)	Dennstaedtiaceae	P	Farr & Rossman 2017
<i>Uredinopsis pteridis</i> Dietel & Holw.	<i>Pteridium aquilinum</i> (L.) Kuhn (= <i>P. aquilinum</i> (L.) Kuhn var. <i>japonicum</i> Nakai)	Dennstaedtiaceae	P	Farr & Rossman 2017
<i>Venustosynnema reniformisporum</i> R. Kirschner & L.C. Liu	<i>Selaginella moellendorffii</i> Hieron.	Selaginellaceae	S	Kirschner & Liu 2014
<i>Xylodon echinatus</i> (Yurchenko & Sheng H. Wu) Riebesehl, Yurchenko & Langer	Dead fern stem	Unknown	S	Yurchenko <i>et al.</i> 2013
<i>Zasmidium dicranopteridis</i> R. Kirschner	<i>Dicranopteris linearis</i> (Burm. f.) Underw.	Gleicheniaceae	P?	Kirschner & Liu 2014

Y.M. Ju *et al.* was discovered as causative agent of wilt disease of *Sphaeropteris lepifera* (J. Sm. ex Hook.) R.M. Tryon in Taiwan (Fu *et al.*, 2013). Phylogenetically it belongs to the large genus *Diaporthe* which contains numerous pathogens mainly of woody plants, but also can grow as saprobes and endophytes. *Mixia osmundae* (Nishida) C.L. Kramer is the single species of Mixiomycetes. It is specific on leaves of *Osmunda* and has an isolated rather basal position among the Basidiomycota (Bauer *et al.*, 2006). This is the single species occurring in Taiwan representing a “primitive” parasitic fungus on a “primitive” fern, whereas *Pseudocercospora* species on ferns and seed plants appeared scattered in phylogenetic analyses (Kirschner and Liu, 2014), which might indicate frequent host jumps during speciation rather than cospeciation with the host plants. Since DNA data are not available for the majority of fungal species, careful morphological identification is necessary before molecular studies make sense, but on the other side molecular approaches allow new insights which are not possible with morphology alone. Fern-specific pathogens from other systematic groups, such as Asterinaceae and Parmulariaceae (Ascomycota) have not yet been recorded from Taiwan, and the phylogenetic relationships of the fern-inhabiting species are largely unknown.

Classification of ferns, however, has been unsettled over the last decades including frequent changes to concepts of families and genera (Kramer *et al.*, 1990 followed in Knapp, 2011; Smith *et al.*, 2006; Frey *et al.*, 2009; Christenhusz *et al.*, 2011; Rothfels *et al.*, 2012; PPG1, 2016). In contrast to fungi parasitic on specific seed plants, which can often be conveniently identified based on the knowledge of the host genera and families, this approach might be misleading for the fungi on ferns. The continuous progress of knowledge of Taiwanese fern plants (Knapp, 2011, 2014; Knapp and Hsu, 2017)

is a highly advantageous condition for clarifying the identities and host specificities of fern-parasitic fungi. According to the family classification in Table 1, most fungi were found in the Cyatheaceae (11 fungi) and Dryopteridaceae (13 fungi), whereas the other fern families contained less than 10 species. Dennstaedtiaceae with 7 fungi was the third-richest family. One to six fungi were recorded for the other fern families.

The diversity of saprobic fungi on certain fern taxa is surely underrepresented in general as well as in Table 1. Their specificity on ferns is not as high as in plant parasites. The decomposition stage of decaying ferns makes identification of the plant difficult so that the specificity of fungi decomposing dead ferns is less well known. Among the saprobic fungi, species of “discomycetes” (mainly Helotiales, Ascomycota) contain specialized decomposers of ferns (ca. 3.5%). Several groups of Basidiomycota contain species predominantly saprobic on ferns, such as Agaricales (Miersch and Lehmann, 2015; Olariaga *et al.*, 2015), “Corticaceae” (Gilbertson and Hemmes, 1997; Hjortstam and Larsson, 1997; Langer, 1994) and “Clavariaceae” (Corner, 1950). Field collection of these fungi, however, is usually focused on the ground or dead wood instead of fern vegetation so that records of fern-associated specimens tend to be underrepresented (Langer, 1994). New records of such fungi are expected for Taiwan. Other fungi recorded from Taiwan (five species) are rather unspecific saprobes which can be detected on other substrates than ferns as well.

#### Biological resources and data

Several species of fern-inhabiting fungi are known only from the type collection and lack cultures and DNA data. Historical type collections of these fungi from Taiwan are available at the herbaria NCHUPP (Taichung), PPMH (Taipei), and TNS (Tsukuba, Japan).



