TAXONOMY AND PHYLOGENY OF OPHIOCORDYCIPITACEAE AND A NOVAL FAMILY POLYCEPHALOMYCIPITACEAE

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DOCTOR OF PHILOSOPHY

IN

BIOSCIENCES

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Yuanpin Xiao

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ABSTRACT

A novel family, Polycephalomycetaceae, is segregated from Ophiocordycipitaceae to accommodate three genera, *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*, based on morphologic and phylogenetic analyses. Most species in this family have a vast range of hosts since they parasitize insects and hyperparasite fungi. The sexual morph of Polycephalomycetaceae is characterized as producing stromatic ascomata, long stipe, thick peridium, and cylindrical secondary spores. Meanwhile, its asexual morph is described as having a colony on the host surface or synnemata with stipes on the host, one or two types of phialides, and cylindrical to fusiform conidia. Moreover, these three genera have formed an independent clade, distinct from the other genera of Ophiocordycipitaceae, while also having a close relationship with Clavicipitaceae.

Polycephalomyces is indicated as the type genus as it is the oldest genus name in the family. All the species of the novel family are in the table listed with the main morphological characters. Six novel species including *Polycephalomyces albiramus*, *Pleurocordyceps parvicapitata*, *Pleurocordyceps lanceolatus*, *Pleurocordyceps nutantis*, *Pleurocordyceps aurantiacus* and *Pleurocordyceps marginaliradians* are introduced in this study based on morphologic and phylogenetic analyses. One new combination *Perennicordyceps elaphomyceticola* and four new hosts are recorded in this study.

Ophiocordycipitaceae is a family in the Hypocreales order and comprises eight genera, *Drechmeria*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Ophiocordyceps*, *Paraisaria*, *Purpureocillium*, and *Tolypocladium*, with numerous entomopathogenic and mycoparasitic fungi. However, the relationship of the genera in Ophiocordycipitaceae has not been investigated since the latter was established. The classification of Ophiocordycipitaceae genera or species has been problematic and challenging due to their complex morphologic details and insufficient molecular data. Thus, in this study the taxonomic and phylogenetic relationships of the genera were revised based on morphologic and multi-gene phylogenetic analysis. Type and new species illustrations are provided.

35 novel species are introduced in this study based on morphology and phylogenetic analyses: *Polycephalomyces albiramus*, *Pleurocordyceps parvicapitata*, *Pleurocordyceps lanceolatus*, *Pleurocordyceps nutantis*, *Pleurocordyceps aurantiacus*, *Pleurocordyceps marginaliradians*, *Ophiocordyceps oecophyllae*, *Ophiocordyceps neoacicularis*, *Ophiocordyceps unicistroma*, *Ophiocordyceps divitis*, *Ophiocordyceps biculcitulistipita*, *Ophiocordyceps thanathonensis*, *Ophiocordyceps yuntaiensis*, *Ophiocordyceps neocylindrocpora*, *Ophiocordyceps pseudoformicarum*, *Ophiocordyceps mandariniae*, *Ophiocordyceps fusiformispora*, *Ophiocordyceps vespae*, *Ophiocordyceps pseudoelongata*, *Ophiocordyceps longisynnema*, *Ophiocordyceps karstii*, *Ophiocordyceps cossidarum*, *Ophiocordyceps sporangifera*, *Ophiocordyceps issidarum*, *Ophiocordyceps globiceps*, *Ophiocordyceps cylindrospora*, *Ophiocordyceps multibrachiata*, *Ophiocordyceps neoacicularis*, *Paraisaria tettigonia*, *Purpureocillium albosynnematum*, *Purpureocillium clavatsis*, *Tolypocladium cucullae*, *Tolypocladium neoophioglossoides*, *Tolypocladium cautis*, *Tolypocladium rutilum*, *Tolypocladium graciliscucullae* and *Tolypocladium roburstipitatum*. 27 reference specimens with each type species of genera are indicated with morphological descriptions and molecular data. Moreover, this study provides a nearly exhaustive list of the species in Ophiocordycipitaceae. A phylogenetic tree using a combined matrix of six genetic markers (ITS, nrSSU, nrLSU, tef-1α, rpb1 and rpb2) was

constructed explore the intergeneric relationships among these species and these are discussed.

Keywords: Ophiocordycipitaceae, Polycephalomycetaceae, Checklist, Phylogeny, Taxonomy, Genera, Species

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	**(3)**
ABSTRACT	**(6)**
LIST OF TABLES	**(11)**
LIST OF FIGURES	**(13)**
ABBREVIATIONS AND SYMBOLS	**(19)**
CHAPTER	
1 INTRODUCTION	**1**
1.1 Introduction to Clavicipitoid Fungi	1
1.2 Introduction to Ophiocordycipitaceae	2
1.3 Research Objectives	15
1.4 Research Contents	15
2 TAXONOMIC AND PHYLOGENETIC PLACEMENT OF A NOVEL FAMILY POLYCEPHALOMYCETACEAE	**16**
2.1 Introduction to Polycephalomycetaceae	16
2.2 Materials and Methods	20
2.3 Results	30
2.4 Discussion	115

TABLE OF CONTENTS (continued)

	Page
CHAPTER	
3 TAXONOMIC AND PHYLOGENETIC PLACEMENT OF OPHIOCORDYCIPITACEAE AND NOVEL SPECIES	**120**
3.1 Introduction	120
3.2 Materials and Methods	123
3.3 Results	150
3.4 Discussion	428
4 CONCLUSIONS	**432**
4.1 Overall Conclusion	432
4.2 Research Advantages	435
4.3 Future Work	436
4.4 Publications	436
REFERENCES	**440**
APPENDICES	**469**
APPENDIX A CHEMICAL REAGENTS AND MEDIA	470
APPENDIX B ABSTRACT OF PUBLICATIONS	472
CURRICULUM VITAE	**487**

LIST OF TABLES

Table	Page
2.1 Sources of isolates and GenBank accession number of three families Clavicipitaceae, Ophiocordycipitaceae and Polycephalomycetaceae	22
2.2 Sources of isolates and GenBank accession number of the family Polycephalomycetaceae	26
2.3 Morphology of asexual morph species of the genus *Polycephalomyces*	59
2.4 Morphology characters of asexual morph species of *Perennicordyceps*	73
2.5 Morphology characters of sexual morph species of *Perennicordyceps*	74
2.6 Morphological comparison of asexual morph species of *Pleurocordyceps*	112
2.7 Morphological comparison of sexual morph species of the genus *Pleurocordyceps*	114
3.1 Sources of isolates and GenBank accession number of the family Ophiocordycipitaceae	124
3.2 Sexual morph species of *Ophiocordyceps*	290
3.3 Asexual morph species of *Ophiocordyceps*	321
3.4 Asexual morph species of the genus *Drechmeria*	329
3.5 Sexual morph species of the genus *Drechmeria*	331
3.6 Morphological characters of asexual morph species of the genus *Harposporium*	337
3.7 Morphological characters of sexual morph species of the genus *Harposporium*	342
3.8 Morphological characters of *Hirsutella* species	345
3.9 Morphological comparison of asexual morph species of *Hymenostilbe*	364

LIST OF TABLES (continued)

Table		Page
3.10	Morphological comparison of asexual morphic species of the genus *Paraisaria*	375
3.11	Morphological comparison of sexual morphic species of the genus *Paraisaria*	376
3.12	Morphological comparison of asexual morph species of the genus *Purpureocillium*	388
3.13	Morphological comparison of closely related species of *Tolypocladium cucullae*	398
3.14	Morphological comparison of asexual morph species of the genus *Tolypocladium*	421
3.15	Morphological comparison of sexual morph species of the genus *Tolypocladium*	423

LIST OF FIGURES

Figure	Page
1.1 Overview of taxa of Ophiocordycipitaceae	6
1.2 Parts of the ascomata and vertical sections of ascomata	7
1.3 Parts of the peridium and stipe sections of ascomata	9
1.4 Asci, ascospores, secondary spores	11
1.5 Synnemata of species of Ophiocordycipitaceae	12
1.6 Conidiophore and phialide of species of Ophiocordycipitaceae	13
2.1 Backbone schematic tree of the order Hypocreales	35
2.2 Phylogenetic tree of three families Clavicipitaceae, Ophiocordycipitaceae and Polycephalomycetaceae	36
2.3 Phylogenetic tree of Polycephalomycetaceae	38
2.4 Overview of fungus species of Polycephalomycetaceae	42
2.5 Perithecia of species of Polycephalomycetaceae	43
2.6 Asci, ascospores and secondary spores of species of Polycephalomycetaceae	44
2.7 Synnemata and colony of species of Polycephalomycetaceae	45
2.8 Phialides and conidia of species of Polycephalomycetaceae	46
2.9 Phylogenetic tree of *Polycephalomyces*	50
2.10 Morphology of Polycephalomyces formosus (Lectotype –: TNS-F-197965 a, b redrawn from Kobayasi, 1941; Neotype –: K(M) 187597, c redrawn from Seifert, 1985)	51
2.11 *Polycephalomyces formosus* (new record WFKQ03-20102201)	53
2.12 Morphology of *Polycephalomyces albiramus*	55
2.13 Morphology of *Polycephalomyces ditmarii*	57

LIST OF FIGURES (continued)

Figure		Page
2.14	Morphology of *Cordyceps pleuricapitata* (Paratype TNS-F-197965 a. redrawn from Sato et al., 2012), (b–e. redrawn from Kobayasi & Shimizu, 1982)	63
2.15	Morphology of *Perennicordyceps prolifica* (b–e: Redrawn from Kobayasi & Shimizu, 1963, a, f–h: Redrawn from Ban et al., 2009)	65
2.16	Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequence data of *Perennicordyceps*	66
2.17	Morphology of *Perennicordyceps elaphomyceticola* (sexual morph)	70
2.18	Morphology of *Perennicordyceps elaphomyceticola* (asexual morph)	71
2.19	Morphology of *Pleurocordyceps sinensis* (Holotype: HMAS 43720; a, redrawn from Chen et al., 1984. Ex-type: CN 80-2, b–e, redrawn from Wang et al., 2012)	78
2.20	Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of *Pleurocordyceps*	79
2.21	Morphology of *Pleurocordyceps sinensis* (new host ZNR0219102301)	82
2.22	Morphology of *Pleurocordyceps sinensis* (new host YYH18111710)	84
2.23	Morphology of *Pleurocordyceps sinensis* (new host YYH18120208)	86
2.24	Morphology of *Pleurocordyceps sinensis* (new host 520326MF865)	88
2.25	Morphology of *Pleurocordyceps sinensis* (new host FC20042304)	90
2.26	Morphology of *Pleurocordyceps parvicapitata* (holotype DG11)	93
2.27	Morphology of *Pleurocordyceps parvicapitata* (new host DG02)	94
2.28	Morphology of *Pleurocordyceps lanceolatus*	96

LIST OF FIGURES (continued)

Figure		Page
2.29	Morphology of *Pleurocordyceps nutantis* (holotype YYH18093019)	98
2.30	Morphology of *Pleurocordyceps aurantiacus* (holotype MFLUCC 17-2113)	101
2.31	Morphology of *Polycephalomyces aurantiacus* (new host PY0803)	104
2.32	Morphology of *Polycephalomyces marginaliradians* (holotype MFLU 17-1582)	107
2.33	Morphology of *Polycephalomyces marginaliradians* in culture	108
3.1	Backbone schematic tree of the family Ophiocordycipitaceae	177
3.2	Phylogenetic tree from a maximum likelihood analysis of Ophiocordycipitaceae	178
3.3	Morphology of *Ophiocordyceps blattae*	191
3.4	Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of *Ophiocordyceps*	192
3.5	Morphology of *Ophiocordyceps karstii* (holotype MFLU 15-3884)	202
3.6	Morphology of *Ophiocordyceps xuefengensis*	204
3.7	Morphology of *Ophiocordyceps formosana*	206
3.8	Morphology of *Ophiocordyceps cossidarum* (holotype MFLU 17-0752)	208
3.9	Morphology of *Ophiocordyceps sporangifera* (holotype MFLU 18-0658)	211
3.10	Morphology of *Ophiocordyceps barnesii* (MFLU 17-1395)	213
3.11	Morphology of *Ophiocordyceps issidarum* (holotype MFLU 17-0751)	215
3.12	Morphology of *Ophiocordyceps globiceps* (holotype MFLU 18-0661)	219
3.13	Morphology of *Ophiocordyceps cylindrospora* (holotype MFLU 17-1961)	221
3.14	Morphology of *Ophiocordyceps multibrachiata*	223

LIST OF FIGURES (continued)

Figure		Page
3.15	Morphology of *Ophiocordyceps neocrinalis*	225
3.16	Morphology of *Ophiocordyceps crinalis* (asexual morph)	227
3.17	Morphology of *Ophiocordyceps crinalis* (sexual morph)	228
3.18	Morphology of *Ophiocordyceps tessaratomidarum*	230
3.19	Morphology of *Ophiocordyceps nutans*	232
3.20	Morphology of *Ophiocordyceps buquetii* (new host K01)	235
3.21	Morphology of *Ophiocordyceps buquetii* (new host PY0805)	237
3.22	Morphology of *Ophiocordyceps buquetii* (new host YRS05)	239
3.23	Morphology of *Ophiocordyceps neoacicularis* (holotype MRC 15082203)	242
3.24	Morphology of *Ophiocordyceps unicistroma* (holotype YYH18100207)	244
3.25	Morphology of *Ophiocordyceps materiae*	246
3.26	Morphology of *Ophiocordyceps longissima*	248
3.27	Morphology of *Ophiocordyceps divitis*	250
3.28	Morphology of *Ophiocordyceps sinensis*	252
3.29	Morphology of *Ophiocordyceps unilateralis*	254
3.30	Morphology of *Ophiocordyceps biculcitulistipita*	256
3.31	Morphology of *Ophiocordyceps myrmecophila*	258
3.32	Morphology of *Ophiocordyceps irangiensis*	260
3.33	Morphology of *Ophiocordyceps thanathonensis*	262
3.34	Morphology of *Ophiocordyceps pseudolloydii*	264
3.35	Morphology of *Ophiocordyceps yuntaiensis*	266
3.36	Morphology of *Ophiocordyceps parautralis*	267
3.37	Morphology of *Ophiocordyceps pacucullae*	269
3.38	Morphology of *Ophiocordyceps pseudoformicarum*	271

LIST OF FIGURES (continued)

Figure		Page
3.39	Morphology of *Ophiocordyceps polistes*	273
3.40	Morphology of *Ophiocordyceps neocylindrocpora*	276
3.41	Morphology of *Ophiocordyceps mandariniae*	278
3.42	Morphology of *Ophiocordyceps fusiformispora*	280
3.43	Morphology of *Ophiocordyceps vespae*	282
3.44	Morphology of *Ophiocordyceps pseudoelongata*	284
3.45	Morphology of *Ophiocordyceps phuwiangensis* (new host PY0811)	286
3.46	Morphology of *Ophiocordyceps phuwiangensis* (asexual morph)	287
3.47	Morphology of *Ophiocordyceps longisynnema*	289
3.48	Morphology of *Drechmeria coniospora* (redrawn from Barron, 1977)	325
3.49	Phylogenetic tree of *Drechmeria* species	326
3.50	Morphology of *Drechmeria gunnii*	328
3.51	Morphology of *Harposporium anguillulae* (redrawn from Zopf, 1888)	334
3.52	Phylogenetic tree of *Harposporium* species	335
3.53	Morphology of *Harposporium microsporum* (holotype IMI 375096)	337
3.54	Morphology of *Hirsutella entomophila* (redrawn from Speare, 1920)	345
3.55	Morphology of *Hymenostilbe muscaria* (redrawn from Van Vooren & Audibert, 2006)	361
3.56	Morphology of *Hymenostilbe muscaria*	363
3.57	Morphology of *Paraisaria gracilis*	367
3.58	Phylogenetic tree of *Paraisaria* species	368
3.59	Morphology of *Paraisaria amazonica*	370
3.60	Morphology of *Paraisaria tettigonia*	372
3.61	Morphology of *Paraisaria rosea*	374

LIST OF FIGURES (continued)

Figure		Page
3.62	Phylogenetic tree of *Purpureocillium* species	379
3.63	Morphology of *Purpureocillium lilacinum*	381
3.64	Morphology of *Purpureocillium takamizusanense*	383
3.65	Morphology of *Purpureocillium albosynnematum*	385
3.66	Morphology of *Purpureocillium clavatsis*	387
3.67	Morphology of *Tolypocladium inflatum* (redrawn from Gams, 1971)	393
3.68	Phylogenetic tree of *Tolypocladium species*	394
3.69	Morphology of *Tolypocladium cucullae* (holotype HKAS 55588)	399
3.70	Morphology of *Tolypocladium rouxii*	402
3.71	Morphology of *Tolypocladium cautis* (holotype HKAS 42995)	404
3.72	Morphology of *Tolypocladium ophioglossoides*	406
3.73	Morphology of *Tolypocladium ophioglossoides* (new records SL11101901)	408
3.74	Morphology of *Tolypocladium neoophioglossoides* (HKAS 17867)	410
3.75	Morphology of *Tolypocladium paradoxum* (reference specimen HKAS 36297)	412
3.76	Morphology of *Tolypocladium rutilum*	414
3.77	Morphology of *Tolypocladium graciliscucullae*	416
3.78	Morphology of *Tolypocladium roburstipitatum*	418
3.79	Morphology of *Tolypocladium capitatum*	420

ABBREVIATIONS AND SYMBOLS

com.	combination
cm^{-1}	reciprocal centimeters
diam.	diameter
et al.	and others
hr.	hour
gen.	genus/genera
i.e.	that is
mg	milligram
min	minute
mm	millimetre
nm	nanometre
nov.	novum (Latin for new thing)
rpm	revolutions per minute
s	second
sp.	species
spp.	Species (plural)
$\bar{x}$	average
℃	degree centigrade
µm	micrometer
µl	microliter
%	percent

CHAPTER 1

INTRODUCTION

1.1 Introduction to Clavicipitoid Fungi

Hypocreales, the largest order in Hypocreomycetidae (Sordariomycetes), contains 14 families, namely Bionectriaceae, Calcarisporiaceae, Clavicipitaceae, Cocoonihabitaceae, Cordycipitaceae, Flammocladiellaceae, Hypocreaceae, Myrotheciomycetaceae, Nectriaceae, Niessliaceae, Ophiocordycipitaceae, Sarocladiaceae, Stachybotryaceae, and Tilachlidiacea (Hyde et al., 2020a; Wijayawardene et al., 2020; Huang et al., 2020). The order also has 29 incertae sedis genera (Wijayawardene et al., 2020). Based on taxonomic and phylogenetic analyses, numerous new taxa have been introduced in this order over the past decade, leading to a better understanding of the classification of this group (Hyde et al., 2020b, Maharachchikumbura et al., 2021). Some of these members, including Clavicipitaceae, Cordycipitaceae, and Ophiocordycipitaceae, are prominent for their medical and economic significance, particularly Ophiocordycipitaceae (Quandt et al., 2014; Kepler et al., 2017). These three families have been known as the clavicipitoid fungi group (Humber & Richard 2008; Kepler et al., 2012; Kepler et al., 2013).

Previously, the three families were recognized as the single family Clavicipitaceae (Eriksson, 1982; Rogerson,1970; Eriksson & Hawksworth, 1985, 1995; White et al., 2000). Earle (1901) was the first to use the name Clavicipitaceae, but no description was provided, until Rogerson (1970) affirmed it and then Eriksson and Hawksworth (1985) validated it. The name was invalid when used in the years before its description (Nannfeldt, 1932, Eriksson, 1982). Luttrell (1951) classified Clavicipitaceae as Xylaria-type and classified Hypocreales as having a Nectria-type

cutrum. Clavicipitaceae has been considered the only family under Clavicipitales (Bessey, 1950; Moreau, 1954). Then, Clavicipitaceae have been moved to Sphaeriales, which included Necteiaceae, Hypocoreaceae, Hypomycetaceae, Clavicipitaceae and Melanosporaceae (Munk, 1957). Alexopoulos (1962) accepted four families, Nectriaceae, Hypocreaceae, Hypomycetaceae and Melanosporaceae, in the Hypocreales. And Clavicipitaceae was considered a singly family in Clavicipitales (Alexopoulos, 1962). Dennis (1968) revised the order Sphaeriales and accepted Hypocreaceae, Nectriaceae, Seliniaceae, Polystigmataceae and Melanosporaceae. However, the hypocrealen complex has been re-classified into two distinct orders: Clavicipitales and Hypocreales by Rogerson (1970). Spatafora and Blackwell (1993) classified Clavicipitaceae under Hypocreales based on phylogenetic analyses and Rehner and Samuels (1994) further confirmed the classification. Diehl (1950) proposed three subfamilies (Oomycetoideae, Clavicipitoideae and Cordycipitoideae) under Clavicipitaceae, but Sung et al. (2007) emended this hypothesis based on phylogenetic analyses. In Sung et al. (2007) phylogenetic and morphology analyses, there were three clearly distinct clades: *Clavicipitaceae*, *Cordycipitaceae* and *Ophiocordycipitaceae*. Members of the three families are found worldwide and have specialized as insect, plant and fungal pathogens (White et al., 2003). Over the last decade these three families were researched more and more clearly using phylogeny and morphological study.

1.2 Introduction to Ophiocordycipitaceae

1.2.1 Studies on Ophiocordycipitaceae

Kingdom: Fungi

Phylum: Ascomycota

Subphylum: Pexixomycotina

Class: Sordariomycetes

Subclass: Hypocreomycetidae

Order: Hypocreales

Family: Ophiocordycipitaceae

Genus: *Ophiocordyceps*

Drechmeria

Harposporium

Hirsutella

Hymenostilbe

Paraisaria

Purpureocillium

Tolypocladium

Sung et al. (2007) introduced Ophiocordycipitaceae based on phylogenetic analyses and Quandt et al. (2014) emended the family. Quandt et al. (2014) included *Ophiocordyceps* plus six genera within Ophiocordycipitaceae also based on morphological and phylogenetic analyses. Joseph et al. (2015) confirmed this classification system and introduced necessary species combinations into four genera of this family, including *Drechmeria*, *Harposporium*, *Ophiocordyceps* and *Purpureocillium*. Most species in this family produce dark pigmented, tough to pliant stromata that often possess perithecial apices (Sung et al., 2007). The main distinguishing characters of this genus are that the ascospores break into part-spores or not break into part-spores at maturity and asci have thin apical caps (Petch, 1931, 1933). Asexual generic names associated with *Ophiocordyceps* include *Sorosporella* (Sorokin, 1888), *Hirsutella* (Doassans & Patouillard, 1892; Gams & Zare, 2003), *Hymenostilbe* (Petch, 1931b), *Stilbella* (Seifert, 1985), *Syngliocladium* (Petch, 1932), and *Paraisaria* (Samson & Brady, 1983). According to morphological and phylogenetic analyses, the name *Ophiocordyceps* was protected, while most of the above names were suppressed in accordance with the “one fungus one name” (Quandt et al., 2014). However, *Hirsutella* and *Paraisaria* were resurrected from *Ophiocordyceps* as separate genera under *Ophiocordycipitaceae* (Simmons et al. 2015, Mongkolsamrit et al., 2019). *Polycephalomyces*, was placed as an incertae sedis genus under Ophiocordycipitaceae (Quandt et al., 2014). *Perennicordyceps* and *Pleurocordyceps* were separated from *Polycephalomyces* (Matočec et al., 2014; Wang

et al., 2020). Thus, eleven genera, *Drechmeria*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Ophiocordyceps*, *Paraisaria*, *Perennicordyceps*, *Pleurocordyceps*, *Polycephalomyces*, *Purpureocillium* and *Tolypocladium*, were included in Ophiocordycipitaceae (Sung et al., 2007; Quandt et al., 2014; Kirk et al., 2013; Spatafora et al., 2015; Simmons et al., 2015; Maharachchikumbura et al., 2015, 2016; Wijayawardene et al., 2018, 2020; Wang et al., 2020).

1.2.2 Morphological Characters of Ophiocordycipitaceae

1.2.2.1 Host

Hosts of Ophiocordycipitaceae species include arthropods, protozoans, rotifers, nematodes, humans, and fungi (Sung et al., 2007; Quandt et al., 2014; Spatafora et al., 2015; Maharachchikumbura et al., 2015, 2016). *Ophiocordyceps* species are mainly parasitic on eight orders of arthropods including Blatteria, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Megaloptera or Orthoptera (Araújo et al., 2019). *Hirsutella* species are parasites on eight orders of arthropods including Araneae, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Trombidiformes or Nematoda. *Tolypocladium* species are parasites on *Elaphomyces* sp. Cicadidae, Diptera, Bdelloidea (Rotifers), *Hevea brasiliensis* (plants) or isolated from soil habitats. *Purpureocillium* species are parasitic on humans, *Atypus karschi* (spider) or separated from soil habitats. *Hymenostilbe* species are parasites on Arachnida, Coleoptera, Diptera, Hymenoptera, and Orthoptera. *Paraisaria* species are parasites on Coleoptera, Diptera, Lepidoptera, Orthoptera, Hymenoptera. *Paraisaria* species are parasites on Lepidoptera, Nematoda, Protozoa, plants, or was isolated from soil habitats. *Drechmeria* and *Harposporium* are mainly parasite on nematodes, rotifers and insects.

1.2.2.2 Morphological characters of sexual morph

1. Ascostomata

The ascostromata of Ophiocordycipitaceae species are stromatic or ascomatic, colorful, hard, pliant or fibrous, sessile (e. g. *Ophiocordyceps sessilis*, Kaitsu et al., 2013) or stipitate (e. g. Ophiocordyceps pseudolloydii, Evans & Samson,

1984), solitary (*Drechmeria gunnii*, Berkeley, 1848) or paired (e. g. *Paraisaria tettigonia*, Wen et al., 2016) or clustered (e. g. *Ophiocordyceps coccidiicola*, Kobayasi & Shimizu, 1978), either branched (e. g. *Ophiocordyceps ramosissimum*, Wen et al., 2014) or unbranched (e. g. *Ophiocordyceps cossidarum*, Hyde et al., 2017), and range from erect to sub-erect (e. g. *Drechmeria gunnii*, Berkeley, 1848) or flexuous (e.g. *Ophiocordyceps cossidarum*, Wen et al., 2014) (see Figure 1.1).

2. Stipe

The stipe of Ophiocordycipitaceae species is colorful, hard, pliant or fibrous, terete, sometimes hollow (e. g. *Ophiocordyceps ramosissimum*, Wen et al., 2014), and branched or unbranched (e. g. *Ophiocordyceps pseudolloydii*, Evans & Samson, 1984). Perithecia congregate to form a fertile head (e. g. *Ophiocordyceps pseudolloydii*, Evans & Samson, 1984) or are scattered on the stipe (e. g. *Ophiocordyceps coccidiicola*, Kobayasi & Shimizu, 1978) (see Figure 1.1).

3. Fertile Part

The fertile head of Ophiocordycipitaceae species is colorful, with distinct stipe differences (e. g. *Ophiocordyceps pseudolloydii*, Evans and Samson, 1984) or slight stipe differences (e. g. *Drechmeria gunnii*, Berkeley, 1848), globose (e. g. *Ophiocordyceps pseudolloydii*, Evans & Samson, 1984), fusiform (e. g. *Ophiocordyceps myrmecophila*, Rabenhorst, 1858) or capitate (e. g. *Ophiocordyceps tianshanensis*, Wei et al., 2020), and other. The fertile head is formed from the apex (e. g. *Paraisaria tettigonia*, Wen et al., 2016) or the side of the stipe (e. g. *Ophiocordyceps unilateralis*, Tulasne, 1856) (see Figure 1.1).

Note a, b Fruiting body congregate or scattered on the host, without stipe. a *Ophiocordyceps pulvinata* (redrawn from Kaitsu et al., 2013), b *Ophiocordyceps sessilis* (redrawn from Kepler et al., 2010), c–l Stromata with stipe. c *Ophiocordyceps pseudolloydii*, d *Ophiocordyceps dive*, e *Drechmeria gunnii*, f *Ophiocordyceps sinensis*, g *Ophiocordyceps coccidiicola*, h *Paraisaria tettigonia*, i *Tolypocladium ophioglossoides*, j *Ophiocordyceps coccidiicola*, k *Ophiocordyceps xuefengensis*, l *Opiocordyceps ramosissimum*.

Figure 1.1 Overview of taxa of Ophiocordycipitaceae

4. Perithecia

The perithecia of Ophiocordycipitaceae species are vertically immersed or semi-immersed to the stipe with or without infertility apex part (e. g. *Ophiocordyceps cossidarum*, Hyde et al., 2017), vertically immersed to the axis of the

capitate fertile head (e. g. *Ophiocordyceps pseudolloydii*, Evans and Samson, 1984), obliquely immersed to the stipe in the fertile head (e. g. *Ophiocordyceps myrmecophila*, Rabenhorst, 1858) or superficial (e. g. *Ophiocordyceps neoacicularis*, this study) (see Figure 1.2).

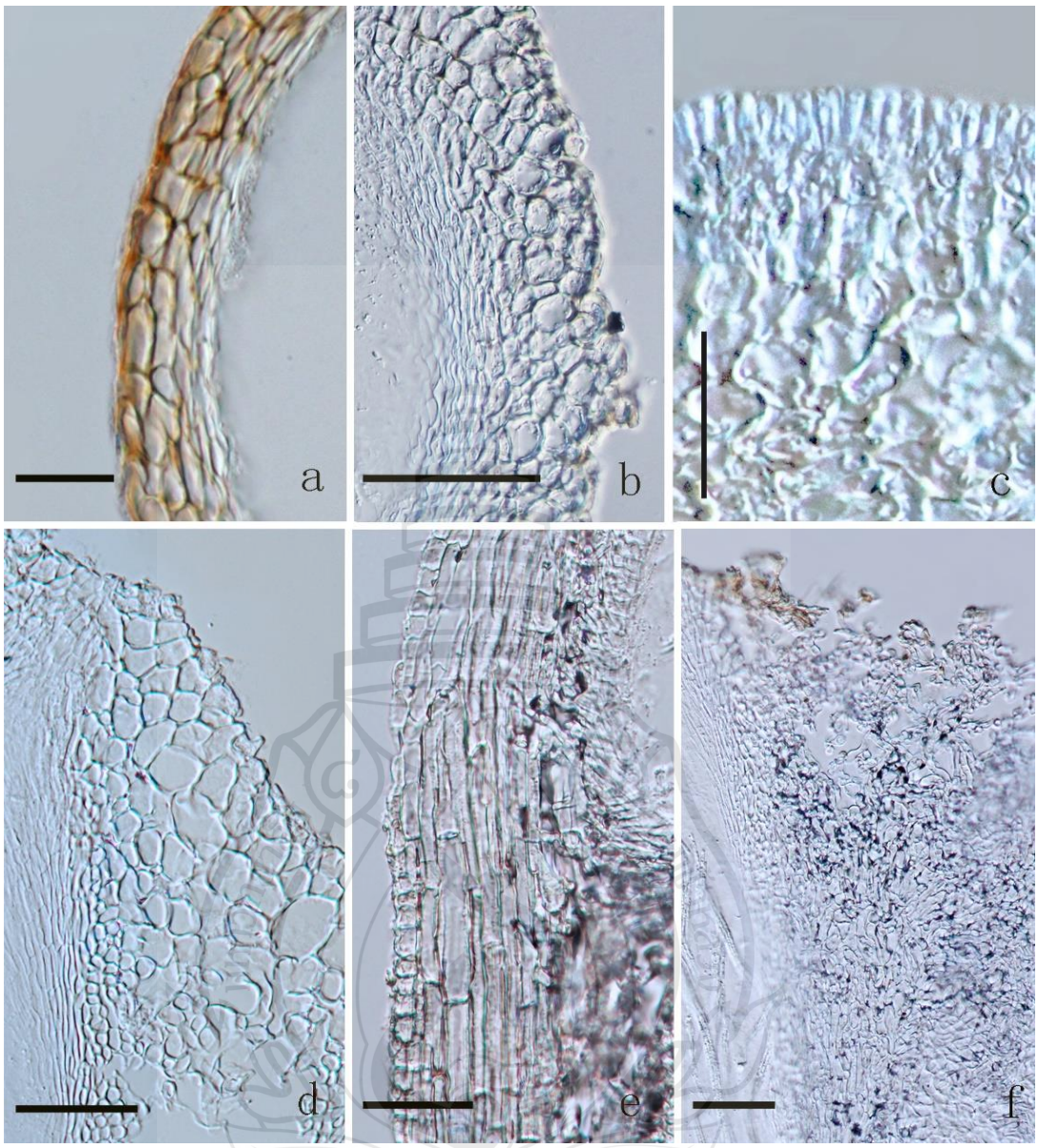
Note a–h Immersed perithecia. i–k Obliquely immersed perithecia. l, m Superficial perithecia. Scale Bars: c, f, h, k, m = 500 µm.

Figure 1.2 Parts of the ascomata and vertical sections of ascomata

5. Peridium

Few peridium textures of Ophiocordycipitaceae species have been described. However, the peridium texture is a key feature of the morphology of this family. Thus, the elements of peridium texture are summarized based on existing descriptors. Clearer peridium texture traits should be determined in the near future.

The peridium of Ophiocordycipitaceae species includes two to three layers. The superficial perithecia commonly form a two-layered peridium, including a colorful textura angularis outer layer and a hyaline *textura porrecta* inner layer (e. g. *Ophiocordyceps unicistroma*, this study). The immersed perithecia normally consist of three or more peridium layers. The outer layer is composed of different kinds of peridium textures including *textura prismatica* (e. g. *Ophiocordyceps sphecocephala*, Berkeley & Curtis, 1869), *textura angularis* (e. g. *Ophiocordyceps pseudolloydii*, Evans & Samson, 1984), *textura epidermoidea* (e. g. *Ophiocordyceps longissima*, Kobayasi & Shimizu, 1963) and *textura angularis* with hyaline cells of palisade tissue (e. g. *Ophiocordyceps cossidarum*, Hyde et al., 2017) (see Figure 1.3). The middle layer is either *textura angularis* (e. g. *Ophiocordyceps pseudolloydii*, Evans and Samson, 1984) or *textura intricata* (e. g. *Tolypocladium paradoxum*, Kobayasi, 1939) (see Figure 1.3) while the inner layer is textura porrecta (e. g. *Ophiocordyceps pseudolloydii*, Evans and Samson, 1984) (see Figure 1.3).

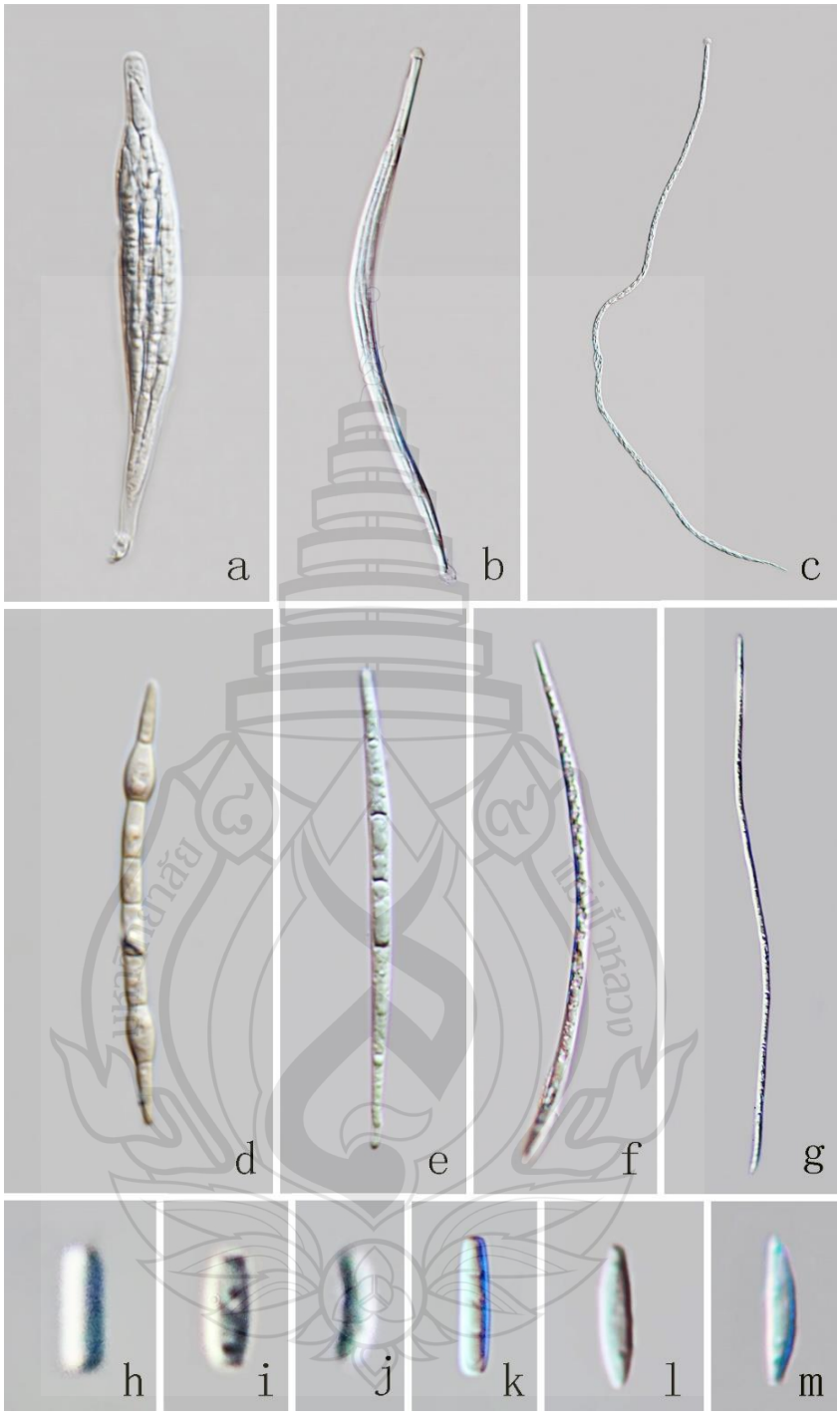


Note a, b Superficial perithecia form two-layered peridium**.** c–f Immersed perithecia consists of more than two peridium layers. l–o Superficial perithecia. Scale Bars: a = 20 µm, f = 20 µm.

Figure 1.3 Parts of the peridium and stipe sections of ascomata

6. Asci; Apical cap; Ascospores; Secondary spores

The asci of Ophiocordycipitaceae species are narrow cylindrical to fusiform (e. g. *Ophiocordyceps blattae*, Petch, 1931) or cylindrical (e. g. *Ophiocordyceps neoacicularis*, this study), or slender cylindrical (e. g. *Ophiocordyceps vespae* this study) with thick or thin apical cap (see Figure 1.4). Ascospores are hyaline, fusiform (e. g. *Ophiocordyceps divitis*, this study) or filiform (e. g. *Ophiocordyceps unicistroma*, this study), with or without septate, breaking or not breaking into secondary spores (see Figure 1.4). The secondary spores are hyaline, cylindrical (e. g. *Ophiocordyceps myrmecophila*, Rabenhorst, 1858) or cylindrical with truncated ends (e. g. *Ophiocordyceps pseudolloydii*, Evans and Samson, 1984), cylindrical with a curve (e. g. *Ophiocordyceps thanathonensis*, Xiao et al., 2017), cylindrical with septa (e. g. *Tolypocladium rouxii*, Candoussau, 1976) or fusiform (e. g. *Ophiocordyceps sphecocephala*, Berkeley & Curtis, 1869) (see Figure 1.4).



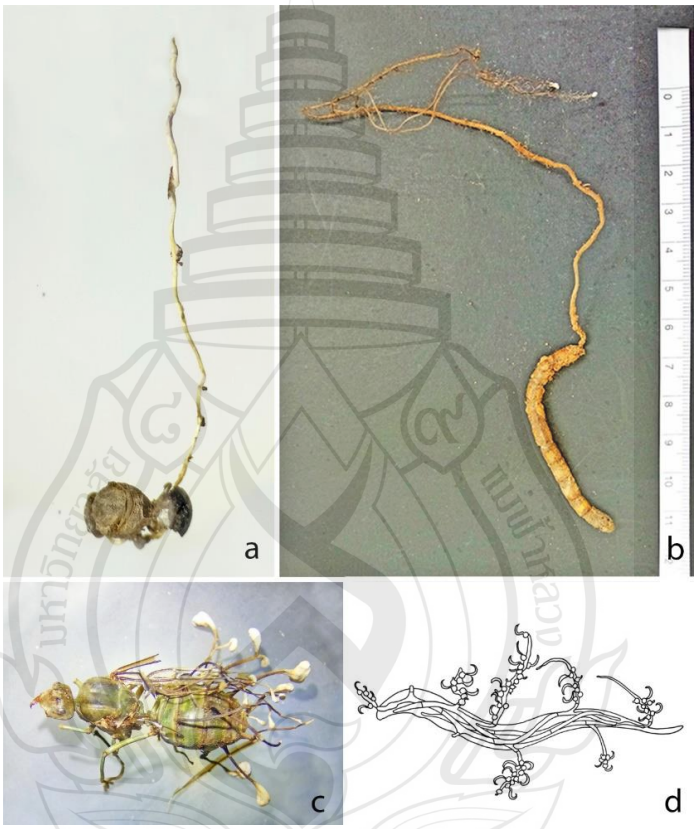
Note a–c Asci, fusiform, cylindrical, filiform. d–g Ascospores. h–m Secondary spores.

Figure 1.4 Asci, ascospores, secondary spores

1.2.2.3 Morphological characters of asexual morph

1. Synnemata

The synnemata of species of Ophiocordycipitaceae were observed or absent (Sung et al., 2007; Quandt et al., 2014; Maha et al., 2017). The synnemata characters were colorful, solitary or numerous, branched or unbranched, have or lacked fertile heads (Figure 1.5).



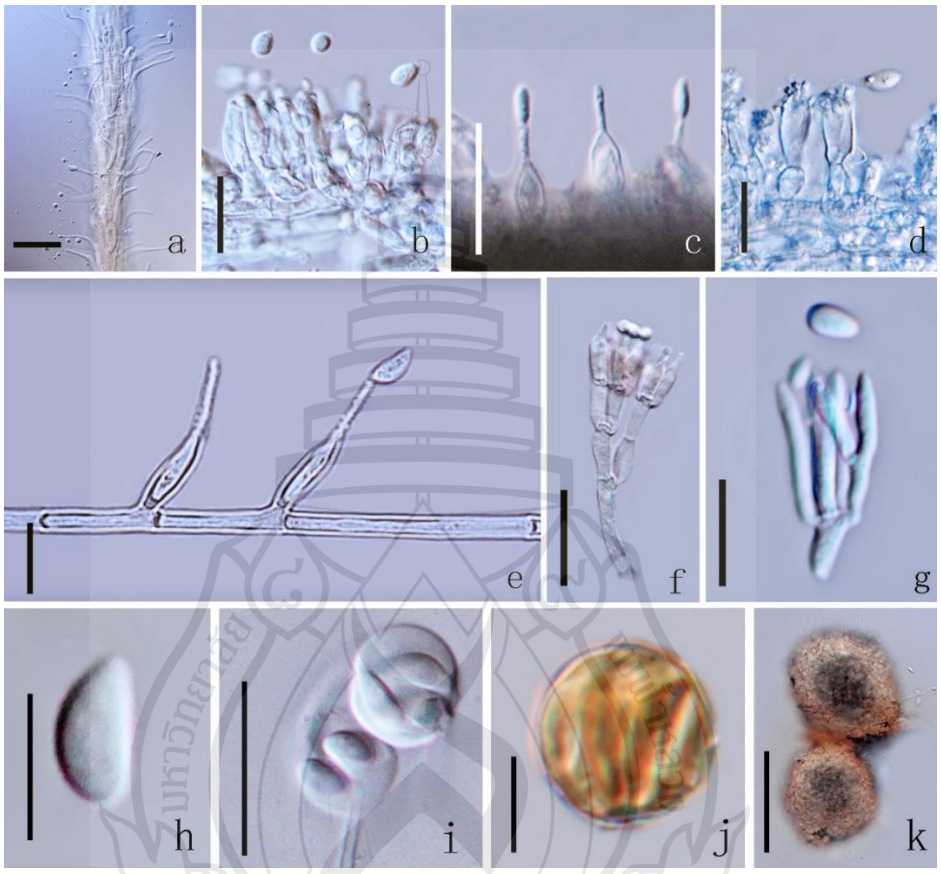
Note a Solitary synnema. b Branched synnema. c Several synnemata. d Conidiophores directly from the host.

Figure 1.5 Synnemata of species of Ophiocordycipitaceae

2. Conidiophore; Phialides (Conidiogenous cells); Conidia

The conidiophore and phialide of Ophiocordycipitaceae were

Hirsutella-like or *Verticillium*-like (see Figure 1.6). The conidia of Ophiocordycipitaceae were regular-shaped or irregular shaped, usually hyaline, one-celled, with or without mucilaginous spheres (see Figure 1.6).



Note a Verticillium-like phialide. b, d Hymenostilbe-like phialide. c, e–g Hirsutella-like phialide.

Figure 1.6 Conidiophore and phialide of species of Ophiocordycipitaceae

1.2.3 Ecological and Economic Significance

Many species in *Ophiocordyceps* are economically essential fungi. For example, *Ophiocordyceps sinensis* is collected throughout the Himalayas and greatly values the local populations. More than ten kinds of nucleoside compounds, including adenine, adenosine, cordycepin, uracil, uridine, guanidine, guanosine, hypoxanthine,

inosine, thymine, thymidine and deoxyuridine, have been isolated from *Ophiocordyceps sinensis*, which has anti-cancer, anti-microbial, anti-plasmodium, antioxidant and immune modulation activities (Zhang et al., 2012; Yu et al., 2012; Xiang et al., 2014; Reis et al., 2017).

Species of *Drechmeria* have been demonstrated to have antibiotic activity (Jansson, 1982a., 1982b., Barron, 2013) and have been used as biocontrol agents against plant-pathogenic nematodes (Dackman et al., 1992). A novel peptaibiotic family of compounds showing antibacterial, antifungal and nematicidal activities was identified in *Drechmeria coniospora* (Zhang et al., 2016). *Drechmeria* sp. has many kinds of indole diterpenoids as natural antimicrobial agents, and natural agonists of human pregnane X receptor (Zhao et al., 2018a, b, Liang et al., 2019). Species of *Harposporium* have been discovered as potential biocontrol agents of livestock-parasitic nematodes (Aschner & Kohn 1958., Charles et al., 1996; Cai et al., 2016).

Hirsutella kobayasii was reported to produce Hirsutellide A, an antimycobacterial metabolite (Vongvanich et al., 2002). Hirsutellones A–E are antimycobacterial alkaloids that were extracted from *Hirsutella nivea* (Isaka et al., 2005). *Hirsutella beakdumountainsis* was reported as a potential substitute for *Ophiocordyceps sinensis* based on their chemical compounds (Li et al., 2011). In addition, two active compounds were reported from different strains of *Hirsutella sp*., which were hirsutide (Lang et al., 2005), and antimalarial tetrapeptide (Thongtan et al., 2006).

Few fungi in *Paraisaria* have been reported for their benefit in the economy except for *Paraisaria gracilis*, which is a traditional Kazakh medicine (Huang et al., 2019). The strains of *Paraisaria gracilis* have been reported to have antioxidation and antibacterial activity (Ma et al., 2012, Suo et al., 2014). *Purpureocillium lilacinum* can cause keratitis and other mycoses in humans and other vertebrates (Pastor & Guarro 2006, Rodríguez et al., 2010).

This group has been recognized as significant, since Borel et al. (1976) found Cyclosporin A from *Tolypocladium inflatum.* Cyclosporin A is an important human medicine with immunomodulatory activities (Ruegger et al., 1976; Traber et al., 1977;

1982; Wenger, 1984; Jegorov et al., 1995). Steroids, ergokonins and efrapeptins have been found from *Tolypocladium inflatum* and *Tolypocladium koningii* (Grafe et al., 1991; Krasnoff & Gupta, 1992), while the bioactivities of these compounds are antifungal, antitumor and insecticidal (Yang et al., 2004; Leung et al., 2006; Survase et al., 2011). *Tolypocladium ophioglossoides* is also reported as Chinese traditional medicine (Quandt et al., 2015; Huang et al., 2017).

1.3 Research Objectives

1.3.1 To examine the morphology and taxonomy of Ophiocordycipitaceae.

1.3.2 To determine the phylogenetic placement and relationships of entomogenous fungi.

1.3.3 To resolve the natural classification of Ophiocordycipitaceae.

1.3.4 To create a monograph and define the affiliation and connectivity between the sexual and asexual states of Ophiocordycipitaceae.

1.4 Research Contents

The thesis has four chapters.

Chapter 1 comprises the general introduction consisting of a brief introduction and the main morphologic characteristics of Ophiocordycipitaceae.

Chapter 2 introduces the novel family Polycephalomycetaceae and provides the morphologic descriptions and illustrations of each genus within this family. New species and records are introduced based on morphologic and phylogenetic analyses.

Chapter 3 discusses the morphologic descriptions and illustrations of each genus of Ophiocordycipitaceae. 30 new species and records are further introduced based on morphologic and phylogenetic analyses.

Chapter 4 provides the conclusions for Ophiocordycipitaceae and Polycephalomycetaceae with suggestions for future work and a list of publications.

CHAPTER 2

TAXONOMIC AND PHYLOGENETIC PLACEMENT OF A NOVEL FAMILY POLYCEPHALOMYCETACEAE

2.1 Introduction to Polycephalomycetaceae

Clavicipitoid fungi have often been re-evaluated with the development of taxonomy and systematics with molecular data over the past two decades (Sung et al., 2007; Kepler et al., 2013; Quandt et al., 2014; Spatafora et al., 2015; Maharachchikumbura et al., 2015, 2016; Mongkolsamriit et al., 2019; Wijayawardene et al., 2018, 2020). Ophiocordycipitaceae was separated from Clavicipitaceae and established as a new family within Hypocreales based on morphology and phylogenetic analyses (Sung et al., 2007). Nine genera were classified in Ophiocordycipitaceae, namely *Elaphocordyceps*, *Haptocillium*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Ophiocordyceps*, *Paraisaria*, *Syngliocladium*, and *Tolypocladium* (Sung et al., 2007). The rarely investigated asexual morphic genus, *Polycephalomyces* was not included in Ophiocordycipitaceae until Quandt et al. (2014), recognised six genera (*Drechmeria*, *Harposporium*, *Ophiocordyceps*, *Polycephalomyces*, *Purpureocillium*, *Tolypocladium*) within the family.

Polycephalomyces has had a long history of being recognised as an incertae sedis taxon in Hypocreales since its establishment by Kobayasi (1941) (Kepler et al., 2013; Matočec et al., 2014). It was described as an entomopathogenic genus with the asexual morph species *Polycephalomyces formosus*, which produces polycephalous synnemata (Kobayasi, 1941). Its asexual morph characters have been described as *Hirsutella*-like and *Acremonium*-like, and no sexual morph is known (Kobayasi, 1941; Kepler et al., 2013). Most species in this family have had a vast range of hosts as they parasitise insects and hyper-parasitise fungi (Sun et al., 2019). Several insect groups have been reported as hosts amongst these three genera (*Perennicordyceps*,

Pleurocordyceps, *Polycephalomyces*), including Coleoptera, Formicidae, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Pentatomidae, and Psocoptera (Kobayasi, 1939; Kobayasi, 1941; Kobayasi & Shimizu 1982; Chen et al., 1984; Bischoff et al., 2003; Van Vooren et al., 2005; Ban et al., 2009; Wang et al., 2012; Matočec et al., 2014; Wang et al., 2015a; Wang et al., 2015b, Crous et al., 2017; Xiao et al., 2018; Poinar & Vega, 2020). Fungi are also recognised as hosts of this group, including *Cordyceps* sp., *Elaphomyces* sp., *Hirsutella guignardii*, Myxomycetes, *Ophiocordyceps crinalis*, *O. nutans*, *O. sinensis*, *Ophiocordyceps* sp., and *O. barnesii* (Seifert, 1985; Chen et al., 1984; Ban et al., 2009; Wang et al., 2012; Wang et al., 2014; Wang et al., 2015a; Xiao et al., 2018; Yang et al., 2020).

Amongst them, *Ophiocordyceps* species have been frequently described as hosts associated with polycephalomyces-like species in recent years. Moreover, *Ophiocordyceps* is a vast genus with more than 250 entomopathogen species (Species Fungorum 2021). It is the type genus of Ophiocordycipitaceae and is characterised by dark-pigmented, tough-to-pliant stromata and filiform asci with an apical cap (Sung et al., 2007; Maharachchikumbura et al., 2016). The placement of *Ophiocordyceps* has been difficult due to insufficient molecular data and vague morphological differences (Kobayasi, 1941; Massee, 1895, Kepler et al., 2013). Additionally, some species of *Polycephalomyces* were associated with other taxa such as *Paecilomyces sinensis* (current name: *Polycephalomyces sinensis*) associated with *Ophiocordyceps sinensis* (Chen et al., 1984; Wang et al., 2012); *Polycephalomyces tomentosus* associated with the Myxomycetes species (Seifert, 1985), *Polycephalomyces ramosus* associated with *Hirsutella guignardii* (Seifert, 1985, Bischoff et al., 2003), and *Polycephalomyces lianzhouensis* associated with *Ophiocordyceps crinalis* (Wang et al., 2014). The host substrate of species in *Polycephalomyces* is complex, leading to conflicting hypotheses based on traditional taxonomy (Kepler et al., 2013).

Later, according to phylogenetic analysis, Kepler et al. (2013) provided molecular data for six species (*Ophiocordyceps cuboidea*, *O. ryogamiensis*, *O. paracuboidea*, *O. prolifica*, *Cordyceps nipponica*, and *C. ramosopulvinata*) and moved them to the genus *Polycephalomyces*. In conclusion, 12 species, including *Polycephalomyces cylindrosporus*, *Po. cuboideus*, *Po. ditmarii*, *Po. formosus*, *Po. kanzashianus*, *Po. nipponicus*, *Po. paracuboideus*, *Po. prolificus*, *Po.*

ramosopulvinatus, *Po. ramosus*, *Po. ryogamiensis* and *Po. tomentosus* were contained within this genus (Kepler et al., 2013). Nevertheless, *Polycephalomyces* was still clarified as incertae sedis (Kepler et al., 2013). *Polycephalomyces formosus*, strain, ARSEF1424, was considered to have represented the type species and grouped with other *Polycephalomyces* species in the same clade (Bischoff et al., 2003; Chaverri et al., 2005; Kepler et al., 2013), and the morphology for this strain was provided by Bischoff et al. (2003). Furthermore, some species for which the sexual morph is known were included in this genus in accordance with the 'One Fungus One Name' nomenclature system (Kepler et al., 2013; Quandt et al., 2014). The sexual morph characters were recognised as firm but pliant, with several white to yellow or brown stromata, branched or several stipes, immersed or superficial perithecia, in a pulvinate cushion or on the stipe, long asci, and small ascospores (Kepler et al., 2013; Quandt et al., 2014). Later, eight new species were introduced to this group in a decade, including *Polycephalomyces lianzhouensis*, *Po. aurantiacus*, *Po. marginaliradians*, *Po. elaphomyceticola*, *Po. phaothaiensis*, *Po. onorei*, *Po. marginaliradians*, and *Po. elaphomyceticola* (Wang et al., 2012; Wang et al., 2015a; Wang et al., 2015b; Xiao et al., 2018; Yang et al., 2020).

The distinctive position of the *Polycephalomyces* clade has brought forth the speculation that it might represent a family rank clade. Kepler et al. (2013) did not establish a new family due to insufficient statistical support in phylogenetic analyses. Additionally, the *Polycephalomyces* clade was sensitive to taxon sampling as two distinct topology results were formed in maximum likelihood and Bayesian inference analyses, when *Cordyceps pleuricapitata* was excluded (Kepler et al., 2013). Quandt et al. (2014) accepted this genus and *Cordyceps pleuricapitata* in Ophiocordycipitaceae by expanding the taxon sampling, considering the similar morphological characters between the Ophiocordycipitaceae group and the *Polycephalomyces* group. Matočec et al. (2014) further separated a new genus, *Perennicordyceps*, from *Polycephalomyces* to accommodate four species (*Perennicordyceps cuboidea*, *Pe. paracuboidea*, *Pe. prolifica*, and *Pe. ryogamiensis*), characterised by superficial perithecia and *Hirsutella*-like or *Acremonium*-like asexual morphs.

The type strains of the type species have been altered based on morphological and molecular development (Kobayasi, 1941, Kepler et al., 2013; Wang et al., 2020). With updating the molecular data of the type species *Polycephalomyces formosus*, and by carefully verifying the strains, the epitype (CGMCC 5.2206), lectotype (TNS-F-197965), and neotype (K(M) 187597) were designated and amended (Wang et al., 2020). The type species' representative strain, ARSEF1424, was confirmed as an erroneous identification as it produced different conidia from the epitype of *Polycephalomyces formosus* (Wang et al., 2020). Furthermore, in the updated phylogenetic analysis, the type species, *Polycephalomyces formosus*, was separated from the *Polycephalomyces* clade. Thus, a new genus, *Pleurocordyceps*, was formed to accommodate the latter ten species (*Pleurocordyceps aurantiacus*, *Pl. nipponica*, *Pl. lianzhouensis*, *Pl. marginaliradians*, *Pl. nipponica*, *Pl. onorei*, *Pl. phaothaiensis*, *Pl. ramosopulvinatus*, *Pl. sinensis*, *Pl. yunnanensis*), with *Pleurocordyceps sinensis* designated as the type species (Wang et al., 2020). However, *Cordyceps pleuricapitata* was still recognised as incertae sedis in Hypocreales (Wang et al., 2020). Moreover, the polycephalomyces-like clade was further mentioned as a possible family rank clade, but was not established by Wang et al. (2020).

Many species have been introduced in the three groups of *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* (Kepler et al., 2013; Quandt et al., 2014; Wang et al., 2014, 2015; Xiao et al., 2018; Yang et al., 2020). Both fungi and insects have been reported associated with these group fungi (Quandt et al., 2014; Wang et al., 2014, 2015; Xiao et al., 2018; Yang et al., 2020). Therefore, the placement, biodiversity, and ecology of these three groups need to be clearly established. In this study, one new family, Polycephalomycetaceae, is introduced to accommodate these genera from the Ophiocordycipitaceae family. Multiple genes (LSU, ITS, SSU, TEF, RPB1, RPB2) were used to analysis the phylogeny relationship of the new family and its closest families. We illustrate the type species of *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*, introducing four new species under the new family, four new species in the *Ophiocordyceps* genus as the host, three new records, and one new combination. Species of *Ophiocordyceps* were the main fungi host for species of the new family. Five species of Ophiocordyceps with three new species were identified by morphology and phylogenetic analysis by Xiao et al. (Impress).

2.2 Materials and Methods

2.2.1 Sample Collection and Specimen Examination

Fresh specimens were obtained with the substrate on insects or fungi and collected from Thailand and southern China**.** Fruiting bodies were examined from free-hand sections using a stereomicroscope. A Nikon ECLIPSE 80i and 90i compound microscope fitted with a Canon 550D, 600D, and 750D digital camera were used to examine the micro-morphological characters, including ascomata, perithecia, peridia, asci, ascospores, secondary spores, conidiophores, phialides (conidiogenous cells), and conidia. Water-mounted slides were prepared for microscopic study and photographed under a compound microscope. The strains were isolated from fresh tissues or single ascospores according to the methods on Senanayake et al. (2020). The cultures were incubated at 25^{o}C for 4–10 weeks on potato extract agar (PDA) under light to promote sporulation. The Tarosoft (R) v.0.9.7 Image Frame Work was used to measure the morphologic structures and the Adobe Photoshop CS6 Extended version 13.0.1 software (Adobe Systems, USA) to edit the photographic plates. Permanent slides were prepared after checking the morphology according to previous protocols (Nag Raj, 1993; Phookamsak et al., 2014).

2.2.2 DNA Extraction, PCR Amplification and Sequencing

DNA was extracted from dried specimens and cultures using E.Z.N.A.TM Fungal DNA MiniKit (Omega Biotech, CA, USA) according to the manufacturer's protocols. Polymerase chain reaction (PCR) was used to amplify six genetic markers: ITS4/ITS5 for internal transcribed spacer gene region (ITS), NS1/NS4 for partial small subunit ribosomal RNA gene region (SSU), LROR/LR5 for partial large subunit rDNA gene region (LSU) (Vilgalys & Hester 1990; White et al. 1990), 983F/2218R for partial translation elongation factor 1-alpha gene region (TEF-1α) (Sung et al., 2007b), and CRPB1A/RPB1Cr for partial RNA polymerase II largest subunit gene region (RPB1) (Castlebury et al., 2004). Amplification reactions were performed in a 50-µl reaction volume as follows: 2 µg DNA template, 2 µl of each forward and reverse primer (10 picomole stock concentration), 25 µl of 2×Taq PCR SuperMix

(TIANGEN BIOTECH Co., Chaoyang District, Beijing, PR China), and 19 μl sterilized distilled water. The amplification conditions of ITS, LSU, and SSU were as follows: initial denaturation at 94ºC for 3 min, followed by 30 cycles of denaturation at 94ºC for 30–50 s, annealing at 55ºC for 1 min, elongation at 72ºC for 90 s, and final extension at 72ºC for 5–10 mins (Liu et al., 2012). The PCR thermal cycle program for the TEF was as follows: initially, 95ºC for 5 min, followed by 30 cycles of denaturation at 95°C for 1 min, annealing at 58ºC for 2 min, elongation at 72°C for 90 s, and final extension at 72ºC for 10 min. The PCR thermal cycle program for RPB1 and RPB2 was the same as TEF except for the annealing step which was at 54ºC for 1 min and 52ºC for 2 min, respectively. The PCR products were sequenced by Sangon Biotech (Shanghai) Co., Ltd., Shanghai, China. In the cases where the PCR products could not be directly sequenced, the TaKaRa PMD™18-T vector system (TaKaRa Biotechnology, Dalian, China) was used for DNA extraction.

2.2.3 Sequence Alignment and Phylogenetic Analyses

The sequences were blasted by using the BLAST tool in NCBI (https://www.ncbi.nlm.nih.gov/) to compare species and assemble the dataset. DNASTAR Lasergene SeqMan Pro v. 7.1.0 (44.1) was used to edit ambiguous bases and assemble the forward and reverse reads. MAFFT v.7 was used to align the individual datasets (Katoh & Standley 2013, http://mafft.cbrc.jp/alignment/server/). Each locus was trimmed by Trimal (Capella-Gutiérrez et al., 2009). BioEdit (Hall, 2011) was used to check the alignment manually.

Six genetic markers, including SSU, ITS, LSU, TEF, RPB1, and RPB2, were used in previous publications as listed in Supplementary Table 2.1 and Table 2.2; three trees containing members of *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* and comprise 17 taxa, 29 taxa, 74 taxa, respectively. A Hypocreales order tree was inferred using 297 taxa spanning the diversity of each family. A Clavicipitaceae, Ophiocordycipitaceae, Cordycipitaceae, and Polycephalomycetaceae tree using 150 taxa. A tree containing members of the newly proposed family consisting of 90 taxa. Three *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* trees using 17 taxa, 29 taxa and 74 taxa, respectively. Moreover,

Supplementary Table 2.1 and Table 2.2 list GenBank numbers for the different phylogenetic trees, respectively.

IQ-Tree v. 2 (Minh et al., 2020) was used to infer intended to determine the partition scheme of each genus and estimated maximum likelihood trees (ML) according to Bayesian information criterion (BIC). Partitioned analyses were carried out for the combined datasets. RAxML-HPC2 on XSEDE (8.2.12) (Stamatakis, 2014) was used to generate the maximum likelihood trees in the CIPRES Science Gateway platform. MrMTgui (Nuin, 2007) determined the best-fit evolution model for Bayesian analyses by the Akaike Information Criterion (AIC). Furthermore, PAUP, ModelTest and MrModelText were associated within the across platforms MrMTgui. MrBayes v.3.1.2 (Ronquist & Huelsenbeck, 2003) was utilized to evaluate posterior probabilities (PP) (Rannala & Yang, 1996; Zhaxybayeva & Gogarten, 2002) by Markov Chain Monte Carlo sampling (BMCMC). The number of generations was obtained within the annotation under each tree figure. The first 25% of the trees were discarded, as they represented the burn-in phase of the analyses, while the remaining were used for calculation posterior probabilities in the majority rule consensus tree (the critical value for the topological convergence diagnostic was 0.01). The trees were figured in FigTree v1.4.0 program (Rambaut, 2012). Bayesian Posterior Probabilities (PP) greater than or equal to 0.90 were provided surrounding each node. The annotations of each tree were present below the tree figures. CONSEL was used for assessing the best tree based on approximately unbiased tests (Shimodaira & Hasegawa, 2001).

Table 2.1 Sources of isolates and GenBank accession number of three families Clavicipitaceae, Ophiocordycipitaceae and Polycephalomycetaceae

Species	Strain	ITS	SSU	LSU	TEF	RPB1	RPB2
Akanthomyces aculeatus	HUA 186145		MF416572	MF416520	MF416465		
Akanthomyces attenuatus	CBS 402 78		AF339614	AF339565	EF468782	EF468888	EF468935
Akanthomyces coccidioperitheciatus	NHJ 6709		EU369110	EU369042	EU369025	EU369067	EU369086
Akanthomyces dipterigenus	CBS 126 27		AF339605	AF339556	KM283820	KR064300	KR064303
Aschersonia badia	BCC 8105		DQ522537	DQ518752	DQ522317	DQ522363	DQ522411
Aschersonia disciformis	P.C. 655			EU392560	EU392643	EU392697	

Table 2.1 (continued)

Species	Strain	ITS	SSU	LSU	TEF	RPB1	RPB2
Aschersonia discoidea	BCC2097				AY986945	DQ000346	
Balansia henningsiana	AEG 96-27a	JN049815	AY545723	AY545727	AY489610	AY489643	DQ522413
Balansia pilulaeformis	AEG 94-2	JN049816	AF543764	AF543788	DQ522319	DQ522365	DQ522414
Beauveria acridophila	HUA 179220	JQ958600	JQ895527	JQ895536	JQ958614	JX003852	JX003842
Beauveria australis	ARSEF 4598	NR_111597			HQ880995	HQ880861	HQ880933
Beauveria bassiana	ARSEF 1564	EU334676	EU334676		HQ880974	HQ880833	HQ880905
Beauveria blattidicola	MCA 1727		MF416593	MF416539	MF416483	MF416640	
Beauveria caledonica	ARSEF 2567	HQ880817	AF339570	AF339520	EF469057	HQ880889	HQ880961
Beauveria kipukae	ARSEF 7032	NR_111600			HQ881005	HQ880875	HQ880947
Blackwellomyces cardinalis	OSC 93609		AY184973	AY184962	DQ522325	DQ522370	DQ522422
Blackwellomyces pseudomilitaris	BCC 1919		MF416588	MF416534	MF416478		MF416440
Calcarisporium arbuscula	CBS 900.68	KT945003	KT945002	KX442598	KX442596		KX442597
Calcarisporium cordycipiticola	MFLUCC 15-0686	KT944999	KT944998	KX442599	KX442593		KX442594
Calcarisporium cordycipiticola	MFLUCC 15-0685	KT945001	KT945000	KX442604	KX442605		KX442607
Calcarisporium xylariicola	HMAS 276836	KX442603	KX442602	KX442601	KX442595		KX442606
Claviceps fusiformis	ATCC 26019		DQ522539	U17402	DQ522320	DQ522366	
Claviceps paspali	ATCC 13892		U32401	U47826	DQ522321	DQ522367	DQ522416
Claviceps purpurea	SA cp11		EF469122	EF469075	EF469058	EF469087	EF469105
Conoideocrella luteorostrata	NHJ 12516	JN049860	EF468994	EF468849	EF468800	EF468905	EF468946
Conoideocrella tenuis	NHJ 345.01		EU369111	EU369045	EU369030		EU369088
Cordyceps albocitrina	spat 07-174		MF416575		MF416467	MF416629	
Cordyceps cicadae	RCEF HP090724-31		MF416605	MF416552	MF416496	MF416653	MF416447
Cordyceps coleopterorum	CBS 110.73		JF415965	JF415988	JF416028	JN049903	JF416006
Cordyceps militaris	YFCC 6587		MN576762	MN576818	MN576988	MN576878	MN576932
Cordyceps morakotii	BCC55820	KT261389			KT261399		
Cordyceps ninchukispora	EGS 38 165		EF468991	EF468846	EF468795	EF468900	
Cordyceps pleuricapitata	NBRC: 100745	JN943304	JN941750	JN941391	KF049679	JN992484	KF049667
Cordyceps pleuricapitata	NBRC: 100746	JN943306	JN941749	JN941392	KF049680	JN992483	KF049668
Cordyceps pruinosa	ARSEF 5413	JN049826	AY184979	AY184968	DQ522351	DQ522397	DQ522451
Cordyceps rosea	spat 09-053		MF416590	MF416536	MF416480	MF416637	MF416442
Cordyceps roseostromata	ARSEF 4871		AF339573	AF339523			
Drechmeria balanoides	CBS 250.82	NR_155044	NG_062629	NG_059128	DQ522342	DQ522388	DQ522442
Drechmeria coniospora	CBS 596.92	AF106018	AF106012				
Drechmeria gunnii	OSC 76404		AF339572	AF339522	AY489616	AY489650	DQ522426
Drechmeria panacis	CBS 142798	MF588878	MF588890	MF588897	MF614144		
Drechmeria rhabdospora	CBS 101432	AF375050					
Drechmeria zeospora	CBS 335.80	MH861269		AF339540	EF469062	EF469091	EF469109
Engyodontium aranearum	CBS 309.85	JN036556	AF339576	AF339526	DQ522341	DQ522387	DQ522439
Engyodontium parvisporum	IHEM 22910			LC092915			

Table 2.1 (continued)

Species	Strain	ITS	SSU	LSU	TEF	RPB1	RPB2
Engyodontium rectidentatum	CBS 206.74			LC092912			
Epichloe elymi	C. Schardl 760			AY986924	AY986951	DQ000352	
Epichloe typhina	ATCC 56429	JN049832	U32405	U17396	AF543777	AY489653	DQ522440
Gibellula cf alba	NHJ 11679				EU369016	EU369054	
Gibellula leiopus	BCC 16025		MF416602	MF416548	MF416492	MF416649	
Gibellula longispora	NHJ 12014		EU369098		EU369017	EU369055	EU369075
Gibellula pulchra	NHJ 10808		EU369099	EU369035	EU369018	EU369056	EU369076
Harposporium anguillulae	ARSEF 5593			AY636081			
Harposporium cycloides	ARSEF 5599			AY636083			
Harposporium harposporiferum	ARSEF 5472		AF339569	NG_060621			
Harposporium helicoides	Arsef 5354		AF339577	AF339527			
Hevansia arachnophilus	NHJ 10469		EU369090	EU369031	EU369008	EU369047	
Hevansia cinereus	NHJ 3510		EU369091		EU369009	EU369048	EU369070
Hevansia nelumboides	BCC 41864	JN201871	JN201863	JN201873	JN201867		
Hevansia novoguineensis	NHJ 13161		EU369093		EU369011	EU369050	
Hirsutella gregis	SB3661 3	EF194155					
Hirsutella rhossiliensis	ARSEF 2931	KM652168	KM652078	KM652121	KM652004	KM652043	
Hirsutella rostrata	SB3697	EF194150					
Hirsutella versicolor	ARSEF 1037		KM652102	KM652150	KM652029	KM652063	
Hypocrella cf discoidea	ARSEF 7697			AY986910	AY986936	DQ000337	
Hypocrella discoidea	I93-901D			EU392567	EU392646	EU392700	
Liangia sinensis	YFCC 3103	MN576831	MN576726	MN576782	MN576952	MN576842	MN576898
Liangia sinensis	YFCC 3104	MN576832	MN576727	MN576783	MN576953	MN576843	MN576899
Metarhizium anisopliae	CBS 130.71	MT078884	MT078868	MT078853	MT078845	MT078861	MT078918
Metarhizium brunneum	CBS 316.51	MT078888	MT078875	MT078860	MT078852		
Metarhizium clavatum	BCC84543T	MN781886		MN781834	MN781689	MN781741	MN781789
Metarhizium gryllidicola	BCC37918	MN781897	MN781935	MN781836	MN781691	MN781743	MN781790
Metarhizium phasmatodeae	BCC2841	MN781911	MN781931	MN781828	MN781681	MN781738	MN781782
Moelleriella madidiensis	CUP 067776			AY986915	AY986941	DQ000342	
Moelleriella rhombispora	CUP 067534			EU392614	EU392679	EU392731	
Ophiocordyceps acicularis	OSC 128580	JN049820	DQ522543	DQ518757	DQ522326	DQ522371	DQ522423
Ophiocordyceps agriotidis	ARSEF 5692	JN049819	DQ522540	DQ518754	DQ522322	DQ522368	DQ522418
Ophiocordyceps annulata	CEM 303		KJ878915		KJ878962	KJ878995	
Ophiocordyceps brunneipunctata	OSC 128576		DQ522542	DQ518756	DQ522324	DQ522369	DQ522420
Ophiocordyceps brunneirubra	BCC 14384	MH754736		MH753690	GU797121	MK751465	MK751468
Ophiocordyceps macroacicularis	NBRC: 105888	AB968401	AB968389	AB968417	AB968575		AB968537
Ophiocordyceps pseudoacicularis	TBRC 8101			MF614645	MF614629	MF614662	MF614676
Ophiocordyceps satoi	J7		KX713653	KX713599	KX713683	KX713711	
Ophiocordyceps sinensis	EFCC7287	JN049854	EF468971	EF468827	EF468767	EF468874	EF468924

Table 2.1 (continued)

Species	Strain	ITS	SSU	LSU	TEF	RPB1	RPB2
Ophiocordyceps sobolifera	NBRC: 106967	AB968409	AB968395	AB968422	AB968590		AB968551
Ophiocordyceps sporangifera	MFLUCC 18-0492	MH725818	MH725814	MH725832	MH727390	MH727392	
Ophiocordyceps stylophora	OSC 111000	JN049828	DQ522552	DQ518766	DQ522337	DQ522382	DQ522433
Ophiocordyceps xuefengensis	GZUH2012HN19	KC631803	KC631788		KC631794	KC631799	
Ophiocordyceps yakusimensis	HMAS 199604		KJ878938	KJ878902		KJ879018	KJ878953
Paecilomyces marquandii	CBS 182.27	AY624193	EF468990	EF468845	EF468793	EF468899	EF468942
Paecilomyces reniformis	ARSEF 429		HQ165671	HQ165733	HQ165690		HQ165650
Paraisaria amazonica	HUA 186143		KJ917562	KJ917571	KM411989	KP212902	KM411982
Paraisaria blattarioides	HUA186093		KJ917559	KJ917570	KM411992	KP212910	
Paraisaria coenomyia	NBRC: 108993	AB968396	AB968384	AB968412	AB968570		AB968532
Paraisaria gracilioides	HUA 186095		KJ917556		KM411994	KP212914	
Paraisaria gracilis	EFCC 8572	JN049851	EF468956	EF468811	EF468751	EF468859	EF468912
Paraisaria heteropoda	EFCC 10125	JN049852	EF468957	EF468812	EF468752	EF468860	EF468914
Perennicordyceps cuboidea	NBRC: 103836	JN943332	JN941721	JN941420	AB972951	JN992455	AB972955
Perennicordyceps elaphomyceticola	DG04						
Perennicordyceps paracuboidea	NBRC: 100942	JN943337	JN941711	JN941430	AB972954	JN992445	AB972958
Perennicordyceps prolifica	NBRC: 101750	JN943340	JN941708	JN941433	AB972953	JN992442	AB972957
Perennicordyceps ryogamiensis	NBRC: 101751	JN943343	JN941703	JN941438	KF049688	JN992437	
Pleurocordyceps agaricus	YHCPA1303	KP276653	KP276657		KP276661	KP276665	KP276669
Pleurocordyceps aurantiacus	MFLUCC 17-2113	MG136916	MG136904	MG136910	MG136875	MG136866	MG136870
Pleurocordyceps elaphomyceticola	NTUCC 17-022	MK840824		MK840813	MK839230	MK839221	MK839212
Pleurocordyceps kanzashianus		AB027371	AB027325	AB027371			
Pleurocordyceps lanceolatus	HSR042020072004b						
Pleurocordyceps lanceolatus	HSR042020072004a						
Pleurocordyceps lianzhouensis	GIMYY9603	EU149922	KF226249	KF226250	KF226252	KF226251	
Pleurocordyceps marginaliradians	MFLU 17-1582	MG136920	MG136908	MG136914	MG136878	MG136869	MG271931
Pleurocordyceps nipponicus	BCC 1682	KF049664	KF049620	KF049638	KF049694		
Pleurocordyceps onorei	BRA:CR23902	KU898841					
Pleurocordyceps parvicapitata	DG11a						
Pleurocordyceps parvicapitata	DG11c						
Pleurocordyceps phaothaiensis	BCC84557	MF959734		MF959738	MF959741	MF959746	
Pleurocordyceps ramosopulvinatus	EFCC 5566	KF049658		KF049627	KF049682	KF049645	
Pleurocordyceps sinensis	HMAS 43720	NR_119928		NG_042573			
Pleurocordyceps yunnanensis	YHCPY1005	KF977848	KF977848	KF977848	KF977850	KF977852	KF977854
Polycephalomyces albiramus	XSMENG						
Polycephalomyces albiramus	XS08						
Polycephalomyces formosus	NBRC: 109993	MN586833	MN586824	MN586842	MN598057	MN598048	MN598064
Polycephalomyces formosus	WFKQ03						

Table 2.1 (continued)

Species	Strain	ITS	SSU	LSU	TEF	RPB1	RPB2
Polycephalomyces nutantis	YYH18093019						
Polycephalomyces ramosus	NBRC: 109983	AB925946		AB925982			
Polycephalomyces tomentosus	BL4	KF049666	KF049623	KF049641	KF049697	KF049656	KF049678
Purpureocillium lavendulum	FMR 10376			FR775489	FR775516	FR775512	
Purpureocillium lilacinum	CBS 284.36	NR_111432	NG_061025				
Purpureocillium sodanum	IBRC-M 30175	KX668542					
Purpureocillium takamizusanense	NHJ 3582		EU369097	EU369034	EU369015		
Samsoniella alpina	YFCC 5818		MN576753	MN576809	MN576979	MN576869	MN576923
Samsoniella antleroides	YFCC 6016		MN576747	MN576803	MN576973	MN576863	MN576917
Samsoniella aurantia	TBRC 7271	MF140764		MF140728	MF140846	MF140791	MF140818
Samsoniella inthanonensis	TBRC7915	MF140761		MF140725	MF140849	MF140790	MF140815
Samuelsia chalalensis	CUP 067856			EU392637	EU392691	EU392743	
Samuelsia rufobrunnea	CUP 067858			AY986918	AY986944	DQ000345	
Simplicillium lamellicola	CBS 116.25	MH854806	AF339601	AF339552	DQ522356	DQ522404	DQ522462
Simplicillium lanosoniveum	CBS 704.86	AJ292396	AF339602	AF339553	DQ522358	DQ522406	DQ522464
Simplicillium obclavatum	CBS 311.74	MH860859	AF339567	AF339517	EF468798		
Simplicillium yunnanense	YFCC 7133		MN576728	MN576784	MN576954	MN576844	
Tolypocladium album	CBS 393.89	MH862176		MH873866			
Tolypocladium amazonense	LA100	HQ022485	KF747309	KF747129	KF747094	KF747208	
Tolypocladium capitatum	OSC 71233		AY489689	AY489721	AY489615	AY489649	DQ522421
Tolypocladium cylindrosporum	ARSEF 2920	MG228381			MG228390	MG228384	MG228387
Tolypocladium endophyticum	MX575	JX155949	KF747323	KF747155			
Tolypocladium fractum	OSC 110990		DQ522545	DQ518759	DQ522328	DQ522373	DQ522425
Tolypocladium geodes	CBS 723 70	NR_164431					
Tolypocladium inegoense	SU 15			DQ118741	DQ118752	DQ127243	
Tolypocladium inflatum	OSC 71235	JN049844	EF469124	EF469077	EF469061	EF469090	EF469108
Tolypocladium longisegmentatum	OSC 110992			EF468816		EF468864	EF468919
Tolypocladium ophioglossoides	CBS 100239	KJ878910	KJ878874	KJ878958	KJ878990	KJ878944	

Table 2.2 Sources of isolates and GenBank accession number of the family Polycephalomycetaceae

Current name	Voucher	SSU	ITS	LSU	rpb2	tef1	rpb1
Cordyceps pleuricapitata	NBRC:109979		AB925941	AB925978			
Cordyceps pleuricapitata	NBRC:109978		AB925940	AB925977			
Cordyceps pleuricapitata	NBRC:109977		AB925939	AB925976			
Cordyceps pleuricapitata	NBRC 100746	JN941749	JN943306	JN941392	KF049668	KF049680	JN992483

Table 2.2 (continued)

Current name	Voucher	SSU	ITS	LSU	rpb2	tef1	rpb1
Cordyceps pleuricapitata	NBRC 100745	JN941750	JN943304	JN941391	KF049667	KF049679	JN992484
Perennicordyceps cuboidea	NBRC:103836	JN941721	JN943332	JN941420	AB972955	AB972951	JN992455
Perennicordyceps cuboidea	NBRC 100941	JN941725	JN943329	JN941416			JN992459
Perennicordyceps cuboidea	NBRC 103834	JN941723	JN943330	JN941418			JN992457
Perennicordyceps cuboidea	NBRC 103835	JN941722	JN943333	JN941419			JN992456
Perennicordyceps cuboidea	NBRC 101740	JN941724	JN943331	JN941417		KF049684	JN992458
Perennicordyceps cuboidea	CEM 1514	KF049609		KF049628		KF049683	
Perennicordyceps cuboidea	NBRC 101739		AB378668	AB378649			
Perennicordyceps cuboidea	NBRC 101742		AB378667	AB378648			
Perennicordyceps elaphomyceticola	DG07H						
Perennicordyceps elaphomyceticola	SL17050801						
Perennicordyceps elaphomyceticola	DG07						
Perennicordyceps elaphomyceticola	DG04H						
Perennicordyceps elaphomyceticola	DG04						
Perennicordyceps paracuboidea	NBRC 101742	JN941710	JN943338	JN941431	KF049669	KF049685	JN992444
Perennicordyceps paracuboidea	NBRC 101742	KF049611		KF049630			KF049647
Perennicordyceps paracuboidea	NBRC:100942	JN941711	JN943337	JN941430	AB972958	AB972954	JN992445
Perennicordyceps prolifica	NBRC:101750	JN941708	JN943340	JN941433	AB972957	AB972953	JN992442
Perennicordyceps prolifica	NBRC:100744	JN941709	AB925942	JN941432	AB972956	AB972952	JN992443
Perennicordyceps prolifica	NBRC 103839	JN941706	JN943342	JN941435			JN992440
Perennicordyceps prolifica	NBRC 103838	JN941707	JN943339	JN941434			JN992441
Perennicordyceps prolifica	NBRC:103833		AB925943	AB925979			
Perennicordyceps prolifica	TNS-F-18547	KF049613	KF049660	KF049632	KF049670	KF049687	KF049649
Perennicordyceps prolifica	TNS-F-18481	KF049612	KF049659	KF049631		KF049686	KF049648
Perennicordyceps prolifica		AB027324		AB027370			
Perennicordyceps ryogamiensis	NBRC 101751	JN941703	JN943343	JN941438		KF049688	JN992437
Perennicordyceps ryogamiensis	NBRC 101751	KF049614	AB378673	AB378654			KF049650
Perennicordyceps ryogamiensis	NBRC 101751			KF049633			
Perennicordyceps ryogamiensis	NBRC 103837	JN941702	JN943346	JN941439			JN992436
Perennicordyceps ryogamiensis	NBRC 103837		AB378674	AB378655			
Perennicordyceps ryogamiensis	NBRC 103842	JN941701	JN943345	JN941440			JN992435
Perennicordyceps ryogamiensis	NBRC 103842		AB378678	AB378662			
Pleurocordyceps agaricus	YHHPA1305	KP276655	KP276651		KP276667	KP276659	KP276663
Pleurocordyceps agaricus	YHCPA1307	KP276658	KP276654		KP276670	KP276662	KP276666

Table 2.2 (continued)

Current name	Voucher	SSU	ITS	LSU	rpb2	tef1	rpb1
Pleurocordyceps agaricus	YHCPA1303	KP276657	KP276653		KP276669	KP276661	KP276665
Pleurocordyceps aurantiacus	MFLUCC 17-2113	MG136904	MG136916	MG136910	MG136870	MG136875	MG136866
Pleurocordyceps aurantiacus	MFLUCC 17-2114	MG136905	MG136917	MG136911	MG136871	MG136874	
Pleurocordyceps aurantiacus	MFLU 17-1394	MG136906	MG136918	MG136912	MG136872	MG136876	MG136867
Pleurocordyceps aurantiacus	MFLU 17-1393	MG136907	MG136919	MG136913	MG136873	MG136877	MG136868
Pleurocordyceps aurantiacus	CPY03b						
Pleurocordyceps aurantiacus	CPY03						
Pleurocordyceps formosus	ARSEF1424	KF049615	KF049661	KF049634	KF049671	KF049689	KF049651
Pleurocordyceps kanzashianus		AB027325	AB027371	AB027371			
Pleurocordyceps lanceolatus	HSR042020072004b						
Pleurocordyceps lanceolatus	HSR042020072004a						
Pleurocordyceps lianzhouensis	HIMGD20918	KF226245	EU149921	KF226246		KF226248	KF226247
Pleurocordyceps lianzhouensis	GIMYY9603	KF226249	EU149922	KF226250		KF226252	KF226251
Pleurocordyceps marginaliradians	MFLU 17-1582	MG136908	MG136920	MG136914	MG271931	MG136878	MG136869
Pleurocordyceps marginaliradians	MFLUCC 17-2276	MG136909	MG136921	MG136915	MG271930	MG136879	
Pleurocordyceps nipponicus	BCC 1682	KF049620	KF049664	KF049638		KF049694	
Pleurocordyceps nipponicus	BCC 18108	MF416624	KF049657	MF416569	MF416462	MF416517	MF416676
Pleurocordyceps nipponicus	NBRC 101408	JN941751	JN943303	JN941390			JN992485
Pleurocordyceps nipponicus	NBRC 101407	JN941752	JN943302	JN941389			JN992486
Pleurocordyceps nipponicus	NBRC 101405	JN941754	JN943442	JN941387			JN992488
Pleurocordyceps nipponicus	BCC 2325	KF049622	KF049665	KF049640	KF049677	KF049696	KF049655
Pleurocordyceps nipponicus	NHJ 4268	KF049621		KF049639	KF049676	KF049695	KF049654
Pleurocordyceps nipponicus	BCC 1881	KF049618		KF049636	KF049674	KF049692	
Pleurocordyceps nipponicus	NBRC 101406	JN941753	JN943301	JN941388			JN992487
Pleurocordyceps nutantis	YTS19061906Z						
Pleurocordyceps nutantis	YTS19061906Zb						
Pleurocordyceps nutantis	YYH18093019						
Pleurocordyceps nutantis	YYH18093019a						
Pleurocordyceps onorei	BRA CR23902		KU898841				
Pleurocordyceps onorei	BRA CR23904		KU898843				
Pleurocordyceps parvicapitata	DG11a						

Table 2.2 (continued)

Current name	Voucher	SSU	ITS	LSU	rpb2	tef1	rpb1
Pleurocordyceps parvicapitata	DG11c						
Pleurocordyceps parvicapitata	DG02b						
Pleurocordyceps parvicapitata	DG02c						
Pleurocordyceps phaothaiensis	BCC84557		MF959734	MF959738		MF959741	MF959746
Pleurocordyceps phaothaiensis	BCC84553		MF959733	MF959737		MF959742	MF959745
Pleurocordyceps phaothaiensis	BCC84552		MF959732	MF959736		MF959740	MF959744
Pleurocordyceps phaothaiensis	BCC84551		MF959731	MF959735		MF959739	MF959743
Pleurocordyceps ramosopulvinatus		AB027326	AB027372				
Pleurocordyceps ramosopulvinatus	EFCC 5566		KF049658	KF049627		KF049682	KF049645
Pleurocordyceps ramosopulvinatus	SU 65			DQ118742		DQ118753	DQ127244
Pleurocordyceps sinensis	CGMCC 3 19069	MH454346	MH459160				
Pleurocordyceps sinensis	CN 80-2	HQ832887	HQ832884	HQ832886	HQ832889	HQ832890	HQ832888
Pleurocordyceps sinensis			HQ918290				
Pleurocordyceps sinensis	HMAS 43720		NR_119928	NG_042573			
Pleurocordyceps sinensis	YYH18111710						
Pleurocordyceps sinensis	FC20052304						
Pleurocordyceps sinensis	ZNQ0119102301						
Pleurocordyceps sinensis	FC20042304						
Pleurocordyceps sinensis	520326MF40865						
Pleurocordyceps sinensis	YYH18120122 1						
Pleurocordyceps sinensis	YYH18093037						
Pleurocordyceps sp	BCC 2637	KF049619	KF049663	KF049637	KF049675	KF049693	
Pleurocordyceps sp	JB07 08 16 08	KF049616	KF049662	KF049635	KF049672	KF049690	KF049652
Pleurocordyceps sp	JB07 08 17 07b	KF049617			KF049673	KF049691	KF049653
Pleurocordyceps sp	NBRC 109987			AB925983			
Pleurocordyceps sp	NBRC 109988			AB925984			
Pleurocordyceps sp	NBRC 109990			AB925968			
Pleurocordyceps sp	NBRC 110224			AB925969			
Pleurocordyceps sp	GIMCC 3 570	JX006097		JX006098		JX006100	JX006101
Pleurocordyceps sp	SJL0906	HM135166	HM135164	HM135165			
Pleurocordyceps yunnanensis	YHCPY1005	KF977848	KF977848	KF977848	KF977854	KF977850	KF977852
Pleurocordyceps yunnanensis	YHHPY1006	KF977849	KF977849	KF977849	KF977855	KF977851	KF977853
Polycephalomyces albiramus	XS08						
Polycephalomyces albiramus	XSMENG						

Table 2.2 (continued)

Current name	Voucher	SSU	ITS	LSU	rpb2	tef1	rpb1
Polycephalomyces formosus	NBRC 101760	MN586818	MN586827	MN586836	MN598060	MN598051	MN598042
Polycephalomyces formosus	NBRC 109984	MN586819	MN586828	MN586837		MN598052	MN598043
Polycephalomyces formosus	NBRC 109985	MN586820	MN586829	MN586838		MN598053	MN598044
Polycephalomyces formosus	NBRC 100686	MN586821	MN586830	MN586839	MN598061	MN598054	MN598045
Polycephalomyces formosus	NBRC 100687	MN586822	MN586831	MN586840	MN598062	MN598055	MN598046
Polycephalomyces formosus	NBRC 103843	MN586823	MN586832	MN586841	MN598063	MN598056	MN598047
Polycephalomyces formosus	NBRC 109993	MN586824	MN586833	MN586842	MN598064	MN598057	MN598048
Polycephalomyces formosus	NBRC 109994	MN586825	MN586834	MN586843	MN598065	MN598058	MN598049
Polycephalomyces formosus	NBRC 109995	MN586826	MN586835	MN586844	MN598066	MN598059	MN598050
Polycephalomyces formosus	WFKQ03						
Polycephalomyces formosus	WFKQ03b						
Polycephalomyces ramosus	RCEF6016		KC782530				
Polycephalomyces ramosus	NBRC 109983		AB925946	AB925982			
Polycephalomyces ramosus	MFLU 18 0162	MK863043	MK863250	MK863050		MK860188	
Polycephalomyces ramosus	RUTPP			AY259543			
Polycephalomyces tomentosus	BL4	KF049623	KF049666	KF049641	KF049678	KF049697	KF049656
Tolypocladium ophioglossoides	NBRC:106330	JN941734	JN943321	JN941407	AB968564	AB968603	JN992468
Tolypocladium ophioglossoides	NBRC:100998	JN941735	JN943319	JN941406	AB968563	AB968602	JN992469

2.3 Results

2.3.1 Phylogenetic Analyses

In the phylogenetic tree for the Hypocreales, the new Polycephalomycetaceae shared the same clade with Clavicipitaceae, Ophiocordycipitaceae, and Cordycipitaceae. It is sister to the Ophiocordycipitaceae in the two phylogenetic trees. Phylogenetic analyses strongly supported the Polycephalomycetaceae clade as a new family rank clade.

2.3.1.1 Backbone tree for Hypocreales

This paper analyzed the final dataset containing 4,929 bp from six loci, including 824 bp for LSU, 484 bp for ITS, 1013 bp for SSU, 898 bp for TEF, 654 bp for RPB1, and 1,056 bp for RPB2. Moreover, the matrix had 3,375 distinct patterns, 2,357 parsimony-informative, 487 singleton sites, and 2,085 constant sites. This paper presented the best-scoring IQ tree as -141648.485. The respective partition best-fit

models were K2P+I+G4 for LSU, TIM2+F+I+G4 for ITS, K2P+G4 for SSU, GTR+F+I+G4 for TEF, GTR+F+I+G4 for RPB1, and GTR+F+I+G4 for RPB2. The final RAxML analysis optimization likelihood value was -143568.392874. The gamma distribution shape parameter α was 0.378108. This paper further used the GTR+I+G model for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 316,624,000 generations, sampling the trees every 1,000th generation, thus obtaining 316,625 trees. It discarded the first 20% of trees (63,325) because they represented the burn-in phase of the analyses while utilizing the remaining (253,300) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

Notes: Three genera (*Perennicordyceps*, *Pleurocordyceps*, and *Polycephalomyces*) formed a clade sister to the Ophiocordycipitaceae, recognized as a new family, Polycephalomycetaceae. Eleven major families, including Polycephalomycetaceae, were selected to evaluate the higher-level relationships of Hypocreales. A Hypocreales backbone tree could be inferred using 237 taxa spanning 11 families, including Bionectriaceae, Calcarisporiaceae, Clavicipitaceae, Cordycipitaceae, Flammocladiellaceae, Hypocreaceae, Nectriaceae, Niessliaceae, Ophiocordycipitaceae, Stachybotryaceae, and Tilachlidiaceae. Furthermore, the tree was rooted with Flammocladiellaceae. Applying six loci analyses, the Polycephalomycetaceae clade was sister to Ophiocordycipitaceae and distinct from other families in the phylogenetic tree.

Based on the RAxML analysis, the Polycephalomycetaceae clade was not stable. Therefore, we obtained two kinds of typology of consensus trees using a six-loci (LSU, SSU, ITS, TEF, RPB1, RPB2) or a five matrix one (LSU, SSU TEF, RPB1, RPB2). One typology of the consensus tree was that alone the Polycephalomycetaceae clade grouped to Clavicipitaceae; the other was the Polycephalomycetaceae clade grouping with Ophiocordycipitaceae. The bootstrap values between the Polycephalomycetaceae and Ophiocordycipitaceae or Clavicipitaceae clades were low (less than 75%) in both ML trees. The approximately unbiased (AU) test evaluated the two consensus trees. The consensus tree of the Polycephalomycetaceae clade grouped with Ophiocordycipitaceae gained the highest *p*-values (0.927) than the rest, and was

assessed as the best tree. Moreover, the typology of the best tree from RAxML was similar to the IQ tree and Bayesian. Therefore, the IQ tree was selected to represent the backbone tree of the Hypocreales.

The Polycephalomycetaceae clade was sister to the Ophiocordycipitaceae clade, distinct from other families in the Hypocreales. However, the three genera in the Polycephalomycetaceae clade could not be classified as a genus under the Ophiocordycipitaceae. Therefore, Polycephalomycetaceae was recognized as a new family to accommodate the three genera.

2.3.1.2 Main closed relationship families' phylogeny

The alignment contained 4,768 bp from six loci, including 765 bp for LSU, 484 bp for ITS, 995 bp for SSU, 913 bp for TEF, 639 bp for TEF RPB1, and 972 bp for RPB2. Moreover, the matrix had 2,689 distinct patterns, 1,766 parsimony-informative, 461 singleton sites, and 2,541 constant sites. This paper presented the IQ tree with the best score of -78169.230. The respective partition best-fit models were: TIM+F+I+G4 for LSU, TVM+F+I+G4 for ITS, K2P+I+G4 for SSU, TIM3+F+I+G4 for TEF, TIM3+F+I+G4 for RPB1, and TIM+F+I+G4 for RPB2. Based on RAxML analysis, the final optimization likelihood value was -79110.991365. This study used the GTR+I+G model for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 1,540,000 generations, sampling the trees every 1,00th generation, thus obtaining 15,401 trees. It discarded the first 25% of trees (3,850) because they represented the burn-in phase of the analyses while using the remaining (11,551) for calculation posterior probabilities in the majority rule consensus tree. The critical value for the topological convergence diagnostic was 0.01.

The Polycephalomycetaceae clade was sensitive to sampling. Hence, five main closest-relationship families, including Calcarisporiaceae, Clavicipitaceae, Ophiocordycipitaceae, Cordycipitaceae, and Polycephalomycetacea, were selected to generate a phylogenetic tree. This paper expanded the sampling to 150 taxa using the main species of these five families. The tree was rooted to Calcarisporiaceae, which included *Calcarisporium xylariicola* HMAS 276836, *Calcarisporium cordycipiticola* MFLUCC 15-0685, *Calcarisporium cordycipiticola* MFLUCC 15-0686, and

Calcarisporium arbuscula CBS 900.68. The typology of the main closest-relationship families reflected the exact typology of the Hypocreales backbone tree.

The typology of ML was similar to BI analyses. Illustrates the ML tree based on the IQ tree. The bootstrap values of the closest family's tree were higher than those of the backbone tree because we expanded the taxa of the Polycephalomycetaceae clade. Phylogenetic results indicated that the Polycephalomycetaceae clade was a sister with the Ophiocordycipitaceae clade, with a low bootstrap value (88) in the IQ tree and a high bootstrap value (1) in the Bayesian tree. Thus, phylogenetic analyses supported that the Polycephalomycetaceae clade was a family clade. We expect that more species will be introduced to this group in the future.

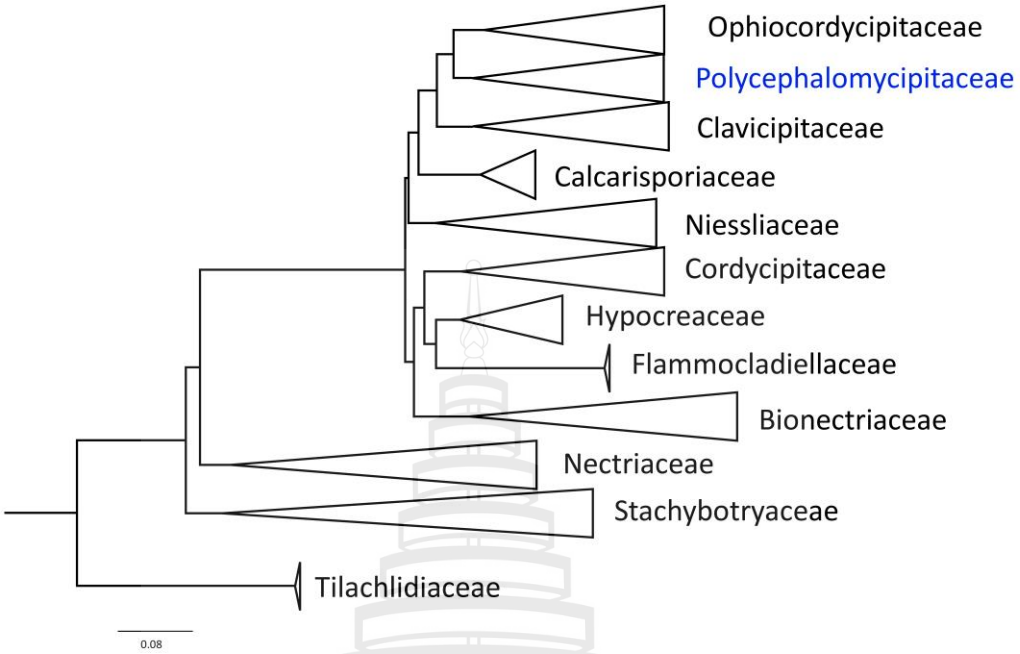
2.3.1.3 Polycephalomycetaceae and the three genera phylogeny

The alignment contained 4,994 bp from six loci, including 823 bp for LSU, 509 bp for ITS, 1,016 bp for SSU, 894 bp for TEF, 700 bp for RPB1, and 1,052 bp for RPB2. Furthermore, the matrix had 1,544 distinct patterns, 1,209 parsimony-informative, 104 singleton sites, and 3,681 constant sites. This paper presented the IQ tree with the best score as -21221.868. The respective partition best-fit models were: TN+F+I+G4 for LSU, HKY+F+I+G4 for ITS, K2P+I for SSU, TN+F+G4 for TEF, and TNe+G4 for RPB1 and RPB2. Based on RAxML analysis, the final optimization likelihood value was -21580.865847. Finally, the gamma distribution shape parameter α was 0.175387. Bayesian analysis used the GTR+I+G model for the LSU, ITS, TEF, RPB1, RPB2, and HKY+G models for SSU based on MrModeltest 2.3 from the MrMTgui platform. This paper ran six simultaneous Markov chains for 1,920,000 generations, sampling the trees every 100th generation, thus obtaining 19,201 trees. We discarded the first 25% of trees (4,800) because they represented the burn-in phase of the analyses while using the remaining (14,401) for calculation posterior probabilities in the majority rule consensus tree. The critical value for the topological convergence diagnostic was 0.01. Moreover, by following this method, we generated three phylogenetic trees for each of the three genera.

Notes: The representative taxa in Polycephalomycetaceae were included in determining the phylogenetic placement of the three genera: *Perennicordyceps*, *Pleurocordyceps*, and *Polycephalomyces*. The alignment contained members of the

newly-proposed family comprised of 90 taxa (Table 2.2). *Tolypocladium ophioglossoides* NBRC 106330 and *Tolypocladium ophioglossoides* NBRC 100998 were the outgroup taxa. The phylogenetic trees for each genera containing all available sequence data were present under each genus description.

Based on phylogenetic analyses, four new species, one new combination, and four new hosts were indicated. *Pleurocordyceps nutantis* belonged to the *Pleurocordyceps* and had a sister relationship with *Pleurcordyceps sinensis* with a high (98% ML / 1.00 PP) support. The MFLU 18-0162 strain named *Polycephalomyces formosus* was wrongly identified, as it was identified based on the wrong identification of the ARSEF1424 strain. Four new samples were parasitizing on a different host clustered with *Pleurocordyceps sinensis*. Moreover, they were identified as *Pleurocordyceps sinensis* with the new host. *Pleurocordyceps parvicapitata* was sister to *Pleurocordyceps lianzhouensis* with a high (99% ML / 1.00 PP) support. A new collection, which parasitized a new host, was indicated as *Pleurocordyceps aurantiacus*. *Pleurocordyceps lanceolatus* was sister to *Pleurocordyceps marginaliradians* with a high (98% ML / 0.99 PP) support. The new samples (DG04, DG04H, and DG07) clustered with *Polycephalomyces elaphomyceticola* in the *Perennicordyceps* clade genus. Hence, the *Polycephalomyces elaphomyceticola* species should be removed to *Perennicordyceps*. This paper thus proposed a new combination, *Perennicordyceps elaphomyceticola*. The new collection (WFKQ03) parasitizing a new host with its isolate (WFKQ03b) clustered with *Polycephalomyces formosus* with high (100% ML / 0.95 PP) support. The new collection was identified as *Polycephalomyces formosus*. A new species, *Polycephalomyces albiramus* (XS08), with its isolate (XSMENG), was sister to *Polycephalomyces formosus*, type species.



Note Backbone schematic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of the order Hypocreales. The new family is indicated in blue bold.

Figure 2.1 Backbone schematic tree of the order Hypocreales

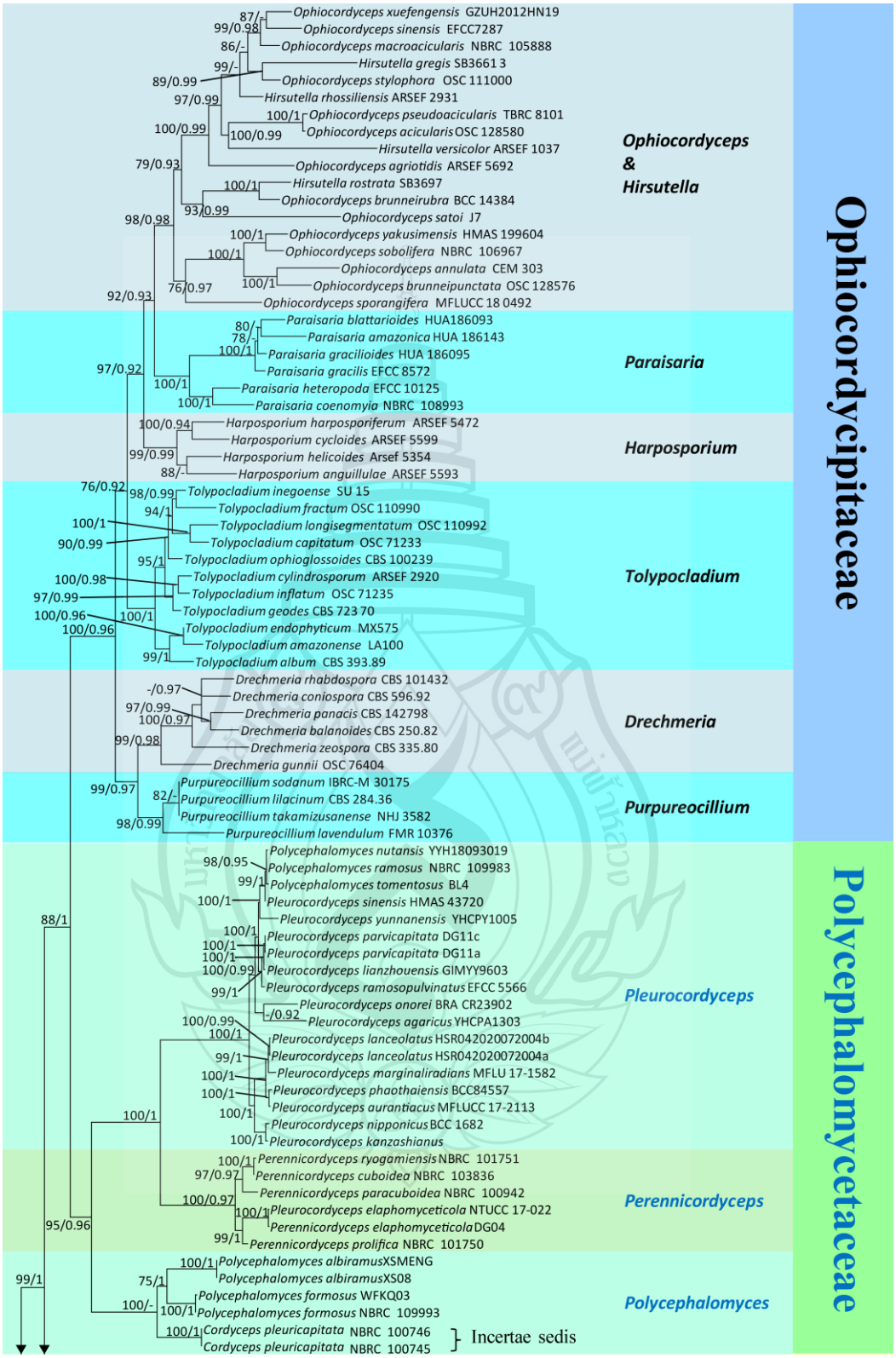
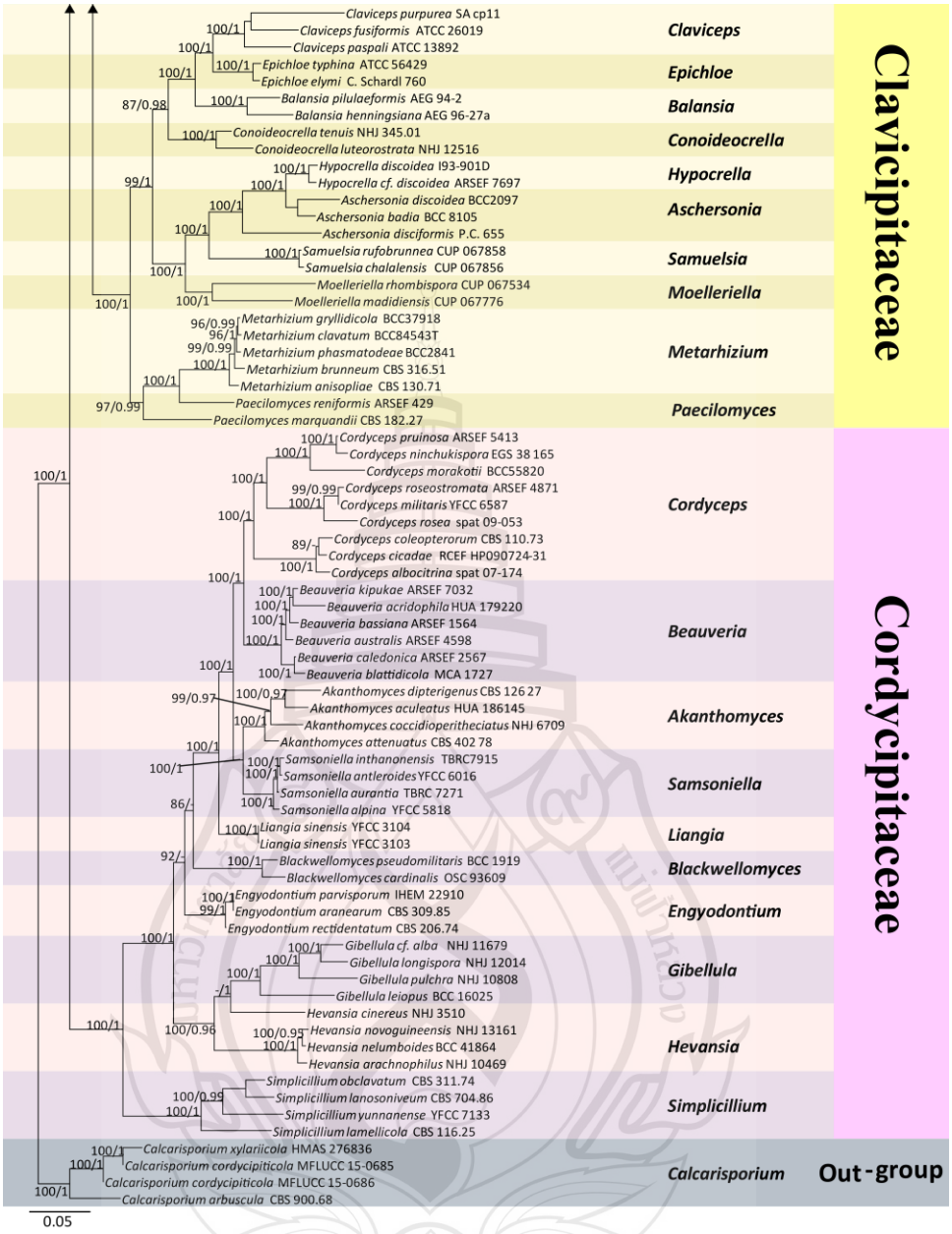
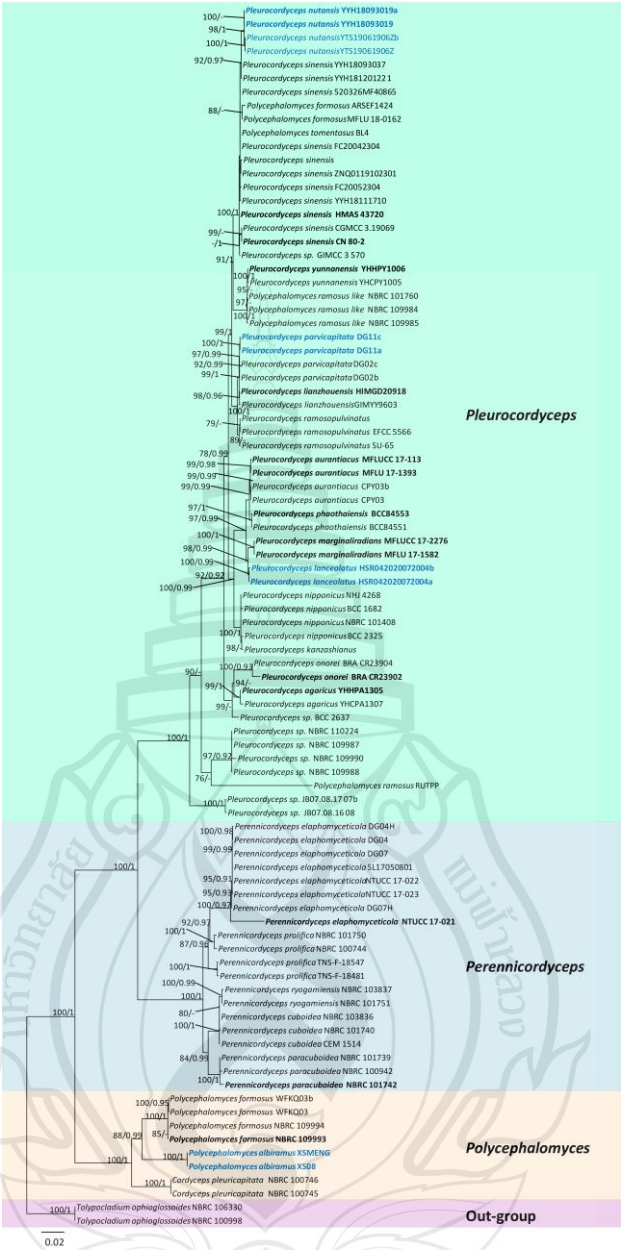


Figure 2.2 Phylogenetic tree of three families Clavicipitaceae, Ophiocordycipitaceae and Polycephalomycetaceae



Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of three families Clavicipitaceae, Ophiocordycipitaceae and Polycephalomycetaceae. 150 taxa and 4768 characters are involved in this phylogenetic tree. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.90 are indicated above the nodes. The new species are indicated in blue. The type strains were indicated in bold.