Our own specimens of fern-associated fungi were all deposited at TNM (Taichung). Species identification of obligate plant parasites in the first instance relies on the correct host identification. The particular contribution of TNM is its administration of a specimen database with photos of the leaf specimens so that the identification of the host ferns can be roughly verified online (<http://collection.nmns.edu.tw/scripts/fungi.dll>).

Numerous specimens of the four saprobic *Lachnum* species listed in Table 1 are also located in TNM. A species of corticioid Basidiomycota, *Tubulicium dussii* (Pat.) Oberw. ex Jülich on a tree fern, was traced in the TNM specimen database, but not in a publication.

It is difficult to rely only on the original morphological descriptions for identification. In particular, conidiophore lengths can vary considerably between different specimens of the same species. It is necessary to have further biological resources of species previously being unknown or only known from the type description for revising their morphology and analyzing DNA sequences. Because of a misleading morphological description and confusing host synonymies, *Pseudocercospora christellae* Phengs. *et al.* was believed to be unique for the genus *Christella* (Phengsintham *et al.*, 2010). The host name, however, *Christella parasitica* (L.) H. Lév. was an invalid combination; the valid one was *Cyclosorus parasiticus* (L.) Farw. After revision of the type specimen of *Ps. pteridophytophila* Goh & W.H. Hsieh and new collection on *Cyclosorus parasiticus* in Taiwan, *Ps. christellae* revealed to be a synonym of *Ps. pteridophytophila* (Kirschner and Liu, 2014). The taxonomy of a further fungus on *Cyclosorus* hosts which might be confused is treated below.

Biodiversity data about fungi on plants in Taiwan are made available publicly by the Fungus-Host-Distribution database in the USA (<https://nt.arsgrin.gov/fungaldatabases>) and the TaiBIF database in Taiwan (Taiwan Biodiversity Information Facility; <http://taibif.tw/>). New taxa from Taiwan have been registered in Index Fungorum (<http://www.indexfungorum.org>). The databases contain numerous names proposed by the pioneer mycologist K. Sawada in Taiwan, but many organisms behind these names are still largely unknown due to lack of revision.

Living strains were deposited as scientific vouchers at BCRC (Bioresource Collection and Research Centre, Hsinchu; <https://catalog.bcrc.firdi.org.tw/>), which also hosts websites with illustrations and descriptions of fungi from Taiwan (<http://www.bcrc.firdi.org.tw/fungi/index.jsp>). Although strain deposit has become very bureaucratic due to recent chronic underfunding through the government, strain deposit is indispensable to science and ex-situ nature conservation.

DNA sequences are deposited at GenBank (<https://www.ncbi.nlm.nih.gov/nucleotide/>). DNA sequence

alignments are occasionally deposited in TreeBASE. Such deposit of complex biodiversity data is a novel contribution compared to most mycological studies from the 20<sup>th</sup> century in Taiwan. For illustrating the chances and challenges of investigating fungi on ferns in Taiwan, some concrete examples derived from the literature and unpublished specimens are presented below.