Figure 2.2 (continued)



Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of Polycephalomycetaceae. 90 taxa and 4768 characters are involved in this phylogenetic tree. Maximum likelihood bootstrap values greater than 75% and Bayesian Posterior Probabilities (BYPP) equal to or greater than 0.90 are given below each node. The new species are indicated in blue. The type strains are indicated in bold.

Figure 2.3 Phylogenetic tree of Polycephalomycetaceae

2.3.2 Taxonomy

2.3.2.1 Outline of Polycephalomycetaceae

Phylum ASCOMYCOTA Caval-Sm.

Subphylum PEZIZOMYCOTINA O.E. Erikss. & Winka

Class Sordariomycetes O.E. Erikss. & Winka

Subclass Hypocreomycetidae O.E. Erikss. & Winka

Hypocreales Lindau

Polycephalomycetaceae

Perennicordyceps

Perennicordyceps cuboidea (Kobayasi & Shimizu) Matočec & I. Kušan 2014

Perennicordyceps paracuboidea (S. Ban, Sakane & Nakagiri) Matočec & I. Kušan 2014

Perennicordyceps prolifica (Kobayasi) Matočec & I. Kušan 2014

Perennicordyceps ryogamiensis (Kobayasi & Shimizu) Matočec & I. Kušan 2014

Pleurocordyceps

Pleurocordyceps agarica (Hong Yu bis & Y.B. Wang) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps marginaliradians (Y.P. Xiao, T.C. Wen & K.D. Hyde) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps nipponica (Kobayasi) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps onorei (Kautman & Kautmanová) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps phaothaiensis (Mongkols., Noisrip., Lamlertthon & Luangsa-ard) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps ramosopulvinata (Kobayasi & Shimizu) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Pleurocordyceps sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk 2021

Pleurocordyceps yunnanensis (Hong Yu bis, Y.B. Wang & Y.D. Dai) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao 2021

Polycephalomyces Kobayasi 1941

Polycephalomyces baltica Poinar & Vega 2020

Polycephalomyces cylindrosporus Samson & H.C. Evans 1981

Polycephalomyces ditmarii Van Vooren & Audibert 2005

Polycephalomyces paludosus paludosus Mains 1948

Polycephalomyces ramosus (Peck) Mains 1948

Polycephalomyces tomentosus (Schrad.) Seifert 1985

Incertae sedis

Cordyceps pleuricapitata Kobayasi & Shimizu 1982

2.3.2.2 Taxonomy of Polycephalomycetaceae

1. Polycephalomycetaceae

Polycephalomycetaceae Y.P. Xiao, Y. Yang & K.D. Hyde, **fam. nov.**

Etymology: Morphology of the type genus *Polycephalomyces.*

Parasites on and pathogens of *Ophiocordyceps sp.*, *Elaphomyces sp.* and insects**. Sexual morph***:*** *Ascomata* stromatic, cylindrical, pallid to yellowish, stipitate**.** *Stipe* cylindrical, simple or branched, rhizomorphs present or absent, forming inflated fertile parts. *Fertile part* distinct from the stipe, globose to ellipsoid, ascoma congregated, capitate, with protruding ostiolar papillae. *Perithecia* immersed or superficial, ovoid to flask-shaped**.** *Peridium* thick, three layers**.** *Asci* unitunicate, narrowly cylindrical, hyaline, with an apical cap. *Ascospores* filiform, hyaline, multiseptate, often separating into secondary spores. *Secondary spores* cylindrical to globose, hyaline, smooth-walled. **Asexual morph***:* Hyphomycetous. *Mycelium* congregated as flat colony on the surface of host or forming synnemata from host**.** *Synnemata* stipitate, single to numerous, branched or unbranched, white to yellow, with or without an enlarged fertile part on the topical or lateral. *Fertile parts* enlarged, normally globose, yellowish to yellow, conidia massed on the surface. *Conidiophores* 1-6 phialides congregated in one, branched or unbranched, divergent. *Conidiogenous*

cells phialidic, hyaline. *Phialides* one or two types, congregated or solitary, intercalary and terminal. *Conidia* one or two types, cylindrical or fusoid or globose, hyaline, smooth, 1-celled, masses of conidia observed or not.

Type genus: *Polycephalomyces* Kobayasi, Sci. Rep. Tokyo Bunrika Daig., Sect. B 5: 245 (1941)

Notes: Three genera, *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*, clustered as a sister clade (Polycephalomycetaceae) with Ophiocordycipitaceae in the Hypocreales. Furthermore, Polycephalomycetaceae shares the same clade with Ophiocordycipitaceae, Clavicipitaceae, Calcarisporiaceae, Hypocreaceae, and Cordycipitaceae. Ophiocordycipitaceae branched two distinguished clades—Polycephalomycetaceae clade and other genera clade, including *Drechmeria*, *Harposporium*, *Hirsutella*, *Ophiocordyceps*, *Polycephalomyces*, *Purpureocillium*, and *Tolypocladium*.

The host includes *Ophiocordyceps sp.*, *Elaphomyces sp*., and insects. Morphologically, Polycephalomycetaceae is similar to Ophiocordycipitaceae and Clavicipitaceae but different in parasitizing on *Ophiocordyceps* sp., *Elaphomyces* sp., and producing congregated or solitary conidiophores, one- or two-type phialides, and conidia**.** Therefore, a new Polycephalomycetaceae family is introduced to accommodate these three genera.

2. Morphological Characters of Polycephalomycetaceae

1) Host

The hosts of Polycephalomycetaceae species include arthropods (e.g., Coleoptera, Formicidae, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Pentatomidae, Psocoptera) and fungi (e.g., *Ophiocordyceps sp*., *Hirsutella sp*., *Cordyceps sp*., *Elaphomyces sp*., Myxomycetes) (Kobayasi 1939, 1941; Kobayasi & Shimizu, 1982; Ban et al., 2009; Wang et al., 2014; Wang et al., 2015a; Wang et al., 2015b; Chen et al., 1984; Wang et al., 2012; Crous et al., 2017; Xiao et al., 2018; Yang et al., 2020).

2) Morphological characters of sexual morph

A. Stromata, stipe and fertile part

The stromata of the Polycephalomycetaceae species are stipitate, either solitary or several, either branched or unbranched, wiry, pigment,

either forming or not forming a fertile part on the top of or lateral to the stipe, or perithecia scattered along the stipe (Kobayasi, 1939; Kobayasi, 1941; Kobayasi & Shimizu, 1982; Ban et al., 2009; Wang et al., 2014; Wang et al., 2015a; Wang et al., 2015b; Chen et al., 1984; Wang et al., 2012; Crous et al., 2017; Xiao et al., 2018; Yang et al., 2020). The fertile part of the Polycephalomycetaceae species is cushion-shaped or with a capitate on the top of or lateral to the stipe, typically with light color, rarely dark.

Note a Solitary stroma. b Branched stromata. c Capitate stomata**.** d Solitary stroma with superficial perithecia (redrawn from Ban et al., 2009). e fertile part lateral to the stipe. f Several stromata scattered on the host.

Figure 2.4 Overview of fungus species of Polycephalomycetaceae

3). Perithecia, peridium

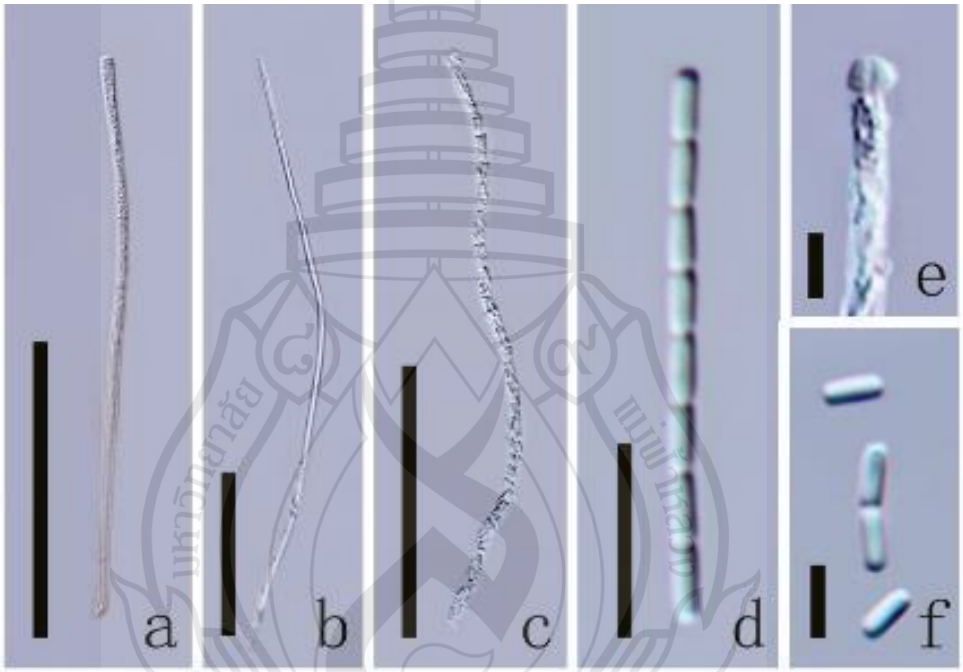
The perithecia of the Polycephalomycetaceae species are either superficial or immersed with an ostiolate up on the surface, and are flask-shaped, ovoid, pyriform, or ellipsoid. The peridium of Polycephalomycetaceae species is 2 layers in superficial perithecia, 3 layers in immersed perithecia.

Note a–c Superficial perithecia with peridium. d–g Immersed perithecia with peridium. c Peridium with 2 layers. e, g Immersed perithecia with the out layer of peridium. e, g Peridium with 3 inner layers.

Figure 2.5 Perithecia of species of Polycephalomycetaceae

4). Asci, ascospores and secondary spores

The asci of the Polycephalomycetaceae species are slender cylindrical. Ascospores are filiform with thin apical caps, easily breaking into secondary spores, which are either truncate, cylindrical, or globose (Kobayasi, 1939, 1941; Kobayasi & Shimizu, 1982; Ban et al., 2009; Wang et al., 2014; Wang et al., 2015a; Wang et al., 2015b; Chen et al., 1984; Wang et al., 2012; Crous et al., 2017; Xiao et al., 2018; Yang et al., 2020).



Note a–c Asci. d–f Part ascospore. f secondary spores. Scale Bars: a–c = 100 µm, d = 10 µm, e, f = 5 µm.

Figure 2.6 Asci, ascospores and secondary spores of species of Polycephalomycetaceae

5) Morphological characters of asexual morph

A. Synnemata and colony

The synnemata of the Polycephalomycetaceae species are either observed or absent, either solitary or several to many, either branched or unbranched, forming a globose part on the top or terminal, and pale to brown. The

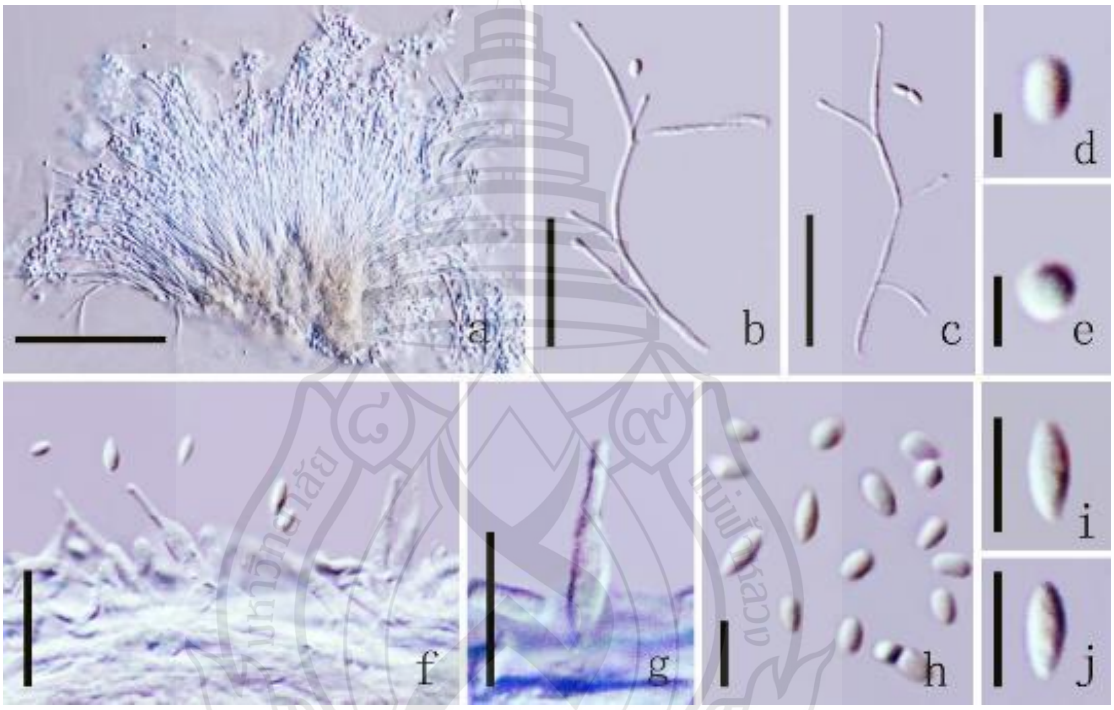
colonies or mycelium of the Polycephalomycetaceae species are covered on the surface of the host, pale to yellow.

Note a, b Synnemata branched or unbranched with fertile part. c, d Synnemata branched without fertile part. e, f Synnemata unbranched with fertile part. g, h Colony or mycelium covered on the surface of the host. i, j Synnemata growing from the insect body.

Figure 2.7 Synnemata and colony of species of Polycephalomycetaceae

B. Phialides and conidia

The phialides of the Polycephalomycetaceae species are of one or two types *Acremonium*-like and *Hirsutella*-like. *Acremonium*-like is slender cylindrical; *Hirsutella*-like denotes a broad base with a tapering neck. The conidia of the Polycephalomycetaceae species are of one or two types: hyaline, globose, or ovoid, fusiform, cylindrical.



Note a–e *Acremonium*-like phialides and conidia. f–j *Hirsutella*-like phialides and conidia. Scale Bars: a = 50 µm, b, c = 20 µm, d, e = 2 µm, f, g = 10 µm, h–j = 5 µm.

Figure 2.8 Phialides and conidia of species of Polycephalomycetaceae

3. *Polycephalomyces*

Polycephalomyces Kobayasi, Sci. Rep. Tokyo Bunrika Daig., Sect. B 5: 245 (1941)

Index Fungorum number: IF9494

Parasites on and pathogens of insects, *Ophiocordyceps* sp**.** and myxomycetes. **Sexual morph*:*** Undetermined*.* **Asexual morph*:*** Hyphomycete. *Synnemata* stipitate, observed on the surface of host or pure culture, single to numerous, branched or unbranched, light colored, *Conidiophores* branched or unbranched, divergent**.** *Conidiogenous cells* phialidic, hyaline**.** *Phialides* 1–4 arising from conidiophores, intercalary and terminal. *Conidia* monomorphic, oblong to cylindrical, hyaline, smooth, 1-celled (Adapted from *Polycephalomyces formosus* and *Polycephalomyces albiramus*).

Type species: ***Polycephalomyces formosus*** Kobayasi, Sci. Rep. Tokyo Bunrika Daig., Sect. B 5: 245 (1941)

Index Fungorum number: IF289806

Notes: – The genus *Polycephalomyces* was introduced as an entomopathogen with one species obtained from Japan, characterized by polycephalous synnemata (Kobayashi, 1941). Twenty-five species (*Po. agaricus*, *Po. aurantiacus*, *Po. baltica*, *Po. cuboideus*, *Po. cylindrosporus*, *Po. ditmarii*, *Po. elaphomyceticola*, *Po. formosus*, *Po. kanzashianus*, *Po. lianzhouensis*, *Po. marginaliradians*, *Po. nipponicus*, *Po. onorei*, *Po. orbicularis*, *Po. paludosus*, *Po. paracuboideus*, *Po. phaothaiensis*, *Po. ponerae*, *Po. prolificus*, *Po. ramosopulvinatus*, *Po. ramosus*, *Po. ryogamiensis*, *Po. sinensis*, *Po. tomentosus*, and *Po. yunnanensis*) have been introduced in the genus based on morphology and phylogenetic analyses (Seifert, 1985; Bischoff et al., 2003; Wang et al., 2012, 2014, 2015a, 2015b; Crous et al., 2017; Xiao et al., 2018; Yang et al., 2020; Poinar & Vega 2020). *Polycephalomyces orbicularis* was treated as a synonym of *Stilbella byssiseda* (Seifert, 1985). Moreover, *Perennicordyceps* was segregated from *Polycephalomyces* with four species, including *Pe. cuboidea*, *Pe. paracuboidea*, *Pe. prolifica*, and *Pe. ryogamiensis* (Matočec et al. 2014). However, the widely used strain (ARSEF 1424) had been represented as the type species for a long time until Wang et al. (2020) detected pivotal type strains and designated the epitype (CGMCC 5.2206), lectotype (TNS-F-197965), and amended the neotype (K(M) 187597). The morphology and phylogenetic evidence of one new record from China in this study further supports the research for the type species by Wang et al. (2020) (See notes for *Polycephalomyces formosus*).

The updated type species phylogenetic group is distinct from the other ten species (*Pleurocordyceps aurantiacus*, *Pl. nipponica*, *Pl. lianzhouensis*, *Pl. marginaliradians*, *Pl. nipponica*, *Pl. onorei*, *Pl. phaothaiensis*, *Pl. ramosopulvinatus*, *Pl. sinensis*, *Pl. yunnanensis*), considered as the same group in a previous study (Wang et al., 2020). Hence, Wang et al. (2020) established a new genus, *Pleurocordyceps*, to accommodate these species (Wang et al., 2020). Yang et al. (2020) described a new species *Polycephalomyces elaphomyceticola*, treating all species of *Perennicordyceps* as *Polycephalomyces*. However, *Polycephalomyces elaphomyceticola* grouped with *Perennicordyceps* with substantial support value (100% ML / 1.00 PP). The morphology of *Polycephalomyces elaphomyceticola* is similar to *Perennicordyceps* in superficial perithecia, cylindrical secondary spores, and hirsutella-like asexual morphs. Therefore, *Polycephalomyces elaphomyceticola* is combined with *Perennicordyceps*. *Polycephalomyces cylindrosporus*, *Po. ditmarii*, and *Po. paludosus* necessitate further investigation as lacking molecular data (Mains, 1948; Samson et al., 1981; Van Vooren et al., 2005). Poinar & Vega (2020) introduced *Polycephalomyces baltica*, parasitic on bark lice (Psocoptera) in the Baltic amber. *Polycephalomyces ramosus* and *Po. tomentosus* require further investigation because the updated strains provided molecular data but lacked sufficient morphological information (Kepler et al., 2013; Matočec et al., 2014; Ban et al., 2016). In conclusion, *Polycephalomyces* consists of eight species: *Polycephalomyces baltica*, *Po. cylindrosporus*, *Po. ditmarii*, *Po. elaphomyceticola*, *Po. formosus*, *Po. paludosus*, *Po. ramosus*, and *Po. tomentosus* (Index Fungorum 2021).

The new *Polycephalomyces albiramus* strain clustered with *Polycephalomyces formosus* and *Cordyceps pleuricapitata* in the same clade (*Polycephalomyces* clade), forming independent branches with substantial support (100% ML / 0.99 PP) (*Polycephalomyces* genus tree). *Polycephalomyces albiramus* differs from *Polycephalomyces formosus* in producing numerous branched synnemata without a fertile head, shorter conidiophores, and smaller conida (See notes for *Polycephalomyces albiramus*).

All GenBank accession numbers for *Polycephalomyces* are listed in Supplementary Table 2.2, excluding ITS: MH859198 *(Polycephalomyces tomentosus*, strain CBS 653.68), ITS: AB208109 *(Polycephalomyces tomentosus*, strain JCM

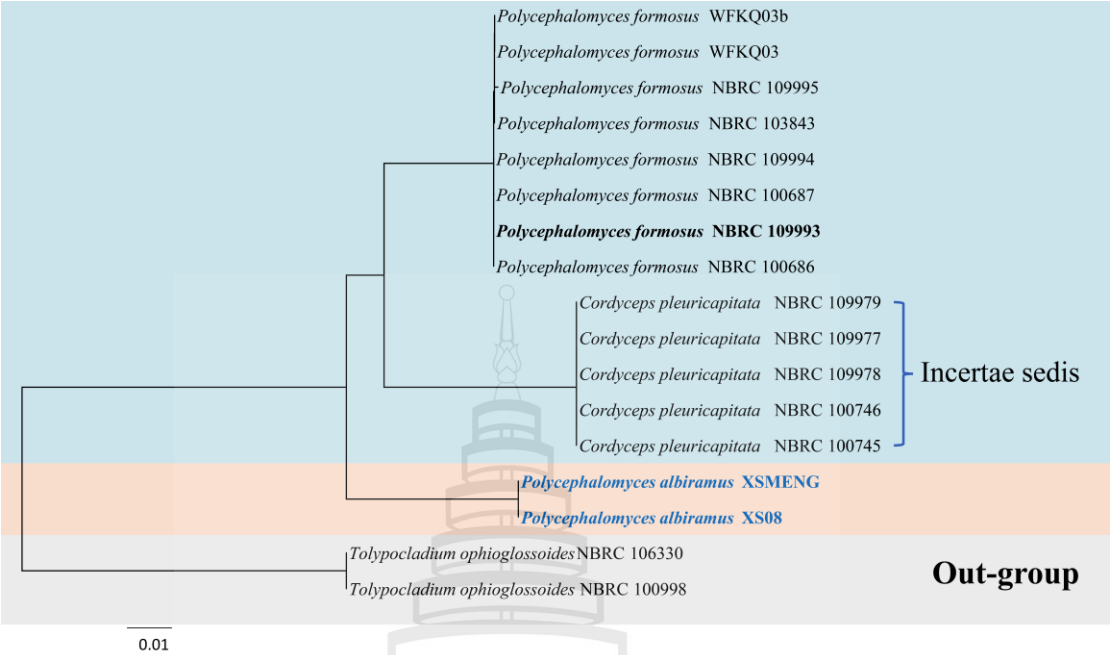
12445*)*, and ITS: AJ786598 (*Polycephalomyces ramosus*, strain 3078.H). Since those DNA sequences do not cluster in the family after blasting in NCBI, all described species are listed in Supplementary.

The ecological and economic significance of Polycephalomyces: Although lacking chemical investigation, this genus has high potential in terms of biotechnological value. *Polycephalomyces formosus* and *Polycephalomyces cylindrosporus* have a broad range of insects or fungal hosts (Mains, 1948; Samson et al., 1981; Wang et al., 2020).

Ecological and economic significance of Polycephalomyces: although lacking chemical investigation, this genus has high potential in terms of biotechnological value. *Polycephalomyces formosus* and *Polycephalomyces cylindrosporus* have a broad range of insects or fungi hosts (Mains, 1948; Samson et al., 1981; Wang et al., 2020).

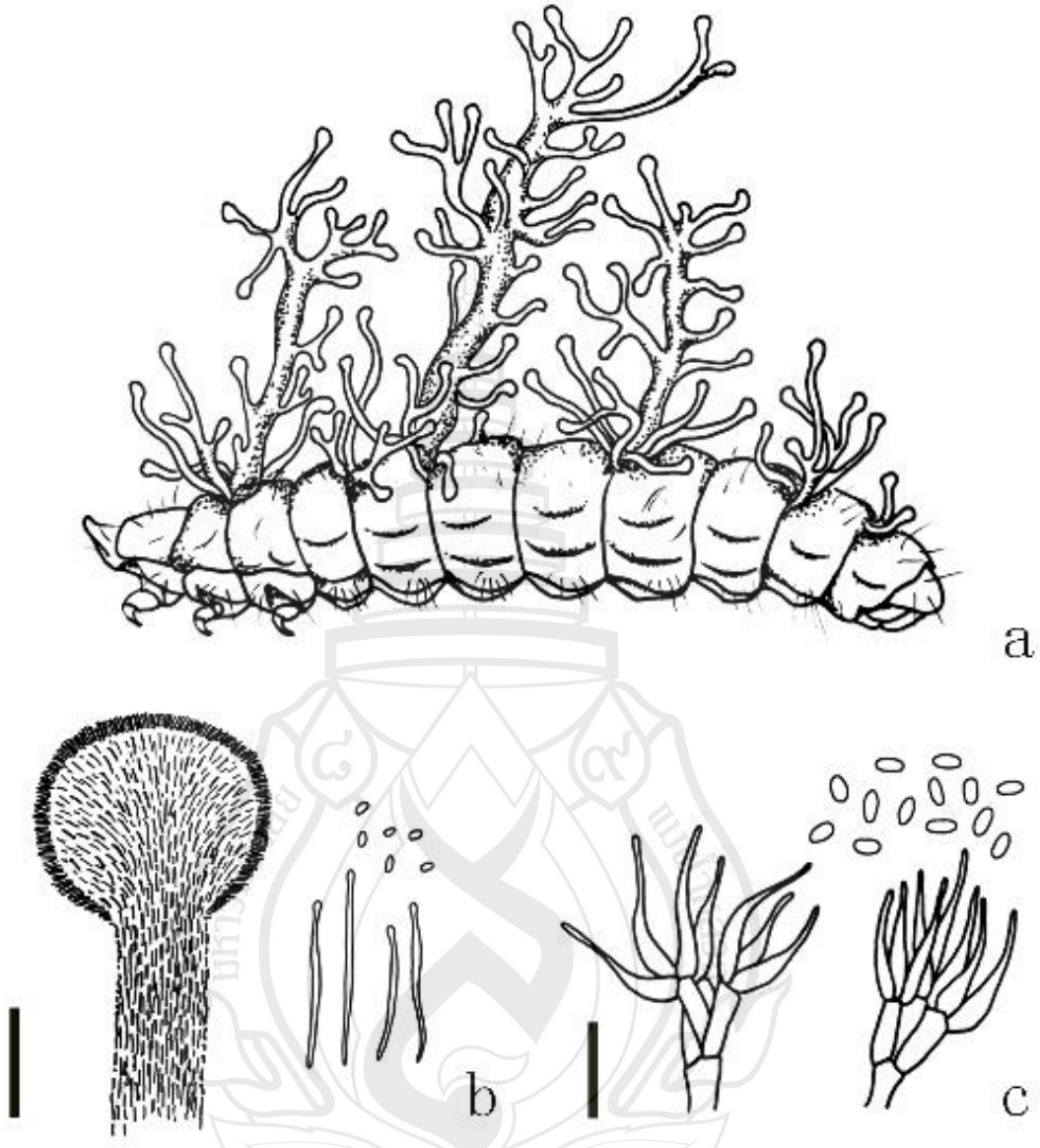
Distribution: America, China, France, Ghana, Japan, Russia, Sir Lank (Kobayasi, 1941, 1948; Seifert, 1985; Bischoff et al., 2003; Van Vooren et al., 2005; Sato et al., 2012; Matočec et al., 2014)

Conclusion: Illustrate the type species. One new records and one new species are introduced.



Note Phylogenetic tree of *Polycephalomyces* generated from maximum likelihood analysis of ITS, SSU, LSU, TEF1α, RPB1, and RPB2 sequence data. *Tolypocladium ophioglossoides* (NBRC 106330) and *T. ophioglossoides* (NBRC 100998) are used as outgroup taxon. The new species are indicated in blue. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.90 are indicated above the nodes. The new species are indicated in blue. The type strains are indicated in bold.

Figure 2.9 Phylogenetic tree of *Polycephalomyces*



Note a Overview of *Polycephalomyces formosus*. b Synnemata, phialides and conidia. c Phialides and conidia. Scale Bars: b, c = 10 µm.

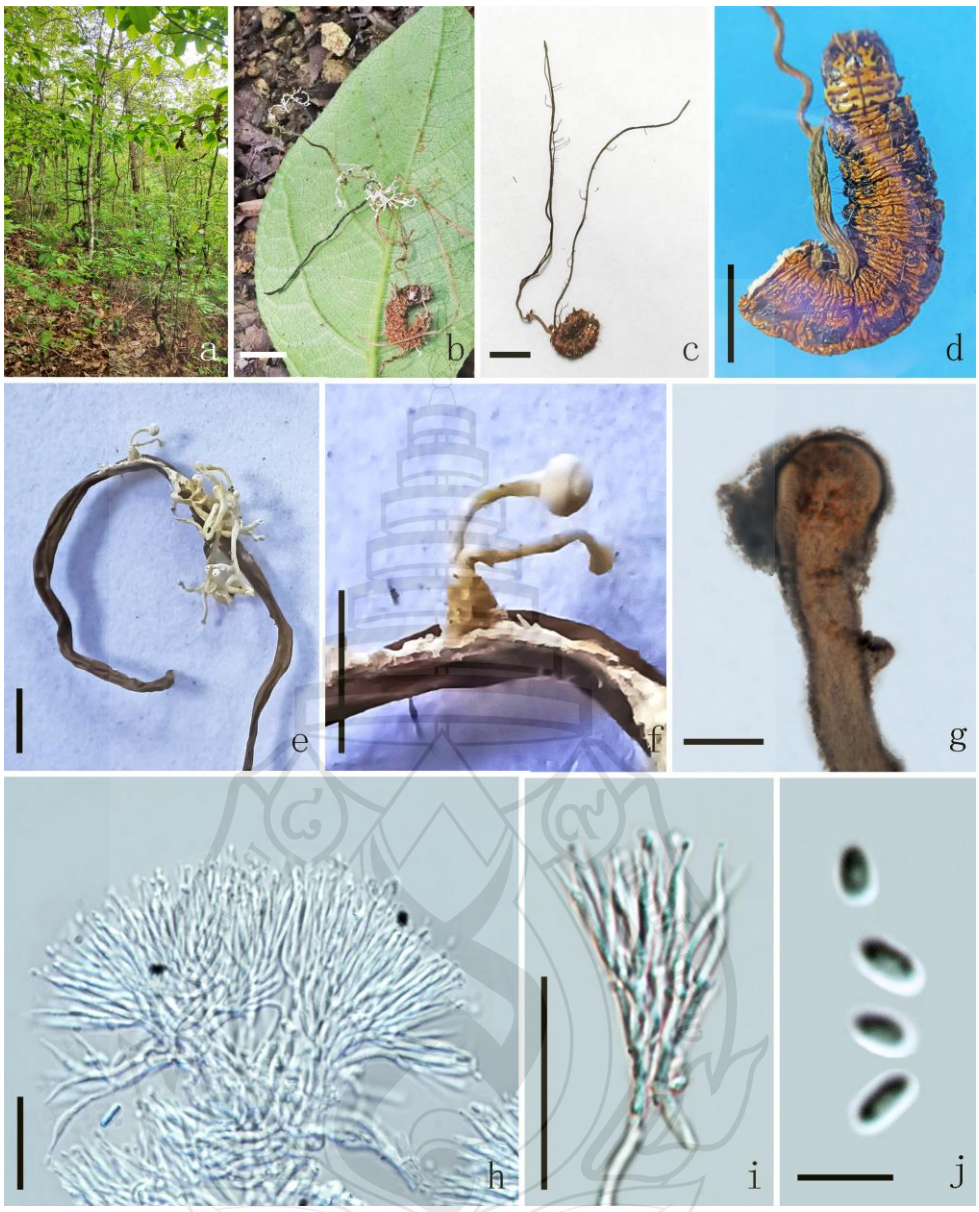
Figure 2.10 Morphology of *Polycephalomyces formosus* (Lectotype –: TNS-F-197965 a, b redrawn from Kobayasi, 1941; Neotype –: K(M) 187597, c redrawn from Seifert, 1985)

Polycephalomyces formosus Kobayasi, Sci. Rep. Tokyo Bunrika Daig., Sect. B 5: 245 (1941).

Host: *Ophiocordyceps multibrachiata*

Parasitism on the *Ophiocordyceps multibrachiata*. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 1–10 mm long, 0.1–0.3 mm wide, scattered or gathered on the stipe of *Ophiocordyceps multibrachiata*, stipitate, solitary or forming 2–3 branches, white to pale yellow, cylindrical or rhizoid with or without an enlarged globose fertile head on the top. *Fertile head* 0.1–0.3 mm wide, globose to subglobose, white to pale yellow, coved with masses conidia. *Stipe* 1–10 mm long, 0.1–0.2 mm wide, cylindrical or rhizoid, white. *Conidiophore* 28–66 µm long ($\overline{x}$ = 47 µm, n = 60), concentrated in the fertile head, monothetic and solitary or acropleurogenous in the whorls, 1–4 phialides in one. *Phialides* 26–46 × 0.5–1.8 µm ($\overline{x}$ = 36 × 1.2 µm, n = 60), tapering gradually from middle to the apex, narrowly cylindrical to subulate, 1–1.8 µm wide at the base and 0.5–0.9 µm wide at the apex, one-type, hyaline, smooth, forming a hymenial layer. *Conidia* 2–4 × 1–1.5 µm ($\overline{x}$ = 3 × 1.2 µm, n = 60), 1-celled, one-type, hyaline, oblong ellipsoid to obovoid.

Material examined: China, Guizhou Province, Zunyi City. Parasitic on *Ophiocordyceps multibrachiata* on Lepidoptera in the soil, 22 October 2020, Qingfeng Meng, WFKQ03-2010220.



Note a Habitat of *Polycephalomyces formosus*. b Synnemata emerging from infected *Ophiocordyceps multibrachiata*. c Overview of *Ophiocordyceps multibrachiata*. d Host of *Ophiocordyceps multibrachiata*. e, f Synnemata. g, h Vertical section of synnemata. i Conidiophores. j Philidies. k Conidia. Scale Bars: b, c = 1 cm, d–f = 5000 µm, g = 200 µm, h = 50 µm, i, j = 20 µm, k = 5 µm.

Figure 2.11 *Polycephalomyces formosus* (new record WFKQ03-20102201)

Polycephalomyces albiramus Y.P. Xiao, T.C. Wen, J.Z. Sun & K.D. Hyde ***sp. nov.***

Etymology: The species name refers to the pale synemata

Holotype: XS08

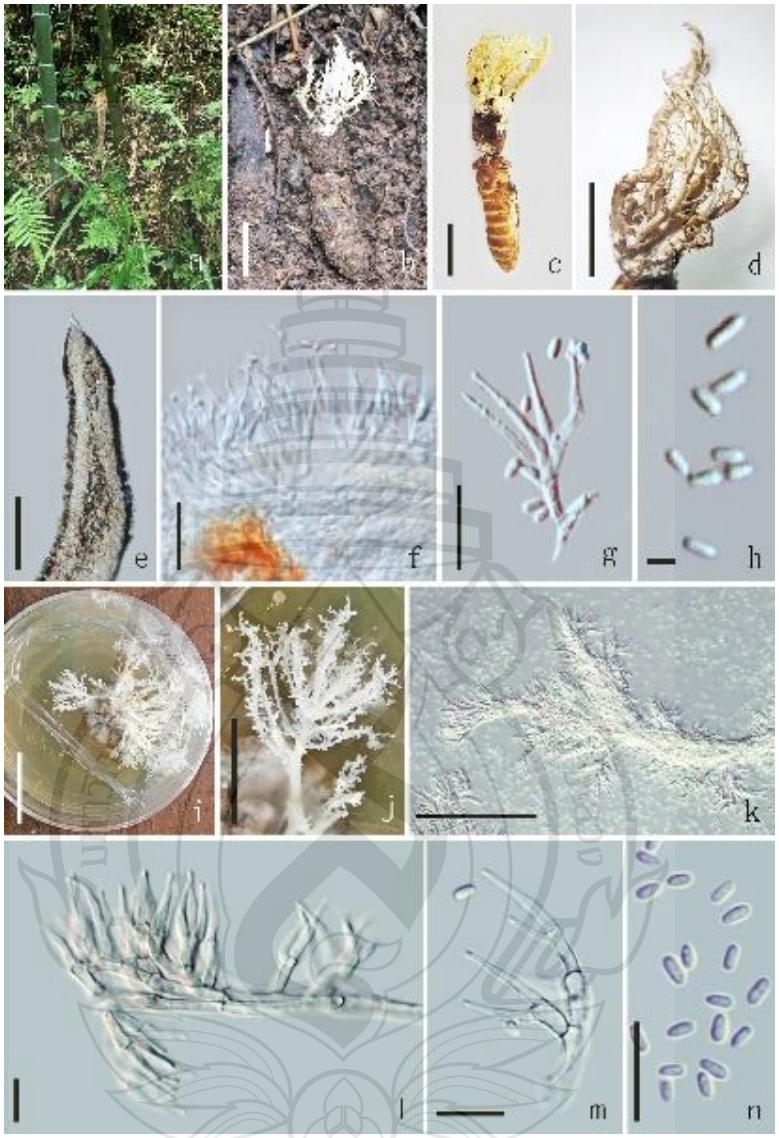
Parasitism on *Gryllotalpa* sp. (Orthoptera, Gryllotalpidae). **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 1–3 cm long, 1–2 mm wide, arising from the head of larvae, stipitate, gathered, branched, white to pale yellow, numerous, cylindrical and tapering on the top, without fertile head. *Stipe* 1–3 cm long, 1–2 mm wide, flexuous, white to pale yellow colored, branched. *Conidiophores* 15–35 µm long ($\bar{x}$ = 27 µm, n = 60), concentrated, mono-, bi- or terverticillate. *Metulae* 3.6–5.2 × 1.9–2.3 µm ($\bar{x}$=4.4 × 2.1 µm, n=60), usually present, as additional branches. *Phialides* 12.8–18.3 × 1.0–2.2 µm ($\bar{x}$ = 16 × 1.1 µm, n = 60), blastic, hyaline, smooth, narrowly subulate, awl-shaped. *Conidia* 2.1–3.2 × 0.9–1.2 µm ($\bar{x}$=2.7 × 1.1 µm, n=60), 1-celled, hyaline, cylindrical to obovoid or subglobose.

Culture characters: Colonies derived from single spore isolation. Colonies on PDA slowly grew, reached to 1 cm diam in 20 days at 25 ℃, grey to dark grey, cottony with high mycelial density, reverse dark brown. *Synnemata* 1.2–2.2 cm long, 0.2–1 mm wide, stipitate, gathered, white, numerous, cylindrical, branched, conidia masses on the surface, without fertile head. *Stipe* 0.2–1 cm long, 0.2–1 mm wide, flexuous, white, numerous branched. *Conidiophore* 14–25 µm long ($\bar{x}$ = 20 µm, n = 60), concentrated, normally 2 phialides in one, rarely 4 phialides in one. Metulae 4.8–10.2 × 2.2–2.8 µm ($\bar{x}$=7.5 × 2.5 µm, n=60), usually present, as an additional branch. *Phialide* 10–18 × 1.0–2.2 µm ($\bar{x}$ = 16 × 1.1 µm, n = 60), blastic, hyaline, smooth, narrowly subulate, awl-shaped. *Conidia* 3.6–4.0 × 0.9–1.2 µm ($\bar{x}$=2.8 × 1.1 µm, n=60), 1-celled, hyaline, subglobose to obovoid to cylindrical.

Material examined: China, Guizhou Province, Zunyi City. Parasitic in Lepidoptera. in the soil, 22 October 2020, Qingfeng Meng, XS08.

Notes: The new species *Polycephalomyces albiramus* sisters with *Polycephalomyces formosus* and *Cordyceps pleuricapitata* in the phylogenetic tree with strong support (100% ML / 1 PP). *Polycephalomyces albiramus* is distinct from other species of *Polycephalomyces* in parasiting *Gryllotalpa* sp. and producing

branched synnemata without a fertile head, narrowly subulate phialides and longer conidia. Thus, a new species, *Polycephalomyces albiramus* is introduced.



Note a Habitat. b, c Overview of *Polycephalomyces albiramus.* d Synnemata. e Synnema under the microscope. f Conidiophores. g Phialidies. h Conidia. (i–n *Polycephalomyces albiramus* in culture.) i *Polycephalomyces albiramus* on PDA. j, k Synnemata from pure culture. l, m Conidiophore and phialides. n Conidia. Scale Bars: b–d, i = 1 cm, j = 5000 µm, e, k = 100 µm, f, g, l, m, n = 10 µm, h = 2 µm.

Figure 2.12 Morphology of *Polycephalomyces albiramus*

Polycephalomyces ditmarii Van Vooren & Audibert, Bull. mens. Soc. linn. Lyon 74(7-8): 231 (2005)

Index Fungorum number: IF 511222

Parasitism on *Paravespula* sp. (Orthoptera, Gryllotalpidae). **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 0.5–2 cm long, 0.5–1 mm wide, arising from the whole body of the wasp, stipitate, scattered, unbranched, white to yellowish, several, cylindrical with an enlarged globose fertile head on the top. *Fertile head* 0.8–1 mm wide, globose, yellowish, coved with masses conidia. *Stipe* 1–1.9 mm long, 0.5–0.6 mm wide, cylindrical, white to pale yellow. *Conidiophore* 28–40 µm long ($\overline{x}$ = 34 µm, n = 60), concentrated in the fertile head, 1–3 phialides in one. *Phialides* 14–26 × 0.8–1.5 µm ($\overline{x}$ = 20 × 1.2 µm, n = 60), elongate oblong with a short tapering apex or narrowly cylindrical, one-type, hyaline, smooth, forming a hymenial layer covered the synnema. *Conidia* 2.7–3.8 × 0.9–1.2 µm ($\overline{x}$ = 3.2 × 1.1 µm, n = 60), 1-celled, one-type, hyaline, subglobose to pyriform.

Material examined – China, Yunnan Province, Jingdong County, Ailao mountain. Parasitic *Paravespula* sp. on the twig, 25 August 1994, Zang, HKAS29637.

Notes: – *Polycephalomyces ditmarii* was described as a pathogen on *Paravespula vulgaris* (wasp) from France (Van Vooren et al., 2005). The new collection is similar to *Polycephalomyces ditmarii* by practice on wasp and produces stipitate synnemata, yellowish fertile head, elongate phialides, subglobose conidia. Thus, the new collection is identified as *Polycephalomyces ditmarii*, and it is a new record collected from China. The molecular data is still lacking for this species.

Note a Herbarium specimen. b Overview of *Polycephalomyces ditmarii.* c Host. d, e Synnema under the microscope. f Vertical section of Synnema g, h Conidiophore with phialides. i–k Conidia. Scale Bars: c = 2 mm, d, e = 1000 µm, f = 500 µm, g, h = 10 µm, i–k = 2 µm.

Figure 2.13 Morphology of *Polycephalomyces ditmarii*

Polycephalomyces baltica Poinar & Vega Mycology, 11 (1): 74 (2020)

Type: Paratype Sy-1-13B

Distribution: Russia

Notes: – Poinar and Vega (2020) introduced *Polycephalomyces baltica*, which parasites bark lice (Psocoptera) in the Baltic amber. No molecular data has been provided.

Polycephalomyces cylindrosporus Samson & H.C. Evans, in Samson, Evans & van de Klashorst, Proc. K. Ned. Akad. Wet., Ser. C, Biol. Med. Sci. 84(3): 297 (1981)

Index Fungorum number: IF 111844

Type: Holotype RS 0082

Distribution: Ghana

Notes: – *Polycephalomyces cylindrosporus* was reported associated with a hemipteran, hymenopteran, and a coleopteran and produces intermediate, branched, conidiophore and one type of cylindrical conidia (Samson et al., 1981). It lacks molecular data.

Polycephalomyces paludosus paludosus Mains, Mycologia 40(4): 414 (1948)

Index Fungorum number: IF 289807

Type: Holotype MICH

Distribution: America

Polycephalomyces ramosus (Peck) Mains, Mycologia 40(4): 414 (1948)

Synonymy: *Stilbum ramosum Peck, Ann. Rep. N.Y. St. Mus. nat. Hist. 26: 78 (1874)*

Botryonipha ramosa (Peck) Kuntze, Revis. gen. pl. (Leipzig) 2: 845 (1891)

Stilbella ramosa (Peck) Petch, Trans. Br. mycol. Soc. 21(1-2): 53 (1937)

Stilbum kervillei Quél., Gardeace de Kerville Champ. entom.: 4 (1884)

Botryonipha kervillei (Quél.) Kuntze, Revis. gen. pl. (Leipzig) 2: 845 (1891)

Stilbella kervillei (Quél.) Samson, Rombach & Seifert, Persoonia 12(2): 126 (1984)

Index Fungorum number: IF 289808

Type: Holotype NYS

Distribution: America

Polycephalomyces tomentosus (Schrad.) Seifert, Stud. Mycol. 27: 175 (1985)

Synonymy: *Stilbum tomentosum* Schrad., J. Bot. (Schrader) 2(1): 65 (1799)

Stilbella tomentosa (Schrad.) Bres., Annls mycol. 1(2): 129 (1903)

Tilachlidium tomentosum (Schrad.) Lindau, Rabenh. Krypt.-Fl., Edn 2 (Leipzig) 1.9: 306 (1908)

Blistum tomentosum (Schrad.) B. Sutton, Mycol. Pap. 132: 19 (1973)

Stilbella tomentosa var. macrospora Ferraris, Annls mycol. 7(3): 277 (1909)

Index Fungorum number: IF 104650

Table 2.3 Morphology of asexual morph species of the genus *Polycephalomyces*

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
P. albiramus	Synnemata 10–3 × 1–2, stipitate, gathered, branched, white to pale yellow, numerous, cylindrical and tapering on the top, without fertile head	Phialides 12.8–18.3 × 1.0–2.2, blastic, narrowly subulate, awl-shaped	Conidia 2.1–3.2 × 0.9–1.2, cylindrical to obovoid or subglobose	This study
P. baltica	Synnema 0.17 × 0.142, simple, roundish	Phialides 3–4 long, light colored, micronematous, flask-shaped	Conidia 2–3, globose, catenulate	Poinar and Vega (2020)

Table 2.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
P. cylindrosporus	Synnemata 5–15 × 0.13–0.3, cylindrical to capitate, stipitate, slender, branched	Phialides 7–25 long, on verticils and/or acropleurogenously forming loosely arranged flared hymenia	Conidia 2.5–4, one-type, cylindrical to bacilliform	Matočec et al. (2014)
P. ditmarii	Synnemata 15–25 long, 2 to 3 distinct branches, yellowish to white, darkening at the base; surmounted by a small subsurface capitulum, 0.5–1 wide	Phialides 20–37 × 1.5–2.5, elongated, cylindrical, attenuating at the top	Conidia 2.2–3 × 1.3–1.6, globose to subglobose	Van Vooren et al. (2005)
P. formosus (Type)	Synnemata 2 long, gathered, branched, with cylindrical stipe, with fertile head, spherical, white	Phialides 16–25 × 1–1.2, cylindrical, tapering gradually	Conidia 2.5–3.2 × 1–1.2, one-type, ellipsoid or ovoid	Kobayasi (1941)
	Synnemata 2–3 branches, 0.5–30 long, arising as several radiating rings on the colony.	Phialides terminal parts of synnemata, cylindrical to sybulate at the base; 5.5–75 long, tapering gradually from 0.9–1.8 at the base to 0.8–1.5 at the apex.	Conidia of one type, 1-celled, smooth-walled, ellipsoid to ovoid, 2–3.4 × 1.0–1.5	Wang et al. (2020)
		Phialides monothetic and solitary or acropleurogenous in the whorls of 1–4, narrowly lageniform or subulate, 7.0–51 long, 1.0–2.5 wide at the base and 0.5–1.0 wide at the apex.	Conidia obovoid to oblong ellipsoidal or cylindrical, 2–6 × 1.2–1.8, forming irregular spore balls near the apex of phialides.	Wang et al. (2020)

Table 2.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
P. ramosus	Synnemata solitary, crowded or caespitose, unbranched or branched, a size of up to 20 × 1, conidial mass yellow to orange-yellow, diam (0.15–1)	α-phialides cylindrical to narrowly lageniform, length (7–24), base width (1–2), neck width (ca. 0.5); β-phialides narrowly lageniform or subulate, length (6–27), base width (2–3.5), neck width (0.5–1)	α-conidia ovoid, size (2.4–3.2 × 1.6–2.4); β-conidia fusiform, catenate, size (3.2–4 × 1.6–2)	Seifert (1985); Bischoff et al. (2003)
P. paludosus	Capitate, 10–20 long 0.5–0.8 thick, cinnamon brown, branched, the branches at right angles, 1–4 long, 0.1–0.2, thick, the branches and the upper poortions of the stems slightly pulverulent	Subulate, 12–20 long, 1–1.5 wide at the base, phialides occurring scattered on the branches below the heads, ventricose, occasionally stellate above, 10.5–14.7 × 1.5–2	Conidia produced singly, hyaline, obovoid, 1.8–2.5 × 1.1–1.3 um covered by a mucus, agglutinating.	Mains (1948)
P. tomentosus	Fructification a synnema		Conidia three-type, globose or ellipsoidal or cylindrical	Seifert (1985)

4. Incertae sedis

Cordyceps pleuricapitata Kobayasi & Shimizu, Bull. Natn. Sci. Mus., Tokyo, B 8(3): 87 (1982).

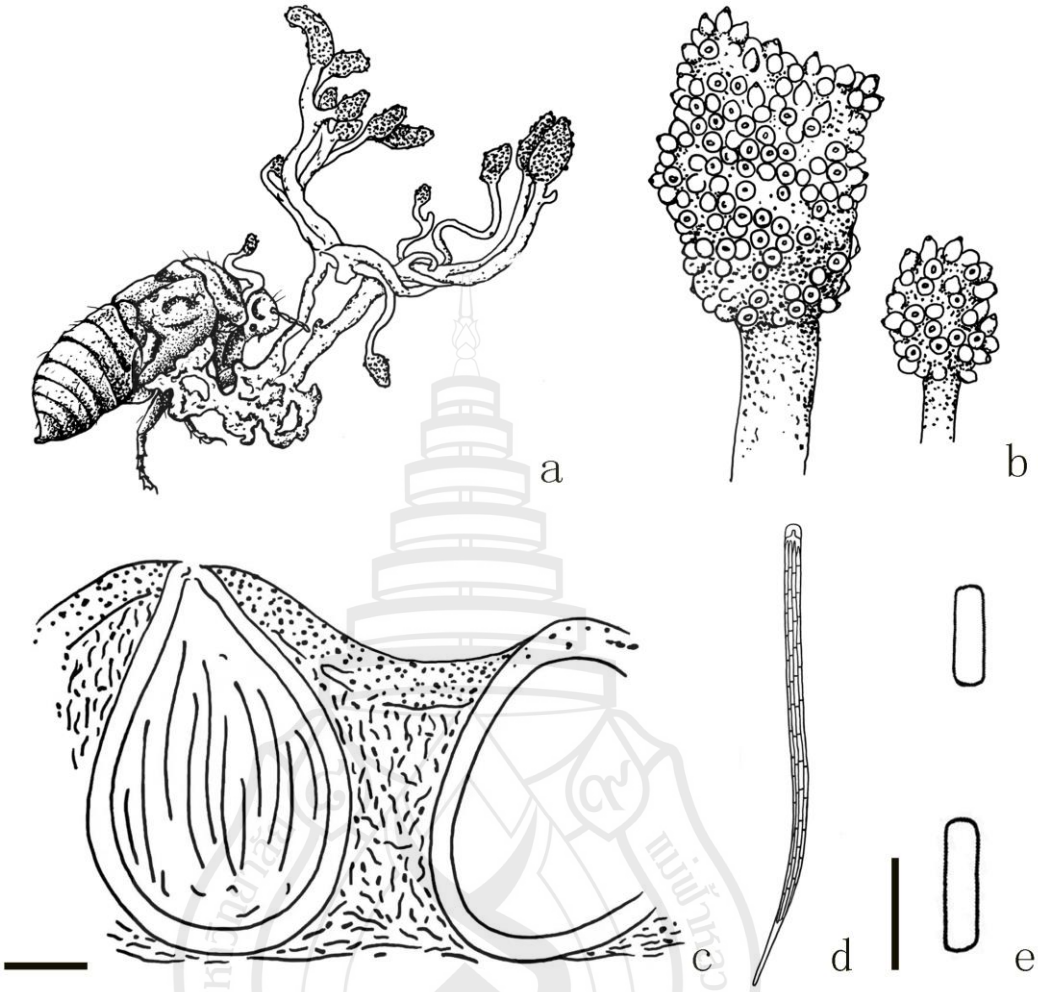
Index Fungorum number: IF 124464

Paratype: TNS-F-197965

Host: Nymph of Cicadidae (Hemitera)

Distribution: Japan (Kobayashi and Shimizu 1982, Sato et al. 2012)

Notes: – *Cordyceps pleuricapitata* was described with an illustration and was collected from Japan (Kobayashi & Shimizu, 1982). It has stipitate, branched stromata with ovoid or globose fertile head, immersed, ovoid perithecia, cylindrical asci with thin apical cap (3 μm), cylindrical, truncated secondary spores (4–5 × 1 μm) (Kobatasi & Shimizu, 1982). The paratype, TNS-F-197965, was reassessed with a photo from TNS (herbarium of the National Museum of Nature and Science) (Sato et al., 2012). Furthermore, two strains' (NBRC 100745, NBRC 100746) molecular data were provided in GenBank but lack morphology information. Kepler et al., (2013) regarded *Cordyceps pleuricapitata* as an incertae sedis species in residual *Cordyceps* sensu lato due to its low bootstrap support and sister relationship to the *Polycephalomyces* clade in the phylogenetic tree. *Polycephalomyces* were later segregated into two genera: *Polycephalomyces* and *Perennicordyceps* (Matocec et al., 2014). Three sister clades—*Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*—are shown in the phylogenetic tree, concatenating five gene datasets (SSU, LSU, TEF, RPB1, RPB2) (Kepler et al., 2013; Wang et al., 2012). Despite *Cordyceps pleuricapitata* (NBRC 100745, NBRC 100746) distinctly clustering with *Polycephalomyces* clade, we regard it as incertae sedis, pending further research. Illustrations are redrawn from Kobayashi & Shimizu (1982).



Note a Overview of *Polycephalomyces pleuricapitata*. b Stromata. c Ascomata. d Asci with ascospores. e Secondary spores. Scale Bars: c = 100 µm, e = 5 µm.

Figure 2.14 Morphology of *Cordyceps pleuricapitata* **(**Paratype TNS-F-197965 a. redrawn from Sato et al., 2012), (b–e. redrawn from Kobayasi & Shimizu, 1982)

5. *Perennicordyceps*

Perennicordyceps Matočec & I. Kušan, Ascomycete.org 6(5): 129 (2014)

Index Fungorum number: IF810775

Parasites and pathogens of insects and fungi. **Sexual morph*:*** *Stromata* cylindrical to clavate, single or several, branched, apically tapered or inflated, pointed

or lanceolate, whitish, yellow, ochre to brown, with stipe. *Stipe* cylindrical to clavate, single or several branched, ochre to brown**.** *Fertile part* cylindrical to clavate, whitish, yellow, ochre to brown, distinct or not distinct with stipe. *Perithecia* superficial, globose to ovoid to pyriform, yellowish to yellow, perpendicular to rarely slightly oblique in relation to the surface, scattered or gregarious, concentrated almost over the whole aerial part of the stroma or on its subapical part, absent from naked, sterile, tapered, pointed tip**.** *Asci* filiform, hyaline, with apical cap**.** *Apical cap* thin or thick**.** *Ascospores* filiform, hyaline, approximately as long as asci, septate and typically disarticulating into secondary ascospores**.** *Secondary spores* cylindrical, hyaline (adapted from Ban et al., 2009; Matočec et al., 2014). **Asexual morph*:*** Hyphomycetous. hirsutella-like or acremonium-like. *Conidiophores* phialidic, hyaline, produced on aerial mycelium, also on sporodochia or directly on stromata**.** *Phialides* 2–10 arising from irregularly branched or quasi-verticillate conidiophores, phialides produce up to 10 conidia enveloped in a common sheath. *Conidia* globose to ellipsoid or limoniform to fusiform, hyaline, smooth, 1-celled (adapted from Ban et al., 2009; Matočec et al., 2014).

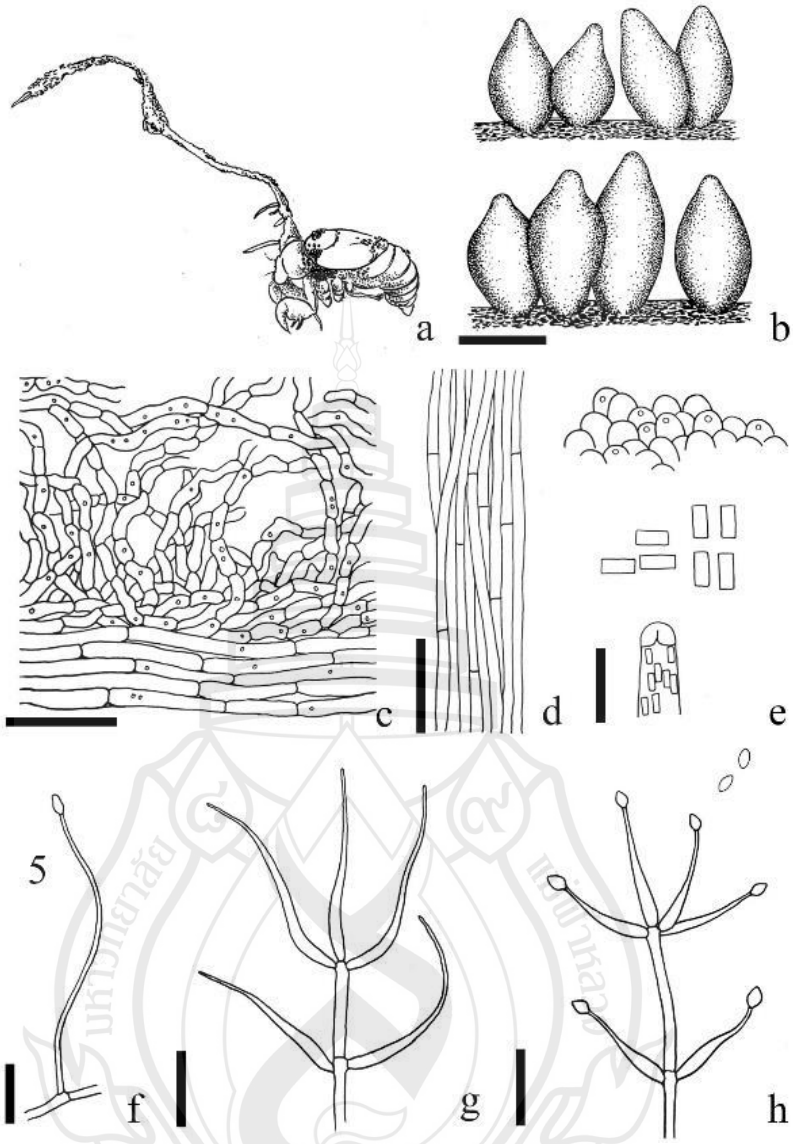
*Type species***: *Perennicordyceps prolifica*** (Kobayasi) Matočec & I. Kušan.

Notes: This genus was introduced by Matočec et al. (2014) to accommodate four species of *Polycephalomyces*. It is characterised by superficial, ovoid perithecia and cuboid to narrowly prismatic part spores and hirsutella-like or acremonium-like asexual morphs (Matočec et al., 2014). A new combination, *Perennicordyceps elaphomyceticola*, is proposed based on morphology and phylogenetic analysis in this study.

Ecological and economic significance of Perennicordyceps: *Perennicordyceps* have been known as entomogenous fungi. This is the first time the genus is reported as fungicolous.

Distribution: Japan, China, Sir Lanka, Austria, Croatia, France, UK, Netherlands, USA (Matočec et al., 2014)

Conclusion: Illustrate the type species, one new combination and one new host records are proposed.



Note a Overview of *Perennicordyceps prolifica*. b Peritheica of ascus. c Contex and medulla. d Medulla. e Surface of perithecia. f Secondary spores. g Apical cap. h Acremonium-like phialide. i *Hirsutella*-like phialides. j Conidiophore. Scale Bars: b = 100 µm, c, d = 10 µm, e–h = 5 µm.

Figure 2.15 Morphology of *Perennicordyceps prolifica* (b–e: Redrawn from Kobayasi & Shimizu, 1963, a, f–h: Redrawn from Ban et al., 2009)

Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequence data of *Perennicordyceps*. *Polycephalomyces formosus* (NBRC 109994) and *Polycephalomyces formosus* (NBRC 109993) were used as outgroup taxa. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.90 are indicated above the nodes. The type strains are indicated in bold.

Figure 2.16 Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequence data of *Perennicordyceps*

Perennicordyceps elaphomyceticola (WY Chuang, Ariyawansa, Jiuein Yang & Stadler) Y.P. Xiao & K.D. Hyde, ***comb. nov.***

Synonymy: *Polycephalomyces elaphomyceticola* W.Y. Chuang, H.A. Ariyaw., J.I. Yang & Stadler, in Yang, Stadler, Chuang & Ariyawansa, Mycol. Progr. 19(1): 102 (2020)

Index Fungorum number: IF 830670

Type: Holotype NTUH 17-021

Host: *Elaphomyces muricatus* (Eurotiales, Elaphomycetaceae)

Distribution: China

Parasitic on *Elaphomyces sp*. (Elaphomycetaceae, Eurotiales), collected from soil. **Sexual morph**: *Host* 1.5–3 cm diam, *Elaphomyces* sp., globose, dark brown to brown, with a hard surface. *Stromata* 2–10 cm long, 0.1–0.5 cm wide, cylindrical, solitary or several, branched, wiry, the color gradually become lighter towards the top, dark brown to titian red to brownish orange to yellow to pale, hard. *Stipe* 2–6 cm long, 0.1–0.5 cm wide, cylindrical, branched, not obviously distinct with fertile head, dark brown to titian red, ascomata scattered to gathered on the stipe. *Fertile head* 3–7 cm long, 0.1–0.5 cm wide, cylindrical, branched, upper surface roughened. *Perithecia* 430–600 × 255–300 µm ($\bar{x}$ = 515 × 280 µm, n = 60), superficial, ovoid to ellipsoid, ostiolate, ostiole lined with periphyses, yellow to brown when mature, pale to yellowish when immature, mature and immature perithecia observed at the same time, usually immature perithecia at the top area of stipe, maturely perithecia at the low area of the stipe, scattered to gathered on the stipe, thick-walled. *Peridium* 50–65 µm ($\bar{x}$ = 60 µm, n = 90) wide, yellow to hyaline, the colour gradually becomes lighter towards the inner layer, three layers, *textura prismatica* to *textura angularis* to *textura porrecta*. *Asci* 365–420 × 5–7.6 µm ($\bar{x}$ = 370 × 6.4 µm, n = 90), 8-spored, hyaline, filiform, with a thin apex. *Apical cap* 2–3.5 × 3.3–5.2 µm ($\bar{x}$ = 3 × 4.2 µm, n = 60), thin, hyaline. *Ascospores* 360–415 × 1.5–2.2 µm ($\bar{x}$ = 390 × 1.8 µm, n = 90), filiform, hyaline, irregular multiseptate. *Secondary spores* 1.5–3.2 × 1.4–2.3 µm ($\bar{x}$ = 2.4 × 1.9 µm, n = 90) globose to cylindrical, one-celled, hyaline, smooth, some up to 6 µm long. **Asexual morph:** Hyphomycetes. Parasitic on *Ophicordyceps sp.* (Ophiocordycipitaceae, Hypocreales), collected from the underside of leaves. *Host Ophicordyceps* sp. *Synnemata* absent. *Conidial mass*

covered the surface of colony on *Ophicordyceps sp.*, white to yellowish**.** *Conidiophores* 18–30.2 µm long ($\bar{x}$ = 24.1 µm, n = 60) hyaline, borne from surface hyphae, predominantly symmetrically monoverticillate, 2–6 phialides in one**.** *Metulae* 3–5 × 0.9–1.2 µm ($\bar{x}$ = 4 × 1.1 µm, n = 50), cylindrical, hyaline, smooth. *Phialides* 12–16 × 0.6–1.5 µm ($\bar{x}$ = 14 × 1.1 µm, n = 50) hyaline, smooth, narrow cylindrical at the low base part, 5–11 µm long, tapering into a long neck, 2–5 µm long. *Conidia* 3.2–4.5 × 1.2–2.1µm ($\bar{x}$ = 3.8 × 1.6 µm, n = 50), aseptate, fusiform to ellipsoid to inequilateral shaped, hyaline, 1-celled, smooth-walled.

Material examined – China, Yunnan Province, Jinghong City, Dadugang Village. Parasitic on *Elaphomyces* sp. in soil, 11 June 2018, YuanPin Xiao, DG01.

China, Yunnan Province, Jinghong City, Dadugang Village. parasitic on *Ophicordyceps* sp. on the underside of leaves (Ophiocordycipitaceae, Hypocreales), 11 June 2018, YuanPin Xiao DG04.

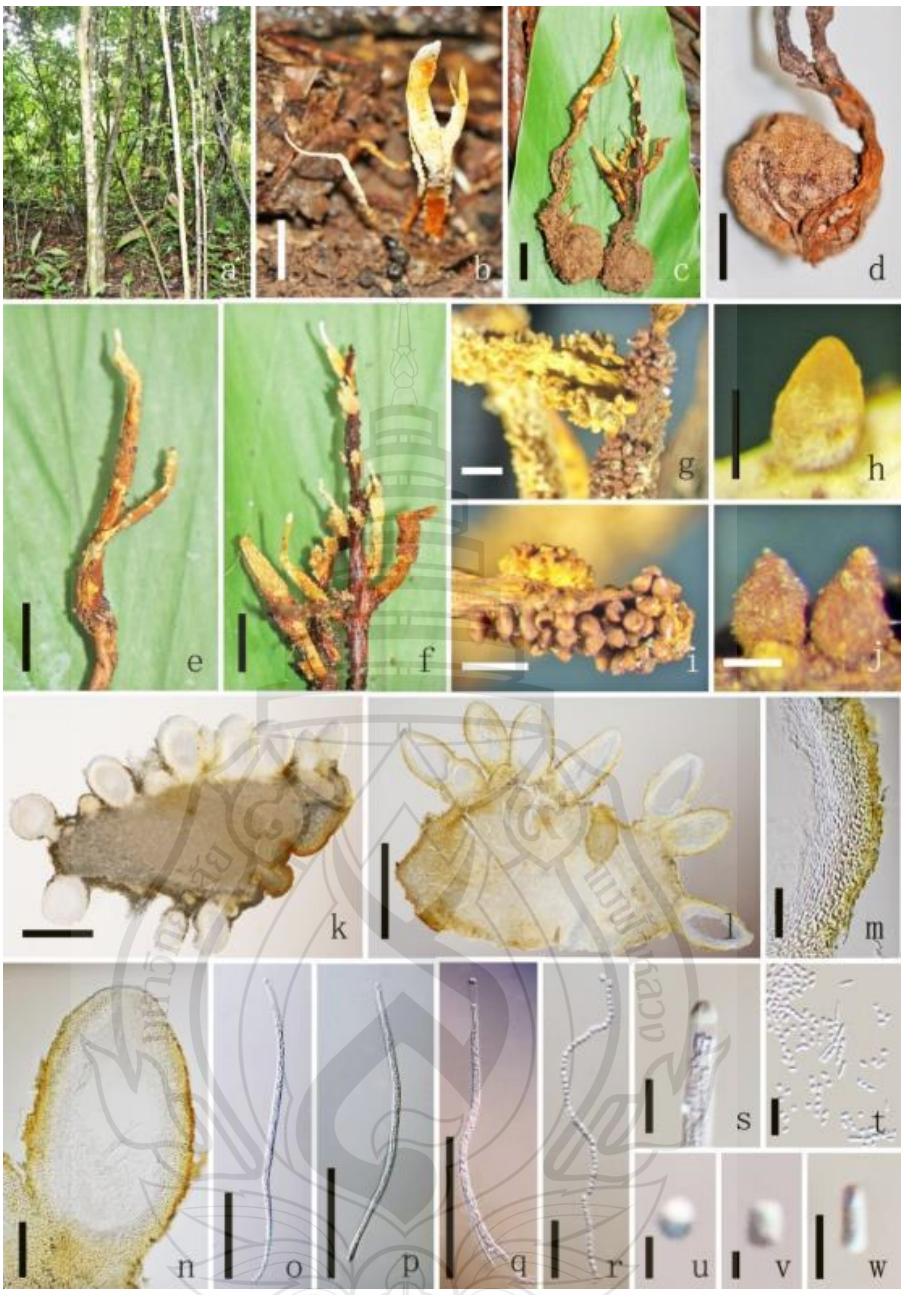
China, Yunnan Province, Jinghong City, Dadugang Village. Parasitic on *Elaphomyces* sp. in soil, 11 June 2018, YuanPin Xiao, DG07. China, Yunnan Province, Jinghong City, Dadugang Village. Parasitic on *Elaphomyces* sp. in soil, 11 June 2018, YuanPin Xiao, DG10.

Notes: – Yang et al. (2020) described a new (*Polycephalomyces elaphomyceticola*) species and treated all species of *Perennicordyceps* as *Polycephalomyces*. We propose a new combination *of Perennicordyceps elaphomyceticola*, initially described as *Polycephalomyces elaphomyceticola* by Yang et al. (2020). These new collections clustered with *Perennicordyceps elaphomyceticola* with high support (95% ML / 0.99 PP) in the *Perennicordyceps* clade of the phylogenetic tree. Three new collections of *Perennicordyceps. elaphomyceticola* collected from Yunnan Province of China are proposed as fungicolous on *Elaphomyces* sp. Two new collections are introduced fungicolous taxa on *Ophicordyceps* sp. *Ophicordyceps* sp. is a new host of *Pe. elaphomyceticola*, broadening the range host. Furthermore, we describe the asexual morph of *Pe. elaphomyceticola*.

The new collections have 1 bp in ITS, 2 bp in LSU, 1 bp in SSU, 2 bp in TEF, 4 bp in RPB1, and 107 bp in RPB2, different from the holotype of

Perennicordyceps elaphomyceticola. The new collections have 1 bp in ITS, 2 bp in LSU, 1 bp in SSU, 2 bp in TEF, 4 bp in RPB1, and 4 bp in RPB2, differing from the other strains of *Pe. elaphomyceticola* provided with the holotype in the same publication. The RPB2 sequence of the holotype (NTUCC 17–021) is distinct from the other strains (NTUCC 17–022, NTUCC 17–023) and the new collections from China. In this case, the holotype (NTUCC 17–021) needs RPB2 sequencing.

Moreover, two new collections were fungicolous on *Ophicordyceps* sp. *Ophicordyceps* sp. is a new host for *Perennicordyceps elaphomyceticola*, which broadens the range of hosts.



Note a, b Habitat of *Perennicordyceps elaphomyceticola.* c Stromata emerging from infected *Elaphomyces sp*. d Overview of the host. e, f Fertile head of ascostroma. g, i Stroma. k, l Vertical section of the stroma. h, j, n Perithecia. m Peridium. o–q Asci. r Part of ascospore. s Apical cap of asci. t–w Secondary ascospores. Scale Bars: b–f = 1 cm, g = 1000 µm, i, k, l = 500 µm, h, j = 200 µm, n–q = 100 µm, r = 20 µm, s, t = 10 µm, w = 5 µm, u, v = 2 um.

Figure 2.17 Morphology of *Perennicordyceps elaphomyceticola* (sexual morph)

Note a. Overview of *Perennicordyceps elaphomyceticola* and *Ophocordyceps* sp. b. Mycelium on the surface of stroma. c. Section of host. d. Mycelium and conidia on the surface of perithecia. e, f. Phialides. g. Conidia. Scale Bars: c = 500 µm, d = 100 µm, e–g = 10 µm.

Figure 2.18 Morphology of *Perennicordyceps elaphomyceticola* (asexual morph)

Perennicordyceps cuboidea (Kobayasi & Shimizu) Matočec & I. Kušan, in Matočec, Kušan & Ozimec, Ascomycete.org 6(5): 129 (2014)

Index Fungorum number: IF 810778

Synonymy: *Cordyceps cuboidea* Kobayasi & Shimizu, Bull. natn. Sci. Mus., Tokyo, B 6(4): 131 (1980)

Ophiocordyceps cuboidea (Kobayasi & Shimizu) S. Ban, Sakane & Nakagiri, in Ban, Sakane, Toyama & Nakagiri, Mycoscience 50(4): 268 (2009)

Polycephalomyces cuboideus (Kobayasi & Shimizu) Kepler & Spatafora, Fungal Biology 117(9): 618 (2013)

Basionym: *Cordyceps cuboidea* Kobayasi & Shimizu, Bull. natn. Sci. Mus., Tokyo, B 6(4): 131 (1980)

Host: Larva of Coleoptera

Distribution: Japan

Perennicordyceps paracuboidea (S. Ban, Sakane & Nakagiri) Matočec & I. Kušan, in Matočec, Kušan & Ozimec, Ascomycete.org 6(5): 129 (2014)

Index Fungorum number: IF 810779

Synonymy: Ophiocordyceps paracuboidea S. Ban, Sakane & Nakagiri, in Ban, Sakane, Toyama & Nakagiri, Mycoscience 50(4): 268 (2009)

Polycephalomyces paracuboideus (S. Ban, Sakane & Nakagiri) Kepler & Spatafora, Fungal Biology 117(9): 618 (2013)

Basionym: *Ophiocordyceps paracuboidea* S. Ban, Sakane & Nakagiri, in Ban, Sakane, Toyama & Nakagiri, (2009)

Type: holotype H-12471

Host: Larva of Coleoptera

Distribution: Japan

Perennicordyceps ryogamiensis (Kobayasi & Shimizu) Matočec & I. Kušan, in Matočec, Kušan & Ozimec, Ascomycete.org 6(5): 129 (2014)

Index Fungorum number: IF 810780

Synonymy: Cordyceps ryogamiensis Kobayasi & Shimizu, Bull. natn. Sci. Mus., Tokyo, B 9(1): 4 (1983)

Ophiocordyceps ryogamiensis (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 46 (2007)

Polycephalomyces ryogamiensis (Kobayasi & Shimizu) Kepler & Spatafora, Fungal Biology 117(9): 618 (2013)

Basionym: *Cordyceps ryogamiensis* Kobayasi & Shimizu 1983

Host: Larva of Coleoptera

Distribution: Japan

Table 2.4 Morphology characters of asexual morph species of *Perennicordyceps*

Species	Phialides	Acremonium-like	Hirsutella-like	Conidia (µm)	Reference
Pe. cuboidea	Slender, cylindrical to Hirsutella-like, broad base with long tapering neck	On the edge of colony 18–46.8 × 0.4–1.9	Sometimes at the aged part Length: 12.9–25, Base: 1–1.6, Neck: 0.4–0.7, Irregular branch	Globose, fusiform 1.9–3.7 × 1.3–2.3	Ban et al. (2009)
Pe. paracuboidea	Conidiogenous cells phialidic, hyaline, verticillate with 2−3 phialides, Quasi-verticillate	Rarely *Acremonium*-like, slender, cylindrical, 10.9–20.9 × 0.5–1.1	mainly *Hirsutella*-like, 10.9–21.5 long, 1.2–1.6 wide at the base, 0.4–0.8 wide at the neck	Conidia hyaline, subglobose to fusiform, 1.3–1.9 × 1–1.9	Ban et al. (2009)
Pe. ryogamiensis	Mainly slender, long cylindrical, but shorter with broad base on the sporodochial part, Quasi-verticillate	Mainly *Acremonium*-like 17.5–55.2 × 0.8–2.7	On the aged and sporodochial part. Length: 17.4–25.7, Base: 1.3–1.6, Neck: 0.3–0.7	Ellipsoid 2.5–3.9 × 1.0–1.4	Ban et al. (2009)
Pe. prolifica	Slender, cylindrical to *Hirsutella*-like, broad base with long tapering neck, Quasi-verticillate	On the edge of colony 19.6–30.6 (24.6) × 0.7–1.7	On the aged and arising synnema. Length: 10.8–16.3; Base: 1.5–1.7; Neck: 0.5–0.7	Globose, fusiform, 1.5–3.5 × 1.1–1.8	Ban et al. (2009)

Table 2.4(continued)

Species	Phialides	Acremonium-like	Hirsutella-like	Conidia (µm)	Reference
Pe. elaphomyceticola	Monophialidic, *Hirsutella*-like, long-necked, solitary, forming in whorls, awl-shaped	Absent	No synnema observed, 25.4–41.1 long; Base: 1.2–1.8; Neck: 0.7–1	Ellipsoid to ovoid, sometimew slightly curved, 3.2–3.7 × 1.8–2.1	Yang et al. (2020)
	Slender, 2-6 in one cluster	On surface of host, *Acremonium*-like, 12–16 × 0.6–1.5	Absent	Fusiform to ellipsoid to inequilateral 3.2–4.5 × 1.2–2.1	This study

Table 2.5 Morphology characters of sexual morph species of *Perennicordyceps*

Species	Stromata	Perithecia (um)	Asci (um)	Secondary spores (um)	Reference
Pe. elaphomyceticola	2–10 × 0.1–0.5 cm, cylindrical, solitary or several, branched, dark brown to brownish orange to yellow to pale	430–600 × 255–300, superficial, ovoid to ellipsoid, yellow when mature, pale when immature	365–420 × 5.0–7.6 filiform	1.5–3.2 × 1.4–2.3 globose to cylindrical	Yang et al. (2020), this study
Pe. cuboidea	Cylindrical attenuate, ochre yellow 3.2–18.1 × 0.3–7.4 mm	Superficial, lemonshaped, glabrate, 400–500 × 250–330	250–570	1.5–3 × 1–1.5	Ban et al. (2009)
Pe. paracuboidea	Stromata solitary or several, cylindrical, not branched, on larva of Coleoptera	Superficial, vertically placed, lemon-shaped, pale orangish brown, 400–600 × 290–400	225–400, cylindrical, 8-spored,	cylindrical, 1.3–2.5 × 1–2	Ban et al. (2009)
Pe. prolifica	Thin cylindrical, glabrous, brown, partly covered with grayish mycelia	Superficial, ovoid or ellipsoid, grayish brown 320–530 × 200–340, Upper side to middle of aerial part	430–650	2–3 × 1–2	Kobayasi and Shimizu (1963)

Table 2.5 (continued)

Species	Stromata	Perithecia (um)	Asci (um)	Secondary spores (um)	Reference
Pe. ryogamiensis	Fleshy, white, palely darkened, glabrate at thebase. Stromata cylindrical, 12–13 × 0.5 mm,	Superficial, ovoid, central clustered on stroma 320–430 × 200–230	450–610	2.5-5 × 1.5-2	Ban et al. (2009)

6. *Pleurocordyceps*

Pleurocordyceps Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, J. Syst. Evol. (2020)

Index Fungorum number: IF 570683

Parasitic or hyperparasitic on insects or fungi. **Sexual morph:** *Stromata* solitary to numerous, fleshy, cylindrical, unbranched, or branched, reddish-brown to yellow, stipitate, growing from the head or the whole body of the host. *Stipe* pigment, cylindrical, sterile tip curved or twisted, with or without a fertile part. *Fertile part* capitate on the top or laterally on the stipe, white to yellow or brown. *Perithecia* immersed in an apical or subapical pulvinate cushion, scattered to gregarious, pyriform, or ovoid, with protruding ostioles. *Asci* cylindrical, hyaline, with apical cap and thick-walled. *Ascospores* filiform, cylindrical, hyaline, breaking into secondary spores. *Secondary spores* cylindrical, hyaline, nearly equal length (adapted from Matočec et al., 2014; Xiao et al., 2018; Wang et al., 2020). **Asexual morph:** Hyphomycetous. *Synnemata* absent or present, white to yellow, solitary to caespitose, stipitate, unbranched or branched, clavate or spatulate or cylindrical, with or without fertile head covered conidia masses. *Stipe* clavate or spatulate or cylindrical, white to yellowish, with or without fertile head on the top or below the apex. *Conidial mass* absent or present, yellowish to yellow, on the surface of the colony on the host or the surface of the fertile part. *Fertile part* absent or present, yellowish to yellow, awl-shaped to cylindrical to globose, on the top or below the top. *Conidiophores* simple or with several phialides, unbranched or branched, hyaline. *Metulae* absent or present, smooth, hyaline. *Phialides* (conidiogenous cells) usually two types, sometimes only

one type observed on the fresh specimen, blastic, verticillately branching, *α-phialides* verticillate and acropleurogenous on conidiophores, cylindrical to subulate at the base, gradually tapering into a long neck: *β-phialides* acropleurogenous and solitary, narrow lageniform or subulate, tapering abruptly from the base to the apex. *Conidia* one-celled, hyaline, smooth, normally two types in culture, rarely two types on the fresh specimen, *α-conidia* globose to subglobose or ellipsoidal, forming conidial masses from the fertile head; *β-conidia* fusiform, produced along stipe as well as on the mycelium surface of the colony, single, often in chains (adapted from Matočec et al., 2014; Xiao et al., 2018; Wang et al., 2020).

Type species: ***Pleurocordyceps sinensis*** (Q.T. Chen, S.R. Xiao & Z.Y. Shi) W.J. Wang, X.L. Wang, Y. Li, S.R. Xiao & Y.J. Yao 2012.

Index Fungorum number: IF 570676

Synonymy: *Polycephalomyces sinensis* (Q.T. Chen et al.) W.J. Wang et al., Syst. Biodiv.

10(2): 228 (2012).

Basionym: *Paecilomyces sinensis* Q.T. Chen et al., Acta Mycol. Sin. 3: 25 (1984).

Type: Holotype HMAS 43720

Host: Larva of *Hepialus armocanus* (Lepidoptera)

Distribution: China

Notes: Wang et al. (2020) established *Pleurocordyceps* by verifying the incorrect strains (ARSEF1424) that represented the type species *Polycephalomyces formosus* for a long time. Ten species were transferred to this genus based on phylogenetic analyses, including *Pleurocordyceps agaricus*, *Pl.* aurantiacus, *Pl. lianzhouensis*, *Pl. marginaliradians*, *Pl. nipponica*, *Pl. onorei*, *Pl. phaothaiensis*, *Pl. ramosopulvinatus*, *Pl. sinensis*, and *Pl. yunnanensis* (Wang et al., 2020). Zha et al. (2021) recognized one collection (MFLU 18–0162) from China as *Polycephalomyces formosus* by following the incorrect morphology and molecular data of ARSEF1424. Thus, the name of the strain MFLU 18–0162 is an incorrect name.

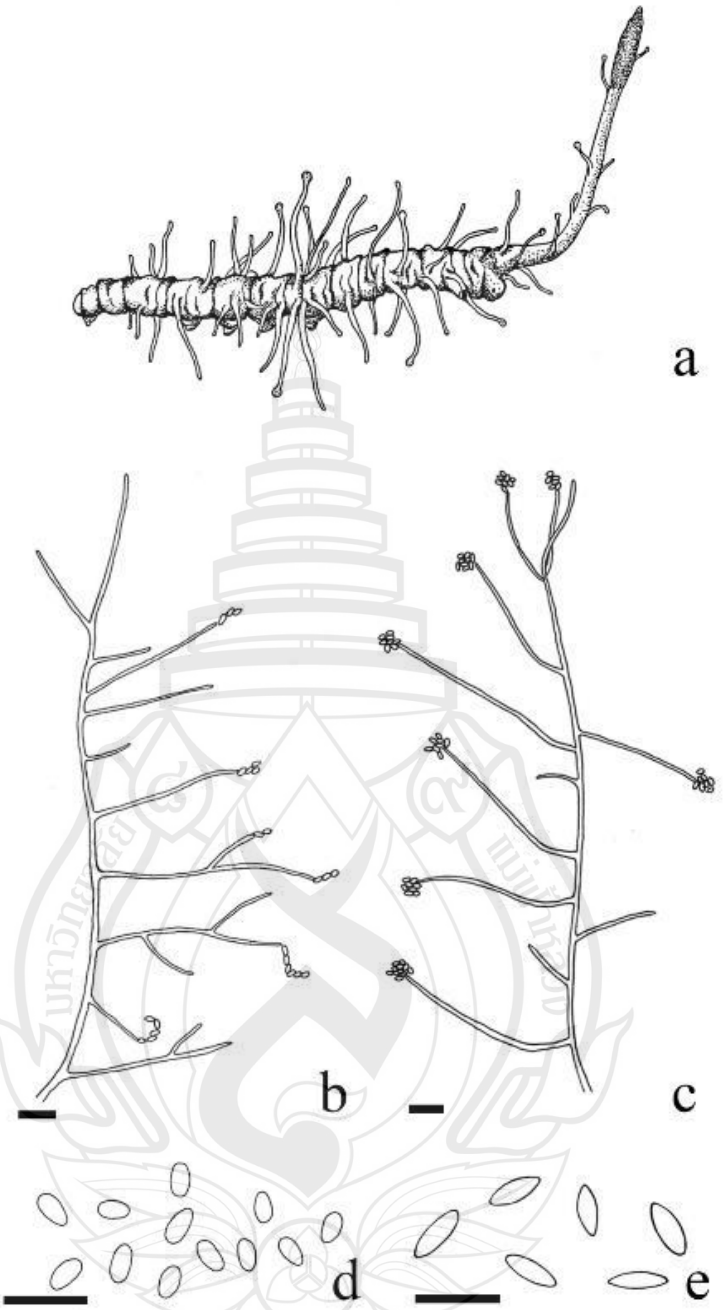
Polycephalomyces ramosus is the oldest species in the *Pleurocordyceps* clade and shares the same branch with *Polycephalomyces tomentosus* and *Pleurocordyceps sinensis*. It is because the representative strains of

Polycephalomyces ramosus and *Polycephalomyces tomentosus* (RCEF 6016, NBRC 109983, BL 4) lack morphological and ecological information (Seifert, 1985; Sutton, 1973; Kepler et al., 2013; Matocec et al., 2014; Ban, 2016). *Pleurocordyceps sinensis* was designated as the type species over the other species based on circumscribing both morphology and phylogeny (Wang et al., 2020).

Ecological and economic significance: *Polycephalomyces nipponicus* mycelia extracts show the potential source of natural antioxidant, antibacterial, anti-breast cancer, and antimicrobial compounds for the pharmaceutical industry (Sangdee et al., 2016; Somsila et al., 2018). *Polycephalomyces phaothaiensis* shows antibacterial and anti-Inflammatory in vitro (Sonyot et al., 2020).

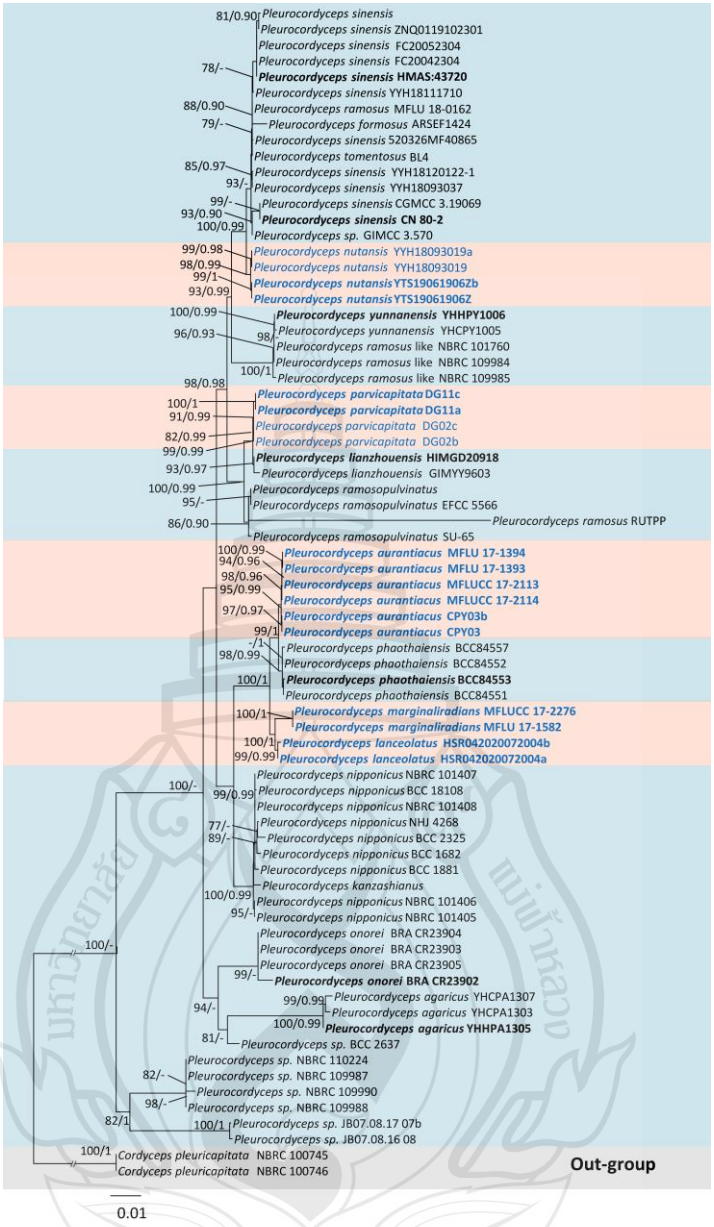
Distribution: China, Ecuador, Japan, Thailand (Kobayasi, 1939; Mains, 1948; Kobayasi & Shimizu, 1982; Seifert, 1985; Alcorn & Irwin 1987; Nag Raj, 1993; Bischoff et al., 2003; Van Vooren et al., 2005; Wang et al., 2012; Wang et al., 2014; Trakunyingcharoen et al., 2014; Wang et al., 2015a, b; Crous et al., 2017; Xiao et al., 2018).

Conclusion: Illustrate the type species, three new species and two new records are described.



Note a Overview of *Pleurocordyceps sinensis* with the host. b Phialides with conidia. c Irregular conidial balls on phialides. d α-conidia. e β-conidia. Scale Bars: b, c = 10 μm, d, e = 5 μm.

Figure 2.19 Morphology of *Pleurocordyceps sinensis* (Holotype: HMAS 43720; a, redrawn from Chen et al., 1984. Ex-type: CN 80-2, b–e, redrawn from Wang et al., 2012)



Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU, ITS, TEF, RPB1 and RPB2 sequences data of *Pleurocordyceps*. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.90 are indicated above the nodes**.** The new species are indicated in blue. The type strains are indicated in bold.

Figure 2.20 Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of *Pleurocordyceps*

Pleurocordyceps sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Index Fungorum number: IF 550007

Parasitic on larvae of Lepidoptera, on leaf litter. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 0.2–1 cm long, 0.2–4 mm wide, cylindrical, clavate, capitate, stipitate, solitary to crowded, simple or branched, brown to yellow to yellowish, with or without fertile head. *Stipe* 0.2–1 cm long, 1–2 mm wide, cylindrical, brown to yellow, with or without fertile head. *Fertile head* 0.2–4 mm wide, globose to subglobose, yellowish, with conidia masses covered. *Phialides* two types, both types observed on the same synnema *α-phialides* 10–24 × 0.9–1.2 µm ($\bar{x}$ = 17 × 1.1 µm, n = 90), gathered on the topical of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrow slender lanceolate; *β-phialides* 10–16 × 1.1–1.8 µm ($\bar{x}$ = 13 × 1.5 µm, n = 90), solitary, scattered along the stipe, lanceolate, ovate at the base, 6–12 µm long, tapering from into a long neck, 2–4 µm long. *Conidia* one-celled, hyaline, smooth, two types. *α-conidia* 1.7–2.4 µm ($\bar{x}$ = 2.1 µm, n = 90), spherical, forming slime conidial masses on the fertile head; *β-conidia* 3–5 × 1.4–2.1 µm ($\bar{x}$ = 4 × 1.7 µm, n = 90), fusiform, produced along stipe of the synnema.

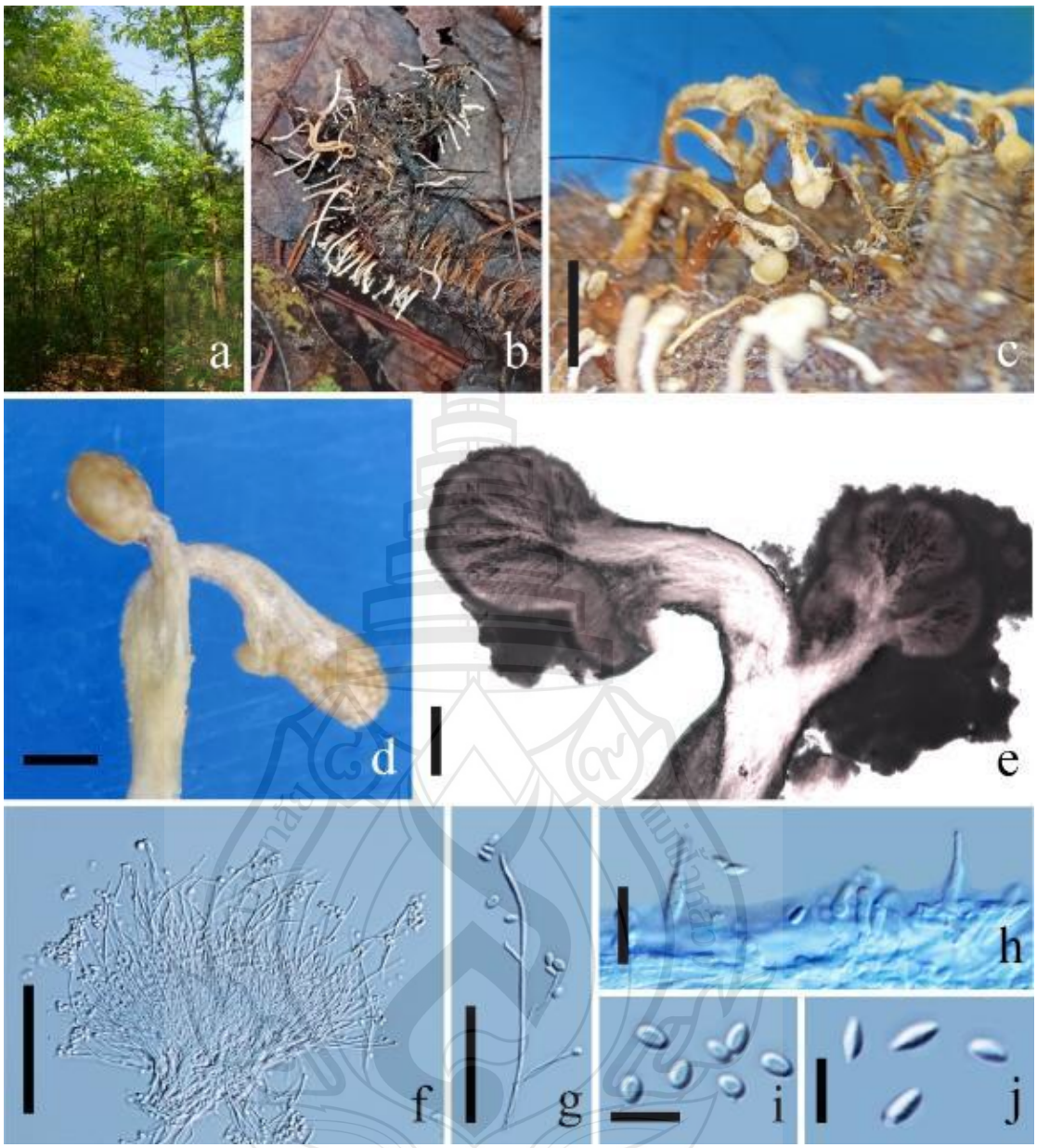
Colonies on PDA medium, growing slowly, attaining 5 cm in 20 days at 25°C, white, reverse yellow. *Synnemata* emerging after 20 days, 0.3–1 cm long, solitary, white, scattered on the surface of colony, branched or unbranched, without fertile head. *Conidial masses* generate from the apex of the synnema. *Conidiophores* undetermined, not clear. *Phialides* exist in two types: α-and β-phialides. *α-phialides* 10.4–18.3 × 0.8–1.8 µm ($\bar{x}$ = 14.4 × 1.3 µm, n = 90) hyaline, narrow slender, smooth. *β-phialides* 22.9–64.2 × 1.0–1.5 µm ($\bar{x}$ = 43.6 × 1.3 µm, n = 90) solitary, growing from hyphae, narrow slender, catenate, smooth. *α-conidia* 1.8–2.2 × 1.4–1.9 µm ($\bar{x}$ = 2 × 1.7 µm, n = 90) globose to subglobose, occurring in the conidial mass on the agar or on the final portion of synnemata, one-celled, smooth-walled, yellow slimy in mass. *β-conidia* 3.2–4.1 × 1.4–1.8 µm ($\bar{x}$ = 3.6 × 1.6 µm, n = 90) fusiform, and

produced on the surface mycelium of colony or on the top of the synnemata, one-celled, smooth-walled, hyaline, usually in chains on a phialide.

Material examined – China, Guizhou Province, Zunyi City, Wuchuan County. Parasitic on larvae of Lepidoptera, on the leaf litter, 23 October 2019, Yu Yang, ZNR0219102301.

Notes: The strains are with the same group with *Pleurocordyceps sinensis* and form a *Pleurocordyceps sinensis* clade. Moreover, the morphology is the same as *Pleurocordyceps sinensis*. These strains are identified as *Pleurocordyceps sinensis* based on morphology and phylogenetic analyses. However, the host of those strains is different from the holotype of *Pleurocordyceps sinensis*, which parasitizes *Ophiocordyceps sinensis*. Larvae of Lepidoptera, *Ophiocordyceps neocrinalis* and *Ophiocordyceps barnesii* are the new hosts of *Pleurocordyceps sinensis*. These specimens were collected from Guizhou and Yunnan, China. We introduced the new host for *Pleurocordyceps sinensis*, and this study shows the geographic distribution of *Pleurocordyceps sinensis*, illustrating its broad host range.

However, these strains share the same clade with *Polycephalomyces ramusus* and *Polycephalomyces tomentosus*, with similar morphology. The representative strains of *Polycephalomyces ramusus* and *Polycephalomyces tomentosus* lack morphological details and require further morphology information (Wang et al., 2020). Thus, these strains were identified as *Pleurocordyceps sinensis*.



Note a Habitat of *Perennicordyceps sinensis*. b Overview of host. c-e Synnemata from infected *Polycephalomyces sinensis*. f Conidiophores. g α-phialides. h β-phialides. i α-conidia. j β- conidia. Scale Bars: c = 2000 μm, d, e = 1000 μm, f = 50 μm, g = 20 μm, h = 10 μm, i, j = 5 μm.

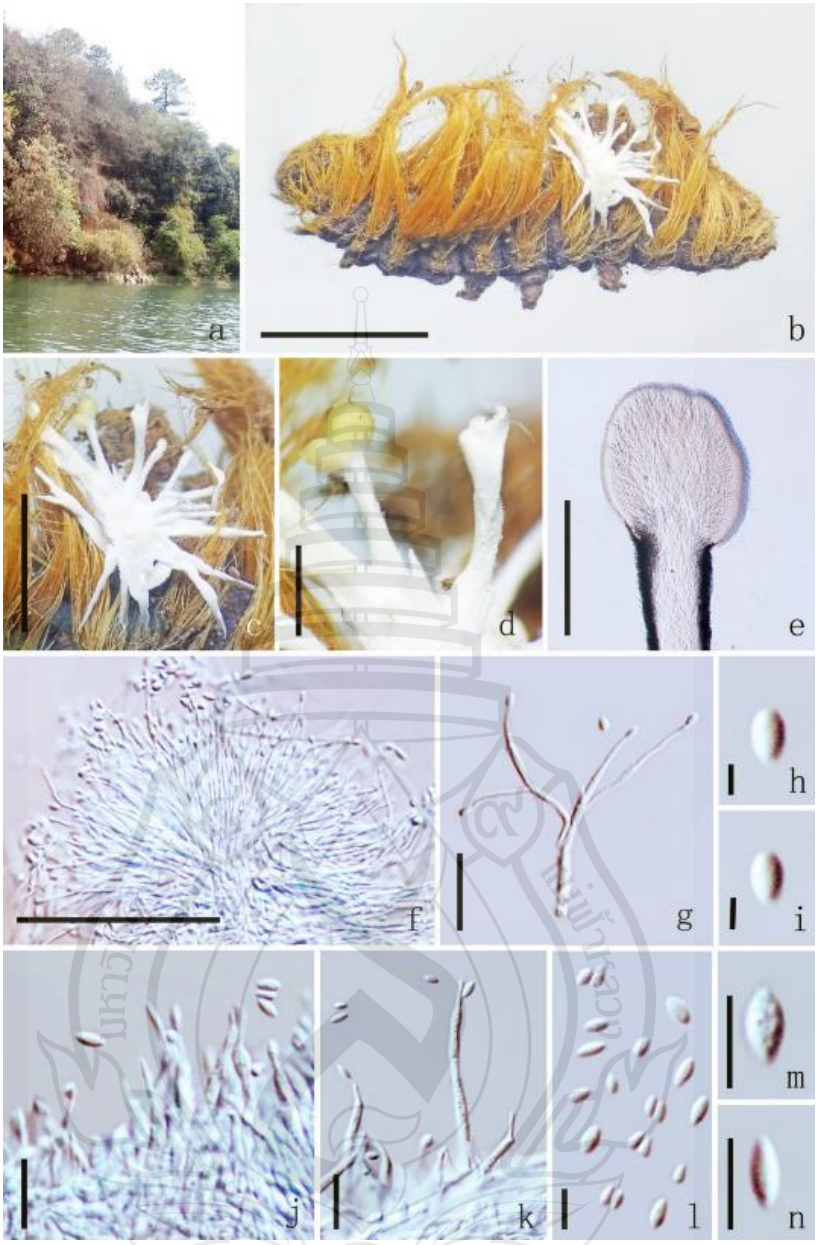
Figure 2.21 Morphology of *Pleurocordyceps sinensis* (new host ZNR0219102301)

Polycephalomyces sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Index Fungorum number: IF 550007

Parasitic on larvae of Lepidoptera, on leaf litter. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 2–8 mm long, 0.2–0.5 mm wide, cylindrical, clavate, capitate, stipitate, simple or branched, white to yellowish, with or without fertile head. *Stipe* 2–8 mm long, 0.2–0.3 mm wide, cylindrical, white, with or without fertile head. *Fertile head* 0.2–0.5 mm wide, globose to subglobose, yellowish, with conidia masses. *Phialides* of two types, both of the types observed on the same synnema *α-phialides* 10–25 × 1–1.2 µm ($\bar{x}$ = 18 × 1.1 µm, n = 90), gathered on the topical of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrow slender lanceolate; *β-phialides* 10–18 × 1.1–1.8 µm ($\bar{x}$ = 14 × 1.5 µm, n = 90), solitary, scattered along the stipe, lanceolate, ovate at the base, 8–16 µm long, tapering into a long neck, 2–4 µm long. *Conidia* one-celled, hyaline, smooth-walled, two types. *α-conidia* 1.6–2.2 µm ($\bar{x}$ = 1.9 µm, n = 90), spherical, forming slime conidial masses on the fertile head; *β-conidia* 3–4.5 × 1.3–2 µm ($\bar{x}$ = 3.8 × 1.7 µm, n = 90), fusiform, produced along stipe of the synnema.

Material examined – CHINA, Yunnan Province, Kunming City, Yeya Lake. parasitic on larvae of Lepidoptera, on leaf litter, 2 December 2018, Juan Meng, YYH181111710.



Note a Habitat of *Perennicordyceps sinensis*. b Overview of *Perennicordyceps sinensis*. c-e Synnemata growing from infected insect. f Conidiophores. g α-phialides. h, i α-conidia. j, k β-phialides. l–n β-conidia. Scale Bars: b = 1 cm, c = 5000 µm, d = 1000 µm, e = 500 µm, f = 50 µm, g, j, k = 10 µm, l–n = 5 µm, h, i = 2 µm.

Figure 2.22 Morphology of *Pleurocordyceps sinensis* (new host YYH18111710)

Polycephalomyces sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021)

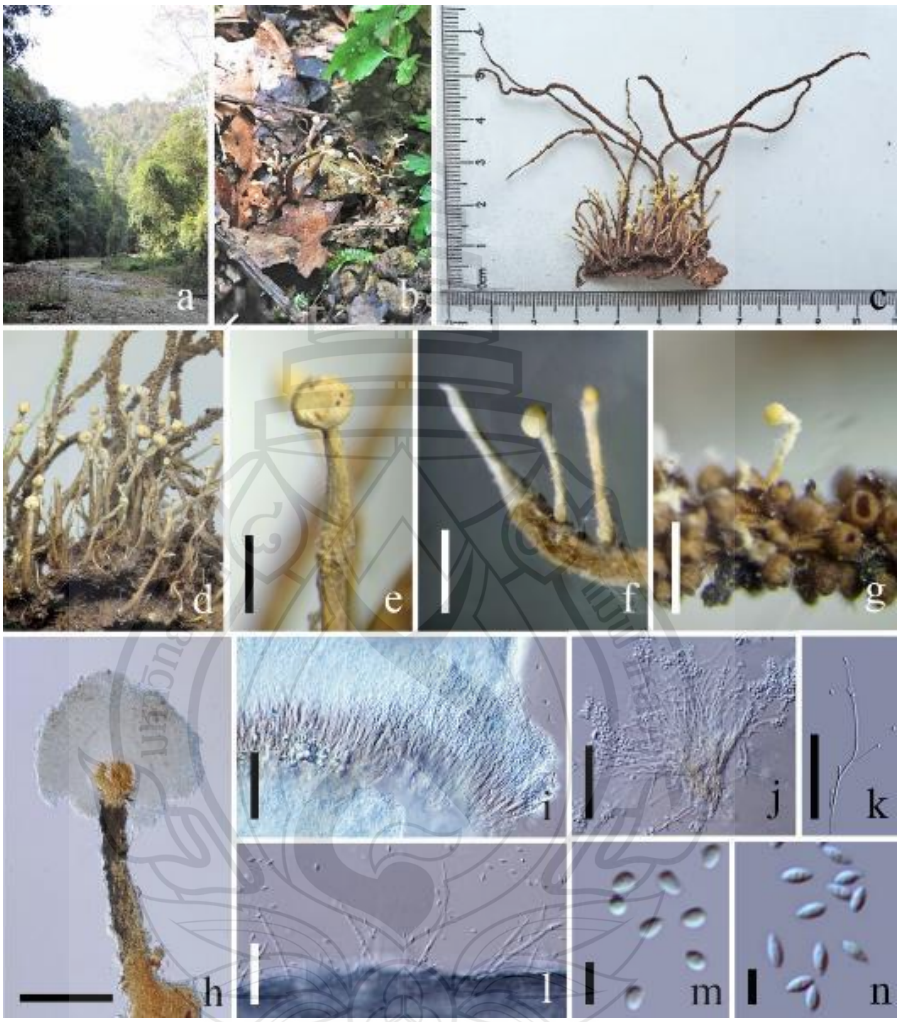
Index Fungorum number: IF 550007

Hyperparasite on *Ophiocordyceps neocrinalis* (Ophiocordycipitaceae) on leaf litter. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 0.5–1.8 cm long, 0.1–3 mm wide, cylindrical, clavate, capitate, stipitate, crowed on the insect body, scattered on the stromata of *Ophiocordyceps neocrinalis*, simple, white to yellowish, with or without fertile head on the top. *Stipe* 0.5–1.7 cm long, 0.1–2.1 mm wide, cylindrical, brown to yellow to yellowish, with or without fertile head. *Fertile head* 0.2–3 mm wide, globose to subglobose, yellowish, with conidia masses. *Phialides* of two types, both of the types observed on the same synnema *α-phialides* 8–25 × 0.9–1.4 µm ($\bar{x}$ = 16 × 1.1 µm, n = 90), gathered on the top of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrowly slender lanceolate; *β-phialides* 12–14 × 1–1.8 µm ($\bar{x}$ = 13 × 1.4 µm, n = 90), directly growing from hyphae, solitary, scattered along the stipe, lanceolate, ovate at the base, 10–12 µm long, tapering into a long neck, 2–4 µm long. *Conidia* one-celled, hyaline, smooth-walled, of two types. *α-conidia* 2.1–2.8 µm ($\bar{x}$ = 2.5 µm, n = 90), spherical, forming slimy conidial masses on the fertile head; *β-conidia* 3.3–5 × 1.4–2 µm ($\bar{x}$ = 4.1 × 1.7 µm, n = 90), fusiform, produced along stipe of the synnema.