## MATERIALS AND METHODS

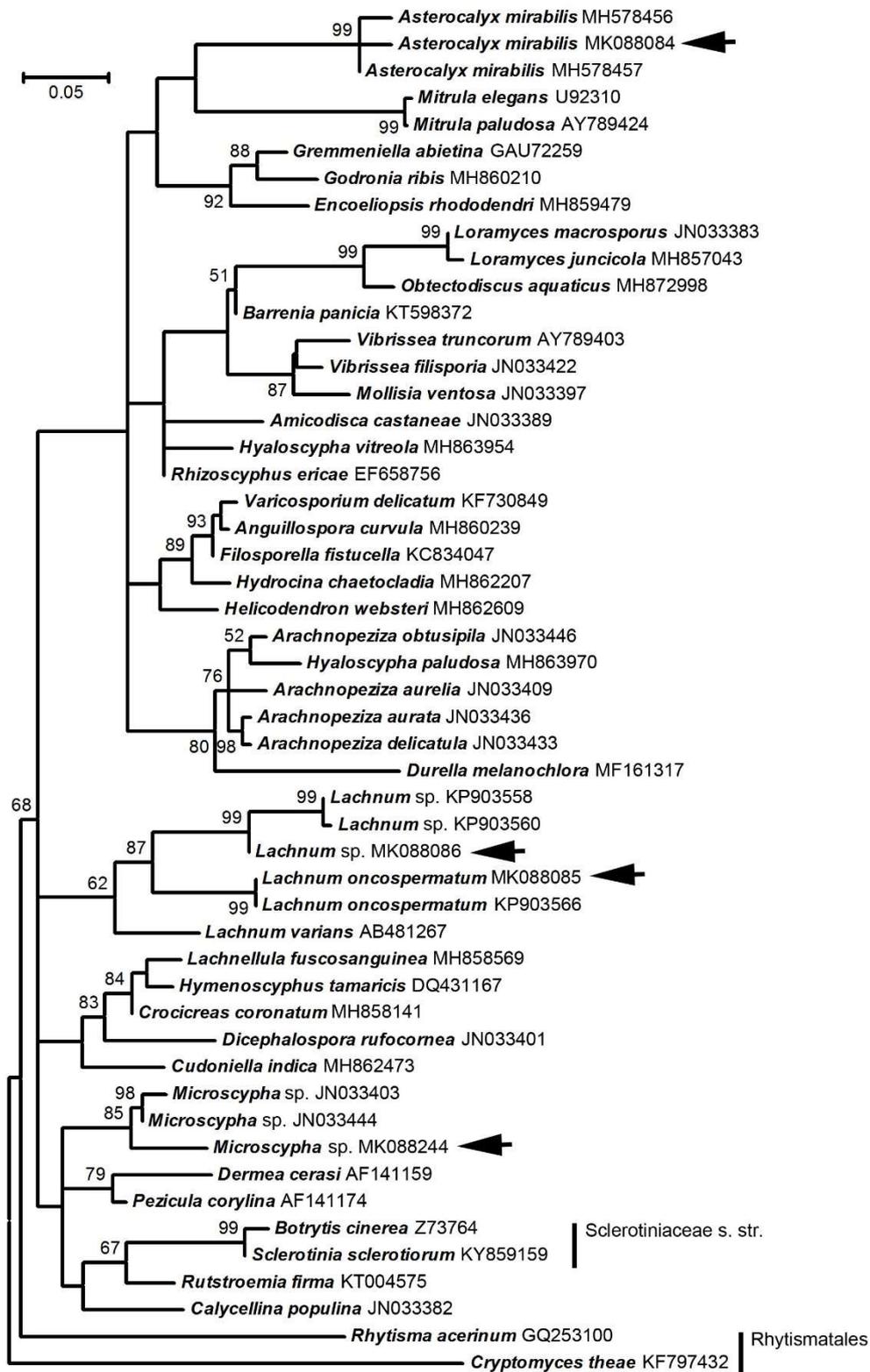
Further specimens of fungi on ferns were collected in Taiwan. Their materials and associated data were deposited in the same collections and databases as outlined in the above review and specified in detail below. DNA was extracted and amplified as in Kirschner and Liu (2014); internal transcribed spacer (ITS) sequences were deposited at GenBank. Cultures were made from the Helotiales except *Asterocalyx mirabilis* and used for DNA isolation and amplification; attempts to cultivate a new species failed. DNA was extracted from ascomata of *A. mirabilis*; since the poor quality of the ITS sequence would require a lot of editing, only a shortened sequence was submitted to GenBank and used for a phylogenetic estimate with Maximum Likelihood with 1000 replicates with MEGA7 (Kumar *et al.*, 2016) (Fig. 1).

## TAXONOMIC TREATMENTS

Some new findings about three groups of fungi presented below rather illustrate our lack of knowledge and the urgent need of basic mycological investigation of fern-associated fungi as indicated above. The first group is based merely on literature research on Mycosphaerellales (Ascomycota). The second group deals with discomycetes of the order Helotiales (Ascomycota) (Figs. 1–3) which are ecologically clearly defined as specific saprobic decomposers of dead plant material. These examples mainly illustrate the lack of morphological revision of this group in the tropics. The third example is a new species (Fig. 2D–G) with unknown relationship within the Ascomycota and with unknown ecological function.

### Mycosphaerellales

An illegitimate homonym (according to Index Fungorum), *Pseudocercospora christellae* Haldar & J.B. Ray on *Christella dentata* (Forssk.) Brownsey & Jermy (*Cyclosorus dentatus* (Forssk.) Ching) from India (Haldar & Ray 2011) was published as a later homonym of *Ps. christellae* Phengs. *et al.* (Phengsintham *et al.*, 2010), which itself is a synonym of *Ps. pteridophytophila* (see above). *Pseudocercospora christellae* Haldar & J.B. Ray differs from *Ps. pteridophytophila* by its external hyphae giving rise to conidiophores and conidia and also sufficiently differs