Material examined – China, Yunnan Province, Kunming City, Yeya Lake. parasitic on *Ophiocordyceps neocrinalis* (Ophiocordycipitaceae), on the leaf litter, 30 September 2018, Juan Meng, YYH18120208.

*Notes***:** The new collection cluster with the holotype of *Pleurocordyceps sinensis* and has the same morphological features. Thus, we identified it as *Pleurocordyceps sinensis*. However, the host of the new collection is a new species in Ophiocordyceps. This new species, *Ophiocordyceps neocrinalis*, clusters with *Ophiocordyceps cf. acicularis* (NHJ10418.01), *Ophiocordyceps coccidiicola* (NHJ199612) and *Ophiocordyceps pseudoacicularis* (TBRC 8101). *Ophiocordyceps neocrinalis* has 11 bp in ITS, 9 bp in SSU, 10 bp in LSU, 12 bp in

TEF, 12 bp in RPB1, 10 bp in RPB2 that differ with *Ophiocordyceps cf. acicularis* (NHJ12622). Morphologically, *Ophiocordyceps neocrinalis* characters by infecting larva of Lepidoptera and producing red-brown superficial perithecia and 12–14 septate ascospores.



Note a, b Habitat of *Perennicordyceps sinensis*. c Overview of *Perennicordyceps sinensis*. d, e Synnemata growing from the infected host of *Polycephalomyces sinensis*. f, g Synnemata growing from stromata of *Ophiocordyceps neocrinalis*. h Synnemata. i, j Conidiophores. k α-phialides. l β-phialides. m α-conidia. n β-conidia. Scale Bars: e–g = 5000 μm, h = 2000 μm, i = 50 μm, j–l = 20 μm, m, n = 5 μm.

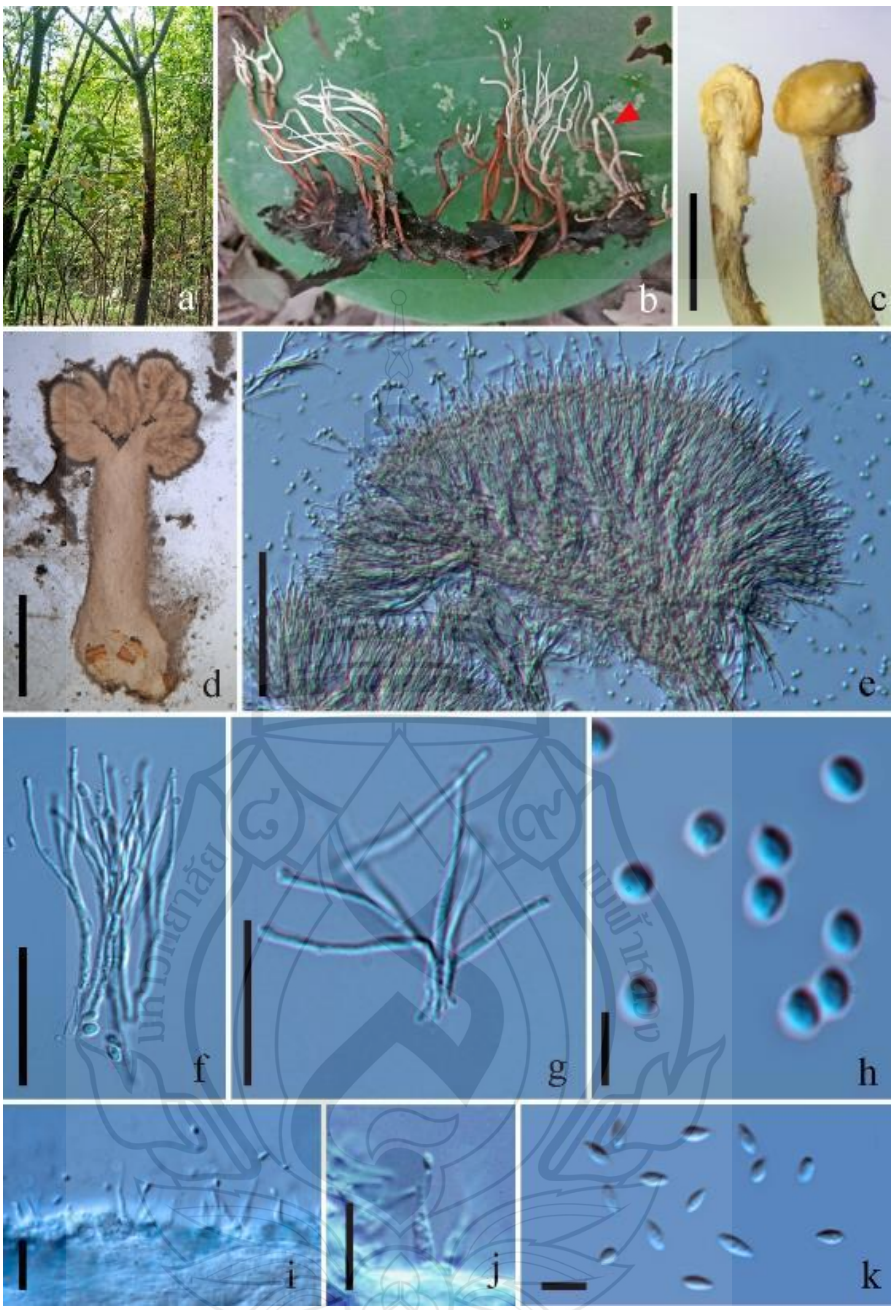
Figure 2.23 Morphology of *Pleurocordyceps sinensis* (new host YYH18120122)

Pleurocordyceps sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Index Fungorum number: IF 550007

Hyperparasitic on *Ophiocordyceps crinalis* (Ophiocordycipitaceae), on insects in leaf litter. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 0.8–1.2 cm long, 0.2–0.5 mm wide, clavate, capitate, stipitate, scattered on *Ophiocordyceps crinalis*, simple, white to yellowish, with fertile head on the top. *Stipe* 0.8–1.2 cm long, 0.2–0.3 mm wide, cylindrical, white to yellowish, with fertile head. *Fertile head* 0.3–1 mm wide, globose to subglobose, yellowish, with conidia masses. *Phialides* of two types, both types observed on the same synnema *α-phialides* 15–25 × 1–1.4 μm ($\bar{x}$ = 20 × 1.2 μm, n = 90), gathered on the topical of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrowly slender lanceolate; *β-phialides* 11–15 × 1–1.8 μm ($\bar{x}$ = 13 × 1.4 μm, n = 90), directly growing from hyphae, solitary, scattered along the stipe, lanceolate, ovate at the base, 10–14 μm long, tapering into a long neck, 2–4 μm long. *Conidia* one-celled, hyaline, smooth-walled, of two types. *α-conidia* 2.2–2.8 μm ($\bar{x}$ = 2.5 μm, n = 90), spherical, forming slime conidial masses on the fertile head; *β-conidia* 3.2–4.5 × 1.4–2 μm ($\bar{x}$ = 3.9 × 1.7 μm, n = 90), fusiform, produced along stipe of the synnema.

Notes: The new collections host, 520326MF865c and 520326MF865b cluster with *Ophiocordyceps crinalis* (GDGM 17327) with strong support (100% ML / 1 PP) and are identified as *Ophiocordyceps crinalis*. This is the first time to report the asexual morph of the species *Ophiocordyceps crinalis* and it is the new host of *Pleurocordyceps sinensis***.**



Note a Habitat of *Perennicordyceps sinensis*. b Overview of *Perennicordyceps sinensis* and its host. c, d Synnemata. e, f Conidiophores. g α-phialides. h α-conidia. i, j β-phialides. k β-conidia. Scale Bars: c = 1000 µm, d = 500 µm, e = 50 µm, f, g = 20 µm, h = 5 µm, i, j = 10 µm, k = 5 µm.

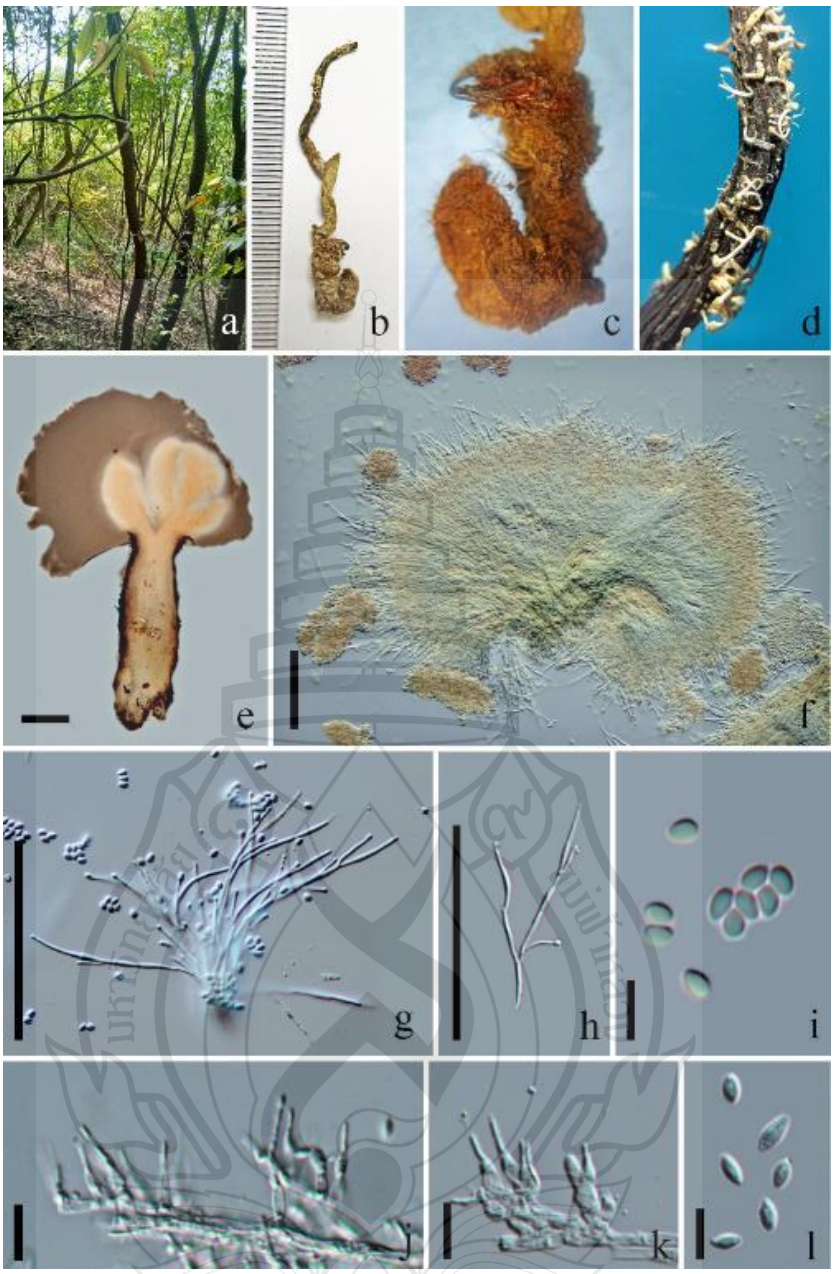
Figure 2.24 Morphology of *Pleurocordyceps sinensis* (new host 520326MF865)

Pleurocordyceps sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.J. Yao, Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang & P.M. Kirk, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Index Fungorum number: IF 550007

Hyperparasitic on *Ophiocordyceps barnesii* (Ophiocordycipitaceae), in leaf litter. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 1–5 mm long, 0.1–0.5 mm wide, clavate, capitate, stipitate, scattered on the stroma of *Ophiocordyceps barnesii*, simple, white to yellowish, with or without fertile head on the top. *Stipe* 1–5 mm long, 0.1–0.3 mm wide, cylindrical, white to yellowish, with or without fertile head. *Fertile head* 0.3–0.5 mm wide, globose to subglobose, yellowish, with conidia masses covered. *Phialides* of two types, both of types observed on the same synnema *α-phialides* 12–21 × 1–1.3 µm ($\bar{x}$ = 17 × 1.2 µm, n = 90), gathered on the topical of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrow slender lanceolate; *β-phialides* 10–16 × 1–1.7 µm ($\bar{x}$ = 13 × 1.3 µm, n = 90), directly growing from hyphae, solitary, scattered along the stipe, lanceolate, ovate at the base, 10–15 µm long, tapering into a long neck, 1–3 µm long. *Conidia* one-celled, hyaline, smooth, of two types. *α-conidia* 2.1–2.9 µm ($\bar{x}$ = 2.6 µm, n = 90), spherical, forming slime conidial masses on the fertile head; *β-conidia* 3.4–4.9 × 1.5–2.2 µm ($\bar{x}$ = 4.2 × 1.8 µm, n = 90), fusiform, produced along stipe of the synnema.

Material examined – China, Guizhou Province, Zunyi City, parasitic on *Ophiocordyceps barnesii* (Ophiocordycipitaceae), on the leaf litter, 30 September 2018, Yu Yang, FC20042304.



Note a Habitat of *Perennicordyceps sinensis*. b Overview of *Perennicordyceps sinensis* and its host. c Host of *Ophiocordyceps barnesii*. d Synnemata growing from infected stromata of *Ophiocordyceps barnesii*. e synnemata. f, g Conidiophores. h α-phialides. i α-conida. j, k β-phialides. l β-conidia. Scale Bars: e = 200 µm, f–h = 50 µm, j, k = 10 µm, i, l = 5 µm.

Figure 2.25 Morphology of *Pleurocordyceps sinensis* (new host FC20042304)

Pleurocordyceps parvicapitata Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology –: The name refers to the small capitate head.

Holotype –: DG11

Hyperparasite on *Elaphomyces* sp. (Elaphomycetaceae, Eurotiales) buried in soil. **Sexual morph:** *Host* 1.5–2.2 cm diam, globose, brown to dark-brown, rough surface. *Stromata* 5–15 cm long, 1–5 mm wide., branched, brown to yellow, hard, cylindrical. *Stipe* 4.5–14 cm long, 0.1–0.45 cm diam., brown to dark brown, branched, with small capitate head. *Fertile part* 1–1.5 mm hight, 1.5–3 mm diam., yellow to pale yellow, single or capitate, rough, with ostiole. *Perithecia* 577–751 × 207–281 µm ($\bar{x}$ = 664 × 244 µm, n = 60), immersed, crowded, ovoid to obpyriform, ostiolate, ostiole lined with periphyses, yellow, thick-walled. *Peridium* 21–31 µm ($\bar{x}$ = 26 µm, n = 90) wide, hyaline to yellow, two layers, of textura angularis to textura porrecta. *Asci* 322–399 × 4.8–6.8 µm ($\bar{x}$ = 361 × 5.8 µm, n = 90), 8-spored, hyaline, filiform, with a thin apex. *Apical cap* 1.6–2.6 × 2.8–3.8 µm ($\bar{x}$ = 2.1 × 3.3 µm, n = 60), thin, hyaline. *Ascospores* 318–396 × 1.2–1.9 µm ($\bar{x}$ = 357 × 1.6 µm, n = 90), filiform, hyaline, multiseptate. *Secondary ascospores* 3.0–4.7 × 1.2–1.8 µm ($\bar{x}$ = 3.9 × 1.5 µm, n = 90) oblong to cylindrical, one-celled, straight, hyaline, smooth-walled.

Hyperparasitic on *Perennicordyceps elaphomyceticola* (Ophiocordycipitaceae, Hypocreales) or *Elaphomyces* sp. (Elaphomycetaceae, Eurotiales), collected from the soil. **Asexual morph:** Hyphomycetes. *Synnemata* absent on *Perennicordyceps elaphomyceticol*, reproduced on *Elaphomyces sp*., 1–1.2 cm long, 1–2 mm wide, stipitate, cylindrical, yellow to white, branched, tapering gradually on the top, without a fertile head. *Conidial mass* covered the surface of the colony on *Perennicordyceps elaphomyceticol*, white when fresh, light yellow when dry. *Conidiophores* 21–30 µm ($\bar{x}$ = 25, n = 60) long, erect, arising from vegetative hyphae, bearing phialides aggregates or clusters, predominantly symmetrically monoverticillate, often additional branches occur which are equal in length form stipe structures, 2–4 phialides in one. *Phialides* 11.7–16.3 × 1.1–1.6 µm ($\bar{x}$ = 14 × 1.4 µm, n = 90), cylindrical at the base, 8–12 µm long, tapering into a long neck, 1–3.5 µm long. *Conidia* 2.8–3.6 × 2.4–3 µm ($\bar{x}$ = 3.2 × 2.7 µm, n = 90) globose to subglobose, hyaline, smooth, 1-celled.

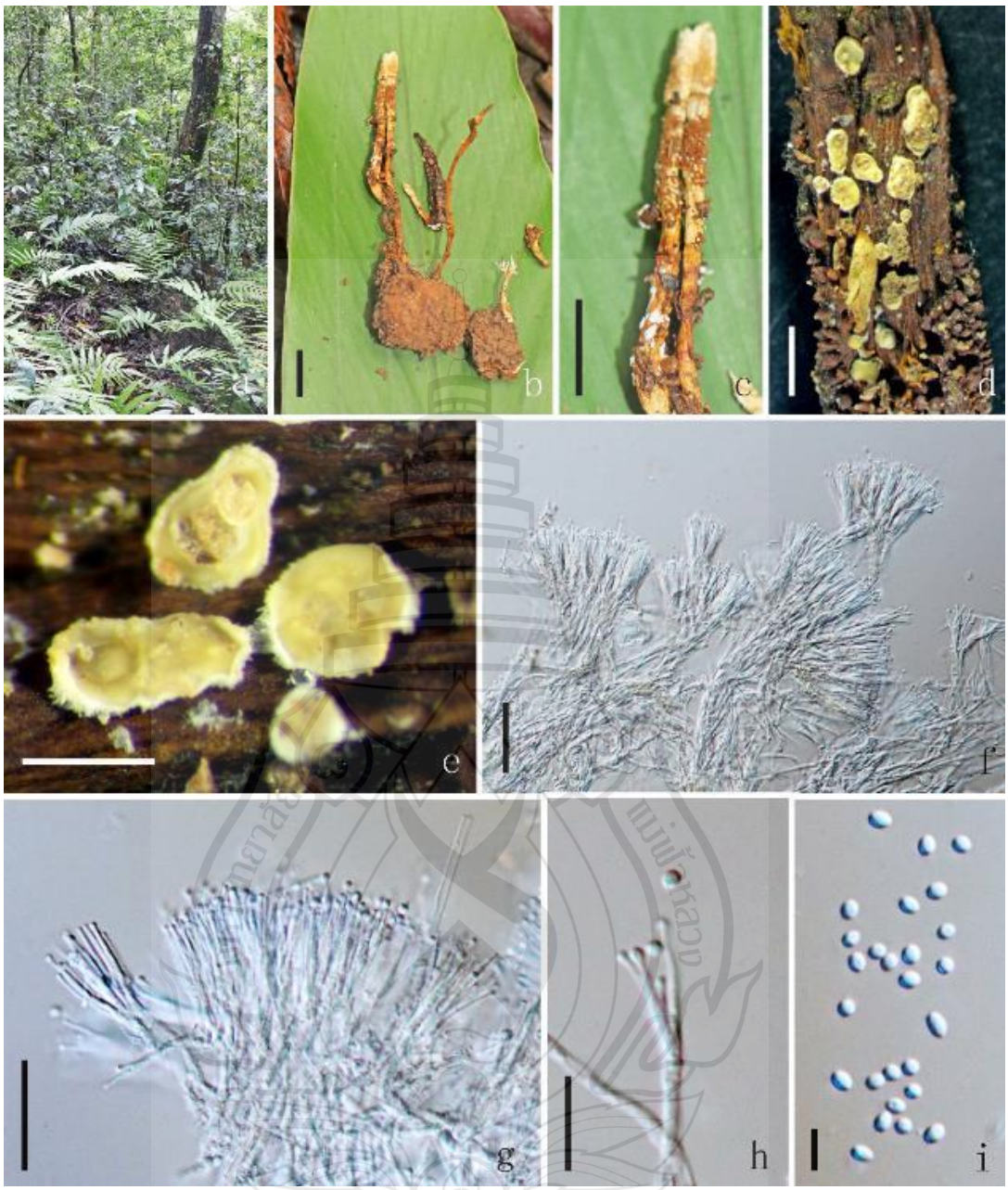
Material examined – China, Yunnan Province, Xishuangbanna City, Dadugang County, on *Elaphomyces sp*. (Elaphomycetaceae, Eurotiales), burin in the soil, 11 June 2018, YuanPin Xiao, DG11.

Notes – The new species, *Pleurocordyceps parvicapitata* parasitizing both *Perennicordyceps elaphomyceticol* (Ophiocordycipitaceae, Hypocreales) and *Elaphomyces sp*. (Elaphomycetaceae, Eurotiales), is a new taxon in the genus. Three specimens of *Pleurocordyceps parvicapitata* formed colonies on the surface of *Pe. elaphomyceticola* and one observed synnema. We could not obtain any isolate from the fresh specimen.

The new species shared the same clades with *Pleurocordyceps lianzhouensis* and *Pleurocordyceps ramosopulvinatu*s and sisters to *Pleurocordyceps lianzhouensis* in the phylogenetic tree with strong support (99% ML / 0.99 PP). The new species, *Pleurocordyceps parvicapitata*, differs from other species of *Pleurocordyceps* in parasitising *Elaphomyces* sp. (Elaphomycetaceae, Eurotiales) and producing capitate fertile heads, long stipes, shorter secondary ascospores. The asexual morph of *Pleurocordyceps parvicapitata* is characterized by parasitizing both *Perennicordyceps elaphomyceticola* and *Elaphomyces* sp., 2–6 in one cluster phialides. Only one type of phialides has been discovered from fresh specimens. Furthermore, the new species, *Pleurocordyceps parvicapitata*, is the first report for fungi parasitic on *Perennicordyceps* among all family species, likely leading to a deeper understanding of the physiology, evolution, and taxonomy of these groups.

Note a Habitat. b, c Stromata emerging from infected *Elaphomyces* sp. d Host. e, f Fertile head of stromata. g Cross-section through part of stroma with perithecia. h Perithecia. i Peridium. j-m Asci. n Ascosopores. o Apical cap of asci. p Part of ascospores. q–s Secondary spores. Scale Bars: b–d = 1 cm, e, f = 1000 µm, g, h = 500 µm, j–n = 100 µm, i, o, p = 20 µm, q–s = 5 µm.

Figure 2.26 Morphology of *Pleurocordyceps parvicapitata* (holotype DG11)



Note a Habitat of *Perennicordyceps parvicapitata* b Overview of host. c–e Colony from infected *Perennicordyceps elaphomyceticol* f, g Conidiophores. h Phialides. i Conidia. Scale Bars: b, c = 1 cm, d = 1000 µm, e = 500 µm, f, g = 20 µm, h = 10 µm, i = 5 µm.

Figure 2.27 Morphology of *Pleurocordyceps parvicapitata* (new host DG02)

Pleurocordyceps lanceolatus Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology –: The species name refers to the lanceolate synnemata both on fresh specimen and culture.

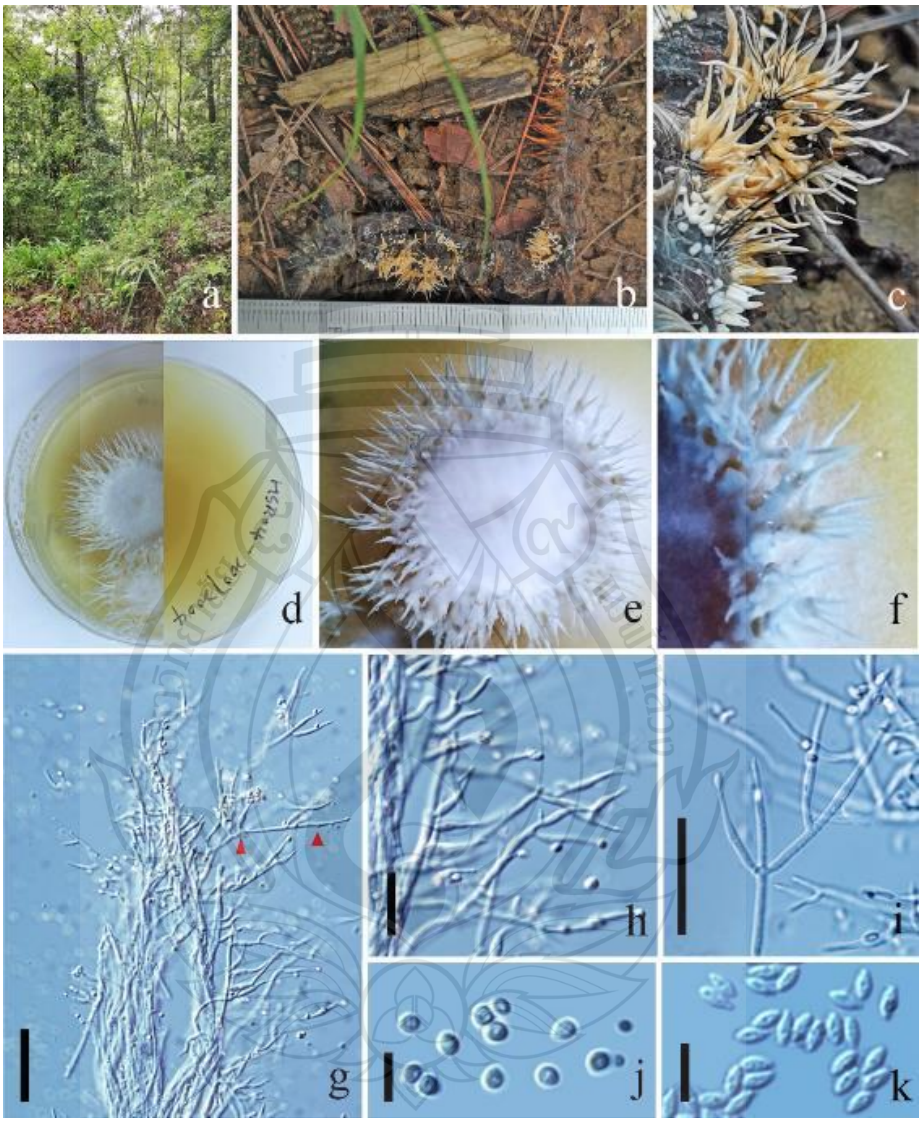
Parasites on larvae of Lepidoptera. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 0.2–1.2 cm long, 1–3 mm wide, lanceolate to corniform, solitary to crowded, stipitate, usually unbranched, rarely branched on the PDA, yellow to yellowish on the fresh specimen, covered with conidial masses, white on the PDA, without a fertile head. *Conidiophores* not clearly identified from hyphae. *Phialides* of two types, both types observed on the same region of synnemata *α-phialides* 12–18 × 1.3–1.6 μm ($\bar{x}$ = 15 × 1.45 μm, n = 90), directly from hyphae, solitary, usually unbranched, subulate, at the base, 8–14 μm long, tapering into a long neck, 2–4 μm long; *β-phialides* 20.2–28.9 × 1.6–2.5 μm ($\bar{x}$ = 21.8 × 2.1 μm, n = 90) usually branched into 2 or 3 phialides, narrowly lageniform to lanceolate, tapering abruptly from the base to the apex. *Conidia* one-celled, hyaline, smooth, of two types both in culture and fresh collection. *α-conidia* 1.8–2.5 μm ($\bar{x}$ = 2.15 μm, n = 90), spherical, forming slimy conidial masses along the synnemata; *β-conidia* 3–4.4 × 1.4–2.4 μm ($\bar{x}$ = 3.7 × 1.9 μm, n = 90), fusiform, produced along the synnemata as well as on the mycelium surface of the colony.

Culture characters: Colonies derived from tissue isolation. Colonies on PDA fast-growing, reached 1 cm diam in 7 days at 25 ℃, white, cottony with low mycelial density, reverse white, synnemata growing from the marginal colony. *Synnemata* 0.2–0.8 cm long, 0.5–2 mm wide, lanceolate to corniform, erect, solitary to crowded, stipitate, branched or unbranched white, covered with conidial masses, without a fertile head. Other characters are the same as the fresh collections.

Material examined – China, Guizhou Province, Zunyi City, Wuchuan County, parasitic on larvae of Lepidoptera, on the leaf litter, 20 July 2020, Yu Yang, HSR0420072004.

Notes: – *Pleurocordyceps lanceolatus* is sister to *Pleurocordyceps marginaliradians*, *Pleurocordyceps aurantiacus* and *Pleurocordyceps phaothaiensis* in the phylogenetic tree. However, *Po. lanceolatus* has 15 bp in ITS, 6 bp in SSU, 4 bp in LSU, 12 bp in TEF, 16 bp in RPB1 and 18 bp in RPB2 differences with

Pleurocordyceps marginaliradians. *Pleurocordyceps lanceolatus* is distinct from other species of *Pleurocordyceps* by parasitizing on larvae of Lepidoptera and producing lanceolate to corniform synnemata without a fertile head. Thus, we introduce *Pleurocordyceps lanceolatus* as a new species under *Pleurocordyceps.*



Note a Habitat of *Perennicordyceps lanceolatus*. b Overview of the host. c Synnemata on the insect. d Culture. e, f Synnemata on the culture. g Conidiophores. h α-phialides. i β-phialides. j α-conidia. k β-conidia. Scale Bars: g, i = 20 µm, h = 10 µm, j, k = 5.

Figure 2.28 Morphology of *Pleurocordyceps lanceolatus*

Pleurocordyceps nutantis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

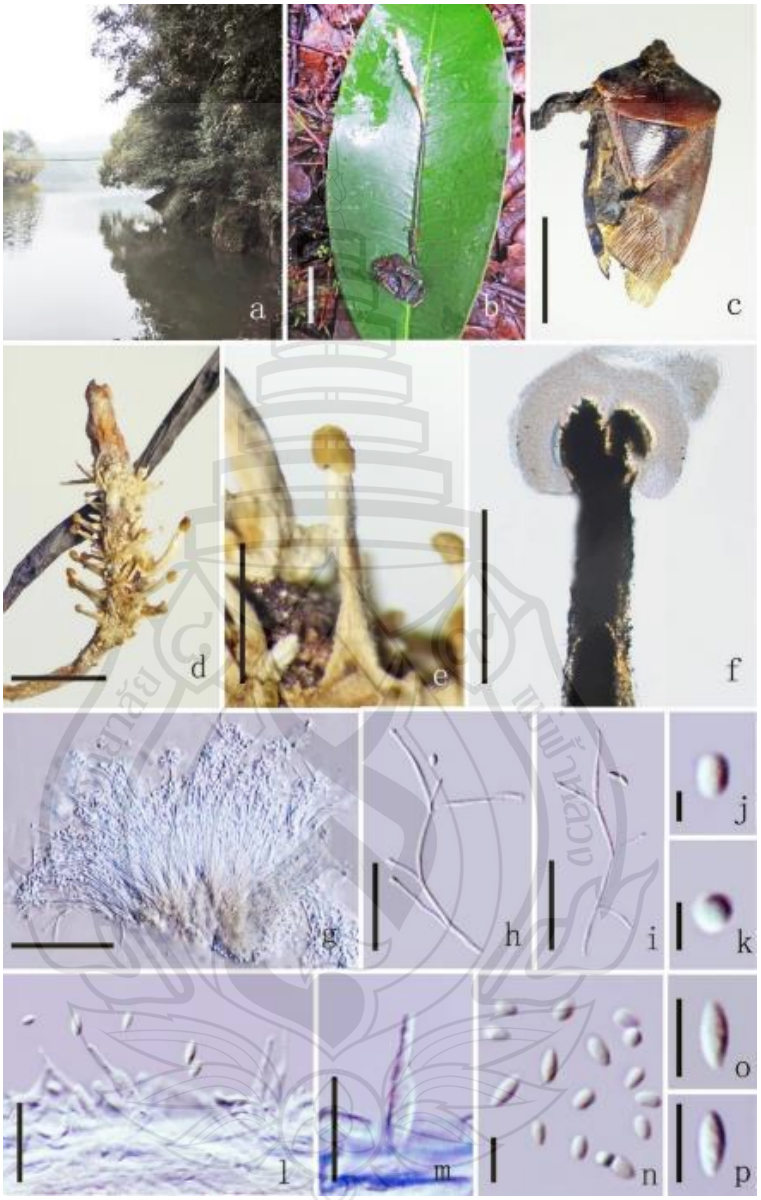
Etymology –: The species name refers to the host species.

Hyperparasitic on *Ophiocordyceps nutans* (Ophiocordycipitaceae), on insects buried in the soil, the stromata erect in the air. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* 2–5 mm long, 0.1–0.4 mm wide, cylindrical, clavate, capitate, stipitate, crowded, simple, white to yellowish, with or without fertile head. *Stipe* 2–5 mm long, 0.1–0.2 mm wide, cylindrical, white to yellowish, with or without fertile head. *Fertile head* 0.2–0.4 mm wide, globose to subglobose, yellowish, with conidia masses. *Phialides* of two types, both of the types observed on the same synnema *α-phialides* 10–24 × 1–1.2 μm ($\bar{x}$ = 18 × 1.1 μm, n = 90), gathered on the top of synnema, arranged in a parallel palisade-like layer around the top of fertile head, hyaline, usually branched into 2–6 phialides, narrowly slender lanceolate; *β-phialides* 10–14 × 1.1–1.8 μm ($\bar{x}$ = 12 × 1.5 μm, n = 90), solitary, scattered along the stipe, lanceolate, ovate at the base, 5–12 μm long, tapering into a long neck, 2–4 μm long. *Conidia* one-celled, hyaline, smooth, of two types. *α-conidia* 1.6–2.3 μm ($\bar{x}$ = 1.9 μm, n = 90), spherical, forming slimy conidial masses on the fertile head; *β-conidia* 3.5–5 × 1.3–2 μm ($\bar{x}$ = 4.2 × 1.7 μm, n = 90), fusiform, produced along stipe of the synnema.

Material examined – China, Yunnan Province, Kunming City, Yeya Lake, parasitic on larvae of Lepidoptera, on the leaf litter, 30 September 2018, Juan Meng, YYH18093019.

Notes: Pleurocordyceps nutantis is sister to *Pleurocordyceps sinensis*, *Polycephalomyces ramosus* and *Polycephalomyces tomentosus* in the phylogenetic tree with strong support value (98% ML / 0.99 PP). More data is needed for *Polycephalomyces ramosus* and *Polycephalomyces tomentosus***.** ***Pleurocordyceps.*** *lanceolatus* is distinct from *Pleurocordyceps sinensis* in producing smaller *α-phialides* and larger *β-conidia*. The new species has the same host with *Pleurocordyceps yunnanensis*, which is *Ophiocordyceps nutans*, but can be distinguished to *Pleurocordyceps yunnanensis* in the phylogenetic tree. The host clade sister to *Ophiocordyceps nutans* **(**NBRC 101749**)** in the phylogenetic tree and share the same morphological characters with *Ophiocordyceps nutans***.** Thus, we introduce

Polycephalomyces nutantis as a new species under *Polycephalomyces* and identify the host as *Ophiocordyceps nutans*.



Note a Habitat of *Pleurocordyceps nutantis*. b Overview of *Pleurocordyceps sinensis*. c Host of *Ophiocordyceps nutans*. d-f Synnemata. g, l Conidiophores. h, i α-phialides. j, k α-conidia. m β-phialides. n–p β-conidia. Scale Bars: b = 1 cm, c = 1 cm, d = 5000 µm, e = 2000 µm, f = 500 µm, g = 50 µm, h, i = 20 µm, l, m = 10 µm, n–p = 5 µm, j, k = 2 µm.

Figure 2.29 Morphology of *Pleurocordyceps nutantis* (holotype YYH18093019)

Polycephalomyces aurantiacus Y.P. Xiao, T.C. Wen & K.D. Hyde, in Xiao, Wen, Hongsanan, Jeewon, Luangsaard, Brooks, Wanasinghe, Long & Hyde, Scientific Reports 8(no. 18087): 2 (2018).

Index Fungorum number: IF553936; Facesoffungi number: FoF 03811

Etymology: The specific epithet refers to the color of conidia in mass in the specimen and colony.

Holotype: MFLU 17-1393

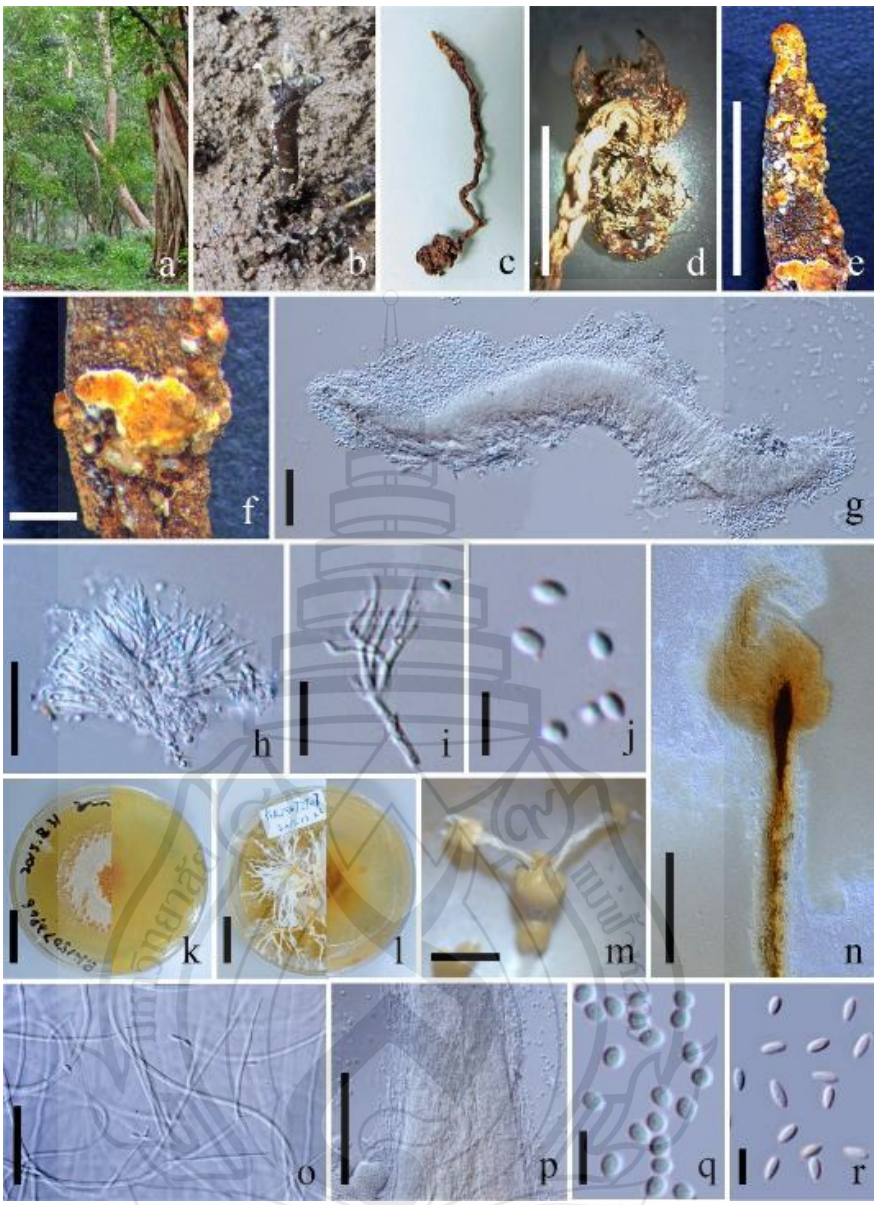
Hyperparasite on *Ophiocordyceps barnesii* (Ophiocordycipitaceae), buried in the soil. **Sexual morph:** undetermined. **Asexual morph:** *Synnemata* solitary or not solitary, arising from the fertile head of the stromata, flat-shaped, orange color. *Phialides* 9.9–14.3 × 0.7–1.4 µm ($\bar{x}$ = 12.1 × 1.1 µm, n = 90) hyaline. *Conidia* 2–2.6 × 1.4–2.1 µm ($\bar{x}$ = 2.3 × 1.8 µm, n = 90), oval to globose shape, hyaline, one-celled, smooth-walled, orange in mass.

Colonies on PDA medium, growing slowly, attaining 4 cm in 17 days at 25°C, white, reverse yellow. *Synnemata* emerging after 30 days, solitary or not solitary, branched or unbranched, 1.3–2.2 µm long ($\bar{x}$ = 60), showing 1–2 radiating ring-like distributions. *Conidial masses* generate from the apex of the synnemata or cover the surface of the colony. *Hyphae* hyaline, branched, smooth-walled, 0.3–50 mm ($\bar{x}$ = 20) wide. *Conidiophores* undetermined, not clear. *Phialides* exist in two types: α-and β-phialides. *α-phialides* 10.4–18.3 × 0.8–1.8 µm ($\bar{x}$ = 14.4 × 1.3 µm, n = 90) hyaline, narrow slender, smooth. *β-phialides* 22.9–64.2 × 1–1.5 µm ($\bar{x}$ = 43.6 × 1.3 µm, n = 90) solitary, growing from hyphae, narrow slender, catenateblasto conidia, smooth. *α-conidia* 1.8–2.2 × 1.4–1.9 µm ($\bar{x}$ = 2 × 1.7 µm, n = 90) globose to subglobose, occurring in the conidial mass on the agar or on the final portion of synnemata, one-celled, smooth-walled, yellow slimy in mass. *β-conidia* 3.2–3.9 × 1.4–1.8 µm ($\bar{x}$ = 3.5 × 1.6 µm, n = 90) fusiform, and produced on the surface mycelium of colony or on the top of the synnemata, one-celled, smooth-walled, hyaline, usually in chains on a phialide.

Material examined: Thailand, Prachuap Khiri Khan. On dead larvae (Coleopteran), 29 July 2015, YuanPin Xiao, BK15072907 (MFLU 17-1393, **holotype**); BK15072902, BK15072906 (MFLU 17-1394, HKAS100693, **paratypes**); ex-type

living cultures, MFLUCC 17-2113, MFLUCC 17-2114, MFLUCC 17-2115, KUMCC 17-0256, KUMCC 17-0257.

Notes: *Polycephalomyces aurantiacus* and *P. marginaliradians* have two types of phialides, while *P. formosus* and *P. sinensis* have only one type of phialide. *Polycephalomyces ponerae* differs from *P. aurantiacus* and *P. marginaliradians* by producing *Akanthomyces*-like β-phialides and parasitic on ant (*Ponera Latreille*). *Polycephalomyces agaricus* differs from *P. aurantiacus* and *P. marginaliradians* by producing agaric shaped synnemata and parasitic on *Ophiocordyceps* sp. *Polycephalomyces yunnanensis* is distinct from *P. aurantiacus* and *P. marginaliradians* as it produces longer α-conidia fusiform, catenate or clump together β-conidia and parasite on *O. nutans*. *Polycephalomyces ramosus* differs from *P. aurantiacus* and *P. marginaliradians* in having longer synnemata, shorter β-phialides and parasitic on *Hirsutella guignardii*. *Polycephalomyces aurantiacus* is distinct from *P. marginaliradians* as it is parasitic on the fungus *Ophiocordyceps barnesii* and produces longer synnemata, shorter β-phialides and catenate α-conidia, wheras *P. marginaliradians* is parasitic on insect and produces shorter synnemata, longer β-phialides and catenate β-conidia. And the phylogenetic analyses also support this is a new species in *Polycephalomyces*.



Note a, b Habitat. c Overview of *Pleurocordyceps aurantiacus* with the host. d Insect. e, f Colony on the surface of stromata. g Cross-section of the colony. h, i Conidiophores with phialides. j Conidia. k, l Culture. m, n Synnemata. o β-phialides. p α-phialides with slime conidia masses. q α-conidia. r β-conidia. Scale Bars: d, e, k, l = 1 cm, f, m, n = 1000 µm, g, o, p = 50 µm, h = 20 µm, i = 10 µm, j, q, r = 5 µm.

Figure 2.30 Morphology of *Pleurocordyceps aurantiacus* (holotype MFLUCC 17-2113)

Pleurocordyceps aurantiacus (Y.P. Xiao, T.C. Wen & K.D. Hyde) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Index Fungorum Number: IF570674; *Facesoffungi Number*: FoF 03812

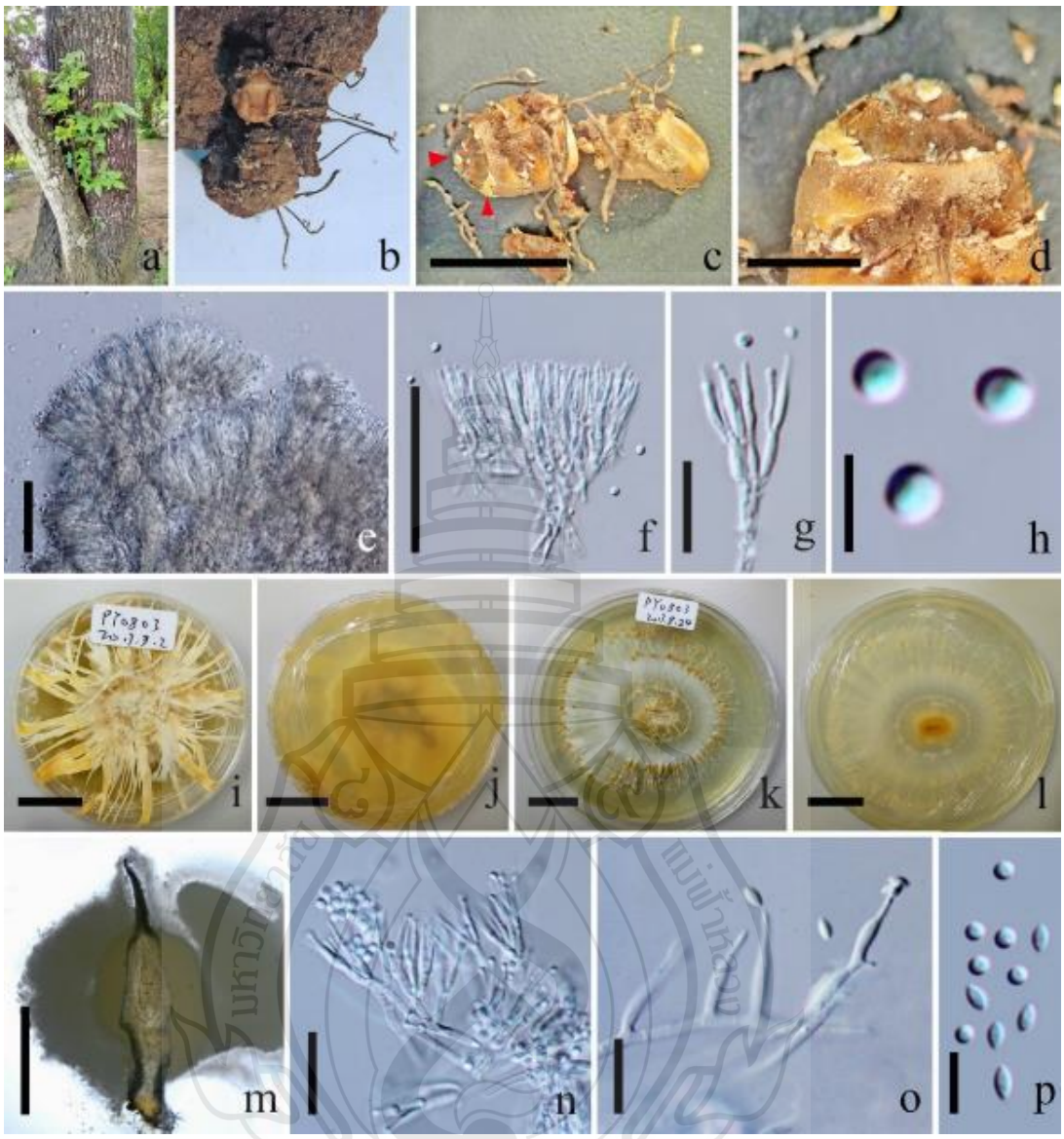
Hyperparasite Ophiocordyceps neouguetii (Ophiocordycipitaceae) on queen of green tree ant *(*Formicidae, *Oecophylla smaragdina)*, in tree hole. **Asexual morph:** Hyphomycetous. *Colony* scattered on the surface of ant, no synnemata observed, white to yellow. *Conidiophores* 20–32.4 × 1.1–1.9 μm ($\bar{x}$ = 26.3 × 1.5 μm, n = 90), arranged in a parallel palisade-like layer on the surface of colony, hyaline, usually brahched into 2 phialides. *Metulae* 3–5.6 × 1.4–2 μm ($\bar{x}$ = 4.3 × 1.7 μm, n = 90), smooth, hyaline. *Phialides* 8–12.2 × 0.8–1.9 μm ($\bar{x}$ = 10.1 × 1.4 μm, n = 90), only one type observed, narrow slender lanceolate, usually 2 phialides in one, 3 branched on one metula hyaline. *Conidia* 2.1–2.7 μm ($\bar{x}$ = 2.4, n = 90), spherical, hyaline, one-celled, smooth-walled, yellowish to yellow slimy in mass, covered the colony.

Colonies on PDA medium, circular, attaining 5 cm in 15 days at 25°C, yellowish, with synnemata on the surface, reverse yellow. *Synnemata* 3–15 mm long, 0.2–3 mm wide, emerging after 10 days in the margin of the colony, single or branched into 2 or 3 branched, showing 1–3 radiating ring-like distributions, long synnemata observed after 30 days, with or without fertile head. *Fertile head* 0.4–3 mm wide, spherical, yellowish to yellow, generating from the middle of the synnemata, with conidial masses on the surface. *Conidial masses* slime, yellowish to yellow, on the short synnemata, longer synnemata not observed. *Conidiophores* 26–32.4 × 1.1–1.9 μm ($\bar{x}$ = 29.2 × 1.5 μm, n = 90), arranged in a parallel palisade-like layer on the surface of colony, hyaline, usually brahched into 2 phialides, with or without metulae. *Metulae* 3–5.6 × 1.4–2.0 μm ($\bar{x}$ = 4.3 × 1.7 μm, n = 90), smooth, hyaline. *Phialides* two types, both of the types obsevered on the same synnema *α-phialides* 9.5–14.6 × 1.2–1.9 μm ($\bar{x}$ = 12.1 × 1.6 μm, n = 90), hyaline, smooth, elongated lageniform, caespitose, palisade-like, crowed, monoverticillate, gathered in the middle of synnema, mostly branched into 2 phialides, 3 branched on one metula. *β-phialides* 11.4–20.5 × 1.9–2.8 μm ($\bar{x}$ = 16.1 × 2.4 μm, n = 90), hyaline, smooth,

solitary, directly growing from hyphae, with or without metula at the base, directly growing from hyphae, solitary, scattered along the stipe, lanceolate, ovate at the base, 9–16 μm long, tapering into a long neck, 3–5 μm long. *α-conidia* 1.8–2.4 μm ($\bar{x}$ = 2.1 μm, n = 90) diam, one-celled, smooth-walled, spherical, catenate, occurring in the fertile head on the middle of synnemata, yellowish slimy in mass. *β-conidia* 3.2–4.1 × 1.4–2.2 μm ($\bar{x}$ = 3.6 × 1.8 μm, n = 90), fusiform, produced on the surface mycelium of colony or along stipe of the synnema, one-celled, smooth-walled, hyaline.

Material examined: Thailand, Phayao. Hyperparasite *Ophiocordyceps neouguetii* (Ophiocordycipitaceae) on the ants (Formicidae, Oecophylla smaragdina) 18 Aug 2017, YuanPin Xiao, PY0803 (MFLU 17-1393); living cultures, MFLUCC 17-2113.

Notes–: The new collections cluster sister to the *Pleurocordyceps aurantiacus* clade with high support (97% ML / 0.97 PP) in the phylogenetic tree. And the morphology on PDA are the same as *Pl. aurantiacus*. *Pleurocordyceps aurantiacus* was hyperparasitic on *Ophiocordyceps neobuquetii*, which parasitised a queen of green the tree ant (Formicidae, *Oecophylla smaragdina*) in a tree hole, collected from Phayao province, Thailand. The host of the holotype was first reported as Cossidae larva (Lepidoptera) (Xiao et al., 2018) and on beetle larvae (Coleoptera) in this study. The β-phialides and β-conidia were observed with synnemata and stromata on the holotype, while α-phialides and α-conidia were observed with the colony on the fresh specimen. Thus, *Ophiocordyceps neouguetii* is the new host for *Pl. aurantiacus*.



Note a Habitat. b Overview of *Pleurocordyceps marginaliradians* and its host. c, d Colony on host surface. e–g Conidiophores. h Conidia. i, k Culture from above on PDA medium. j, l Culture from below on PDA medium**.** m Synnema. n α-phialides. o β-phialides p α-conida and β-conidia**.** Scale bars: c, i–l = 1 cm, d = 2000 *µm*, m = 1000 *µm*, e, f = 20 *µm*, g, n, o = 10 *µm*, h, p = 5 *µm*.

Figure 2.31 Morphology of *Polycephalomyces aurantiacus* (new host PY0803)

Pleurocordyceps marginaliradians (Y.P. Xiao, T.C. Wen & K.D. Hyde) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021).

Etymology: The specific epithet refers to the feature of the colonies on the culture.

Holotype: MFLU 17-1582

Parasitic on a Cossidae larva (Lepidoptera), buried in the soil. **Sexual morph**: *Thallus* within host. *Host* 3.2–3.5 long × 0.4–0.6 cm wide, yellow to brown, without hyphae on the surface. *Stromata* 3–3.5 long × 0.2–0.45 cm wide, mostly single, stipitate, cylindrical, unbranched or branched, arising from the head of larva, brown to yellow. *Stipe* 1–2 cm long, 2–3 mm wide, cylindrical, yellow to brown, with one or two lateral fertile head. *Fertile head* 0.40–0.42 cm long, 0.3–0.45 mm diam., capitate, lateral, globose to subglobose, pale yellow to yellow, with protruding ostiolar necks. *Ascomata* 676–803 × 246–328 μm ($\bar{x}$ = 739 × 287 μm, n = 60), immersed, yellow, flask-shaped, thick-walled. *Peridium* 11–19 μm ($\bar{x}$ = 15 μm, n = 60) wide, brown, textura angularis to textura globulosa to textura prismatica. *Asci* 459–556 × 3.1–4.3μm ($\bar{x}$ = 508 × 3.7 μm, n = 90), 8-spored, hyaline, filiform, with a thin apex. *Apical cap* 1.4–2.5 × 2.2–3.2 μm ($\bar{x}$ = 2 × 2.7 μm, n = 60), with a small channel in the center. *Ascospores* as long as the asci, easily breaking into part-spores, filiform. *Secondary ascospores* 3.2–4.2 × 1.3–1.7 μm ($\bar{x}$ = 3.8 × 1.5 μm, n = 90) cylindrical, straight, hyaline, smooth. **Asexual morph***: Synnemata* solitary or not solitary, arising from the fertile head of the host, cylindrical, pale yellow. *Phialides* 11–14.4 × 1.2–1.8 μm ($\bar{x}$ = 12.7 × 1.5 μm, n = 90) hyaline. *Conidia* 3.6–4.9 × 1.8–2.5 μm ($\bar{x}$ = 4.2 × 2.1 μm, n = 90), fusiform, hyaline, one-celled, smooth-walled.

Colonies on PDA medium, circular, attaining 4 cm in 10 days at 25°C, white, reverse yellow. *Synnemata* emerging after 14 days in the margin of the colony, single or branched into 2 or 3 branched, 3200.8–4566.3 × 142.9–661.8 μm ($\bar{x}$ = 3883.5 × 402.3 μm, n = 30), showing 1–2 radiating ring-like distributions. *Conidial masses* generating from the middle of the synnemata or covering the surface of the colony, pale yellow to yellow, with hyaline to pale yellow exucate. *Hyphae* hyaline, branched, smooth-walled, 1.8–2.7 μm ($\bar{x}$ = 2.2) wide. *Conidiophores* undetermined,

not clear. *Phialides* existing in two types: α-and β-phialides. *α-phialides* 11–14.4 × 1.2–1.8 µm ($\bar{x}$ = 12.7 × 1.5 µm, n = 90), hyaline, smooth, elongated lageniform, caespitose, palisade-like, crowed, monoverticillate, mostly branched into 2 phialides, 3 branched on one metula. *β-phialides* 12.8–23.9 × 1.8–2.7 µm ($\bar{x}$ = 18.3 × 2.2 µm, n = 90), hyaline, smooth, solitary, growing from hyphae, narrow slender to narrow lageniform, with or without metula at the base. *α-conidia* 1.9–2.6 µm ($\bar{x}$ = 2.3 µm, n = 90) diam, globose, catenate, occurring in the conidial mass on the middle of synnemata, one-celled, smooth-walled, pale yellow slimy in mass. *β-conidia* 3.1–3.9 × 1.6–2.1 µm ($\bar{x}$ = 3.5 × 1.8 µm, n = 90) fusiform, and produced on the surface mycelium of colony or on the branch of the synnemata, one-celled, smooth-walled, hyaline.

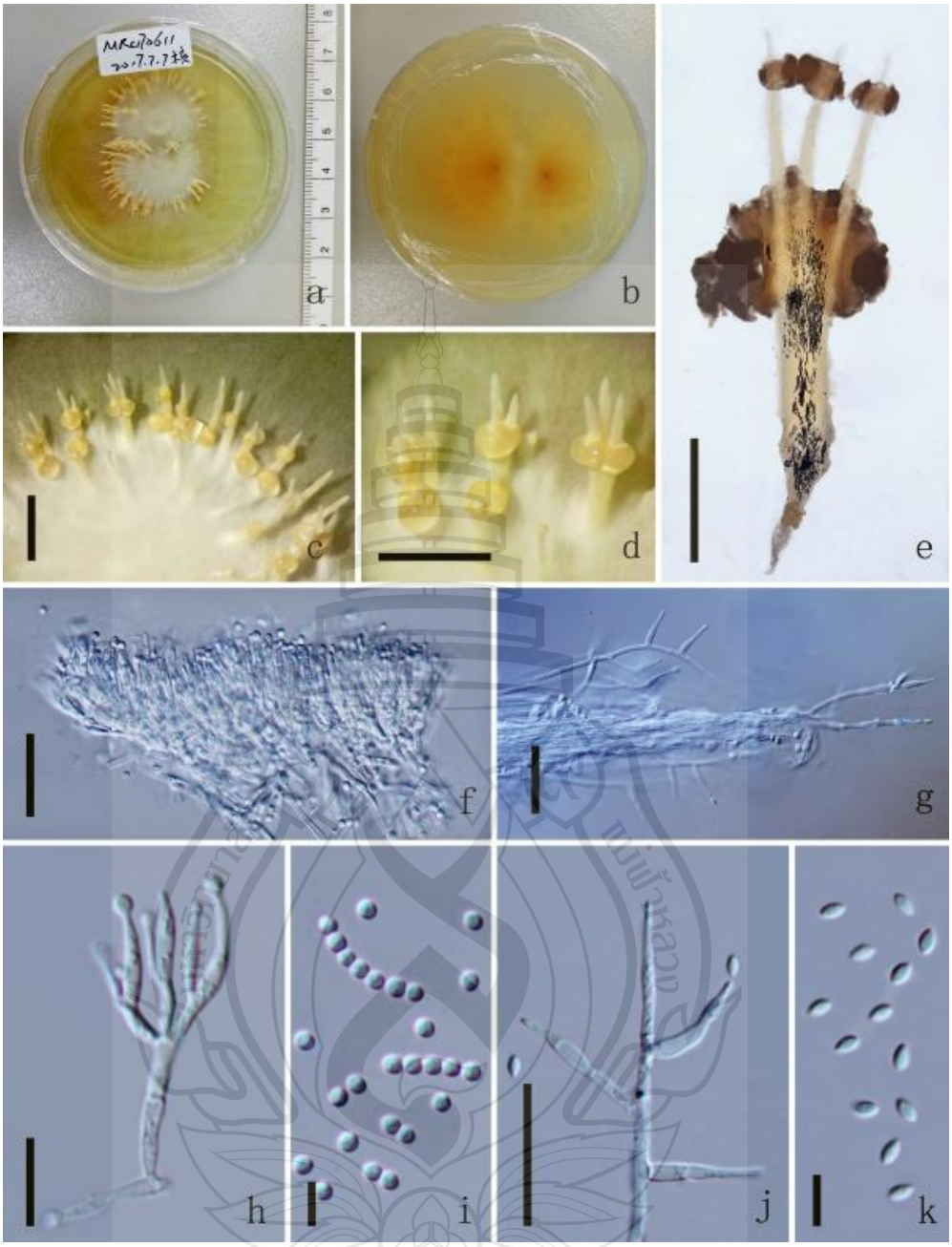
Material examined: Thailand, Chiang Mai, The Mushroom Research Center. On dead Cossidae larvae (Lepidoptera), 11 June 2017, Yuan Pin Xiao, MRC170611 (MFLU 17-1582, **holotype**); Thailand, Chiang Mai, The Mushroom Research Center. On dead Cossidae larvae (Lepidoptera), 11 June 2017, Yuan Pin Xiao, CM48 (MFLU 17-1583 MFLU 17-1584, HKAS100694, **paratypes**); ex-type living cultures, MFLUCC 17-2276, MFLUCC 17-2277, MFLUCC 17-2278, KUMCC 17-0258, KUMCC 17-0259.

Notes–: *Polycephalomyces ramosopulvinatus* is closely related to *P. lianzhouensis*, but each species is positioned in different well-supported subclades and hence merit species status. *Polycephalomyces ramosopulvinatus* is also different from *P. lianzhouensis* with respect to being parasitic on nymph of Cicada and characterised by a long stipe and pseudo-immersed, pyriform perithecia. While phylogeny resolves our new species into well-segregated subclades, we note that relationships of *P. formosus, P. tomentosus, P. ramosus* and *P. sinensis* are still obscure and the concatenated dataset used herein did not provide adequate species resolution. A similar phylogenetic scenario is observed for *P. nipponicus* and *P. kazanshianus.* Whether these species are conspecific warrants further taxonomic investigations. The latter two species do share some morphological resemblances to *P. marginaliradians* especially with respect to the yellow cylindrical stipe with capitate lateral fertile part (known from their sexual morph). However, *P. marginaliradians* differs in having capitate stromata with stipe, smaller perithecia and parasitic on Cossidae, while *P.*

nipponicus and *P. kanzashianus* have polycephalous stromata and parasitic on Cicadidae. Meanwhile, *P. onorei* and *P. ramosopulvinatus* are distinct from *P. marginaliradians* by producing bigger perithecia and parasitic on caterpillar (*Arctinae*) and nymph of Cicada respectively. Phylogenies retrieved herein also support them as separate taxonomic entities.

Note a Habitat. b, d Overview of the host and stromata. c Part of the stroma. e, f Stroma. g Cross sections showing the immersed perithecia. h Perithecia. j–l Asci. m Part of the ascospores. n Apical cap. o Secondary ascospores. p, q Synnemata. r Phialide. s Conidia. Scale Bars: b–d = 1 cm, e, f = 2000 µm, g = 1000 µm, h = 500 µm, p, q = 200 µm, j–l = 100 µm, i = 50 µm, m, r = 10 µm, n, o, s = 5 µm.

Figure 2.32 Morphology of *Polycephalomyces marginaliradians* (holotype MFLU 17-1582)



Note a Upper side of the culture. b Reverse side of the culture. c, d Synnemata growing on PDA medium. e Synnemata. f, h α-phialides. g, j β-phialides with hyphae. i α-conidia. k β-conidia**.** Scale Bars: c, d = 5000 µm, e = 1000 µm, f, g, j = 20 µm, h = 10 µm, i, k = 5µm.

Figure 2.33 Morphology of *Polycephalomyces marginaliradians* in culture

Polycephalomyces agaricus (Hong Yu bis & Y.B. Wang) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021)

Index Fungorum number: IF 811158

Synonymy: *Polycephalomyces agaricus* Hong Yu bis & Y.B. Wang, in Wang, Yu, Dai, Wu, Zeng, Yuan & Liang, Mycol. Progr. 14(no. 70): 4 (2015)

Basionym: *Polycephalomyces agaricus* H. Yu & Y.B. Wang, Mycological Progress 14 (9/70): 4 (2015)

Type: Holotype YHH PA1305

Host: On *Ophiocordyceps barnesii*

Distribution: China Yunnan

Pleurocordyceps marginaliradians (Y.P. Xiao, T.C. Wen & K.D. Hyde) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021)

Index Fungorum number: IF 570674

Synonymy: *Polycephalomyces marginaliradians* Y.P. Xiao, T.C. Wen & K.D. Hyde, in Xiao, Wen, Hongsanan, Jeewon, Luangsaard, Brooks, Wanasinghe, Long & Hyde, Scientific Reports 8(no. 18087): 4 (2018)

Basionym: *Polycephalomyces marginaliradians* Y.P. Xiao, T.C. Wen & K.D. Hyde, in Xiao, Wen, Hongsanan, Jeewon, Luangsaard, Brooks, Wanasinghe, Long & Hyde, (2018)

Type: Holotype MFLU 17-1582

Host: On larva of Cossidae

Distribution: Thailand

Pleurocordyceps nipponica (Kobayasi) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 11 (2021)

Index Fungorum number: IF 570680

Synonymy: *Cordyceps nipponica* Kobayasi, Bulletin of the Biogeogr. Soc. Jap. 9: 151 (1939)

Polycephalomyces nipponicus (Kobayasi) Kepler & Spatafora, Fungal Biology 117(9): 618 (2013)

Basionym: *Cordyceps nipponica* Kobayasi, Bulletin of the Biogeographical Society of Japan 9: 151 (1939)

Type: KOBAYASI Herb.

Host: on Graptopsaltria nigrofiscata (Hemiptera)

Distribution: Japan

Pleurocordyceps onorei (Kautman & Kautmanová) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 12 (2021)

Index Fungorum number: IF 570675

Synonymy: *Polycephalomyces onorei* Kautman & Kautmanová, in Crous et al., Persoonia 38: 367 (2017)

Basionym: *Polycephalomyces onorei* Kautman & Kautmanova, Persoonia 38: 367 (2017)

Type: Holotype BRA CR23902

Host: On caterpillar of Lepidoptera

Distribution: Ecuador

Pleurocordyceps phaothaiensis (Mongkols., Noisrip., Lamlertthon & Luangsa-ard) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 12 (2021)

Index Fungorum number: IF 570684

Synonymy: *Polycephalomyces phaothaiensis* Mongkols., Noisrip., Lamlertthon & Luangsa-ard, in Crous et al., Persoonia 39: 327 (2017)

Basionym: *Polycephalomyces phaothaiensis* Mongkols., Noisripoom, Lamlertthon & Luangsa-ard, Persoonia 39: 327 (2017)

Type: Holotype BBH 42883

Host: On larva of Coleoptera

Distribution: Thailand

Pleurocordyceps ramosopulvinata (Kobayasi & Shimizu) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 12 (2021)

Index Fungorum number: IF 570682

Synonymy: *Cordyceps ramosopulvinata* Kobayasi & Shimizu, Bull. natn. Sci. Mus., Tokyo, B 9(1): 2 (1983)

Polycephalomyces ramosopulvinatus (Kobayasi & Shimizu) Kepler & Spatafora, Fungal Biology 117(9): 618 (2013)

Basionym: *Cordyceps ramosopulvinata* Kobayasi & Shimizu, Bulletin of the National Science Museum Tokyo 9: 2 (1983)

Host: On Cicadidae

Distribution: Japan Honshu

Pleurocordyceps sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Sh) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 12 (2021)

Index Fungorum number: IF 570676

Synonymy: *Paecilomyces sinensis* Q.T. Chen, S.R. Xiao & Z.Y. Shi, Acta Mycol. Sin. 3(1): 25 (1984)

Polycephalomyces sinensis (Q.T. Chen, S.R. Xiao & Z.Y. Shi) W.J. Wang, X.L. Wang, Y. Li, S.R. Xiao & Y.J. Yao, in Wang, Wang, Li, Xiao, Kepler & Yao, Syst. Biodiv. 10(2): 228 (2012)

Basionym: *Paecilomyces sinensis* Q.T. Chen, S.R. Xiao & Z.Y. Shi, Acta Mycologica Sinica 3: 25 (1984)

Type: HMAS 43720

Host: From larva of *Hepialus armocanus*

Distribution: China Sichuan

Pleurocordyceps yunnanensis (Hong Yu bis, Y.B. Wang & Y.D. Dai) Y.H. Wang, S. Ban, W.J. Wang, Yi Li, Ke Wang, P.M. Kirk & Y.J. Yao, in Wang, Ban, Wang, Li, Wang, Kirk, Bushley, Dong, Hawksworth & Yao, Journal of Systematics and Evolution: 10.1111/jse.12705, 12 (2021)

Index Fungorum number: IF 570681

Synonymy: *Polycephalomyces yunnanensis* Hong Yu bis, Y.B. Wang & Y.D. Dai, in Wang, Yu, Dai, Chen, Zeng, Yuan & Liang, Phytotaxa 208(1): 39 (2014)

Basionym: *Polycephalomyces yunnanensis* H. Yu, Y.B. Wang & Y.D. Dai, Phytotaxa 208 (1): 39 (2015)

Type: Holotype YHH PY1006

Host: On stroma of *Ophiocordyceps nutans*

Distribution: China Yunnan

Table 2.6 Morphological comparison of asexual morph species of *Pleurocordyceps*

Species	Synnemata (mm)	Phialides (μm)	Conidia (μm)	Reference
P. agaricus	Solitary, unbranched, agaricshaped, size 0.34– 1.2 × 0.11–0.42; conidial mass pileus-like, light yellow to pale brown, size 0.08–0.25 × 0.36–0.99	α-phialides lanceolate, length 30.7–81.9, base width 1.3–2.4, neck width 0.5–1.1; β-phialides narrowly lageniform or subulate, length 4.9–28.6, base width 1.8–3, neck width 0.4–0.8	α-conidia globose to subglobose, 2–3.1 × 1.8–2.9; β-conidia fusiform, catenate or clump together, 3.8–6.8 × 1.7–3.2	Wang et al. (2015b)
P. aurantiacus	Emerging after 30 days, solitary or not solitary, branched or unbranched, 1.3–2.2 long, showing 1–2 radiating ring-like distributions	α-phialides 9.9–14.3 × 0.7–1.4, narrowly lageniform. β-phialides 22.9–64.2 × 1–1.5, lanceolate or narrowly lageniform	α-conidia 1.8–2.2 × 1.4–1.9 globose to subglobose, yellow slimy in mass. β-conidia 3.2–3.9 × 1.4–1.8 fusiform, one-celled, catenate	Xiao et al. (2018)
P. lanceolatus	0.2–1.2 cm long, 1–3 mm wide, lanceolate to corniform, solitary to crowded, stipitate, usually unbranched	α -phialides 12–18 × 1.3–1.6, subulate; β -phialides 20.2–28.9 × 1.6–2.5, narrowly lageniform to lanceolate	α -conidia 1.8 – 2.5, spherical; β -conidia 3–4.4 × 1.4–2.4, fusiform	This study

Table 2.6 (continued)

Species	Synnemata (mm)	Phialides (μm)	Conidia (μm)	Reference
P. lianzhouensis	Unbranched or dichotomously branched, 10–20 tall, 0.5–1.5 wide, conidial mass not seen	In whorls or intercalary and terminal, terminally awl-shaped, length 6–12, base width 1.3–1.7, neck width 0.5–0. 8	Ellipsoidal, oblong to cylindrical, size 5–7 × 1.3–1.6	Wang et al. (2014)
P. marginaliradians	Emerging after 14 days, single or branched into 2 or 3 branched, 3.2–4.6 long, showing 1–2 radiating ring-like distributions	α-phialides 11–14.4 × 1.2–1.8, elongated lageniform, caespitose, monoverticillate; β-phialides 12.8–23.9 × 1.8–2.7, solitary, narrow slender to narrow lageniform	α-conidia 1.9–2.6 μm diam, globose, catenate. β-conidia 3.1–3.9 × 1.6–2.1 μm fusiform, one-celled	Xiao et al. (2018)
P. parvicapitata	1–1.2 cm long, 1–2 mm wide, stipitate, cylindrical, yellow to white, branched	Phialides 11.7–16.3 × 1.1–1.6, cylindrical at the base, 8–12 long, tapering into a long neck	2.8–3.6 × 2.4–3 globose to subglobose	This study
P. nutantis	Synnemata 2–5 mm long, 0.1–0.4 mm wide, cylindrical, clavate, capitate, stipitate, crowded, simple, white to yellowish	α-phialides 10–24 × 1–1.2, narrowly slender lanceolate; β-phialides 10–14 × 1.1–1.8, solitary, lanceolate, ovate at the base	α-conidia 1.6–2.3, spherical, β-conidia 3.5–5 × 1.3–2, fusiform	This study
P. sinensis (Type)	Solitary, crowded, branched or unbranched, a length of up to 50–60 in culture, conidial mass yellow or yellow-orange	Lanceolate or narrowly lageniform, length 12.5–66, base width 1.4–3.5, neck width 0.6–1.8	α-conidia ovoid, size 1.7–2.6 × 1.3–2; β-conidia fusiform, catenate or clump together, size 3.3–4.5 × 1.3–2	Chen et al. (1984), Wang et al. (2012)
P. yunnanensis	Solitary, caespitose or crowded, branched or unbranched, 0.7–14 × 0.05–1.2; conidial mass white to yellow-brown, 0.2–1.5 × 0.2–1.4	α-phialides cylindrical to subulate, length 20.1–57.8; β-phialides narrowly lageniform or subulate, length 7.1–30.6	α-conidia subglobose, ellipsoidal, 1.4–2.5 × 1.2–2.2; β-conidia fusiform, catenate or clump together, 2.8–5.7 × 1.1–2.7	Wang et al. (2015a)

Table 2.7 Morphological comparison of sexual morph species of the genus *Pleurocordyceps*

Species	Stromata	Perithecia (µm)	Asci (µm)	Secondary spores (µm)	Reference
P. marginaliradians	30–35 long, 2–4.5 mm diam, mostly single, stipitate, unbranched or branched brown to yellow	676–803 × 246–328, immersed, yellow, flask-shaped	459–556 × 3.1–4.3, 8-spored, hyaline, filiform	3.2–4.2 × 1.3–1.7 cylindrical, straight	Xiao et al. (2018)
P. kanzashianus	Stipitate, branched, polycephalous	Entirely immersed, flask-shaped, 900–1050 × 270–300	Asci 3 um thick, apical cap 3 um diam	3–5 × 1 both truncate	Kobayasi and Shimizu (1982)
P. lianzhouensis	Numerous, simple, fleshy, arising from the head, abdomen, and back of the host	Narrowly ovoid, vertically immersed, 355–473 × 158–197	89–194 × 2–4	Cylindrical, 3.9–7.8 × 1	Wang et al. (2014)
P. nipponica	Solitary or arranged in twos or threes 20–70 mm, branched	Immersed flask-shaped or ovoid, 800–950 × 300–370		2.8–4.8 × 0.7 truncate	Kobayasi (1939)
P. onorei	Numerous, solitary, simple or 2–3 times branched	Immersed, 854–950 × 330–395, pyriform, with dark brown	450–510	4 × 0.5–1, truncate, bacilliform	Crous et al. (2017)
P. parvicapitata	5–15 × 0.1–0.5 cm, branched, brown to yellow, cylindrical	577–751 × 207–281, immersed, crowded, ovoid to obpyriform	322–399 × 4.8–6.8	3.0–4.7 × 1.2–1.8 oblong to cylindrical	This study
P. ramosopulvinatus	Stroma 100 mm long	Pyriform, 750–925 × 275–300	3.5–5 wide	3 × 1 truncate	Kobayasi and Shimizu (1982)

2.4 Discussion

Polycephalomycetaceae is established to accommodate *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* based on morphology and phylogenetic analyses. The newly established family groups with Ophiocordycipitaceae within Hypocreales. Species of the new family grow on insects or other fungi, particularly *Ophiocordyceps* species, distributed from tropical to subtropical regions (Bischoff et al., 2003; Wang et al., 2012; Matočec et al., 2014; Wang et al., 2015a, 2015b; Crous et al., 2017; Xiao et al., 2019; Poinar & Vega, 2020). The sexual morphs produce stromatic ascomata with long stipe, thick peridium, and cylindrical secondary spores. The asexual morph is characterized by synnemata, with stipes on the host, one or two types of phialides, and cylindrical-to-fusiform conidia.

Twelve families were included in these multiple gene analyses of the backbone tree of the Hypocreales. In addition, five closely related families were selected to analyze the relationships of the closest families. In the second tree, extensive taxon sampling was carried out to include all genera and breadth of species diversity. As a result, six (LSU, ITS, SSU, TEF, RPB1, and RPB2) and five gene (LSU, SSU, TEF, RPB1, and RPB2) trees were generated using ML and BI analyses. Hence, two kinds of topology were obtained. Polycephalomycetaceae was sister to Ophiocordycipitaceae when six genes were used. Polycephalomycetaceae was sister to Clavicipitaceae when five genes were used. Removed of ITS resulted in a change in the relationships among the families. When other genes were removed, the topology did not change. This indicates that genetic marker selection plays a role in determining deeper relationships among these families.

Using six genes and three different methods of analysis also resulted in two different topologies. The IQ-tree and BI analysis Polycephalomycetaceae grouped with Ophiocordycipitaceae. In RAxML analysis the new family grouped with Clavicipitaceae. Thus, an AU-test was performed to test the topology. Neither hypothesis was rejected. Therefore, the sister relationship remains unclear. Thus, Polycephalomycetaceae has a closer relationship with Ophiocordycipitaceae.

This relationship was further confirmed by morphology analyses. Polycephalomycetaceae shared similar characteristics with Ophiocordycipitaceae in having hard stromata, ovoid or obpyriform perithecia, cylindrical asci, filiform ascospores that easily break into secondary spores, and *Hirsutella*- or *Acremonium*-like asexual morphs.

The *Polycephalomyces* clade with three strains was sister to the *Perennicordyceps*/*Pleurocordyceps* clade, which received low support in the ML tree based on RAxML. The clade sisters to the *Perennicordyceps*/*Pleurocordyceps* clade, which received substantial support in the IQ tree and the Bayesian tree. However, the *Perennicordyceps* clade was sister to the *Pleurocordycep* clade, with strong support in ML and Bayesian analyses. Based on phylogeny, the relationship between *Polycephalomyces* and *Perennicordyceps*/*Pleurocordyceps* was still quite vague. The *Polycephalomyces* clade was independent of the *Perennicordyceps*/*Pleurocordyceps* clade. It formed a further possible family clade in phylogenetic analysis. However, this study still recognizes *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* under a new family, because molecular data is limited in Polycephalomyces, while the three genera shared similar morphologic attributes.

Polycephalomycetaceae is similar to Ophiocordycipitaceae in parasitizing insects and fungi (Kobayashi, 1941; Seifert, 1985; Bischoff et al., 2003; Sung et al., 2007; Wang et al., 2012; Matočec et al., 2014; Wang et al., 2015a, 2015b; Crous et al., 2017; Xiao et al., 2019; Poinar & Vega, 2020; Wang et al., 2020). However, Clavicipitaceae species are parasitic on insects and plants (Sung et al., 2007). Polycephalomycetaceae and Ophiocordycipitaceae have similar characteristics producing stipitate ascomata, cylindrical asci, and ascospores easily break into secondary spores, and *Hirsutella*- or *Acremonium*-like asexual morphs. However, Polycephalomycetaceae differs from Ophiocordycipitaceae ecologically by parasitizing insects or fungi and having a thick peridium. Several Polycephalomycetaceae species have been reported as hyperparasitizing fungi, and involve species of *Cordyceps*, *Elaphomyces*, *Hirsutella*, Myxomycetes, and *Ophiocordyceps* (Seifert, 1985; Bischoff et al., 2003; Wang et al., 2012; Wang et al., 2015a, 2015b).

Polycephalomyces species share a similar morphology with *Perennicordyceps* and *Pleurocordyceps*, parasitizing both insects and fungi and producing *Hirsutella*- or *Acremonium*-like phialides. *Polycephalomyces* is characterized by oblong to cylindrical conidia (Kobayashi, 1941; Wang et al., 2021). *Perennicordyceps* and *Pleurocordyceps* species share similar morphology in having stipitate stromata, ovoid to flask-shaped perithecia, a thick peridium, cylindrical asci, filiform ascospores, and cylindrical to globose secondary spores (Matočec et al., 2014, Wang et al., 2020). The *Pleurocordyceps* species are distinct from *Perennicordyceps* in producing capitate stromata and superficial perithecia (Matočec et al., 2014, Wang et al., 2020). Most *Perennicordyceps* and *Pleurocordyceps* species produce two types of conidia, except *Perennicordyceps ryogamiensis* and *Pleurocordyceps lianzhouensis* (Ban et al., 2009, Wang et al., 2014).

This study made a new collection of, *Polycephalomyces formosus*, the type species from China, as having one-type conidia. This collection was growing on *Ophiocordyceps multibrachiata*, which first specimen was growing on Coleopteran larvae (Kobayashi, 1941), while the second was growing on larvae of insects on *Cordyceps barnesii* (Current name: *Ophiocordyceps barnesii*) or *Cordyceps cantharelloides* (Current name: *Ophiocordyceps cantharelloides*) (Seifert, 1985). Additionally, a new species, *Polycephalomyces albiramus*, was characterized as parasitizing *Gryllotalpa* sp. (Orthoptera, Gryllotalpidae) and producing cylindrical-to-oval conidia from a fresh specimen and in pure culture. The other six species, *Polycephalomyces baltica* with a single type of conidia (Poinar & Vega, 2020), *Polycephalomyces cylindrosporus* with a single type of conidia (Matočec et al., 2014), *Polycephalomyces ditmarii* (Van Vooren et al., 2005), *Polycephalomyces ramosus* with two types of conidia (Seifert, 1985; Bischoff et al., 2003), *Polycephalomyces paludosus* with a singly type of conidia (Mains, 1948), and *Polycephalomyces tomentosus* with three types of conidia (Seifert, 1985), are included in this genus. However, these species lack molecular data, or their updated strains descriptions do not match the protologue descriptions (Wang et al., 2020).

Cordyceps pleuricapitata clustered in the *Polycephalomyces* clade. We regard it as incertae sedis, requiring more study for a clearer identification. It was depicted as a sexual species that lacked an asexual morph (Kobayasi & Shimizu, 1982). Sato et al.

(2012) reassessed several species' type allies, including the paratype of *Cordyceps pleuricapitata* (TNS-F-197965), but without molecular data. Kepler et al. (2013) updated the molecular data of *Cordyceps pleuricapitata* (NBRC 100745, NBRC 100746) with a photo plate and with little morphologic data. Moreover, it was recognized as incertae sedis due to low bootstrap support in the phylogenetic (Kepler et al., 2013; Wang et al., 2020).

Polycephalomycetaceae species do not only parasitize insects, but are also hyperparasitize on fungi. Some Polycephalomycetaceae species were reported to have more than one host (Bischoff et al., 2003; Wang et al., 2012; Matočec et al., 2014; Wang et al., 2015a, 2015b; Crous et al., 2017; Xiao et al., 2019). *Polycephalomyces formosus* parasitize on stromata of *Ophocordyceps barnesii*, and *Ophiocordyceps cantharelloides* on larvae of Coleopteran, (Kobayasi, 1941; Seifert, 1985). *Polycephalomyces ramosus* parasitizes both *Hirsutella guignardii* on larvae of Lepidopteran and larvae of Lepidopteran (Seifert, 1985; Bischoff et al., 2003). *Perennicordyceps cuboidea* parasitizes on both *Cordyceps* sp. and larvae of beetle (Ban et al., 2009). *Pleurocordyceps aurantiacus* parasitize on *Ophiocordyceps barnesii* and *Ophiocordyceps neobuquetii* (Xiao et al., 2019; this study). This study has determined that Polycephalomycetaceae species occur on *Ophiocordyceps* species in the same region.

New hosts infected by *Pleurocordyceps sinensis*, were *Ophiocordyceps barnesii*, *Ophiocordyceps crinalis*, and *Ophiocordyceps neocrinalis*. In addition, the Lepidoptera larvae were hosts of *Pleurocordyceps sinensis*. Three species were collected from the same region in Yunnan province of China, while two were collected from the same region in Guizhou Province of China. *Pleurocordyceps sinensis* was initially reported as a hyperparasitic fungus growing on *Ophiocordyceps sinensis* (Chen et al., 1984; Wang et al., 2012).

Thailand and southern China have been shown to be an area of high fungal biodiversity (Hyde et al., 2018). In this study, we collected seven specimens belonging to Ophiocordycipitaceae, which is a relatively well-studied family. As a result, we identified 20 novel species Xiao et al. (Impress) from South China (Yunnan and Guizhou Province) and Thailand. Our study was confined to five collecting sites in northern Thailand, indicating that further collections will result in numerous new

taxa being discovered. Thus, confirming the comment of Hyde et al. (2020). The numerous new species will be discovered following intense study of any genus. The phylogenetic analyses are resolved a novel family, Polycephalomycetaceae, indicating we are far from fully understanding the classification of the fungi, even in it relate well-studied Hypocreales

CHAPTER 3

TAXONOMIC AND PHYLOGENETIC PLACEMENT OF OPHIOCORDYCIPITACEAE AND NOVEL SPECIES

3.1 Introduction

The family Ophiocordycipitaceae is placed in the order Hypocreales and previously comprised *Drechmeria*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Ophiocordyceps*, *Paraisaria*, *Perennicordyceps*, *Pleurocordyceps*, *Polycephalomyces*, *Purpureocillium* and *Tolypocladium* (Sung et al., 2007; Quandt et al., 2014; Kirk et al., 2013; Spatafora et al., 2015; Simmons et al., 2015; Maharachchikumbura et al., 2015, 2016; Wijayawardene et al., 2018, 2020). *Polycephalomyces*, *Perennicordyceps*, *Pleurocordyceps* were segregated from the family and placed in a new family, Polycephalomycipitaceae. This was based on morphology and phylogenetic analysis (Xiao et al., 2021 in press). Ophiocordycipitaceae is a large family that comprises more than 400 species (Species Fungorum, 2021). Morphologically, Ophiocordycipitaceae are entomopathogen and also parasitize protozoans, rotifers, nematodes, humans, and other fungi (Sung et al., 2007; Quandt et al., 2014; Spatafora et al., 2015; Simmons et al., 2015). The family is characterized by dark-pigmented, hard-to-pliant stromata and filiform ascospores that break or do not break into secondary spores (Sung et al. 2007., Quandt et al., 2014).

Historically, Ophiocordycipitaceae was segregated from Clavicipitaceae by Sung et al. (2007). Ophiocordycipitaceae consisted of two sexual morph genera (Elaphocordyceps and Ophiocordyceps) and seven asexual morph genera (*Haptocillium*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Paraisaria*, *Synglíocladium*, and *Tolypocladium*) in Hypocreales (Sung et al., 2007). Purpureocillium was revised and placed in the family by Luangsa-ard et al. (2011) based on phylogenetic and morphology analysis. *Chaunopycnis*, *Drechmeria*, *Harposporium*, *Hirsutella*,

Hymenostilbe, *Ophiocordyceps*, *Paraisaria*, *Podocrella*, *Polycephalomyces*, and *Tolypocladium* were listed as protected names based on the International Code of Nomenclature for algae, fungi, and plantae (Kirk et al., 2013). Quandt et al. (2014) recognised six genera (*Drechmeria*, *Harposporium*, *Ophiocordyceps*, *Polycephalomyces*, *Purpureocillium*, and *Tolypocladium*) within the family. Additionally, Didymobotryopsis, Mahevia, Synnematium, Trichosterigma, Didymobotrys, Troglobiomyces, and Cordycepioideus were synonymised under Ophiocordyceps; Polyrhina and Atricordyceps were synonymised under Harposporium, and Blistum was synonymised under Polycephalomyces (Quandt et al. 2014). Meanwhile, *Sorosporella*, *Hirsutella*, *Hymenostilbe*, *Synglіocladium*, *Paraisaria*, *Chaunopycnis*, *Elaphocordyceps*, *Podocrella*, and *Haptocillium* were proposed to be suppressed under Ophiocordycipitaceae (Quandt et al., 2014). Several new combinations were established for *Polycephalomyces* (Kepler et al., 2013), *Tolypocladium* (Quandt et al., 2014), Drechmeria, *Harposporium*, *Ophiocordyceps*, and *Purpureocillium* (Spatafora et al., 2015). The above system was followed by Maharachchikumbura et al. (2015) in a natural classification of Sordariomycetes. Simmons et al. (2015) and Xiao et al. (2019) described a new species in Ophiocordyceps that produced the hirsutella-like stage. Paraisaria was resurrected with three new species by Mongkolsamriit et al. (2019). Matočec et al. (2014) established a new genus, *Perennicordyceps*, to accommodate four species of *Polycephalomyces*. Sequential data from *Hirsutella* species were remedied further to investigate Ophiocordycipitaceae by Simmons et al. (2015).

Although the oldest genus name in Ophiocordycipitaceae is *Sorosporella*, a synonym of *Synglіocladium* (Evans & Shah, 2002; Quandt et al., 2014), *Ophiocordyceps* has been proposed as the type of genus of this family due to morphological and economic considerations (Sung et al., 2007). Furthermore, *Synglіocladium* was previously treated concerning the second-oldest name *Hirsutella* in this family (Evans & Samson, 1982). Arguably, the asexually reproducing genus Hirsutella was suppressed, favouring *Ophiocordyceps* (Quandt et al., 2014). Spatafora et al. (2015) reserved *Hirsutella* as a large and complex genus, with the name applicable to a broad and heterogeneous fungi group across several families of

Hypocreales. A more detailed taxonomic and phylogenetic information is necessary for *Hirsutella* (Spatafora et al., 2015).

Most species in the family produce dark-pigmented, hard-to-pliant stromata that typically possess perithecial apices (Sung et al., 2007). The primary distinguishing characteristics of this genus are that the ascospores do not break into part-spores at maturity, and that the asci have thin apical caps (Petch, 1931, 1933). The type species is *Ophiocordyceps blattae* (Petch). This taxon was obtained from Sri Lanka with only one collection without cultural or molecular data. Luangsa-ard et al. (2020) typified the type species with a new collection from Thailand. Asexual generic names associated with *Ophiocordyceps* include *Sorosporella* (Sorokin, 1888), *Hirsutella* (Doassans & Patouillard, 1892; Gams & Zare, 2003), *Hymenostilbe* (Petch, 1931b), Stilbella (Seifert, 1985), *Synglíocladium* (Petch, 1932), and *Paraisaria* (Samson & Brady, 1983). *Ophiocordyceps* was protected, and the other names were suppressed (Quandt et al., 2014).

Tolypocladium was protected against *Elaphocordyceps* and *Chaunopycnis*. (Quandt et al., 2014). A tremendous range of asexual lineages associated with this family exists. Some are restricted in their phylogenetical distribution, while others are typically found in disparate lineages (Quandt et al., 2014). For instance, *Verticillium* is a common asexual morph of various species in several hypocrealean families, including Ophiocordycipitaceae, Cordycipitaceae, and Clavicipitaceae (Zare et al., 2000; Sung et al., 2001, 2007; Gams & Zare, 2001).

Although, this family has recently attracted a lot of attention, the Ophiocordycipitaceae genera and species remain ambiguous. There is a lack of molecular data for many Ophiocordycipitaceae species. In addition, the morphology of the species is complex when comparing morphological traits due to the high numbers of species. This study lists almost all Ophiocordycipitaceae species, summarizes morphological characteristics in each genus, and introduces 30 new species, ten new records, two new combinations, and 24 reference specimens; all described and illustrated with phylogenetic analyses and morphology. To identify Ophiocordycipitaceae species, ITS, LSU, SSU, TEF, RPB1, RPB2 were used in phylogenetic analysis

3.2 Materials and Methods

3.2.1 Sample Collection and Specimen Examination

Fresh specimens were collected in China, Thailand and Slovakia. Herbarium specimens were from China, Denmark and USA. Fruiting bodies were examined using freehand sections under a stereomicroscope. Water-mounted slides were prepared for microscope study and photographed under a compound microscope. Strains were isolated from single spores using the protocol in Chomnunti et al. (2014). Cultures were incubated at 25 oC for 4–10 weeks on potato extract agar (PDA) in light promote sporulation.

3.2.2 DNA Extraction, PCR Amplification and Sequencing

DNA was extracted from both dried specimens and cultures using E.Z.N.A.TM Fungal DNA MiniKit (Omega Biotech, CA, USA), according to the manufacturer's protocols. Universal known primers were used in PCR amplification; ITS4/ITS5 for internal transcribed spacer gene region (ITS), NS1/NS4 for partial small subunit ribosomal RNA gene region (SSU), LROR/LR5 for partial large subunit rDNA gene region (LSU) (Vilgalys & Hester, 1990, White et al., 1990), 983F/2218R for partial translation elongation factor 1-alpha gene region (TEF-1α) (Sung et al., 2007b), and CRPB1A/RPB1Cr for partial RNA polymerase II largest subunit gene region (RPB1) (Castlebury et al., 2004). PCR products were sequenced by Sangon Biotech (Shanghai) Co., Ltd., Shanghai, China. The specimen was performed using the TaKaRa PMD™18-T vector system (TaKaRa Biotechnology, Dalian, China), while PCR products could not be directly sequenced.

3.2.3 Sequence Alignment and Phylogenetic Analyses

Sequence data were obtained from GenBank based on previous studies as listed in Table 3.1. MAFFT v.7 was used to align combined datasets of ITS, SSU, LSU, TEF1α, RPB1 and RPB2 regions (Katoh & Standley, 2013, http://mafft.cbrc.jp/alignment/server/). BioEdit (Hall, 2011) was used to check alignment manually. Gaps were treated as missing data. *Tolypocladium inflatum* W. Gams and *T. ophioglossoides* (J.F. Gmel.) C.A. Quandt et al. (Kepler et al., 2012;

Schoch et al., 2012) were selected as outgroup taxa.

Maximum likelihood trees (ML) were estimated by using the software RAxML 7.2.8 Black Box (Stamatakis 2006., Stamatakis et al., 2008) in the CIPRES Science Gateway platform (Miller et al., 2010). MrModeltest v.2.3 (Nylander, 2004) was used to determine the best-fit evolution model for Bayesian analyses. MrBayes v.3.1.2 (Ronquist & Huelsenbeck, 2003) was used to evaluate posterior probabilities (PP) (Rannala & Yang, 1996, Zhaxybayeva & Gogarten, 2002) by Markov Chain Monte Carlo sampling (BMCMC). Six simultaneous Markov chains were run for 10,000,000 generations, and trees were sampled every 100th generation, and 100,001 trees were obtained. The first 25% of trees (25,000) were discarded, as they represented the burn-in phase of the analyses, while the remaining trees (75,001) were used for calculation posterior probabilities in the majority rule consensus tree (critical values for the topological convergence diagnostic is 0.01). Trees were figured in FigTree v1.4.0 program (Rambaut, 2012). Bayesian Posterior Probabilities (BYPP) equal to or great than 0.90 were given below each node.

Table 3.1 Sources of isolates and GenBank accession number of the family Ophiocordycipitaceae

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Drechmeria balanoides	CBS 250.82	NR_155044	NG_062629	NG_059128	DQ522342	DQ522388	DQ522442
Drechmeria campanulata	IMI 356051	NR_155045	NG_064867	NG_059063			
Drechmeria campanulata	CBS 101240	MH862723					
Drechmeria coniospora	CBS 596.92	AF106018	AF106012				
Drechmeria gunii	OSC 76404	JN049822	AF339572	AF339522	AY489616	AY489650	DQ522426
Drechmeria gunii	GN01						
Drechmeria gunii	GN02						
Drechmeria panacis	CBS 142798	MF588878	MF588890	MF588897	MF614144		
Drechmeria rhabdosporum	CBS 101432	AF375050					
Drechmeria sinensis	CBS 567.95	MH862540	AF339594	AF339545	DQ522343	DQ522389	DQ522443
Drechmeria sp.	UFMGCB 14051	MK638840					
Drechmeria zeospora	CBS 335.80	NR_155046		NG_063928	EF469062	EF469091	EF469109
Harposporium anguillulae	ARSEF 5593			AY636081			
Harposporium anguillulae	ARSEF 5407			AY636080			

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Harposporium botuliforme	CBS 570.84	MH861782					
Harposporium bysmatosporum	BCRC 34226	FJ380935					
Harposporium cerberi	CBS 129580	MH865377					
Harposporium cycloides	ARSEF 5599			AY636083			
Harposporium cylindrosporum	CBS 299.83	MH861596					
Harposporium harposporiferum	CBS 213.86	NR_160171					
Harposporium harposporiferum	ARSEF 5472		AF339569	NG_060621			
Harposporium harposporiferum	GJS 81-358A			U17400			
Harposporium helicoides	CBS 944.70	MH860014					
Harposporium helicoides	Arsef 5354		AF339577	AF339527			
Harposporium janus	G-jav3-ITS2_OTU-0-192_3	KY591457					
Harposporium janus	ARSEF 5601	AF169198					
Harposporium sp.	G-fon1-LSU2_OTU-0-292_2			MF336134			
Harposporium sp.	G-fon1-LSU2_OTU-0-186_4			MF336027			
Harposporium sp.	INBio2959G	HM770993					
Harposporium subuliforme	ARSEF 5605	AF169199					
Hirsutella aphidis	SB3701	EF194156					
Hirsutella cf. haptospora	ARSEF 2228	KM652166	KM652075	KM652118	KM652001	KM652041	
Hirsutella changbeisanensis	GZUIFR hir160527	KY415578		KY415586	KY415592		
Hirsutella citriformis	ARSEF1035	KM652153	KM652064	KM652105	KM651989	KM652030	
Hirsutella citriformis	ARSEF 1446	KM652154	KM652065	KM652106	KM651990	KM652031	
Hirsutella citriformis	ARSEF 2598	KM652155		KM652107	KM651991		
Hirsutella cryptosclerotium	ARSEF 4517	KM652157	KM652066	KM652109	KM651992	KM652032	
Hirsutella fusiformis	ARSEF 5474		KM652067	KM652110	KM651993	KM652033	
Hirsutella gigantea	ARSEF 30			JX566977	JX566980	KM652034	
Hirsutella gregis	SB3661 3	EF194155					
Hirsutella guyana	ARSEF 878	KM652158	KM652068	KM652112	KM651994	KM652035	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Hirsutella guyana	ARSEF878	DQ345595		DQ075676			
Hirsutella haptospora	ARSEF 2226	KM652159			KM651995	KM652036	
Hirsutella homalodiscae				DQ075674			
Hirsutella huangshanensis	RCEF0868	EF689043					
Hirsutella illustris	ARSEF 5539	KM652160	KM652069	AY518380	KM651996	KM652037	
Hirsutella kirchneri	ARSEF 5551	KM652161	KM652070	KM652113	KM651997		
Hirsutella kirchneri	SB3560 1a2	EF194154					
Hirsutella kuankuoshuiensis	GZUIFR 2012KKS3 1	KY415575		KY415582	KY415590	KY945360	
Hirsutella kuankuoshuiensis	GZUIFR 2012KKS3 2	MF623038		MF623044	MF623048		
Hirsutella kuankuoshuiensis	GZUIFR 2012KKS3 3	MF623039		MF623045	MF623049		
Hirsutella lecaniicola	ARSEF 8888	KM652162	KM652071	KM652114	KM651998	KM652038	
Hirsutella leizhouensis	GZUIFR hir130707	KY415573			KY415587	KY945358	
Hirsutella liboensis	ARSEF 9603	KM652163	KM652072	KM652115			
Hirsutella liboensis	GZUIFR Libo1	FJ957892			KY415588	KY945367	
Hirsutella longicolla	1458	FJ973071					
Hirsutella minnesotensis	SB3612	EF194145					
Hirsutella minnesotensis	SB3730 e	EF194144					
Hirsutella necatrix	ARSEF 5549	KM652164	KM652073	KM652116	KM651999	KM652039	
Hirsutella nodulosa	ARSEF 5473	KM652165	KM652074	KM652117	KM652000	KM652040	
Hirsutella nodulosa	SB3700	EF194146					
Hirsutella proturicola	NBRC 103239	AB378557					
Hirsutella radiata	ARSEF 1369		KM652076	KM652119	KM652002	KM652042	
Hirsutella repens nom. inval.	ARSEF 2348	KM652167	KM652077	KM652120	KM652003		
Hirsutella rhossiliensis	ARSEF 2931	KM652168	KM652078	KM652121	KM652004	KM652043	
Hirsutella rhossiliensis	ARSEF 3207	KM652169	KM652079	KM652122	KM652005	KM652044	
Hirsutella rostrata	SB3697	EF194150					
Hirsutella satumaensis	ARSEF 996	KM652172	KM652082	KM652125	KM652008	KM652047	
Hirsutella satumaensis	CBS 214 73			MH878324			
Hirsutella shennongjiaensis	420526MF0666			MH668075			

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Hirsutella shennongjiaensis	GZUIFR Snj121022	KT390721		KY945357		KY945364	
Hirsutella sinensis	HMAS 55469	AJ243980					
Hirsutella sp	ARSEF 7578				JX566981	KJ680152	
Hirsutella sp	NHJ11941 02	GU723770			GU797114		
Hirsutella sp	NHJ12699 02	GU723773			GU797115		
Hirsutella stilbelliformis var. myrmicarum	IMI 396397			GQ866966	GQ866964		
Hirsutella stilbelliformis var. myrmicarum	IMI 396398			GQ866967	GQ866965		
Hirsutella strigosa	ARSEF 2044	KM652174		KM652128	KM652011		
Hirsutella strigosa	ARSEF 2197	KM652175	KM652085	KM652129	KM652012	KM652050	
Hirsutella subramanianii var. myrmicarum	IMI 396400			EU797601	EU797598		
Hirsutella subramanianii var. myrmicarum	IMI 396401			EU797602	EU797599		
Hirsutella subulata	ARSEF 2227	KM652176	KM652086	KM652130	KM652013	KM652051	
Hirsutella thompsonii	ARSEF 241	KM652178		KM652132	KM652015		
Hirsutella thompsonii	ARSEF 253	KM652179	KM652088	KM652133	KM652016		
Hirsutella thompsonii var. synnematosa	ARSEF 1947	KM652191		KM652146	KM652026		
Hirsutella thompsonii var. synnematosa	ARSEF 2459	KM652192	KM652099	KM652147	KM652027	KM652061	
Hirsutella thompsonii var. synnematosa	ARSEF 5412	KM652193	KM652100	KM652148			
Hirsutella thompsonii var. thompsonii	ARSEF 137	KM652177	KM652087	KM652131	KM652014	KM652052	
Hirsutella thompsonii var. vinacea	ARSEF 254	KM652194	KM652101	KM652149	KM652028	KM652062	
Hirsutella tortricicola	GZUIFR hir090704	KT368152			KY415591	KY945361	
Hirsutella tunicata	CBS 131647	JN247824					
Hirsutella uncinata	DAOM 229256	AY365468	NG_064891				
Hirsutella vermicola	AS3 7877	NR_137547					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Hirsutella vermicola	AS3 7879	DQ345581					
Hirsutella versicolor	ARSEF 1037		KM652102	KM652150	KM652029	KM652063	
Hirsutella versicolor	ARSEF10 34	DQ345594					
Hymenostilbe aurantiaca	NHJ8	AJ786596					
Hymenostilbe aurantiaca	OSC 128578	JN049833	DQ522556	DQ518770	DQ522345	DQ522391	DQ522445
Hymenostilbe dipterigena	NHJ1217 0 02	GU723771			GU797127		
Hymenostilbe dipterigena	HUA 186134			KJ917573			KC610712
Hymenostilbe odonatae	TNS F18563			KJ878877		KJ878992	
Ophiocordyceps camponoti-atricipis	ATRI3		KX713666		KX713677		
Ophiocordyceps acicularis	OSC 110988		EF468951	EF468804	EF468745	EF468853	
Ophiocordyceps acicularis	OSC 110987		EF468950	EF468805	EF468744	EF468852	
Ophiocordyceps acicularis	OSC 128580	JN049820	DQ522543	DQ518757	DQ522326	DQ522371	DQ522423
Ophiocordyceps agriotidis	NBRC 101737	AB968403					
Ophiocordyceps agriotidis	ARSEF 5692	JN049819	DQ522540	DQ518754	DQ522322	DQ522368	DQ522418
Ophiocordyceps albacongiuae	RC20		KX713633		KX713670		
Ophiocordyceps annulata	CEM 303		KJ878915		KJ878962	KJ878995	
Ophiocordyceps aphodii	ARSEF 5498		DQ522541	DQ518755	DQ522323		DQ522419
Ophiocordyceps aphrophoridarum	YCHQ05 20061515						
Ophiocordyceps aphrophoridarum	YTS1906 1907						
Ophiocordyceps aphrophoridarum	YTS1906 1912						
Ophiocordyceps appendiculata	NBRC 106959	JN943325	JN941729	JN941412	AB968578	JN992463	AB968540
Ophiocordyceps appendiculata	NBRC 106960	JN943326	JN941728	JN941413	AB968577	JN992462	AB968539
Ophiocordyceps araracuarensis	HUA 186135		KC610788	KC610769	KC610738	KF658665	KC610716
Ophiocordyceps arborescens	NBRC 105891	AB968398	AB968386	AB968414	AB968572		AB968534
Ophiocordyceps asiana	BBH 42268	NR_173316					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps asiana	BBH 42269	MW285709		MW280202	MW292439		
Ophiocordyceps asiatica	BCC 30516	MH754722		MH753675	MK284263	MK214105	MK214091
Ophiocordyceps asiatica	BCC 86435	MH754723		MH753676		MK214106	MK214092
Ophiocordyceps australis	HUA 186147	KF937351	KC610784	KC610764	KC610734	KF658678	
Ophiocordyceps australis	HUA 186104		KC610783	KC610763	KC610733		KC610713
Ophiocordyceps australis	HUA 186097		KC610786	KC610765	KC610735	KF658662	
Ophiocordyceps australis	TSJ926	KF937350		KJ130989			
Ophiocordyceps australis	Ophaus992		KC610785	KC610766	KC610731	KF658663	
Ophiocordyceps barnesii	BCC 28561		EU408775			EU408774	EU408772
Ophiocordyceps barnesii	BCC28560		EU408776			EU408773	EU418599
Ophiocordyceps barnesii	FC20052303a						
Ophiocordyceps barnesii	FC20052303b						
Ophiocordyceps vespae	0620						
Ophiocordyceps vespae	BK073002						
Ophiocordyceps vespae	BKS15073002C						
Ophiocordyceps vespae	MSCM15071904						
Ophiocordyceps vespae	MSCM15071904C						
Ophiocordyceps bicephala	K M 335	AJ309365					
Ophiocordyceps binata	Binat			MK393323			
Ophiocordyceps bispora	KVL 606		AH006986	AF009654			
Ophiocordyceps blakebarnesii	MISSOU5		KX713641	KX713610	KX713688	KX713716	
Ophiocordyceps blakebarnesii	MISSOU4		KX713642	KX713609	KX713685	KX713715	
Ophiocordyceps blakebarnesii	MISSOU3		KX713643	KX713608	KX713687	KX713714	
Ophiocordyceps blakebarnesii	MISSOU1		KX713644		KX713686	KX713713	
Ophiocordyceps blattae	BCC 38241			MT512657	MT533485	MT533479	
Ophiocordyceps blattae	BCC 34765				MT533484	MT533478	
Ophiocordyceps blattae	CD0802						
Ophiocordyceps borealis	MFLU 180163	MK863251	MK863044	MK863051	MK860189		
Ophiocordyceps borealis	GACPR16002	MK863252	MK863045	MK863052	MK860190		
Ophiocordyceps borealis	GACPR16003	MK863253	MK863046	MK863053	MK860191		

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps brunneinigra	BCC 69015			MF614653	MF614637		MF614680
Ophiocordyceps brunneinigra	TBRC 8093			MF614654	MF614638	MF614668	MF614681
Ophiocordyceps brunneiperitheciata	BCC 49312			MF614660	MF614642		MF614686
Ophiocordyceps brunneiperitheciata	TBRC 8100			MF614658	MF614643		MF614685
Ophiocordyceps brunneiperitheciata	TBRC 8099			MF614659	MF614644		MF614684
Ophiocordyceps brunneipunctata	OSC 128576		DQ522542	DQ518756	DQ522324	DQ522369	DQ522420
Ophiocordyceps brunneirubra	BCC 14384	MH754736		MH753690	GU797121	MK751465	MK751468
Ophiocordyceps brunneirubra	BCC 14478	MH754734		MH753688	GU797122	MK751466	MK214102
Ophiocordyceps brunneirubra	BCC 14477	MH754735		MH753689	GU797123	MK751467	MK214103
Ophiocordyceps buquetii	HMAS 199613		KJ878939	KJ878904	KJ878984	KJ879019	
Ophiocordyceps buquetii	HMAS 199617		KJ878940	KJ878905	KJ878985	KJ879020	
Ophiocordyceps buquetii	K01						
Ophiocordyceps buquetii	K17121001						
Ophiocordyceps buquetii	RJSP18112703						
Ophiocordyceps buquetii	SDYRS18112603						
Ophiocordyceps campes	BCC36938			MT118175	MT118167	MT118183	MT118188
Ophiocordyceps campes	BCC36940			MT118176	MT118168		MT118189
Ophiocordyceps campes	BCC55764			MT118177	MT118169	MT118182	MT118190
Ophiocordyceps campes	1729						
Ophiocordyceps camponoti-balzani	G143		KX713658	KX713595	KX713690	KX713705	
Ophiocordyceps camponoti-balzani	G104		KX713660	KX713593	KX713689	KX713703	
Ophiocordyceps camponoti-bispinosi	OBIS5		KX713636	KX713616	KX713693	KX713721	
Ophiocordyceps camponoti-bispinosi	OBIS4		KX713637	KX713615	KX713692	KX713720	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps camponoti-bispinosi	OBIS3		KX713638	KX713614	KX713695		
Ophiocordyceps camponoti-bispinosi	OBIS		KX713639	KX713612	KX713694	KX713718	
Ophiocordyceps camponoti-bispinosi	BISPI2		KX713665	KX713588		KX713700	
Ophiocordyceps camponoti-bispinosi	OBIS2			KX713613	KX713691	KX713719	
Ophiocordyceps camponoti-femorati	FEMO2		KX713663	KX713590	KX713678	KX713702	
Ophiocordyceps camponoti-floridani	Flx1		KX713661				
Ophiocordyceps camponoti-floridani	Flo4		KX713662	KX713591			
Ophiocordyceps camponoti-floridani	Flx2			KX713592	KX713674		
Ophiocordyceps camponoti-hippocrepidis	HIPPOC		KX713655	KX713597	KX713673	KX713707	
Ophiocordyceps camponoti-indiani	INDI2		KX713654	KX713598			
Ophiocordyceps camponoti-nidulantis	NIDUL2		KX713640	KX713611	KX713669	KX713717	
Ophiocordyceps camponoti-novogranadensis	Mal63		KX713648	KX713603			
Ophiocordyceps camponoti-novogranadensis	Mal4		KX713649	KX713602			
Ophiocordyceps camponoti-renggeri	RENG2		KX713632		KX713672		
Ophiocordyceps camponoti-renggeri	ORENG		KX713634	KX713617	KX713671		
Ophiocordyceps camponoti-rufipedis	G177		KX713657	KX713596	KX713680		
Ophiocordyceps camponoti-rufipedis	G108		KX713659	KX713594	KX713679	KX713704	
Ophiocordyceps cf. acicularis	NHJ10418 01	GU723765			GU797116		
Ophiocordyceps cf. acicularis	NHJ12622	GU723772			GU797117		
Ophiocordyceps citrina	TNS F18537			KJ878903	KJ878983		
Ophiocordyceps clavata	NBRC 106961	JN943327	JN941727	JN941414	AB968586	JN992461	AB968547