**Fig. 1.** Molecular phylogenetic estimate of ITS sequences of Helotiales and two sequences of Rhytismatales (with GenBank accession numbers given behind the species name) by Maximum Likelihood method based on the Kimura 2-parameter model (Gamma distributed with Invariant sites) conducted in MEGA7 (Kumar *et al.*, 2016). New sequences indicated with arrow. Taxon sampling was largely reproduced from Han *et al.* (2014) and Razikin (2016).



from other fungi on ferns (Braun *et al.*, 2013) so that a new name is proposed here *Pseudocercospora cyclosori* Haldar & J.B. Ray ex R. Kirschner, **nom. nov.**, **Index Fungorum**: IF556310; replaced synonym: *Pseudocercospora christellae* Haldar & J.B. Ray, J. Mycol. Res. 49(1): 152 (2011), nom. illegit., Art. 53.1, non *Pseudocercospora christellae* Phengs., McKenzie, K.D. Hyde & U. Braun, in Phengsintham, Chukeatirote, McKenzie, Moslem, Hyde & Braun, Mycosphere 1(3): 207 (2010).

## Helotiales

*Asterocalycella* Höhn. ex R. Kirschner, **nom. nov.**

**Index Fungorum**: IF556311

Replaced synonym: *Asterocalyx* Höhn., Sber. Akad. Wiss. Wien, Math.-naturw. Kl., Abt. 1, 121: 402 (1912), nom. illegit., Art. 53.1, non *Asterocalyx* Ettingsh. Foss. Fl. Leoben, (1): 281 (1888)

**Type species**: *Asterocalycella mirabilis* (Höhn.) R. Kirschner, **comb. nov.** **Fig. 2A**

**Index Fungorum**: IF556312

**Basionym**: *Asterocalyx mirabilis* Höhn., Sber. Akad. Wiss. Wien, Math.-naturw. Kl., Abt. 1 121: 402 (1912)

**Specimens examined**: On dead rachis of *Sphaeropteris lepifera*, Taiwan, Taipei, Yangmingshan, 4. Apr. 2015, R. Kirschner 4185 (TNM); Taitung, Donghe Township, Dulan Mountain, ca. 600 m, 7. Feb. 2018, R. Kirschner 4605, ITS sequence GenBank MK088084; white mutant on the same substrate R. Kirschner 4606 (TNM).

*Lachnum oncospermatum* (Berk. & Broome) M.L. Wu & J.H. Haines, in Wu, Haines & Wang, Mycotaxon 67: 346 (1998). **Fig. 2B, C**

**Specimen examined**: On dead petiole of *Alsophila spinulosa* (Wall. ex Hook.) R.M. Tryon, Nantou County, Ren'ai Township, Huisun Forest, Shanlan Trail, 11. Mar. 2018, R. Kirschner 4626 (TNM). Living strain BCRC FU30992. ITS sequence GenBank MK088085.

*Lachnum* sp. (?= *Lachnum* sp. 1 sensu Razikin 2016)

**Specimen examined**: On dead petiole of *Alsophila spinulosa* (Wall. ex Hook.) R.M. Tryon, Nantou County, Ren'ai Township, Huisun Forest, Shanlan Trail, 11. Mar. 2018, R. Kirschner 4620 (TNM). Living strain BCRC FU30991. ITS sequence GenBank MK088086.

*Microscypha* sp.