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps clavata	NBRC 106962	JN943328	JN941726	JN941415	AB968587	JN992460	AB968548
Ophiocordyceps clavata	CEM1762			KJ878882	KJ878963	KJ878996	
Ophiocordyceps clavata	CEM1763			KJ878883	KJ878964	KJ878997	
Ophiocordyceps coccidiicola	NBRC 100682	AB968404	AB968391	AB968419	AB968583		AB968545
Ophiocordyceps coccidiicola	HMAS19 9612	AB027377	KJ878917	KJ878884	KJ878965	KJ878998	
Ophiocordyceps communis	BCC 1842	MH754726		MH753680	MK284266	MK214110	MK214096
Ophiocordyceps communis	BCC 1874	MH754725		MH753679	MK284267	MK214109	MK214095
Ophiocordyceps communis	BCC 2754	MH754727		MH753681	MK284268	MK214111	MK214097
Ophiocordyceps corriemoreau	C2014A		MK393831	MK393324			MK491926
Ophiocordyceps cossidarum	CM47						
Ophiocordyceps cossidarum	MFLU 17 0752		MF398186	MF398187	MF928403		
Ophiocordyceps crinalis	520326MF40726						
Ophiocordyceps crinalis	520326MF865b						
Ophiocordyceps crinalis	86643a						
Ophiocordyceps crinalis	86643b						
Ophiocordyceps crinalis	FYQ0120041502						
Ophiocordyceps crinalis	FYQ0120041503						
Ophiocordyceps crinalis	LG1030						
Ophiocordyceps crinalis	Y20						
Ophiocordyceps crinalis	HIMGD17327	EU149926					
Ophiocordyceps curculionum	OSC 151910			KJ878885			
Ophiocordyceps cylindrospora	MFLU 17 1961	MG553635	MG553651	MG553652			MG647029
Ophiocordyceps daceti	MF01			KX713604	KX713667		
Ophiocordyceps desmidiospora	SJS3Des		MH536515	MH536514	MN785129	MN785131	
Ophiocordyceps diabolic	BDS 32		MK393830	MK393322	MK491907		
Ophiocordyceps diabolic	Imp1B		MK393846				
Ophiocordyceps diabolic	IMP1			MK393339			
Ophiocordyceps dipterigena	MRCIF71	EU573346					
Ophiocordyceps dipterigena	OSC 151911		KJ878919	KJ878886	KJ878966	KJ879000	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps dipterigena	OSC 151912		KJ878920	KJ878887	KJ878967	KJ879001	
Ophiocordyceps dipterigena	HUA 186102		KC610787	KJ917568		KF658664	KC610715
Ophiocordyceps dipterigena	MY621	GU723764			GU797126		
Ophiocordyceps divitis	M01						
Ophiocordyceps divitis	M03						
Ophiocordyceps elongata	OSC 110989			EF468808	EF468748	EF468856	
Ophiocordyceps emeiensis	G96031	AJ309347					
Ophiocordyceps entomorrhiza	3070 4	AJ786561					
Ophiocordyceps entomorrhiza	3070 2	AJ786560					
Ophiocordyceps entomorrhiza	2709 H	AJ786559					
Ophiocordyceps entomorrhiza	KEW 53484	JN049850	EF468954	EF468809	EF468749	EF468857	EF468911
Ophiocordyceps evansii	HUA 186159	KP200889	KC610796	KC610770	KC610736	KP212916	
Ophiocordyceps evansii	HUA 186163	KP200890	KC610797	KC610771	KC610737	KF658670	
Ophiocordyceps evansii	MF78		MK874749	MK875540		MK863830	
Ophiocordyceps evansii	MF79		MK874750	MK875539		MK863831	
Ophiocordyceps flavacapita	YTS1906 1903						
Ophiocordyceps flavacapita	zn190826 06						
Ophiocordyceps formicarum	TNS F18565		KJ878921	KJ878888	KJ878968	KJ879002	KJ878946
Ophiocordyceps formicarum	XBZQ02_ 20052603						
Ophiocordyceps formicarum	BCMU CF 01	AB222678					
Ophiocordyceps formicarum	BCMU CF 02	AB222679					
Ophiocordyceps formosana	TNM F13893		KJ878908		KJ878956	KJ878988	KJ878943
Ophiocordyceps formosana	MFLU 15 3888		KU854951		KU854949	KU854947	
Ophiocordyceps forquignonii	OSC 151902		KJ878912	KJ878876		KJ878991	KJ878945
Ophiocordyceps forquignonii	OSC 151908		KJ878922	KJ878889		KJ879003	KJ878947
Ophiocordyceps fulgoromorphila	QCNE 186286		KC610793	KC610759			
Ophiocordyceps fulgoromorphila	HUA 186139		KC610794	KC610760	KC610729	KF658676	KC610719

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps fulgoromorphila	HUA 186142		KC610795	KC610761	KC610730	KF658677	
Ophiocordyceps furcatosubulata	YFCC 903		MT774215	MT774222	MT774243	MT774229	MT774236
Ophiocordyceps furcatosubulata	YFCC 902		MT774214	MT774221	MT774242	MT774228	MT774235
Ophiocordyceps furcatosubulata	YFCC 904		MT774216	MT774223	MT774244	MT774230	MT774237
Ophiocordyceps geometridicola	TBRC 8095			MF614648	MF614632	MF614663	MF614679
Ophiocordyceps geometridicola	TBRC 8094			MF614647	MF614631	MF614664	MF614678
Ophiocordyceps globiceps	MFLUCC 18 0495	MH725815	MH725811	MH725829	MH727387		
Ophiocordyceps globiceps	MFLU 18 0661	MH725816	MH725812	MH725830	MH727388		
Ophiocordyceps gracillima	HUA 186132	KF937353		KC610768	KC610744	KF658666	
Ophiocordyceps granospora	BBH43209	MH028143		MH028156	MH028183	MH028168	MH028177
Ophiocordyceps granospora	BBH43210	MH028144		MH028157		MH028169	MH028178
Ophiocordyceps granospora	BBH43213	MH028145		MH028158	MH028184	MH028170	
Ophiocordyceps granospora	0606						
Ophiocordyceps halabalaensis	MY1038	GU723758		MH028152	GU797109		
Ophiocordyceps hemisphaerica	FLOR 59525	KX197233					
Ophiocordyceps highlandensis	HKAS83207 2		KM581285			KM581277	KM581281
Ophiocordyceps highlandensis	HKAS83207 1		KM581284			KM581276	KM581280
Ophiocordyceps highlandensis	HKAS83206 2		KM581283			KM581275	KM581279
Ophiocordyceps highlandensis	HKAS83206 1		KM581282			KM581274	KM581278
Ophiocordyceps houaynhangensis	BBC82809	MH092892		MH092908	MH092899		
Ophiocordyceps houaynhangensis	TBRC8428	MH092891		MH092902	MH092894		

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps houaynhangensis	BCC82810	MH092893		MH092909	MH092900		
Ophiocordyceps houaynhangensis	BCC78421			MH092904	MH092897		
Ophiocordyceps houaynhangensis	BCC78167			MH092905	MH092898		
Ophiocordyceps irangiensis	BCC 82793	MH028141			MH028185	MH028163	MH028173
Ophiocordyceps irangiensis	BCC 82795	MH028142			MH028186	MH028164	MH028174
Ophiocordyceps irangiensis	OSC 128577	JN049823	DQ522546	DQ518760	DQ522329	DQ522374	DQ522427
Ophiocordyceps irangiensis	OSC 128579		EF469123	EF469076	EF469060	EF469089	EF469107
Ophiocordyceps irangiensis	NBRC 101400	JN943335	JN941715	JN941426		JN992449	
Ophiocordyceps issidarum	MFLU 17 0751	MF398185		MF398188			
Ophiocordyceps karstii	MFLU 15 3884		KU854952		KU854945	KU854943	
Ophiocordyceps khaoyaiensis	BBH43205	MH028150		MH028153	MH028187	MH028165	MH028175
Ophiocordyceps khaoyaiensis	BBH43218	MH028149		MH028155	MH028189	MH028167	MH028182
Ophiocordyceps khaoyaiensis	BBH43206	MH028151		MH028154	MH028188	MH028166	MH028176
Ophiocordyceps khokpasiensis	BCC 48071	MH754728		MH753682	MK284269	MK214112	
Ophiocordyceps khokpasiensis	BCC 48072	MH754729		MH753683	MK284270	MK214113	
Ophiocordyceps khokpasiensis	BCC 1764	MH754730		MH753684	MK284271	MK214114	MK214098
Ophiocordyceps kimflemingiae	SC30		KX713629	KX713622	KX713699	KX713727	
Ophiocordyceps kimflemingiae	SC09B		KX713631	KX713620	KX713698	KX713724	
Ophiocordyceps kniphofioides	HUA 186148		KC610790		KC610739	KF658667	KC610717
Ophiocordyceps konnoana	EFCC 7295		EF468958			EF468862	EF468915
Ophiocordyceps konnoana	EFCC 7315		EF468959		EF468753	EF468861	EF468916
Ophiocordyceps lanpingensis	YHOS0707		KC417459	KC417461	KC417463	KC417465	
Ophiocordyceps lanpingensis	YHOS0705		KC417458	KC417460	KC417462	KC417464	KC456333

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps lloydii	HUA 186164	KP200892	KC610805		KC610741		
Ophiocordyceps lloydii	HUA 186130	KP200893	KC610791				
Ophiocordyceps lloydii	OSC 151913		KJ878924	KJ878891	KJ878970	KJ879004	KJ878948
Ophiocordyceps longissima	EFCC 6814			EF468817	EF468757	EF468865	
Ophiocordyceps longissima	TNS F18448		KJ878925	KJ878892	KJ878971	KJ879005	
Ophiocordyceps longissima	PYI09						
Ophiocordyceps longissima	PYI09b						
Ophiocordyceps longissima	NBRC 108989	AB968407	AB968394	AB968421	AB968585		
Ophiocordyceps longissima	HMAS 199600		KJ878926		KJ878972	KJ879006	KJ878949
Ophiocordyceps longistromata	BCC44497			MT118178	MT118170		MT118191
Ophiocordyceps macroacicularis	BCC 22918			MF614655	MF614639	MF614669	MF614675
Ophiocordyceps macroacicularis	NBRC 105888	AB968401	AB968389	AB968417	AB968575		AB968537
Ophiocordyceps macroacicularis	NBRC 100685			AB968416	AB968574		AB968536
Ophiocordyceps mandariniae	BKS15073001						
Ophiocordyceps materiae	CM33						
Ophiocordyceps materiae	CM34						
Ophiocordyceps materiae	YTS1906 1916						
Ophiocordyceps materiae	YTS1906 1923						
Ophiocordyceps megacuculla	BBH43211	MH028147		MH028159	MH028190	MH028171	MH028179
Ophiocordyceps megacuculla	BBH43217	MH028148		MH028162	MH028192		MH028181
Ophiocordyceps megacuculla	BBH43216	MH028146		MH028161	MH028191	MH028172	MH028180
Ophiocordyceps megacuculla	ST03						
Ophiocordyceps melolonthae	OSC 110993		DQ522548	DQ518762	DQ522331	DQ522376	
Ophiocordyceps monacidis	MF74C		KX713646	KX713606			
Ophiocordyceps monacidis	MF74		KX713647	KX713605		KX713712	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps mosingtoensis	BCC 30904	MH754732		MH753686	MK284273	MK214115	MK214100
Ophiocordyceps mosingtoensis	BCC 36921	MH754731		MH753685	MK284272	MK214116	MK214099
Ophiocordyceps multibrachiata	WFQ02 19092401						
Ophiocordyceps multibrachiata	WFQ1910 0701						
Ophiocordyceps multiperitheciata	BCC 22861			MF614656	MF614640	MF614670	MF614683
Ophiocordyceps multiperitheciata	BCC 69008			MF614657	MF614641		MF614682
Ophiocordyceps myrmecophila	ARSEF 11864	JX566954	KJ680150	JX566965	JX566973	KJ680151	
Ophiocordyceps myrmecophila	MY 163	GU723759			GU797132		
Ophiocordyceps myrmecophila	CEM 1710		KJ878928		KJ878974	KJ879008	
Ophiocordyceps myrmecophila	HMAS 199620		KJ878927		KJ878973	KJ879007	
Ophiocordyceps myrmecophila	TNS 27120		KJ878929	KJ878895	KJ878975	KJ879009	
Ophiocordyceps myrmecophila	MFLU 16 2912	MF351726	MF351730	MF372585	MF372759		
Ophiocordyceps myrmecophila	MFLU 16 2913	MF351727	MF351731	MF372586			
Ophiocordyceps myrmecophila	MRC1508 2207						
Ophiocordyceps myrmecophila	MSCM15 071902						
Ophiocordyceps naomipierceae	DAWKS ANT		KX713664	KX713589		KX713701	
Ophiocordyceps neoacicularis	MRC1508 2203						
Ophiocordyceps neocylindrocpora	KKS2007 0273						
Ophiocordyceps neocylindrocpora	LGS2007 0508						
Ophiocordyceps neonutans	KEL110	KX197240					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps neonutans	KEL113	KX197239					
Ophiocordyceps neovolkiana	OSC 151903		KJ878930	KJ878896	KJ878976	KJ879010	
Ophiocordyceps nigra	TNS 16252		KJ878941	KJ878906	KJ878986		
Ophiocordyceps nigra	TNS 16250		KJ878942		KJ878987	KJ879021	
Ophiocordyceps nigrella	EFCC 9247	JN049853	EF468963	EF468818	EF468758	EF468866	EF468920
Ophiocordyceps nutans	NBRC 101749	AB968408	JN941712	JN941429	AB968589	JN992446	AB968550
Ophiocordyceps nutans	06Fuka3	AB544463					
Ophiocordyceps nutans	03Y3	AB544452					
Ophiocordyceps nutans	06Tank22	AB544486					
Ophiocordyceps nutans	06Tank21	AB544485					
Ophiocordyceps nutans	JGS29						
Ophiocordyceps nutans	OSC 110994		DQ522549	DQ518763	DQ522333	DQ522378	
Ophiocordyceps nutans	BN21H						
Ophiocordyceps nutans	CM35						
Ophiocordyceps odonatae	TNS F27117			KJ878878			
Ophiocordyceps odontomachi	Odonto1			MK393342		MK491939	
Ophiocordyceps odontomachi	Odonto2			MK393343			
Ophiocordyceps oecophyllae	OECO1		KX713635				
Ophiocordyceps ootakii	J14		KX713651		KX713682	KX713709	
Ophiocordyceps ootakii	J13		KX713652	KX713600	KX713681	KX713708	
Ophiocordyceps paltothyrei	Palt2		MK393849	MK393346		MK491943	
Ophiocordyceps paltothyrei	Palt3		MK393850	MK393347		MK491944	
Ophiocordyceps paltothyrei	Palt1		MK393848	MK393345		MK491942	
Ophiocordyceps paltothyrei	Palt4		MK393851				
Ophiocordyceps parautralis	ML01						
Ophiocordyceps parautralis	ML01b						
Ophiocordyceps parcucullae	ZNQ01_1 9102309						
Ophiocordyceps pauciovoperitheciata	TBRC 8096			MF614649	MF614636	MF614665	MF614672

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps pauciovoperitheciata	TBRC 8097			MF614650	MF614635	MF614667	MF614671
Ophiocordyceps pauciovoperitheciata	TBRC 8098			MF614651	MF614634	MF614666	MF614674
Ophiocordyceps pauciovoperitheciata	TBRC 8106			MF614652	MF614633		MF614673
Ophiocordyceps phuwiangensis	PYI01						
Ophiocordyceps phuwiangensis	PYI02						
Ophiocordyceps phuwiangensis	PYI11						
Ophiocordyceps polistes	CM10						
Ophiocordyceps polistes	CM13						
Ophiocordyceps ponerinarum	HUA 186140		KC610789		KC610740	KF658668	
Ophiocordyceps ponerinarum	HUA 186133					KF658669	
Ophiocordyceps ponerus	CGMCC 3 18756	KP890688	KY953152		KY953153		
Ophiocordyceps pruinosa	NHJ 12994		EU369106	EU369041	EU369024	EU369063	EU369084
Ophiocordyceps pseudoacicularis	TBRC 8101			MF614645	MF614629	MF614662	MF614676
Ophiocordyceps pseudoacicularis	TBRC 8102			MF614646	MF614630	MF614661	MF614677
Ophiocordyceps pseudocommunis	NHJ 12581		EF468973	EF468831	EF468775		EF468930
Ophiocordyceps pseudocommunis	NHJ 12582			EF468830	EF468771		EF468926
Ophiocordyceps pseudocommunis	BCC 16757	MH754733		MH753687	MK284274	MK214117	MK214101
Ophiocordyceps pseudoelongata	DPR0120 061613						
Ophiocordyceps pseudoelongata	KKS2007 0228						

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps pseudoformicarum	520326mf 40522						
Ophiocordyceps pseudolloydii	MFLUCC 15 0689	MF351725			MF372758	MF372761	
Ophiocordyceps pseudolloydii	MRCIF59	EU573351					
Ophiocordyceps pseudolloydii	LHC	KX714602			KX714603		
Ophiocordyceps pseudomyrmexi	P10B1		MK393847	MK393344			
Ophiocordyceps pseudorhizoidea	BCC 48879	MH754720		MH753673	MK284261	MK214104	MK214089
Ophiocordyceps pseudorhizoidea	BCC 86431	MH754721		MH753674	MK284262	MK751469	MK214090
Ophiocordyceps pseudorhizoidea	NHJ 12529		EF468969	EF468824	EF468765		EF468922
Ophiocordyceps pulvinata	TNS F 30044		GU904208		GU904209	GU904210	
Ophiocordyceps purpureostromata	TNS F18430		KJ878931	KJ878897	KJ878977	KJ879011	
Ophiocordyceps ramosissimum	GZUHHN 8	KJ028007	KJ028012		KJ028014	KJ028017	
Ophiocordyceps ramosissimum	MFLU12 2165	KJ028011				KJ028021	
Ophiocordyceps ramosissimum	GZUH20 12HN2	KJ028008	KJ028013		KJ028016	KJ028018	
Ophiocordyceps ramosissimum	GZUH20 12HN10	KJ028009				KJ028019	
Ophiocordyceps ramosissimum	GZUH20 12HN12	KJ028010			KJ028015	KJ028020	
Ophiocordyceps ravenelii	OSC 151914		KJ878932		KJ878978	KJ879012	KJ878950
Ophiocordyceps ravenelii	OSC 110995		DQ522550	DQ518764	DQ522334	DQ522379	DQ522430
Ophiocordyceps rhizoidea	NHJ 12522	JN049857	EF468970	EF468825	EF468764	EF468873	EF468923
Ophiocordyceps robertsii	KEW 27083			EF468826	EF468766		
Ophiocordyceps rubiginosiperitheciata	NBRC 100946	JN943341	JN941705	JN941436	AB968581	JN992439	AB968543

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps rubiginosiperitheciata	NBRC 106966	JN943344	JN941704	JN941437	AB968582	JN992438	AB968544
Ophiocordyceps ryogamiensis	NBRC 101751		KF049614	KF049633	KF049688	KF049650	
Ophiocordyceps satoi	J7		KX713653	KX713599	KX713683	KX713711	
Ophiocordyceps satoi	J19		KX713650	KX713601	KX713684	KX713710	
Ophiocordyceps sinensis	ARSEF 6282	KM652173	KM652083	KM652126	KM652009	KM652048	
Ophiocordyceps sinensis	EFCC7287	JN049854	EF468971	EF468827	EF468767	EF468874	EF468924
Ophiocordyceps sobolifera	KEW 78842	JN049855	EF468972	EF468828		EF468875	EF468925
Ophiocordyceps sobolifera			AB027328				
Ophiocordyceps sobolifera	TNS F18521		KJ878933	KJ878898	KJ878979	KJ879013	
Ophiocordyceps sobolifera	NBRC 106967	AB968409	AB968395	AB968422	AB968590		AB968551
Ophiocordyceps sp	Gh41		KX713656		KX713668	KX713706	
Ophiocordyceps sp	TNS F18495		KJ878937	KJ878901		KJ879017	
Ophiocordyceps sp	OSC 151904		KJ878934	KJ878899	KJ878980	KJ879014	
Ophiocordyceps sp	OSC 151905		KJ878935		KJ878981	KJ879015	KJ878951
Ophiocordyceps sp	OSC 151909		KJ878936	KJ878900	KJ878982	KJ879016	KJ878952
Ophiocordyceps sp	YHH 16755			MT222278	MT222279	MT222280	MT222281
Ophiocordyceps sp	FMF147	KX197238					
Ophiocordyceps sp	OSC 110997		EF468976		EF468774	EF468879	EF468929
Ophiocordyceps spataforae	NHJ 12525		EF469125	EF469078	EF469063	EF469092	EF469111
Ophiocordyceps spataforae	BCC 86480			MG831747	MG831746	MG831748	MG831749
Ophiocordyceps spataforae	OSC 128575	JN049845	EF469126	EF469079	EF469064	EF469093	EF469110
Ophiocordyceps sphecocephala	OSC 110998		DQ522551	DQ518765	DQ522336	DQ522381	DQ522432
Ophiocordyceps sphecocephala	DMSL15031201						
Ophiocordyceps sphecocephala	NBRC 101416	JN943348		JN941443		JN992432	
Ophiocordyceps sphecocephala	NBRC 101752	JN943351	JN941696	JN941445	AB968591	JN992430	AB968552
Ophiocordyceps sphecocephala	NBRC 101753	JN943350	JN941695	JN941446	AB968592	JN992429	AB968553
Ophiocordyceps spicatus	MFLU 18 0164	MK863254	MK863047	MK863054	MK860192		

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps sporangifera	MFLUCC 18 0492	MH725818	MH725814	MH725832	MH727390	MH727392	
Ophiocordyceps sporangifera	MFLU 18 0658	MH725817	MH725813	MH725831	MH727389	MH727391	
Ophiocordyceps stigma	0626						
Ophiocordyceps stigma	MRC1507 1826						
Ophiocordyceps stylophora	OSC 110999		EF468982	EF468837	EF468777	EF468882	EF468931
Ophiocordyceps stylophora	OSC 111000	JN049828	DQ522552	DQ518766	DQ522337	DQ522382	DQ522433
Ophiocordyceps superficialis	MICH 36253		EF468983			EF468883	
Ophiocordyceps termiticola	BCC 1920	MH754724		MH753678	MK284265	MK214108	MK214094
Ophiocordyceps termiticola	BCC 1770	GU723780		MH753677	MK284264	MK214107	MK214093
Ophiocordyceps tessaratomidarum	BBH42363	MW285723		MW280219	MW292435		
Ophiocordyceps tessaratomidarum	BBH41196	MW285722		MW280218			
Ophiocordyceps tessaratomidarum	BBH41194	MW285721		MW280217	MW292433		
Ophiocordyceps tessaratomidarum	BN20						
Ophiocordyceps thanathonensis	0605						
Ophiocordyceps thanathonensis	MRC0623						
Ophiocordyceps thanathonensis	MFU 16 2910	MF850375	MF882926	MF850378	MF872614	MF872616	
Ophiocordyceps thanathonensis	MFU 16 2909	MF850376		MF850377	MF872613	MF872615	
Ophiocordyceps tiputini	QCNE 186287		KC610792	KC610773	KC610745	KF658671	
Ophiocordyceps tricentri	NBRC 106968	AB968410	AB968393	AB968423	AB968593		AB968554
Ophiocordyceps tricentri	CEM 160		AB027330				
Ophiocordyceps unilateralis	SERI2		KX713627		KX713676	KX713731	
Ophiocordyceps unilateralis	SERI1		KX713628	KX713626	KX713675	KX713730	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Ophiocordyceps unilateralis	HUA 186161		KC610799		KC610742	KF658674	KC610718
Ophiocordyceps unilateralis	HUA 186126		KC610798			KF658673	
Ophiocordyceps unilateralis	OSC 128574		DQ522554	DQ518768	DQ522339	DQ522385	DQ522436
Ophiocordyceps variabilis	ARSEF 5365		DQ522555	DQ518769	DQ522340	DQ522386	DQ522437
Ophiocordyceps variabilis	OSC 111003		EF468985	EF468839	EF468779	EF468885	EF468933
Ophiocordyceps vespulae	GACP2017064	MN044857		MN044858	MN117075		MN107547
Ophiocordyceps vespulae	GACP2017079			MN044859	MN117076		MN107548
Ophiocordyceps xuefengensis	GZUH2012HN11	KC631800	KC631786		KC631791	KC631796	
Ophiocordyceps xuefengensis	GZUHHN13	KC631804	KC631785		KC631790	KC631795	
Ophiocordyceps xuefengensis	GZUH2012HN13	KC631801	KC631787		KC631792	KC631797	
Ophiocordyceps xuefengensis	GZUH2012HN14	KC631802	KC631789		KC631793	KC631798	
Ophiocordyceps xuefengensis	GZUH2012HN19	KC631803	KC631788		KC631794	KC631799	
Ophiocordyceps yakusimensis	HMAS 199604		KJ878938	KJ878902		KJ879018	KJ878953
P. formosus	ARSEF1424	KF049661	KF049615	KF049634	KF049689		
Paecilomyces aff. Lilacinus	ROG-2010 LA219	HQ022455					
Paecilomyces aff. Lilacinus	ROG-2010 LA203b	HQ022454					
Paecilomyces aff. Lilacinus	ROG-2010 LA193a	HQ022453					
Paecilomyces aff. Lilacinus	ROG-2010 LA259	HQ022452					
Paecilomyces aff. Lilacinus	ROG-2010 LA258	HQ022451					
Paecilomyces aff. Lilacinus	ROG-2010 LA160b	HQ022450					
Paecilomyces aff. Lilacinus	ROG-2010 LA81	HQ022449					
Paecilomyces aff. Lilacinus	ROG-2010 LA42	HQ022448					
Paecilomyces aff. Lilacinus	ROG-2010 LA39	HQ022447					
Paraisaria alba	HKAS 102484	MN947219	MN943843	MN943839	MN929085	MN929078	MN929082

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Paraisaria amazonica	HUA 186143		KJ917562	KJ917571	KM411989	KP212902	KM411982
Paraisaria amazonica	HUA 186113		KJ917566	KJ917572		KP212903	KM411980
Paraisaria amazonica	HUA 186107		KJ917561			KP212904	
Paraisaria amazonica	HUA 186136		KJ917560		KM411991	KP212905	
Paraisaria amazonica	HUA 186094		KJ917565		KM411986	KP212906	
Paraisaria amazonica	HUA 186100		KJ917564		KM411987	KP212907	
Paraisaria amazonica	HUA 186101				KM411988	KP212908	KM411981
Paraisaria amazonica	HUA 186106		KJ917563			KP212909	
Paraisaria amazonica	SL130803 04						
Paraisaria arcta	HKAS 102553	MN947221	MN943845	MN943841	MN929087	MN929080	
Paraisaria arcta	HKAS 102552	MN947220	MN943844	MN943840	MN929086	MN929079	MN929083
Paraisaria blattarioides	HUA186093		KJ917559	KJ917570	KM411992	KP212910	
Paraisaria blattarioides	HUA 186108		KJ917558	KJ917569		KP212912	KM411984
Paraisaria coenomyiae	NBRC 106964	AB968397	AB968385	AB968413	AB968571		AB968533
Paraisaria coenomyiae	NBRC 108993	AB968396	AB968384	AB968412	AB968570		AB968532
Paraisaria gracilioides	HUA 186095		KJ917556		KM411994	KP212914	
Paraisaria gracilioides	HUA 186092		KJ917555	KJ130992		KP212915	
Paraisaria gracilis	EFCC 3101		EF468955	EF468810	EF468750	EF468858	EF468913
Paraisaria gracilis	EFCC 8572		EF468956	EF468811	EF468751	EF468859	EF468912
Paraisaria heteropoda	OSC 106404		AY489690	AY489722	AY489617	AY489651	
Paraisaria heteropoda	EFCC 10125	JN049852	EF468957	EF468812	EF468752	EF468860	EF468914
Paraisaria orthopterorum	BBC 88305	MH754742		MK332583	MK214080	MK214084	
Paraisaria orthopterorum	TBRC 9710	MH754743		MK332582	MK214081	MK214085	
Paraisaria phuwiangensis	BBH 43491	MH188542		MK192058		MH211351	
Paraisaria phuwiangensis	TBRC 9709	MK192015		MK192057	MK214082	MK214086	
Paraisaria phuwiangensis	BBH 43492	MH188541		MH201169	MH211355	MH211352	
Paraisaria rosea	HKAS 102546	MN947222	MN943846	MN943842	MN929088	MN929081	MN929084
Paraisaria rosea	SCWW01						
Paraisaria tettigonia	GZUH CS140627 09	KT345954	KT345955		KT375440	KT375441	
Paraisaria yodhathaii	BBH 43163	MH188539		MK332584	MH211353	MH211349	
Paraisaria yodhathaii	TBRC 8502	MH188540		MH201168	MH211354	MH211350	

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Podocrella harposporifera		G.J.S. 81-358					DQ127238
Purpureocillium albosynnematum	CR001						
Purpureocillium albosynnematum	CR001b						
Purpureocillium clavatsis	DHKQ03 20102003a						
Purpureocillium clavatsis	DHKQ03 20102003b						
Purpureocillium lavendulum	CBS 128678	MH864977		MH876430			
Purpureocillium lavendulum	CBS 128677	MH864976		MH876429			
Purpureocillium lavendulum	PlGX6801	MH483900					
Purpureocillium lavendulum	PlGX6503	MH483895					
Purpureocillium lavendulum	PlGZ5004	MH483813					
Purpureocillium lavendulum	PlGZ4902	MH483806					
Purpureocillium lavendulum	PlGZ4603	MH483801					
Purpureocillium lavendulum	PlGZ4402	MH483794					
Purpureocillium lavendulum	PlGZ3501	MH483772					
Purpureocillium lavendulum	PlYN0402	MH483745					
Purpureocillium lavendulum	R43	MK513860					
Purpureocillium lavendulum	VS3302	MG654718		MG654728			
Purpureocillium lavendulum	P6371	MH063652					
Purpureocillium lilacinum	CBS 284.36	NR_111432	NG_061025				
Purpureocillium lilacinum	ATCC 10114			NG_056277			
Purpureocillium lilacinum	NBRC:32861	LC008208			LC008342		
Purpureocillium lilacinum	0716a						
Purpureocillium lilacinum	0853b						
Purpureocillium lilacinum	CPY01						
Purpureocillium lilacinum	CPY01b						
Purpureocillium lilacinum	CPY05						
Purpureocillium lilacinum	CY05						
Purpureocillium lilacinum	Z01						
Purpureocillium sodanum	IBRC-M 30175	KX668542					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Purpureocillium sp	CBS 731.73	HE792981			HE792982		
Purpureocillium sp.	PspHN05	MH483721					
Purpureocillium sp.	PspGD20	MH483666					
Purpureocillium sp.	PspGD19	MH483664					
Purpureocillium sp.	AHB10_9A	MH268077					
Purpureocillium sp.	PXB04_1B	MH268076					
Purpureocillium sp.	MAFF307198	LC433835					
Purpureocillium sp.	MAFF307193	LC433834					
Purpureocillium sp.	H15_1	MK041916					
Purpureocillium sp.	64F3F_AC	MK026985					
Purpureocillium sp.	Mal02-Mod	MH426603					
Purpureocillium sp.	SNT1-15	KY379571					
Purpureocillium sp.	DR 015 MC	KY318491					
Purpureocillium sp.	BA1	KY410343	KY410347	KY410345			
Purpureocillium sp.	BRO-2013	KF367471					
Purpureocillium sp.	1H3_M3_P1_2	KM232437	KM222228				
Purpureocillium sp.	4H1_P0_P1_2	KM232450					
Purpureocillium sp.	2 BRO-2013	KF367485					
Purpureocillium sp.	WE004			KJ577797			
Purpureocillium sp.	WE003			KJ577796			
Purpureocillium sp.	WE002			KJ577795			
Purpureocillium sp.	WE001			KJ577794			
Purpureocillium sp.	JCM 28120			LC133957			
Purpureocillium sp.	JCM 28386			LC134078			
Purpureocillium sp.	JCM 28390			LC134082			
Purpureocillium sp.	JCM 28486			LC134177			
Purpureocillium sp.	MCM_HumanF8-1	AB915809					
Purpureocillium sp.	MSEF59	KT310973					
Purpureocillium sp.	MSEF80	KT310982					
Purpureocillium sp.	NWHC 24266-03-02-02	KX148714					
Purpureocillium sp.	NWHC 24393-01-01-01	KX148711					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Purpureocillium sp.	NWHC 24852-02-01-01	KX148712					
Purpureocillium sp.	NWHC 44736-22-05-01	KX148713					
Purpureocillium sp.	OKA-F11b	LC009007					
Purpureocillium sp.	RS2		KM205078				
Purpureocillium sp.	snB12H1	KJ170309					
Purpureocillium sp.	SPuFAF		KT356200				
Purpureocillium sp.	TKB-F31b	LC009008					
Purpureocillium sp.	xz16	KJ935014					
Purpureocillium takamizusanense	TCTeb01	MK592777		MK598823	LC469050		
Purpureocillium takamizusanense	NHJ 3497		EU369096	EU369033	EU369014		
Purpureocillium takamizusanense	NBRC:108982	LC008204			LC008338		
Purpureocillium takamizusanense	NBRC:110232	LC008205			LC008339		
Purpureocillium takamizusanense	NBRC 110231	LC008203			LC008337		
Purpureocillium takamizusanense	ST01						
Tolypocladium album	CBS 869.73	NR_155018					
Tolypocladium album	CBS 393.89	MH862176	MH873866				
Tolypocladium album	CBS 968.73B	MH860832	MH872567				
Tolypocladium album	CBS 830.73	MH860811	MH872543				
Tolypocladium album	hs19082805						
Tolypocladium amazonense	LA100	HQ022485	KF747129	KF747309	KF747094	KF747208	
Tolypocladium amazonense	MS308	JQ905653	KF747134	KF747314	KF747099	KF747214	
Tolypocladium amazonense	BPI 892889			NG_065021			
Tolypocladium capitatum	OSC 67004	EU834212					
Tolypocladium capitatum	FLAS-F-60359	MF074845					
Tolypocladium capitatum	OSC 71233		AY489721	AY489689	AY489615	AY489649	DQ522421

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Tolypocladium capitatum	SL06101301						
Tolypocladium cucullae	55588						
Tolypocladium cylindrosporum	IP 425	MG228380			MG228389	MG228383	MG228386
Tolypocladium cylindrosporum	IP 419	MG228379			MG228388	MG228382	MG228385
Tolypocladium dujiaolongae	RCEF6201	KF696558					
Tolypocladium dujiaolongae	ZBAH632	KF696557					
Tolypocladium endophyticum	MX575	JX155949	KF747155	KF747323			
Tolypocladium endophyticum	MX486	KF747245	KF747152	KF747321	KF747116	KF747232	
Tolypocladium extinguens	CBS 34577	NR_160156	MH872842				
Tolypocladium fractum	OSC 110990		DQ518759	DQ522545	DQ522328	DQ522373	DQ522425
Tolypocladium geodes	ARSEF 2684	FJ973059					
Tolypocladium geodes	CBS 723.70	NR_164431					
Tolypocladium guangdongensis	GDGM 24020	EU039881					
Tolypocladium inegoense	SU-15		DQ118741		DQ118752	DQ127243	
Tolypocladium inegoense			AB027368	AB027322			
Tolypocladium inflatum	OSC 71235	JN049844	EF469077	EF469124	EF469061	EF469090	EF469108
Tolypocladium inflatum	CBS 714.70	MH859916	MH871710				
Tolypocladium japonicum	OSC 110991	JN049824	DQ518761	DQ522547	DQ522330	DQ522375	DQ522428
Tolypocladium japonicum	IFO 9647	AB027366		AB027320			
Tolypocladium jezoense			AB027365	AB027319			
Tolypocladium lignicola	JFL14081002	MH861631	MH873346				
Tolypocladium longisegmentatum	OSC 110992		EF468816			EF468864	EF468919
Tolypocladium longisegmentatum	HMJAU6903	KJ866879					
Tolypocladium longisegmentatum	2731 S	AJ786568					

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Tolypocladium longisegmentatum	MHHNU 8699	MK253762					
Tolypocladium neoophioglossoides	520326MF40704B						
Tolypocladium neoophioglossoides	NGQ02_20041201						
Tolypocladium nubicola	CBS 944.72		MH878304				
Tolypocladium nubicola	CBS 568.84		MH873478				
Tolypocladium ophioglossoides	OSC 106405		AY489723	AY489691	AY489618	AY489652	DQ522429
Tolypocladium ophioglossoides	CBS 100239	KU382155	KJ878874	KJ878910	KJ878958	KJ878990	KJ878944
Tolypocladium ophioglossoides	SL11080301						
Tolypocladium ophioglossoides	SL17050801						
Tolypocladium ophioglossoides	NBRC 106330	JN943321	JN941407	JN941734	AB968603	JN992468	AB968564
Tolypocladium ophioglossoides	NBRC 100998	JN943319	JN941406	JN941735	AB968602	JN992469	AB968563
Tolypocladium ophioglossoides	NBRC 8992	JN943316	JN941405	JN941736	AB968601	JN992470	AB968562
Tolypocladium ovalisporum	CBS 70092	NR_155019					
Tolypocladium paradoxum	JFL14081002	KX017278					
Tolypocladium paradoxum	HKAS 87772	KX017279					
Tolypocladium paradoxum	HMG 20938	DQ901630		AB027323			
Tolypocladium paradoxum	NBRC 106958	JN943324	JN941411	JN941730	AB968600	JN992464	AB968561
Tolypocladium paradoxum	NBRC 100945	JN943323	JN941410	JN941731	AB968599	JN992465	AB968560
Tolypocladium paradoxum	36297						
Tolypocladium paradoxum	61468						
Tolypocladium paradoxum	YN13070814						

Table 3.1 (continued)

Species	Voucher	ITS	SSU	LSU	TEF1α	RPB1	RPB2
Tolypocladium paradoxum	YN13070815						
Tolypocladium paradoxum	YN13070818						
Tolypocladium pustulatum	MRL GB6597		AF389190				
Tolypocladium pustulatum	MRL MF5368LR		AF373282				
Tolypocladium pustulatum	KaP8.2.2.1	KP698195					
Tolypocladium roburstipitatum	SL07090201						
Tolypocladium rouxii	SL10072301						
Tolypocladium rutilum	BN09						
Tolypocladium rutilum	BN09b						
Tolypocladium tropicale	MX337	KF747259	KF747149	KF747318	KF747113	KF747229	
Tolypocladium tropicale	IQ35	KF747256	KF747127		KF747092	KF747206	
Tolypocladium tropicale	CBS 136897	NR_159005					
Tolypocladium tundrense	ARSEF 3400	FJ973069					
Tolypocladium tundrense	CBS 569.84	MH861781	MH873479				
Tolypocladium tundrense	CBS 429.94	MH862472	MH874122				

3.3 Results

3.3.1 Outline of Ophiocordycipitaceae

Phylum: ASCOMYCOTA Caval-Sm.

Subphylum: PEZIZOMYCOTINA O.E. Erikss. & Winka

Class: Sordariomycetes O.E. Erikss. & Winka

Subclass: Hypocreomycetidae O.E. Erikss. & Winka

Order: Hypocreales Lindau

Family: Ophiocordycipitaceae G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps Petch 1931

Ophiocordyceps acicularis (Ravenel) Petch 1933

Ophiocordyceps acridiorum (H.C. Evans & P.A. Shah) B. Shrestha, G.H. Sung

& Spatafora 2015

Ophiocordyceps acridiorum var. acridiorum (H.C. Evans & P.A. Shah) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps agriotis G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps ainictos (Möller) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps albacongiuae Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps alboperitheciata H. Yu, Q. Fan & Y.B. Wang 2021

Ophiocordyceps annulata (Kobayasi & Shimizu) Spatafora, Kepler & C.A. Quandt 2015

Ophiocordyceps aphidis (Petch) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps aphodii (Mathieson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps appendiculata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps arachneicola (Kobayasi) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps aranearum (Petch) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps araracuarensis Sanjuan & Spatafora 2015

Ophiocordyceps arborescens S. Ban, Sakane & Nakagiri 2015

Ophiocordyceps arbuscula (Teng) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps armeniaca (Berk. & M.A. Curtis) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps asiana Mongkols., Khao-ngam, Himaman, Rungjind. & Luangsa-ard 2021

Ophiocordyceps asiatica Tasan., Noisrip. & Luangsa-ard 2019

Ophiocordyceps asyuensis (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps aurantia (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps australiensis (Mains) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps australis (Speg.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps barnesii (Thwaites) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps bicephala (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps binata (H.C. Evans & Samson) J.P.M. Araújo, H.C. Evans & D.P. Hughes 2020

Ophiocordyceps bispora (Stifler) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps blakebarnesii Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps blattae (Petch) Petch 1931

Ophiocordyceps borealis L.S. Zha & P. Chomnunti 2021

Ophiocordyceps brunneinigra Tasan., Thanakitp., Khons. & Luangsa-ard 2018

Ophiocordyceps brunneiperitheciata Tasan., Thanakitp., Khons. & Luangsa-ard 2018

Ophiocordyceps brunneipunctata (Hywel-Jones) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps brunneirubra Tasan., Noisrip., Luangsa-ard & Hywel-Jones 2019

Ophiocordyceps buquetii (Mont. & C.P. Robin) Spatafora, Kepler & C.A. Quandt 2015

Ophiocordyceps caloceroides (Berk. & M.A. Curtis) Petch 1933

Ophiocordyceps campes Tasan., Thanakitp. & Luangsa-ard 2020

Ophiocordyceps camponoti (Mains) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps camponoti-atricipis J.P.M. Araújo, H.C. Evans & D.P. Hughes 2015

Ophiocordyceps camponoti-balzani H.C. Evans & D.P. Hughes 2011

Ophiocordyceps camponoti-bispinosi J.P.M. Araújo, H.C. Evans & D.P. Hughes 2015

Ophiocordyceps camponoti-chartificis Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-femorati Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-floridani Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-hippocrepidis Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-indiani J.P.M. Araújo, H.C. Evans & D.P. Hughes 2015

Ophiocordyceps camponoti-leonardi Kobmoo, Mongkols., Tasan., Thanakitp. & Luangsa-ard 2012

Ophiocordyceps camponoti-melanotici H.C. Evans & D.P. Hughes 2011

Ophiocordyceps camponoti-nidulantis Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-novogranadensis H.C. Evans & D.P. Hughes 2011

Ophiocordyceps camponoti-renggeri Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps camponoti-rufipedis H.C. Evans & D.P. Hughes 2011

Ophiocordyceps camponoti-saundersi Kobmoo, Mongkols., Tasan., Thanakitp. & Luangsa-ard 2012

Ophiocordyceps camponoti-sexguttati Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps cantharelloides (Samson & H.C. Evans) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps carabidicola (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps cicadellidicola (Kobayasi & Shimizu) Spatafora, Kepler & C.A. Quandt 2015

Ophiocordyceps cicadicola (Teng) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps citrina (Kobayasi & Shimizu) Spatafora, Kepler & C.A. Quandt 2015

Ophiocordyceps clavata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps clavulata (Schwein.) Petch 1933

Ophiocordyceps cleoni (Wize) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps coccidiicola (Kobayasi) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps coccigena (Tul. & C. Tul.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps cochlidiicola (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps communis Hywel-Jones & Samson 2007

Ophiocordyceps corallomyces (Möller) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps corriemoreauae J.P.M. Araújo, H.C. Evans & D.P. Hughes 2020

Ophiocordyceps cossidarum Y.P. Xiao, T.C. Wen, Zha & K.D. Hyde 2017

Ophiocordyceps crassispora (M. Zang, D.R. Yang & C.D. Li) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps crinalis (Ellis ex Lloyd) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps cucumispora (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps curculionum (Tul. & C. Tul.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps cylindrospora Y.P. Xiao, T.C. Wen & K.D. Hyde 2018

Ophiocordyceps cylindrostromata (Z.Q. Liang, A.Y. Liu & M.H. Liu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps daceti Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps dayiensis (Z.Q. Liang) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps dermapterigena (Z.Q. Liang, A.Y. Liu & M.H. Liu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps desmidiospora J.P.M. Araújo & Saltamachia 2020

Ophiocordyceps diabolica J.P.M. Araújo, H.C. Evans & D.P. Hughes 2020

Ophiocordyceps dipterigena (Berk. & Broome) G.H. Sung, J.M. Sung, Hywel-

Jones & Spatafora 2007

Ophiocordyceps discoideicapitata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps ditmarii (Quél.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps dolichoderi (H.C. Evans & Samson) Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps dovei (Rodway) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps elateridicola (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps elongata (Petch) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps elongatiperitheciata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps elongatistromata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps emeiensis (A.Y. Liu & Z.Q. Liang) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps engleriana (Henn.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps entomorrhiza (Dicks.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps evansii Sanjuan 2015

Ophiocordyceps evdogeorgiae (Koval) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps falcata (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps falcatoides (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps fasciculatistromata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps ferruginosa (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps filiformis G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps flavida Mongkols., Noisrip., Pumiputikul & Luangsa-ard 2021

Ophiocordyceps formicarum (Kobayasi) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps formosana (Kobayasi & Shimizu) Yen W. Wang, S.H. Tsai, Tzean & T.L. Shen 2015

Ophiocordyceps forquignonii (Quél.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps fulgoromorphila Sanjuan 2015

Ophiocordyceps furcata (Aung, J.C. Kang, Z.Q. Liang, Soytong & K.D. Hyde) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps furcicaudata (Z.Q. Liang, A.Y. Liu & M.H. Liu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps gansuensis (K.Y. Zhang, C.J.K. Wang & M.S. Yan) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps geniculata (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps gentilis (Ces.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps geometridicola Tasan., Thanakitp., Khons. & Luangsa-ard 2018

Ophiocordyceps ghanensis (Samson & H.C. Evans) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps glaziovii (Henn.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps globiceps Y.P. Xiao, T.C. Wen & K.D. Hyde 2019

Ophiocordyceps goniophora (Speg.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps gracillima (Kobayasi) Sanjuan & Spatafora 2015

Ophiocordyceps granospora Khons., Luangsa-ard, Thanakitp., Kobmoo & Piasai 2018

Ophiocordyceps gryllotalpae Petch 1942

Ophiocordyceps halabalaensis Luangsa-ard, Ridkaew, Tasan. & Hywel-Jones 2011

Ophiocordyceps hemisphaerica Mafalda-Freire, Reck & Drechsler-Santos 2016

Ophiocordyceps highlandensis Zhu L. Yang & J. Qin 2015

Ophiocordyceps hirsutellae (Petch) D. Johnson, G.H. Sung, Hywel-Jones & Spatafora 2009

Ophiocordyceps hiugensis (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps houaynhangensis Keochanpheng, Thanakitp., Mongkols. & Luangsa-ard 2018

Ophiocordyceps huberiana (Henn.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps humbertii (C.P. Robin) Petch 1935

Ophiocordyceps ichneumonophila (Van Vooren & Audibert) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps insignis (Cooke & Ravenel) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps intricata (Petch) B. Shrestha, G.H. Sung & Spatafora 2015

Ophiocordyceps irangiensis (Moureau) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps issidarum Y.P. Xiao, T.C. Wen, Zha & K.D. Hyde 2017

Ophiocordyceps japonensis (Hara) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps jiangxiensis (Z.Q. Liang, A.Y. Liu & Yong C. Jiang) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps jinggangshanensis (Z.Q. Liang, A.Y. Liu & Yong C. Jiang) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kangdingensis (M. Zang & Kinjo) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps karsti T.C. Wen, Y.P. Xiao & K.D. Hyde 2016

Ophiocordyceps khaoyaiensis Khons., Luangsa-ard, Thanakitp., Kobmoo & Piasai 2018

Ophiocordyceps khokpasiensis Tasan., Noisrip. & Luangsa-ard 2019

Ophiocordyceps khonkaenensis Tasan., Thanakitp. & Luangsa-ard 2019

Ophiocordyceps kimflemingiae Araújo, H.C. Evans & D.P. Hughes 2018

Ophiocordyceps kniphofioides (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kniphofioides var. dolichoderi (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kniphofioides var. kniphofioides (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kniphofioides var. monacidis (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kniphofioides var. ponerinarum (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps kobayasii Mongkols., Thanakitp., Luangsa-ard & Hywel-Jones 2020

Ophiocordyceps koningsbergeri (Penz. & Sacc.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps konnoana (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps koreana G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps krachonicola Tasan., Thanakitp. & Luangsa-ard 2020

Ophiocordyceps lachnopoda (Penz. & Sacc.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps lacrimoidis Mafalda-Freire, Reck & Drechsler-Santos 2016

Ophiocordyceps lanpingensis Hong Yu bis & Zi H. Chen 2013

Ophiocordyceps laojunshanensis Ji Y. Chen, Y.Q. Cao & D.R. Yang 2011

Ophiocordyceps larvarum (Westwood) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Ophiocordyceps larvicola (Quél.) Van Vooren 2009

Ophiocordyceps liangshanensis (M. Zang, D.Q. Liu & R.Y. Hu) H. Yu, Y. Wang, Y.D. Dai, Zhu L. Yang & Y.B. Wang 2021

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Hirsutella crinita Z.Q. Liang 2006

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Hirsutella ovalispora var. dolichoderi H.C. Evans & Samson 1982

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Purpureocillium Luangsa-ard, Hywel-Jones, Houbraken & Samson 2011

Purpureocillium atypicola (Yasuda) Spatafora, Hywel-Jones & Luangsa-ard 2015

Purpureocillium lavendulum Perdomo, Dania García, Gené, Cano & Guarro 2013

Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson 2011

Purpureocillium roseum Calvillo & Raymundo 2020

Purpureocillium sodanum Papizadeh, Soudi, Wijayaw., Shahz. Faz. & K.D. Hyde 2016

Purpureocillium takamizusanense (Kobayasi) S. Ban, Azuma & Hiroki Sato 2015

Tolypocladium W. Gams 1971

Tolypocladium album (W. Gams) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium amazonense Gazis, Skaltsas & P. Chaverri 2014

Tolypocladium capitatum (Holmsk.) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium cylindrosporum W. Gams 1971

Tolypocladium delicatistipitatum (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium dujiaolongae Y.P. Cao & C.R. Li 2018

Tolypocladium endophyticum Gazis, Skaltsas & P. Chaverri 2014

Tolypocladium extinguens Samson & Soares 1984

Tolypocladium flavonigrum Noisrip., Tasan., Khons. & Luangsa-ard 2020

Tolypocladium fractum (Mains) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium fumosum Ruszk.-Mich., J. Pawłowska & Wrzosek 2017

Tolypocladium geodes W. Gams 1971

Tolypocladium guangdongense (T.H. Li, Q.Y. Lin & B. Song) V. Papp 2017

Tolypocladium inflatum W. Gams 1971

Tolypocladium inegoense (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium intermedium (S. Imai) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium intermedium f. intermedium (S. Imai) C.A. Quandt, Kepler &

Spatafora 2014

Tolypocladium intermedium f. michinokuense (Kobayasi & Shimizu) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium japonicum (Lloyd) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium jezoense (S. Imai) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium lignicola G.L. Barron 1983

Tolypocladium longisegmentatum (Ginns) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium microsporum (Jaap) Bissett 1983

Tolypocladium minazukiense (Kobayasi & Shimizu) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium miomoteanum (Kobayasi & Shimizu) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium niveum (O. Rostr.) Bissett 1983

Tolypocladium nubicola Bissett 1983

Tolypocladium ophioglossoides (J.F. Gmel.) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium ophioglossoides f. album (Kobayasi & Shimizu ex Y.J. Yao) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium ophioglossoides f. cuboides (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium ophioglossoides f. ophioglossoides (J.F. Gmel.) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium ovalisporum (C. Möller & W. Gams) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium paradoxum (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium pustulatum (Bills, Polishook & J.F. White) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium ramosum (Teng) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium rouxii (Cand.) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium sinense C. Lan Li 1986

Tolypocladium szemaoense (M. Zang) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium tenuisporum (Mains) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium terricola J. Weiser, Matʼha & Jegorov 1991

Tolypocladium toriharamontanum (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium trigonosporum G.L. Barron 1981

Tolypocladium tropicale Gazis, Skaltsas & P. Chaverri 2014

Tolypocladium tundrense Bissett 1983

Tolypocladium valliforme (Mains) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium valvatistipitatum (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

Tolypocladium virens (Kobayasi) C.A. Quandt, Kepler & Spatafora 2014

3.3.2 Phylogenetic Analyses

3.3.2.1 Backbone tree of the Ophiocordycipitaceae

This backbone tree of Ophiocordycipitaceae comprises 466 taxa (including the 106 newly collected taxa) analyzed herein and their accession numbers (Figure 3.1). This paper analyzed the final dataset containing 4,823 bp from six loci genes, including 831 bp for LSU, 488 bp for ITS, 965 bp for SSU, 914 bp for TEF, 650 bp for RPB1, and 971 bp for RPB2. Moreover, the matrix had 3,292 distinct patterns, 2,158 parsimony-informative, 482 singleton sites, and 2,183 constant sites. This paper presented the best-scoring IQ tree as -130703.624. The respective partition best-fit models were TIM+F+I+G4 for LSU and RPB1, TIM2+F+I+G4 for ITS and TEF, TIM3e+I+G4 for SSU and TN+F+I+G4 for RPB2. The final RAxML analysis optimization likelihood value was -130703.234. This paper further used the GTR+I+G model to LSU, ITS, TEF, RPB1 and RPB2, SYM+I+G model to SSU for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 160,000,000 generations, sampling the trees every 1,000th generation, thus obtaining 160,001 trees. It discarded the first 20% of trees (32,000) because they represented the burn-in phase of the analyses while utilizing the remaining (128,001) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

3.3.2.2 *Ophiocordyceps*, *Hirsutella* and *Hymenostilbe* phylogeny

This phylogenetic tree of *Ophiocordyceps*, *Hirsutella* and *Hymenostilbe* comprises 440 taxa (including the 80 newly collected taxa) analyzed herein and their accession numbers (Figure3.2). The alignment contained 4,565 bp from six loci, including 818 bp for LSU, 460 bp for ITS, 965 bp for SSU, 880 bp for TEF, 620 bp for RPB1, and 822 bp for RPB2. Furthermore, the matrix had 2,697 distinct patterns, 1,850 parsimony-informative, 383 singleton sites, and 2,332 constant sites. This paper presented the IQ tree with the best score as -87464.989. The respective partition best-fit models were: TN+F+I+G4 for LSU and RPB1, HKY+F+I+G4 for ITS, TIM3e+I+G4 for SSU, TIM2+F+I+G4 for TEF, and TIM3+F+I+G4 for RPB2. Based on RAxML analysis, the final optimization likelihood value was -88702.481188. Bayesian analysis used the GTR+I+G model for the LSU, ITS, TEF, RPB1, RPB2, and SYM+I+G models for SSU based on MrModeltest 2.3 from the MrMTgui platform. This paper ran simultaneous Markov chains for 110,000,000 generations, sampling the trees every 1000th generation, thus obtaining 110,001 trees. It discarded the first 20% of trees (22,000) because they represented the burn-in phase of the analyses while using the remaining trees (88,001) for calculation posterior probabilities in the majority rule consensus tree. The critical value for the topological convergence diagnostic was 0.01. Moreover, by following this method, it generated three phylogenetic trees for each genus.