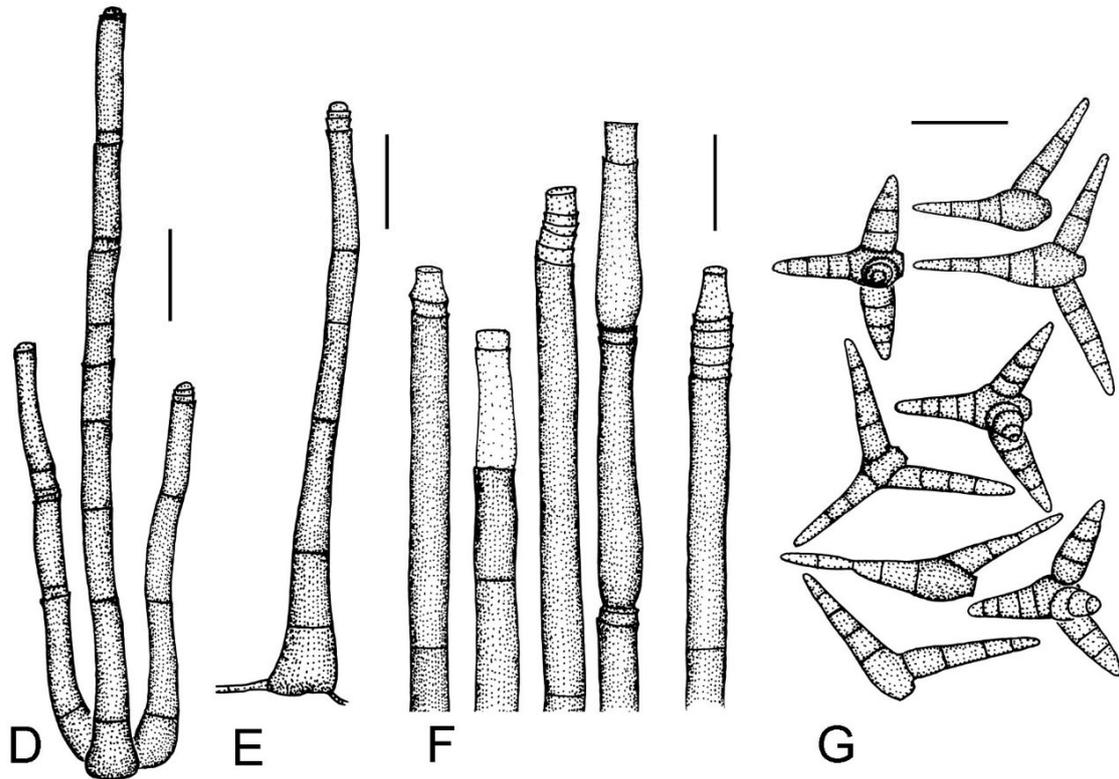
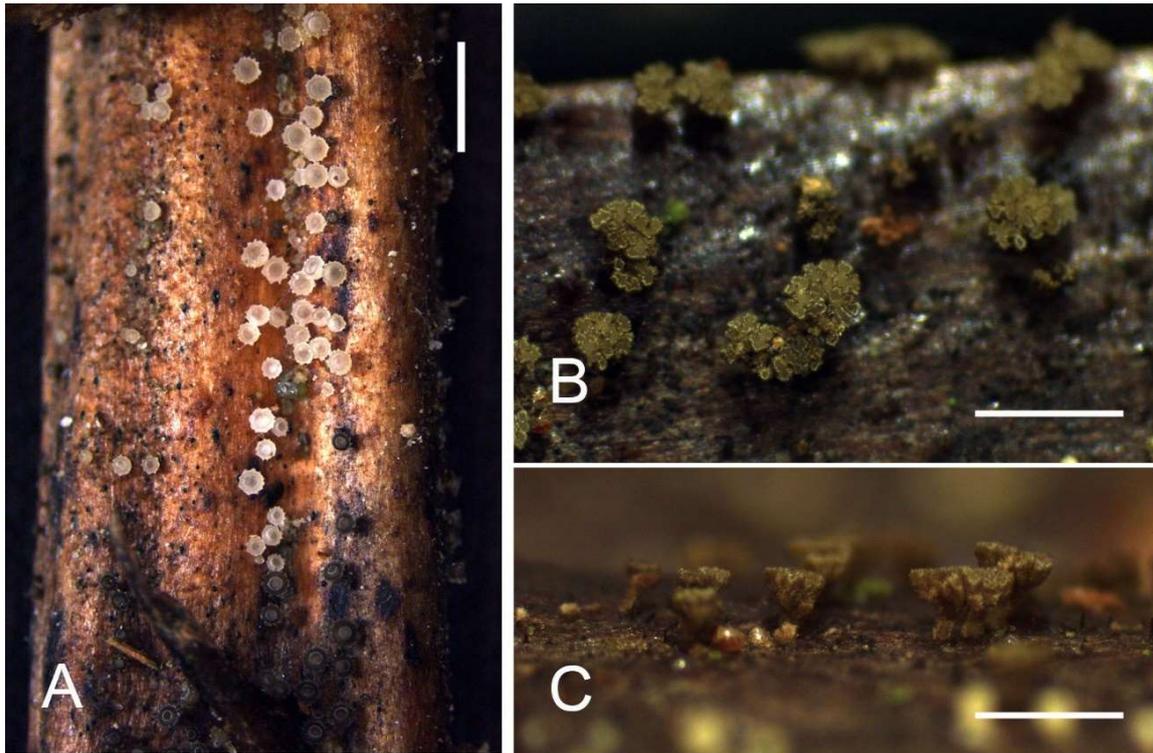
**Specimen examined**: On dead petiole of *Alsophila spinulosa* (Wall. ex Hook.) R.M. Tryon, Nantou County, Ren'ai Township, Huisun Forest, Shanlan Trail, 11. Mar. 2018, R. Kirschner 4627 (TNM). Living strain BCRC FU30993. ITS sequence GenBank MK088087; LSU rDNA sequence GenBank MK088244.

**Notes**: According to **Index Fungorum** (<http://www.indexfungorum.org/>), the generic name *Asterocalyx* Höhn. was illegitimate because it was a synonym of the fossil plant *Asterocalyx* Ettingsh. (1888), which was confirmed by checking the by International Fossil Plant Names Index (<http://fossilplants.info>). Therefore, the new name *Asterocalycella* and the new

combination *Asterocalycella mirabilis* are proposed. This fungus was recorded from Taiwan by Wu (2002) with detailed information on morphology and distribution on dead petioles and rachises of Cyatheaceae, namely *Alsophila spinulosa* (Wall. ex Hook.) Tryon and *Sphaeropteris lepifera* (J. Sm. ex Hook.) Tryon, but also of *Angiopteris lygodiiifolia* Rosenst. (Marattiaceae), all from northern Taiwan (Taipei, Yilan). Our specimen from southeast Taiwan (Pingtung) contained unpigmented (white) ascospores on the same substrate as the usually pigmented ones and are considered albino mutants which have not been recorded previously for this species (Fig. 2A).

The former genus *Asterocalyx*, hitherto only containing the type species *A. mirabilis*, and a neotropical species, *A. ecuadorensis* S.E. Carp. & Dumont, in the past was placed in Bulgariaceae, Helotiaceae, Leotiaceae, Sclerotiniaceae, and Tribliaceae (Dumont and Carpenter, 1978). von Höhnel (1912) described the growth of the fungus as tightly packed cells inside the cells of the plant epidermis and lower tissue, followed by forming a plectenchymatic layer between the epidermis and cuticle. Ascospores penetrate the cuticle of the plant. This feature was confirmed and considered the stroma typical of Sclerotiniaceae by Dumont and Carpenter (1978), whose concept was generally adopted by subsequent authors. Our phylogenetic estimate based on internal transcribed spacer (including 5.8S ribosomal RNA gene) sequences of Helotiales (with Rhytismatales being outgroup) shows that our sequence from Taiwan forms a highly supported clade with two sequences of the same species from Australia without any significant relationship to Sclerotiniaceae or any other family (Fig. 1). Due to limited taxon sampling and short DNA sequences, we are not able to suggest any other more appropriate family for accommodation of *Asterocalycella* in the Helotiales. The deviations between our ITS sequence and the Australian ones might be partially caused by the difficulty to obtain a technically good quality from the ascospores directly compared to those from pure cultures. For obtaining longer sequences for evaluating the phylogenetic position of this genus, cultures should be prepared from freshly specimens.

The other three species belonging to three different genera were found on the same substrate, a dead leaf of *Alsophila spinulosa* in Taiwan. From these species, we obtained cultures and ITS sequences in standard quality. As shown in Fig. 1, our DNA data support our identification of *Lachnum oncospermatum* with data from Malaysia (Razikin, 2016) which was recorded as decomposer of dead fern leaves in Taiwan by Wu *et al.* (1998). *Lachnum* sp. from Taiwan was closely related to *Lachnum* sp. 1 from dead leaf of Cyatheaceae in Malaysia (Razikin, 2016). Our specimen of *Microscypha* sp. from the same substrate was closely related to



**Fig. 2.** Three species of fungi on ferns. **A.** *Asterocalycella mirabilis*, brown and white ascomata on decaying petiole of *Sphaeropteris lepifera* (R. Kirschner 4606). Scale bar = 2 mm. **B, C.** Composed apothecia of *Lachnum oncospermatum* on decaying petiole of *Alsophila spinulosa* (R. Kirschner 4626) seen from the top (**B**) and the side (**C**). Scale bars = 1 mm. **D–G.** *Teratosperma dicranopteridis* (from type material). **D.** Three-fasciculate conidiophores. **E.** Solitary conidiophore. **F.** Conidiophore apices. **G.** Conidia (with hila mostly aligned to the right side). Scale bars = 20  $\mu$ m, except for F = 10  $\mu$ m.



*Microscypha* sp. from ferns in Japan (Han *et al.*, 2014). According to the conventional classification, the three genera belong to Hyaloscyphaceae, which are, however, considered polyphyletic as well as the above mentioned Sclerotiniaceae (Han *et al.*, 2014). Our collections show that several species of fern-specific saprobic Helotiales belonging to different genera can occur together on the same leaf and that DNA data indicate their wide distribution in Asia (Han *et al.*, 2014; Razikin, 2016), but are insufficient for exact species identification because a multiphasic revision of these fungi is lacking. At the present stage, we deposited some specimens, living strains and DNA sequences in the hope that by gradual accumulation of materials, specialists for the systematics of these fungi may come to a resolution of the taxonomic boundaries of species, genera, and families.

### Ascomycota, incertae sedis

*Teratosperma dicranopteridis* R. Kirschner, **sp. nov.**

芒萁畸臂孢 Fig. 2D-E

**Index Fungorum:** IF556313

**Type:** on discolored living and dead leaves of *Dicranopteris linearis* (Burm. f.) Underw., mixed with inconspicuous hyphae of other fungi, TAIWAN, Nantou County, Yuchi Township, Lienhuachi, 17. Mar. 2016, leg. Pei-Huan Lee, R. Kirschner 4235 (TNM, **holotype**).

**Description:** Hyphae epi- and hypophyllous, effuse and inconspicuous, superficial, pale brown, smooth, 1–2  $\mu\text{m}$  wide. Conidiophores solitary or in groups of three, macronematous, dark brown, paler towards the apex, smooth except for scattered percurrent extensions, erect, straight or slightly flexuous, unbranched, rounded and swollen to 9–13  $\mu\text{m}$  wide at base, (5–)6–8(–11)  $\mu\text{m}$  above the first cell, (53–)88–190(–230)  $\mu\text{m}$  long ( $n=30$ ), ca. 2–13-septate, septa approx. 15–25  $\mu\text{m}$  apart. Conidiogenous cells terminal, becoming intercalary by percurrent extension, subcylindrical, dark brown, paler towards the apex, with up to 6 percurrent extensions at the apex, (20–)25–43(–50)  $\mu\text{m}$  long, (4–)4.5–5(–6)  $\mu\text{m}$  wide at the widest part, conidiogenous locus narrowed to 3–4  $\mu\text{m}$ . Conidia medium brown, paler towards the apices, smooth, composed of a main body, 3–5-septate, (24–)26–35(–40)  $\times$  (6–)7.5–9(–10)  $\mu\text{m}$  ( $n=30$ ), with basal hilum 4  $\mu\text{m}$  wide, and 1–3 lateral arms attached at the center of the basal cell and pointed downwards, 2–4-septate, (13–)16–26(–30)  $\times$  5–6(–7)  $\mu\text{m}$  ( $n=30$ ). Arms at the tip ca. 2–3  $\mu\text{m}$ , germinating with a 1  $\mu\text{m}$  wide, very pale brown hypha arising from the apex of the terminal cell; secondary conidium production not found. Teleomorph not found.

**Notes:** The genus *Teratosperma* Syd. & P. Syd. was based on the hyphomycete *T. singulare* by H. & P. Sydow (Sydow 1909). It is defined by macronematous unbranched dematiaceous conidiophores terminating into percurrent conidiogenous cells with conspicuous

annellations and conidia with branches arising from the basal cell (Ellis, 1957). Since teleomorphic connections have neither been indicated by cultivation experiments nor DNA data, the genus is classified as “incertae sedis” among Ascomycota (Index Fungorum, <http://www.indexfungorum.org>). About ten species have been assigned to the genus, often more or less conspicuously associated with other fungi on living plants or on dead plant tissues. The most important generic characteristics are annellidic conidiogenesis from unbranched pigmented conidiophores and lateral conidial appendages, if present, arising from the basal (exceptionally suprabasal) cell of the conidium (Ellis, 1957).

The transfer of *T. meliolae* Hansf. to *Hansfordiella* is justified because of the particular structure of the conidium with oblique septa and the lack of annellidic conidiogenesis (Hughes, 1951). The combination *Podocosis anacardii* (Hansf.) S. Hughes, however, is not accepted here, but following Ellis (1957), the original basionym *T. anacardii* Hansf. is considered more appropriate. *Teratosperma oligocladum* Uecker *et al.* (1980) is excluded here from *Teratosperma*, because the lateral arms arise consistently from suprabasal cells and evidence of annellidic conidiogenesis is lacking. The species is better placed in *Pentaster* Koukol (Koukol and Rihova, 2013), but we did not investigate type specimens and cannot conclude whether *T. oligocladum* and *P. cepaeophilus* Koukol may not only belong to the same genus, but also be conspecific. Recent transfers of *T. litchii* Matsush. and *T. subulatum* (Cooke & Ellis) S. Hughes to *Solicorynespora* and *Repetophragma*, respectively, are preliminarily adopted here as long as the absence of molecular data does not allow more conclusive generic placements. The main diagnostic features of the 11 species accepted here in *Teratosperma* are listed in Table 2.

The new species is most similar to *T. anacardii* and *T. singulare*, but its conidial size is intermediate between both species, i.e. larger than that of *T. anacardii* and smaller than that of *T. singulare*. Furthermore, *T. anacardii* is lichenicolous (Hawksworth, 1979), and the minimum conidium length of the foliicolous *T. singulare* is 50  $\mu\text{m}$ , whereas the maximum is 40  $\mu\text{m}$  in the new species. Aseptate lateral appendages as occurring in *T. anacardii* and *T. singulare* were not found.

The new species and related ones can be distinguished clearly by morphology, but due to the lack of further investigation, their relationships on the levels of family, order, and class are unknown. Our specimen was found to overgrow living leaves of *D. linearis* without being connected to plant disease symptoms, but could not be cultivated. Because of the presence of lichenicolous/fungicolous species in the same genus, some kind of dependence from nutrients provided by other fungi may also occur in the present species.

**Table 2.** Conidial characteristics of the newly proposed and accepted species of *Teratosperma* compiled from the literature.

<i>Teratosperma</i> species	Main body of conidium		Lateral arms of conidium		
	Number of septa	Size (µm)	Number	septa	Size (µm)
<i>T. dicranopteridis</i>	3–5	(24–)26–35(–40) × (6–)7.5–9(–10)	1–3	2–4	(13–)16–26(–30) × 5–6(–7)
<i>T. anacardii</i> Hansf.	(2–)3(–4) <sup>b</sup>	(17–)20–30(–35) × 4.5–7 <sup>b</sup>	1–2(–3) <sup>b</sup>	0–2 <sup>a</sup>	2–10(–18) × 2–3 <sup>b</sup>
<i>T. appendiculatum</i> (S. Hughes) M.B. Ellis <sup>a</sup>	1–4 (mostly 3)	15–50 × 7–9	1	0	4–6 × 4.5–5.5
<i>T. cornigerum</i> (Ellis & Everh.) M.B. Ellis	4–12 <sup>a</sup>	70–200 × 14–17 <sup>a</sup> , 115–145 × 12–14 <sup>e</sup>	1–3 <sup>a</sup>	0–2 <sup>a</sup>	10–50 × 2–4 <sup>a</sup> , 10–25 × 4.5–6 <sup>e</sup>
<i>T. lichenicola</i> D. Hawksw <sup>b</sup>	2(–3)	18–25 × 5–6	0	–	–
<i>T. macrosporium</i> W.P. Wu <sup>c</sup>	17–55	100–300 × 5–7	0	–	–
<i>T. microsporium</i> P.M. Kirk <sup>d</sup>	4(–5)	Up to 45 × 3–4	1	0	1–2 × 1
<i>T. pulchrum</i> (Ellis & Everh.) M.B. Ellis <sup>c</sup>	8–9	100–125 × 18–24	Mostly 3	0	4–6 × 5–7
<i>T. sclerotivorum</i> (Uecker, W.A. Ayers & P.B. Adams) S. Hughes <sup>c</sup>	8–19	55–130 × 5–6.5 <sup>c</sup>	0	–	–
<i>T. singulare</i> Syd. & P. Syd.	3–10	50–65(–90) × 13–15 <sup>c</sup> , 60–130 × 17–22 <sup>a</sup>	1–3	0–3	10–25 × 8–10 <sup>c</sup> , up to 55 × 5–12 <sup>a</sup>
<i>T. uniappendiculatum</i> Matsush.	6–9	110–250 × 17–22	1	0–1	18–23 × 5–7

<sup>a</sup>Ellis (1957), <sup>b</sup>Hawksworth (1979), <sup>c</sup>Wu & Zhuang (2005), <sup>d</sup>Kirk (1985), <sup>e</sup>Xia *et al.* (2016)

## DISCUSSION

Taiwan provides a unique environment for studies of ferns and associated organisms because of the high natural resources of fern plants on the one hand and high-tech research facilities on the other. Among tropical countries, Taiwan is leading with respect to mycological exploration on fern plants. Many more species await discovery, since only ca. 60 species of the estimated 800 to 8,000 species are known. For resolving the remaining unknown species, parasitic fungi are most quickly addressable because of their host specificity and often conspicuous diseases symptoms, followed by saprobic fungi. Study of endophytic and mycorrhiza fungi needs to focus on a few selected fern species. While in endophytic fungi, numerous new strains and a broad range of fungal species can be expected, mycorrhiza fungi pose major problems because of their cryptic habitat and the need to confirm their mycorrhizal nature along with special techniques for species identification.

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