3.3.2.3 *Drechmeria* phylogeny

This phylogenetic tree of *Drechmeria* comprises 13 taxa (including the 2 newly collected taxa) analysed herein and their accession numbers. This paper analyzed the final dataset containing 3,127 bp from four loci genes, including 494 bp for ITS, 488 bp for LSU, 923 bp for SSU, 931 bp for TEF. Moreover, the matrix had 315 distinct patterns, 166 parsimony-informative, 212 singleton sites, and 2,749 constant sites. This paper presented the best-scoring IQ tree as -6985.475. The respective partition best-fit models were TPM2+F+G4 for ITS, TN+F+I for LSU, TIM2e+I for SSU and TN+F+G4 for TEF. The final RAxML analysis optimization likelihood value was -6985.942. This paper further used the GTR+I+G model to ITS, GTR+I model to LSU and SSU, GTR+G model to TEF for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov

chains for 1000,000 generations, sampling the trees every 1,00th generation, thus obtaining 10,001 trees. It discarded the first 25% of trees (2500) because they represented the burn-in phase of the analyses while utilizing the remaining (7,501) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

3.3.2.4 *Harposporium* phylogeny

This phylogenetic tree of *Harposporium* comprises 19 taxa analysed herein and their accession numbers. This paper analyzed the final dataset containing 2,112 bp from three loci genes, including 462 bp for ITS, 770 bp for LSU, 880 bp for SSU. Moreover, the matrix had 255 distinct patterns, 139 parsimony-informative, 106 singleton sites, and 1,867 constant sites. This paper presented the best-scoring IQ tree as -4848.564. The respective partition best-fit models were GTR+G for ITS, GTR+I for LSU and GTR for SSU. The final RAxML analysis optimization likelihood value was -4848.565. This paper further used the GTR+I+G model to ITS, GTR+I model to LSU and SSU, GTR+G model to TEF for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 1000,000 generations, sampling the trees every 1,00th generation, thus obtaining 10,001 trees. It discarded the first 25% of trees (2500) because they represented the burn-in phase of the analyses while utilizing the remaining (7,501) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

3.3.2.5 *Paraisaria* phylogeny

This phylogenetic tree of *Paraisaria* comprises 34 taxa (including the 3 newly collected taxa) analysed herein and their accession numbers. This paper analyzed the final dataset containing 4,459 bp from six loci genes, including 919 bp for SSU, 756 bp for LSU, 840 bp for TEF, 541 bp for RPB1, 940 bp for RPB2 and 454 bp for ITS. Moreover, the matrix had 942 distinct patterns, 703 parsimony-informative, 252 singleton sites, and 3,503 constant sites. This paper presented the best-scoring IQ tree as -14144.692. The respective partition best-fit models were SYM+I for SSU, GTR+I+G for LSU and TEF, GTR+G for RPB1, RPB2, and ITS. The final RAxML analysis optimization likelihood value was -14144.695. This paper further used the GTR+I+G model to ITS, GTR+I model to LSU and SSU, GTR+G

model to TEF for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 275,000 generations, sampling the trees every 1,00th generation, thus obtaining 2,751 trees. It discarded the first 25% of trees (687) because they represented the burn-in phase of the analyses while utilizing the remaining (2,064) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

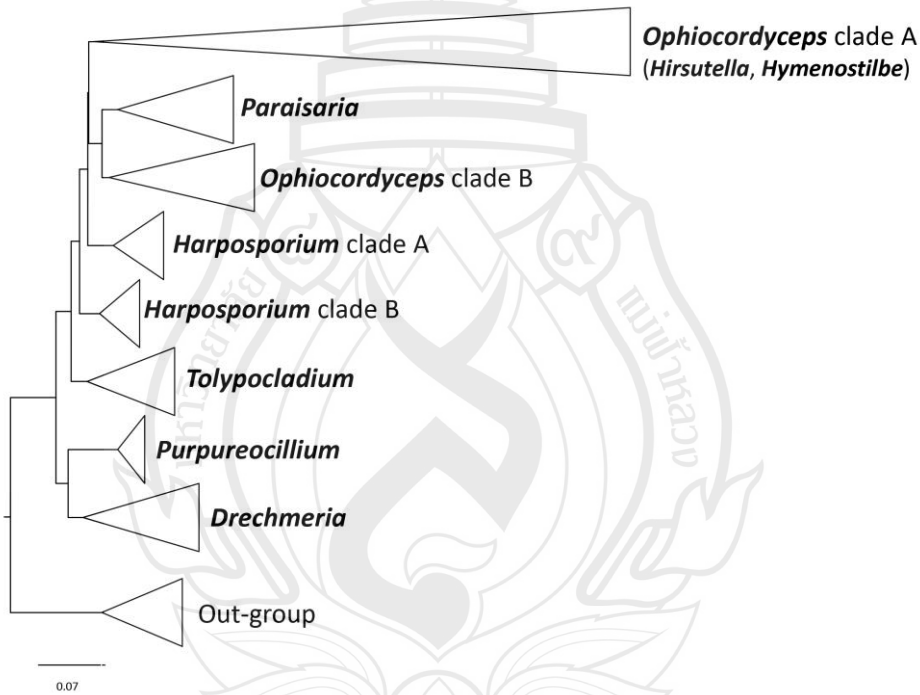
3.3.2.6 *Purpureocillium* phylogeny

This phylogenetic tree of *Purpureocillium* comprises 92 taxa (including the 10 newly collected taxa) analysed herein and their accession numbers. This paper analyzed the final dataset containing 3,243 bp from four loci genes, including 501 bp for ITS, 865 bp for LSU, 1013 bp for SSU, 864 bp for TEF. Moreover, the matrix had 426 distinct patterns, 212 parsimony-informative, 127 singleton sites, and 2,904 constant sites. This paper presented the best-scoring IQ tree as -7153.756. The respective partition best-fit models were HKY+I+G for ITS, GTR+I for LSU, HKY+I for SSU and GTR+G for TEF. The final RAxML analysis optimization likelihood value was -130703.234. This paper further used the GTR+I+G model to LSU, ITS, TEF, RPB1 and RPB2, SYM+I+G model to SSU for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 5,715,000 generations, sampling the trees every 1,00th generation, thus obtaining 57,151 trees. It discarded the first 25% of trees (14287) because they represented the burn-in phase of the analyses while utilizing the remaining (42,864) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.

3.3.2.7 *Tolypocladium* phylogeny

This phylogenetic tree of *Tolypocladium* comprises 87 taxa (including the 18 newly collected taxa) analysed herein and their accession numbers. This paper analyzed the final dataset containing 3,902 bp from five loci genes, including 508 bp for ITS, 1025 bp for SSU, 822 bp for LSU, 904 bp for TEF and 640 bp for RPB1. Moreover, the matrix had 995 distinct patterns, 568 parsimony-informative, 243 singleton sites, and 3,091 constant sites. This paper presented the best-scoring IQ tree as -15218.308. The respective partition best-fit models were HKY+F+I+G4 for ITS,

TNe+I for SSU, TN+F+I+G4 for LSU, TIM+F+I+G4 for TEF, TN+F+G4 for RPB1. The final RAxML analysis optimization likelihood value was -15218.553. This paper further used the GTR+I+G model to ITS, LSU, SSU, GTR+I model to TEF and RPB1 for Bayesian analysis based on MrModeltest 2.3 from the MrMTgui platform. It ran six simultaneous Markov chains for 10,000,000 generations, sampling the trees every 1,00th generation, thus obtaining 100,001 trees. It discarded the first 25% of trees (25,000) because they represented the burn-in phase of the analyses while utilizing the remaining (75,001) for calculation posterior probabilities in the majority rule consensus tree. The critical value for topological convergence diagnostic was 0.01.



Note Backbone schematic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of the family Ophiocordycipitaceae. This backbone tree of Ophiocordycipitaceae comprises 466 taxa (including the 106 newly collected taxa) analyzed.

Figure 3.1 Backbone schematic tree of the family Ophiocordycipitaceae

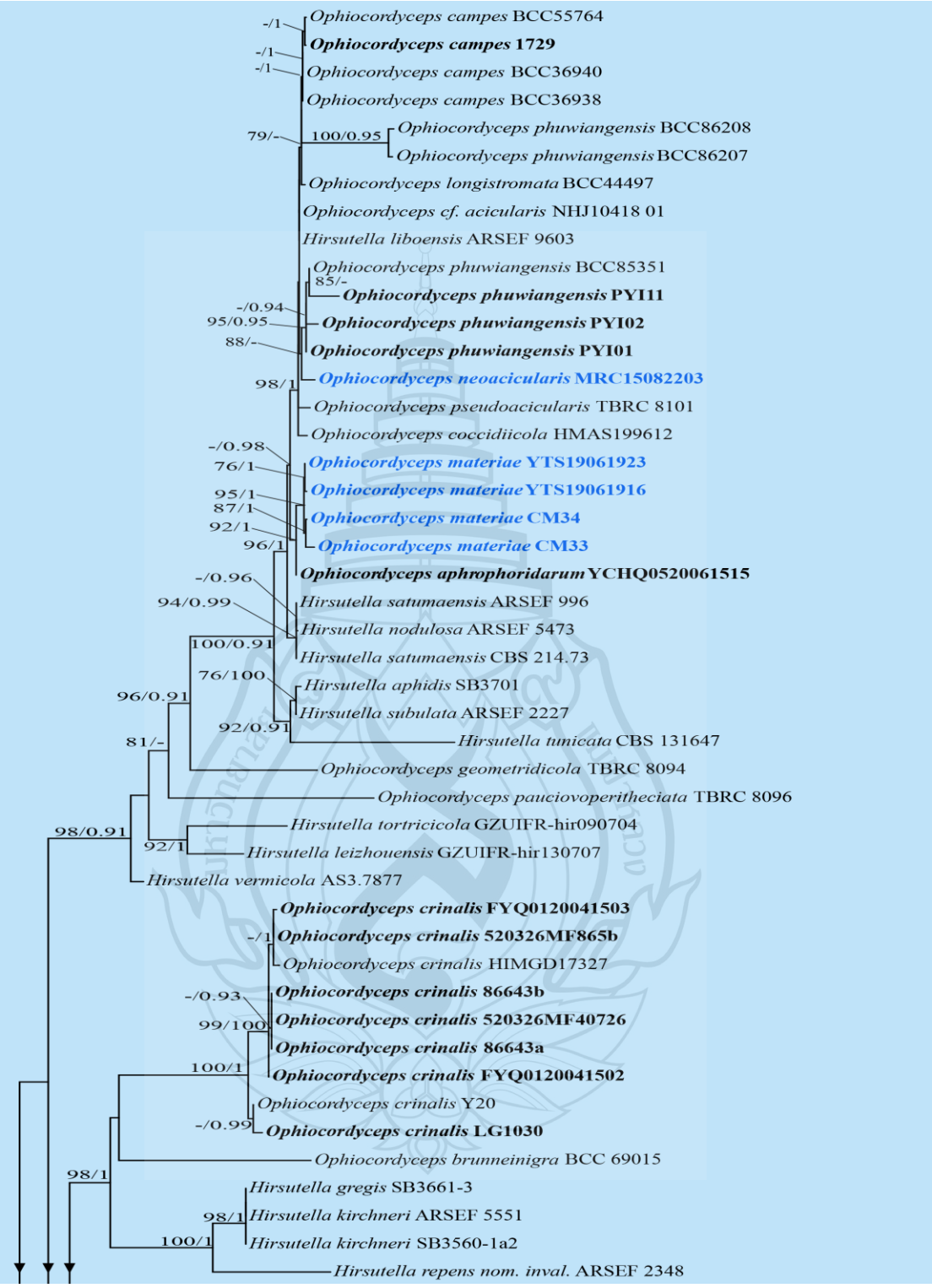


Figure 3.2 Phylogenetic tree from a maximum likelihood analysis of Ophiocordycipitaceae

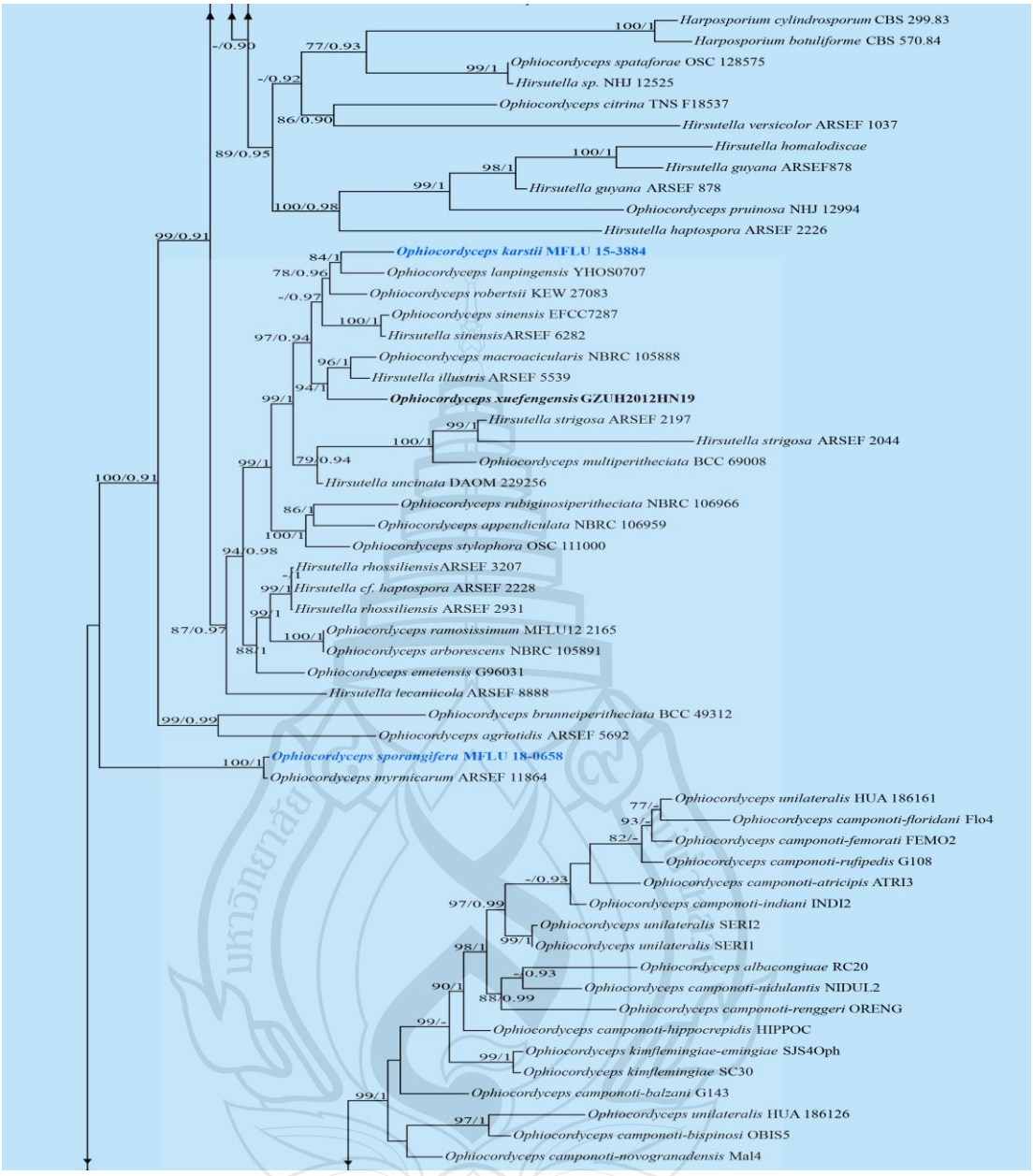


Figure 3.2 (continued)

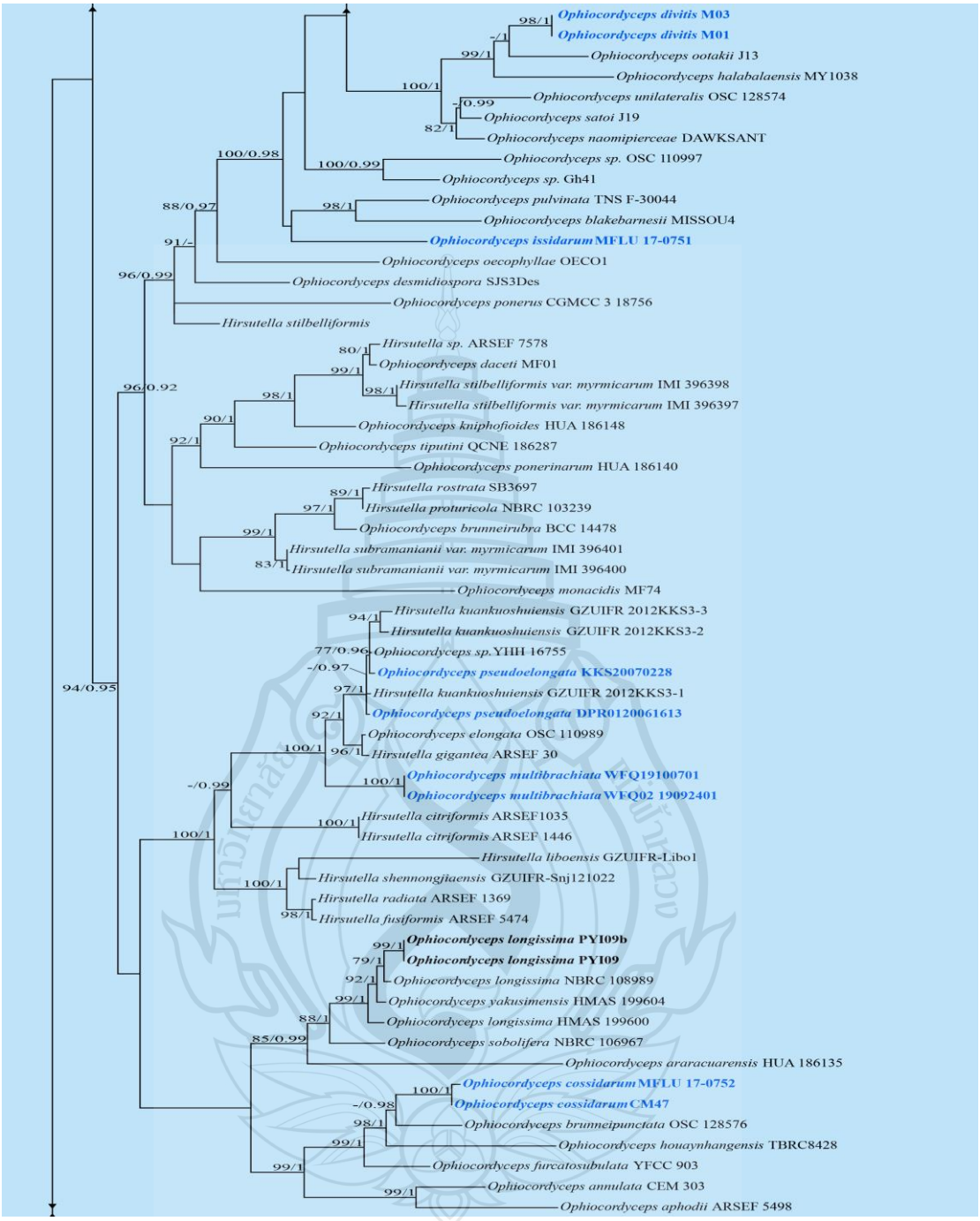


Figure 3.2 (continued)

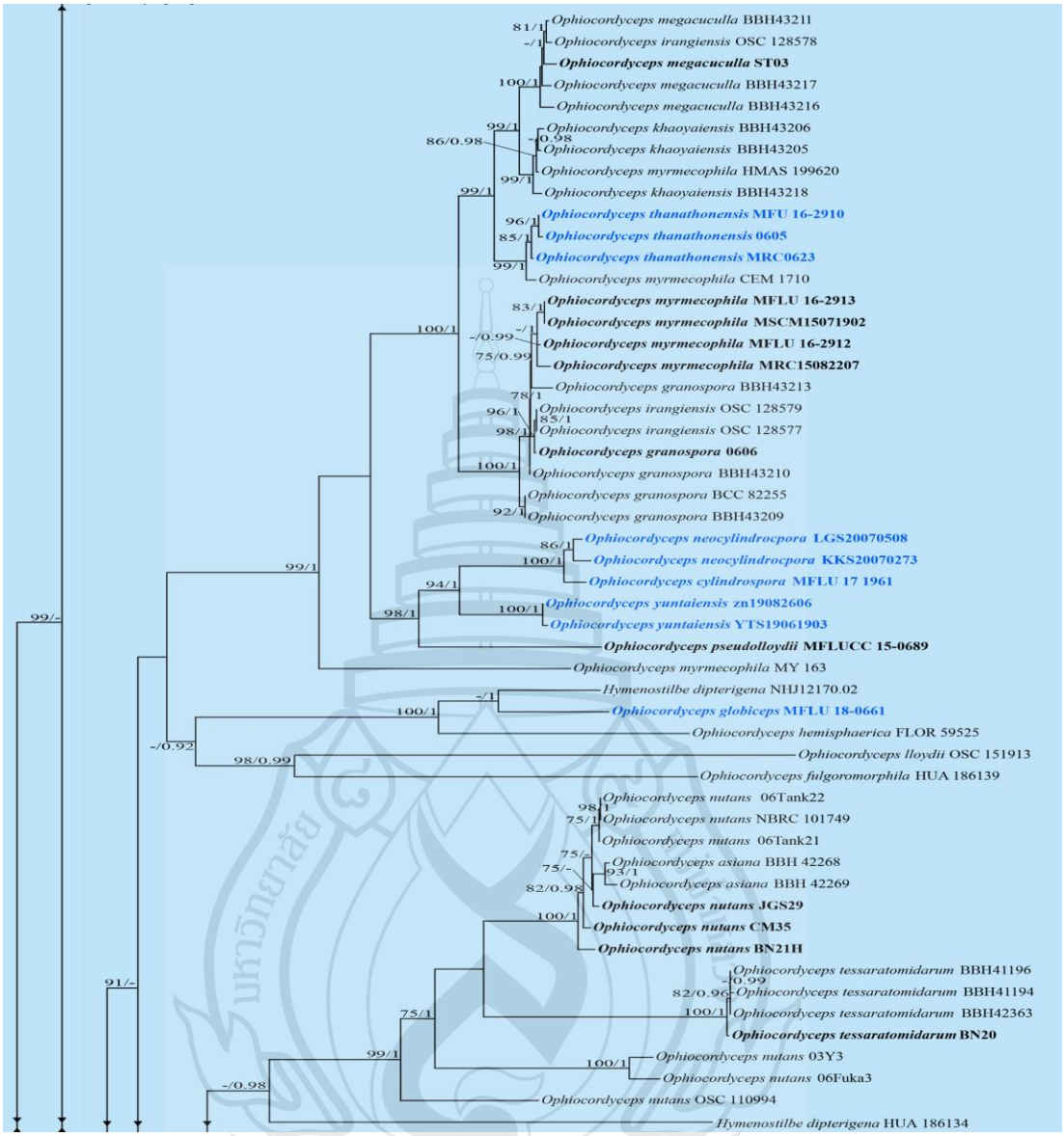


Figure 3.2 (continued)

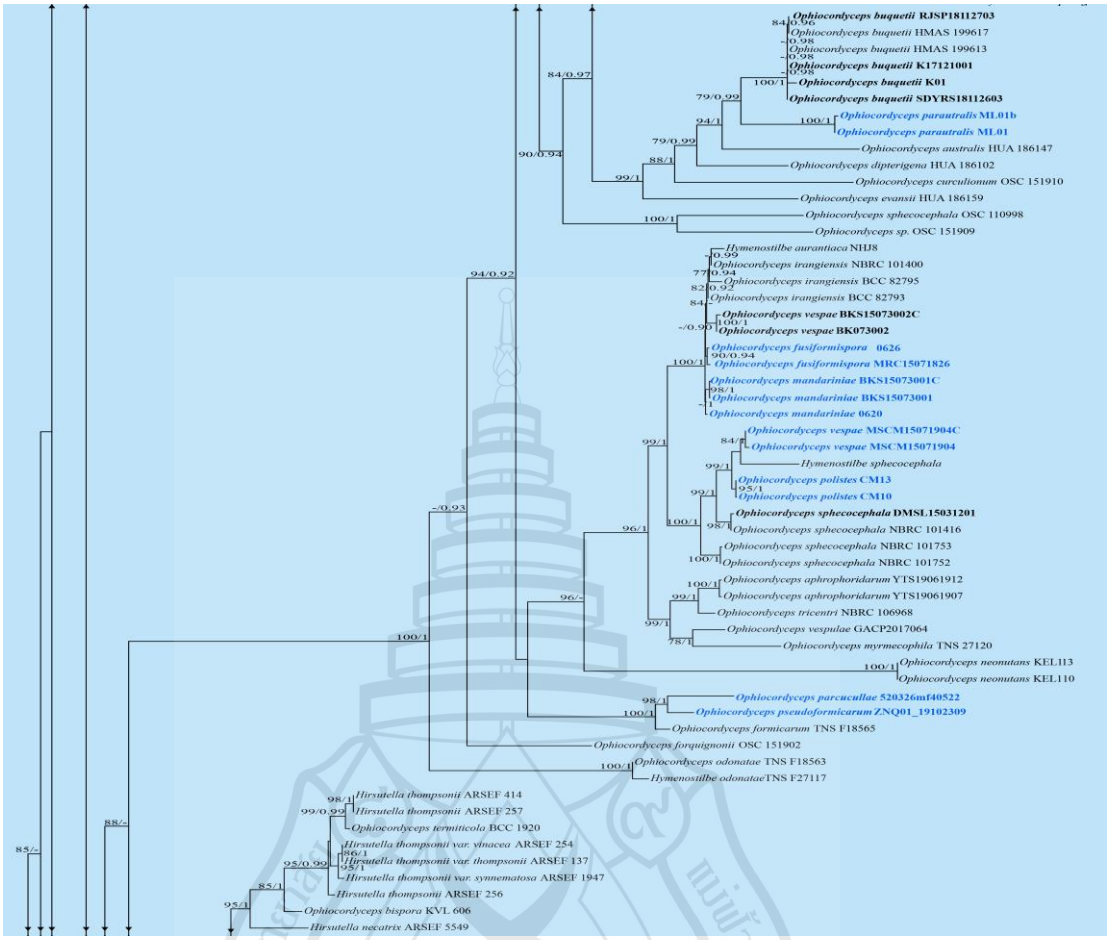


Figure 3.2 (continued)

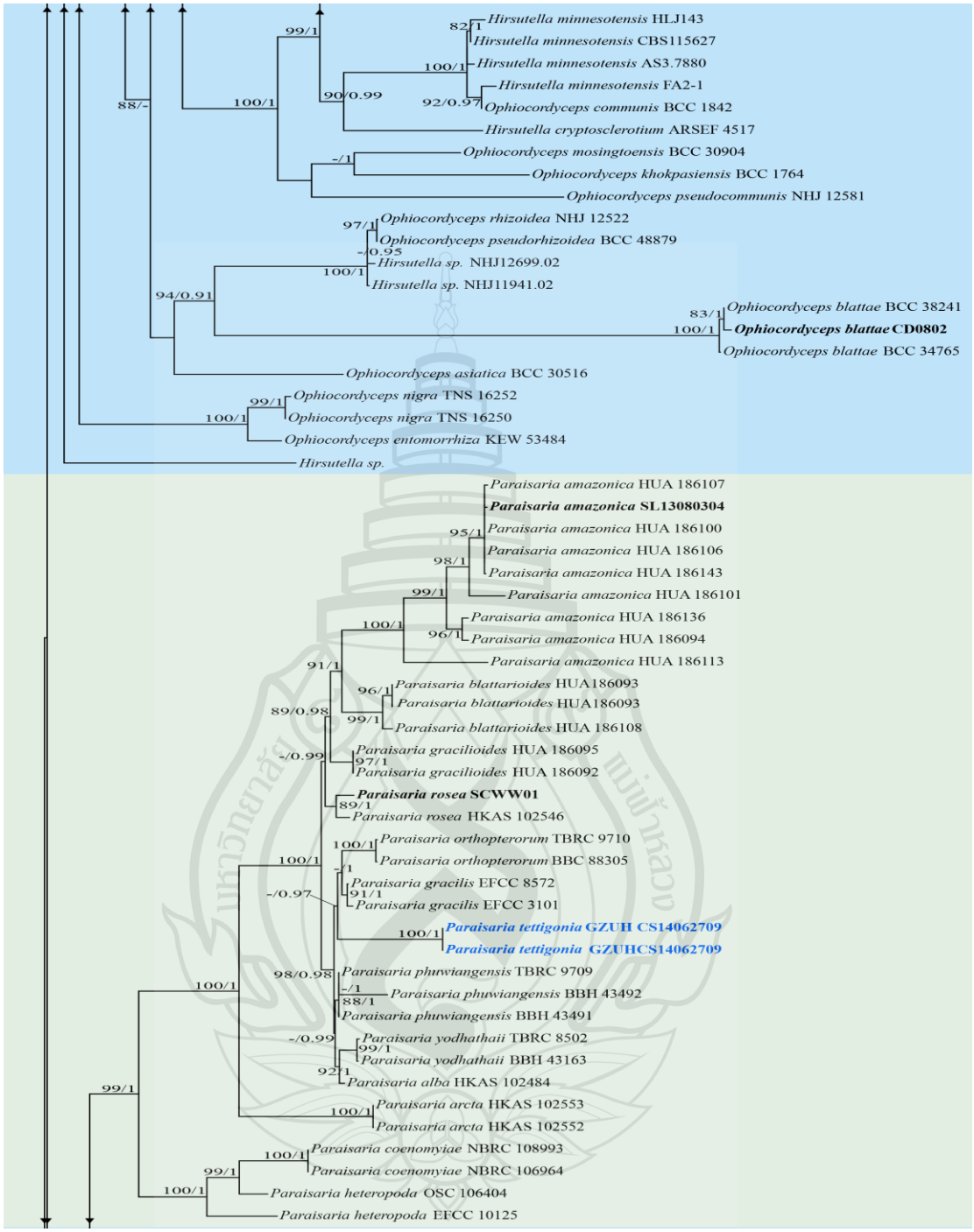


Figure 3.2 (continued)

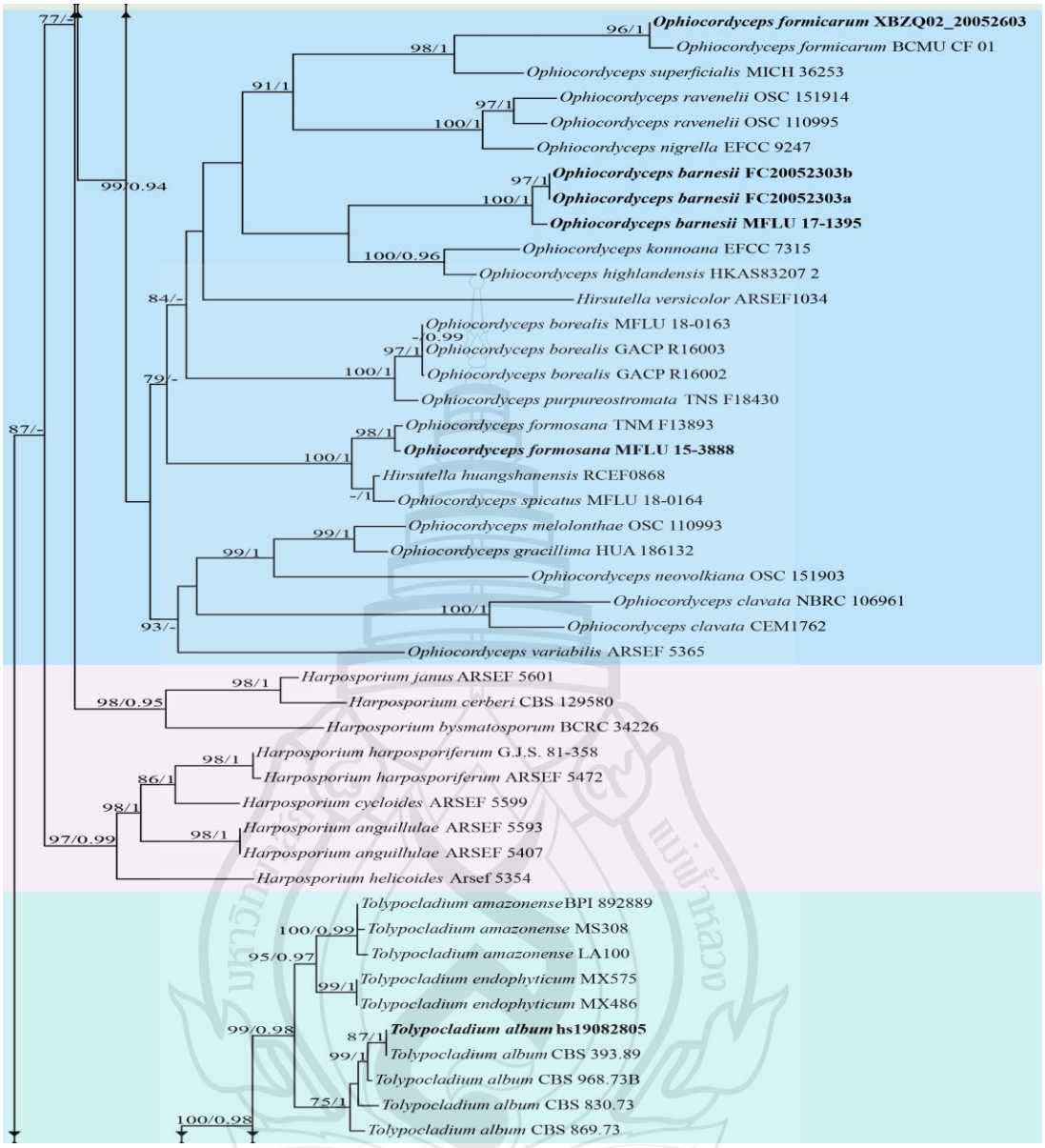


Figure 3.2 (continued)

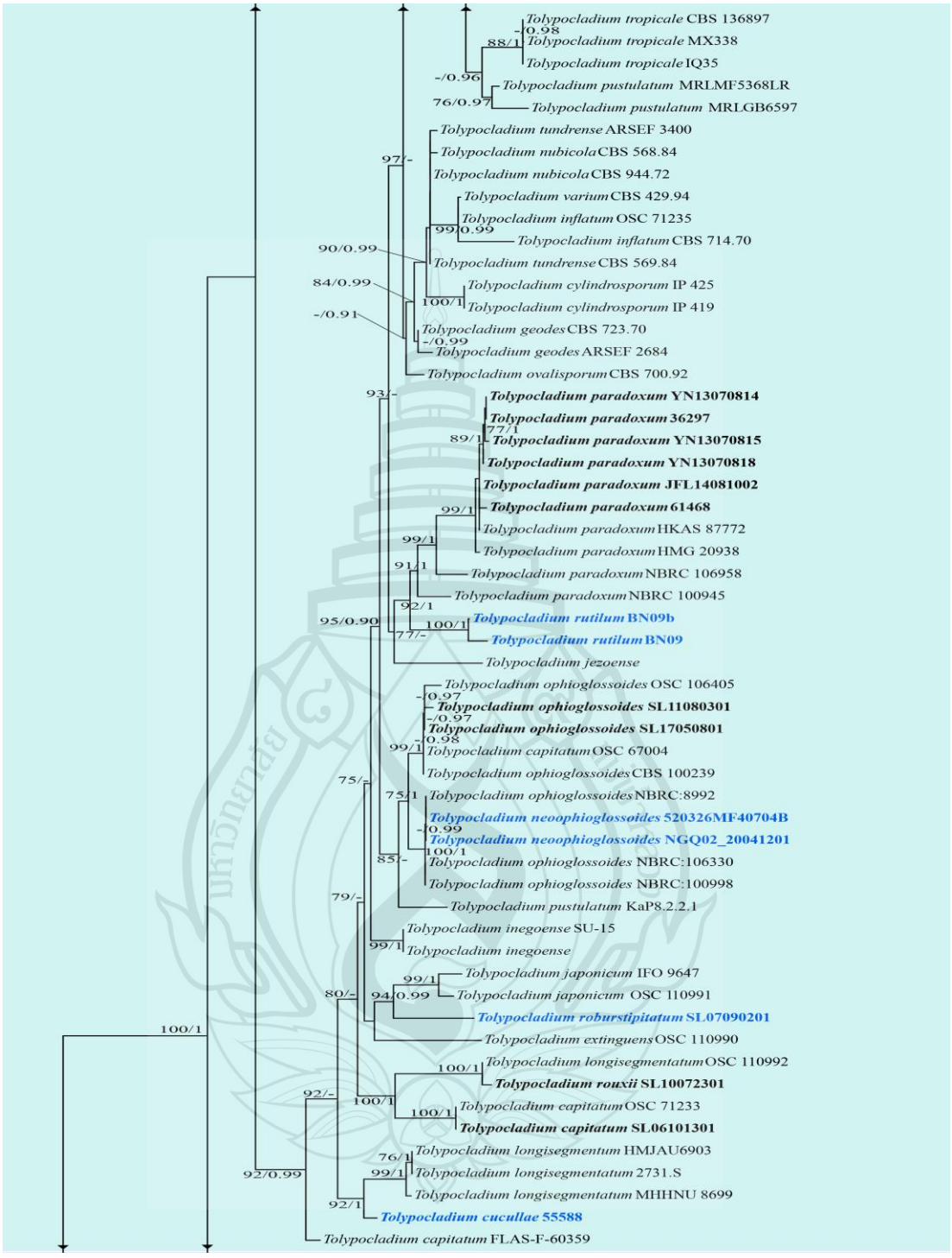
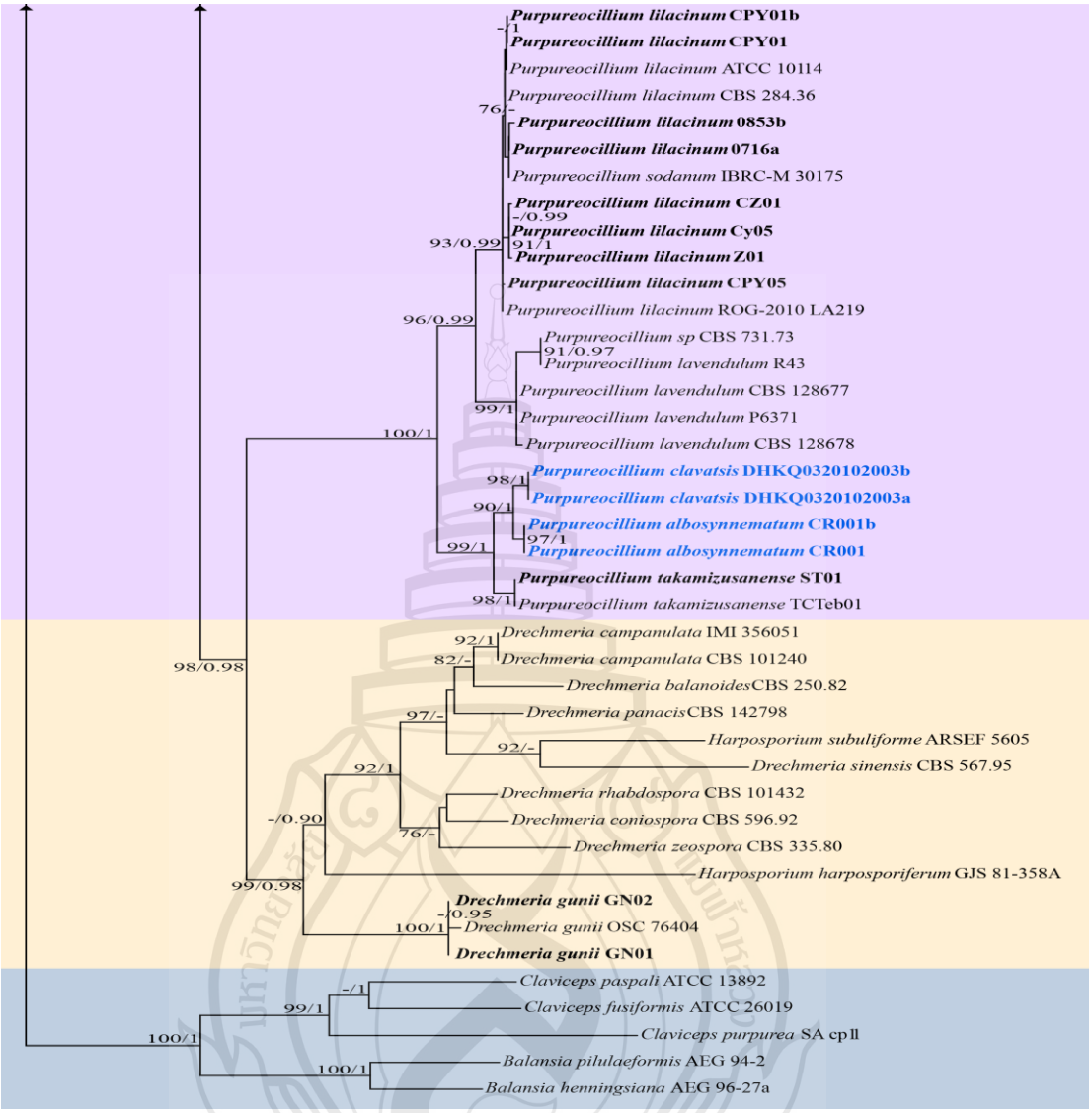


Figure 3.2 (continued)



Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of Ophiocordycipitaceae. 440 taxa (including the 80 newly collected taxa) are analyses in the phylogenetic tree. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.90 are indicated above the nodes. *Claviceps paspali* (ATCC 13892), *Claviceps fusiformis* (ATCC 26019), *Claviceps purpurea* (SA cp 11), *Balansis pilulaeformis* (AEG 94-2), *Balansia henningsiana* (AEG 96-27a) are slected as the outgroup. The new species are indicated in blue. The new collections are indicated in bold.

Figure 3.2 (continued)

3.3.3 Taxonomy

3.3.3.1 Ophiocordycipitaceae

Ophiocordycipitaceae G.H. Sung et al., in Sung et al., *Stud. Mycol.* **57**: 35 (2007)

Index Fungorum: IF 504190; Facesoffungi number: FoF 01315

Parasitic on arthropods, protozoans, rotifers, nematodes, humans, animals and other fungi worldwide. **Sexual morph**: *Stromata* darkly pigmented or rarely brightly coloured, hard, fibrous, pliant or wire, rarely fleshy, usually stipitate, rarely sessile, often with fertile head. *Perithecia* superficial to completely immersed, ordinal or oblique in arrangement. *Asci* unitunicate, cylindrical, rarely fusiform to ellipsoid, usually with thin or thick apical cap. *Ascospores* fasciculate, usually filiform, sometimes slender fusiform, hyaline, multi-septate, disarticulating into secondary spores or not disarticulating. **Asexual morph**: Hyphomycetes. *Synnemata* observed or absent, single or several, simple or branched, usually white, sometimes pigment. *Conidiophores* observed or reduced to sessile conidiogenous cells, erect, lateral or verticillate. *Phialides* (Conidiogenous cells) scattered to crowded, single or cluster, swollen or inflated base with or without one or several short or long tapering neck, sometimes forming two or more than types of phialides. *Conidia* globose or ellipsoid or fusiform or cylindrical or falcate or irregular shape, sometimes forming two or more than two types of conidia, hyaline or pigment, with or without mucus. (Adapted from Mains 1950, Samson and Evans 1975).

Type: ***Ophiocordyceps*** Petch, Trans. Br. mycol. Soc. 16(1): 73 (1931)

Index Fungorum number: IF 3598

Synonymy: *Cordycepioideus* Stifler, Mycologia 33(1): 83 (1941)

Syngliocladium Petch, Trans. Br. mycol. Soc. 17(3): 177 (1932)

Type species: ***Ophiocordyceps blattae*** (Petch) Petch, Trans. Br. mycol. Soc. 16(1): 74 (1931).

Parasitic on arthropods, **Sexual morph**: *Stromata* or subiculum darkly pigmented or rarely brightly colored, hard, fibrous, pliant to wiry, rarely fleshy, often with perithecial apices or lateral pads. *Perithecia* superficial to completely immersed, ordinal or oblique in arrangement. *Peridium* 2 or 3 layers. *Asci* unitunicate, cylindrical, fusiform to ellipsoid, usually with thickened and almost bulbous ascus apex.

Ascospores fasciculate, usually filiform, hyaline, multi-septate, disarticulating into part-spores or not disarticulating. **Asexual morph**: *Hirsutella*-like or *Hymenostible*-like (See below).

Notes: *Ophiocordyceps* was proposed by Petch (1931) to accommodate four species. It was emended as one of the three subgenera of *Cordyceps*, including Subg. *Ophiocordyceps*, Subg. *Eucordyceps* and Subg. *Neocordyceps* (Kobayasi, 1941). *Ophiocordyceps* has been formally recognized as the type of genus of *Ophiocordycipitaceae* (Sung et al., 2007). The oldest name in the Ophiocordycipitaceae clade is *Sorosporella*, a synonym of *Syngliocladium*. *Sorosporella* was suppressed (Quandt et al., 2014), while *Syngliocladium* was previously treated with respect to the second oldest name *Hirsutella* (Evans & Samson, 1982). According to morphological analyses and economic value, *Ophiocordyceps* should be protected over the other names (Sung et al., 2007). The genus is characterised by infecting insects and producing darkly pigmented, hard, fibrous, pliant to wiry, stipitate or sessile stromata, superficial to completely immersed perithecia, with ascospores disarticulating into secondary spores or non-disarticulating (Sung et al., 2007). The asexual morphs of this genus are members of *Hirsutella*, *Hymenostible*, *Paraisaria* and *Syngliocladium* (Sung et al., 2007).

Ecological and economic significance: Many species in *Ophiocordyceps* are important economic fungi and *Ophiocordyceps* has significant economic value and is collected throughout the Himalaya's with great value to the local populations. More than ten kinds of nucleoside compounds including adenine, adenosine, cordycepin, uracil, uridine, guanidine, guanosine, hypoxanthine, inosine, thymine, thymidine and deoxyuridine were isolated from *Ophiocordyceps sinensis*, which has anti-cancer, anti-microbial, anti-plasmodium, antioxidant and immune modulation, activities (Zhang et al., 2012; Yu et al., 2012; Xiang et al., 2014; Reis et al., 2017).

Distribution: Australia, Austria, Brazil, Canada, China, Denmark, Finland, France, Germany, Japan, South Korea, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Russia, United Kingdom, United States (Lloyd, 1920, Imai, 1929, 1934; Petch, 1937; Kobayasi, 1939; Kobayasi & Shimizu, 1960, 1963, 1982; Mains, 1957; Gams 1971, 1980; Candoussau, 1976; Barron, 1981; Fries & Hoffmann, 1982; Bissett, 1983; Samson & Soares, 1984; Ginns, 1988; Weiser et al., 1991; Moller & Gams,

1993; Hodge, 1996; Zang, 2001; Sato et al., 2010; Gazis et al., 2014; Crous et al., 2017; Li et al., 2018)

Conclusion: 4 reference specimens are illustrated; 7 new species are described; 1 new combination; 1 new records; 3 revised species.

Type species: *Ophiocordyceps blattae* (Petch) Petch, Trans. Br. mycol. Soc. 16(1): 74 (1931).

Synonymy: *Cordyceps blattae* Petch, Trans. Br. mycol. Soc. 10(1-2): 35 (1924)

Hymenostilbe ventricosa Hywel-Jones, Mycol. Res. 99(10): 1201 (1995)

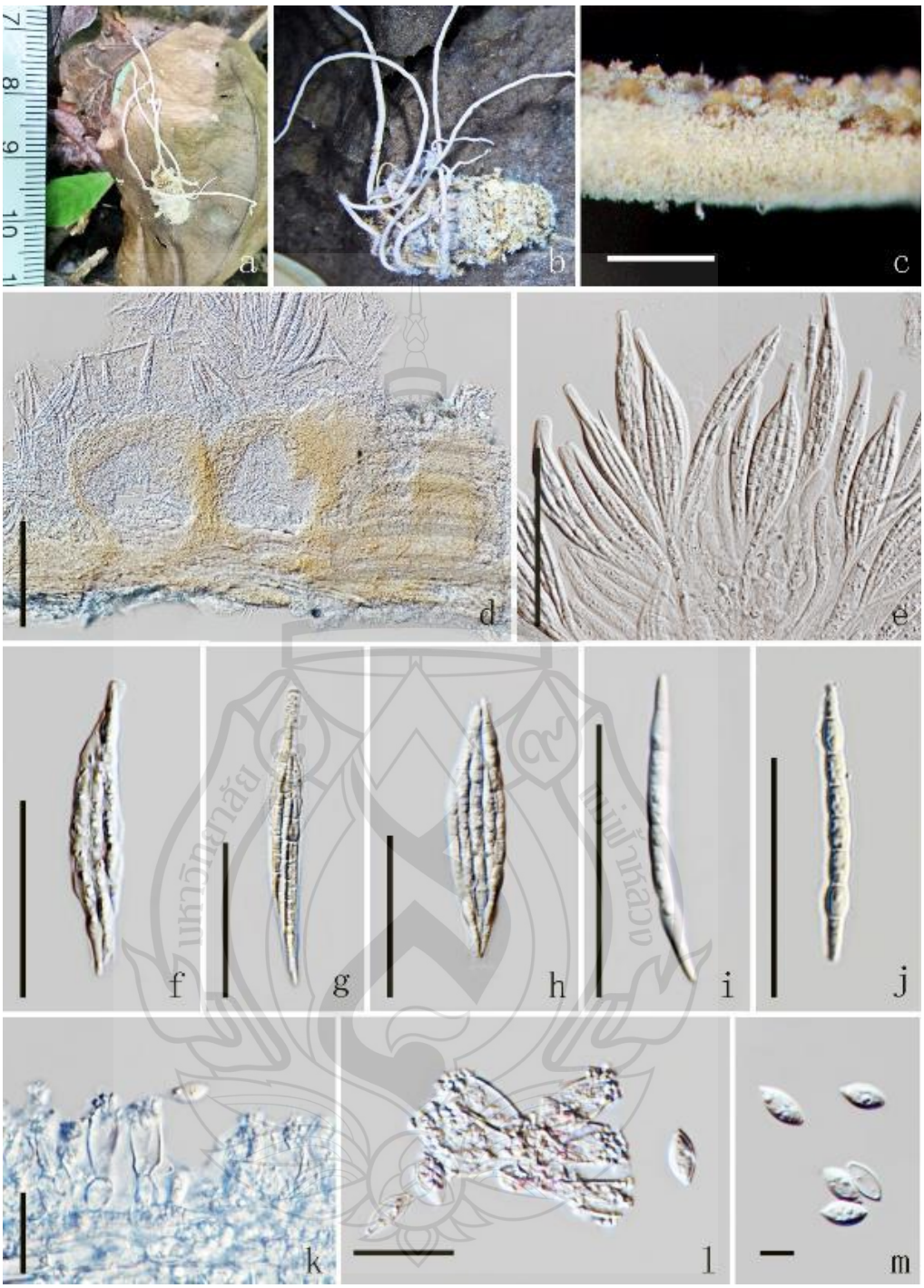
Parasitism on cockroach (Blattodea, Blattellidae), collected from the underside of leaves litter. **Sexual morph:** *Host* 7 mm long, 4 mm wide, with white hyphae on the surface. *Stromata* 0.5–2.5 cm long, 0.1–0.5 mm wide, single to multiple, stipitate, cylindrical, white to light grey, arising from the joint of the host body. *Fertile head* 1–2 cm long, 0.1–0.5 mm wide, cylindrical, white to light grey, with asexual morph at the apex. *Perithecia* 123–162 × 103–112 µm ($\bar{x}$ = 142 × 108 µm, n = 30), flask-shaped, semi-immersed. *Peridium* 14–19 mm ($\bar{x}$ = 17 µm, n = 60) wide, hyaline, two layers, outer layer textura prismatica, inner layer textura angularis. *Asci* 80–100 × 11–16 µm ($\bar{x}$ = 90 × 14 µm, n = 60), 8-spored, hyaline, narrow cylindrical to fusiform, with a thin apex. *Apical cap* 1.2–1.6 × 2.8–3.8 µm ($\bar{x}$ = 1.4 × 3.3 µm, n = 60), hyaline, thin. *Ascospores* 51–60 × 2.5–3.8 µm ($\bar{x}$ = 56 × 3.2 µm, n = 90), slender fusiform, aseptate, not breaking into part-spores. **Asexual morph:** Hyphomycetes. *Synnemata* 0.5–2.5 cm long, 0.1–0.5 mm wide, single to multiple, cylindrical, white to light grey, arising from the joint of the host body. *Conidiophore* 20–25 µm wide ($\bar{x}$ = 23 µm, n = 60), usually simple, unbranched, septate, hyaline, bearing numerous conidia. *Metula* 4–7 × 4–6 µm ($\bar{x}$ = 6 × 5 µm, n = 60), hyaline, cylindrical, smooth. *Phialide* 13–17 × 7–9 µm ($\bar{x}$ = 15 × 8 µm, n = 60), polyblastic, hyaline, cylindrical to ovoid. *Conidia* 8–12 × 4–6 µm ($\bar{x}$ = 10 × 5 µm, n=60), 1-celled, hyaline, ovoid with acute ends, simultaneously developing along the tip of the phialide.

Material examined: Thailand, Chiang Mai, on dead cockroach (Blattodea, Blattellidae), 18 August 2017, Deping Wei, CD08.

Notes: The holotype of *Ophiocordyceps blattae* from Sri Lanka was lost, and there was not any reference specimen designated until Luang-sar et al. (2020)

reported a new collection from Thailand. We obtained one a new collection with the sexual and asexual states from Thailand. We provide a description of it asexual morph and additional molecular data for it.

In addition, a comparison of the morphologic traits between *Hymenostilbe ventricosa* and *Ophiocordyceps blattae* indicates that *Hymenostilbe ventricosa* should be a synonym of *Ophiocordyceps blattae*. *Hymenostilbe ventricosa* was introduced as an asexual morph species that parasitizes on species of cockroach nymph (Orthoptera, Blattidae) in Thailand (Hywel-Jones et al., 1995). No molecular data was provided (Hywel-Jones et al. 1995). *Hymenostilbe ventricosa* traits include the production of several synnemata, polyblastic (11.3–20.0 × 4.5–6.0 μm) conidiogenous cells (phialide) and solitary, ventricose, (10.0–14.0 × 3.7–5.3 μm) conidia (Hywel-Jones et al., 1995). A new collection of *Ophiocordyceps blattae* showed morphological traits similar to those of *Hymenostilbe ventricosa*). Thus, in this study, *Hymenostilbe ventricosa* is synonymized under *Ophiocordyceps blattae*.



Note a Habitat. b Overview of the host and stromata. c Part of the stroma. d Vertical section of stroma. e–h Asci. i, j Ascospores. k, l Conidiophores. m Conidia. Scale Bars: c = 200 µm, d, e = 100 µm, f–j = 50 µm, k, l = 20 µm, m = 5 µm.

Figure 3.3 Morphology of *Ophiocordyceps blattae*

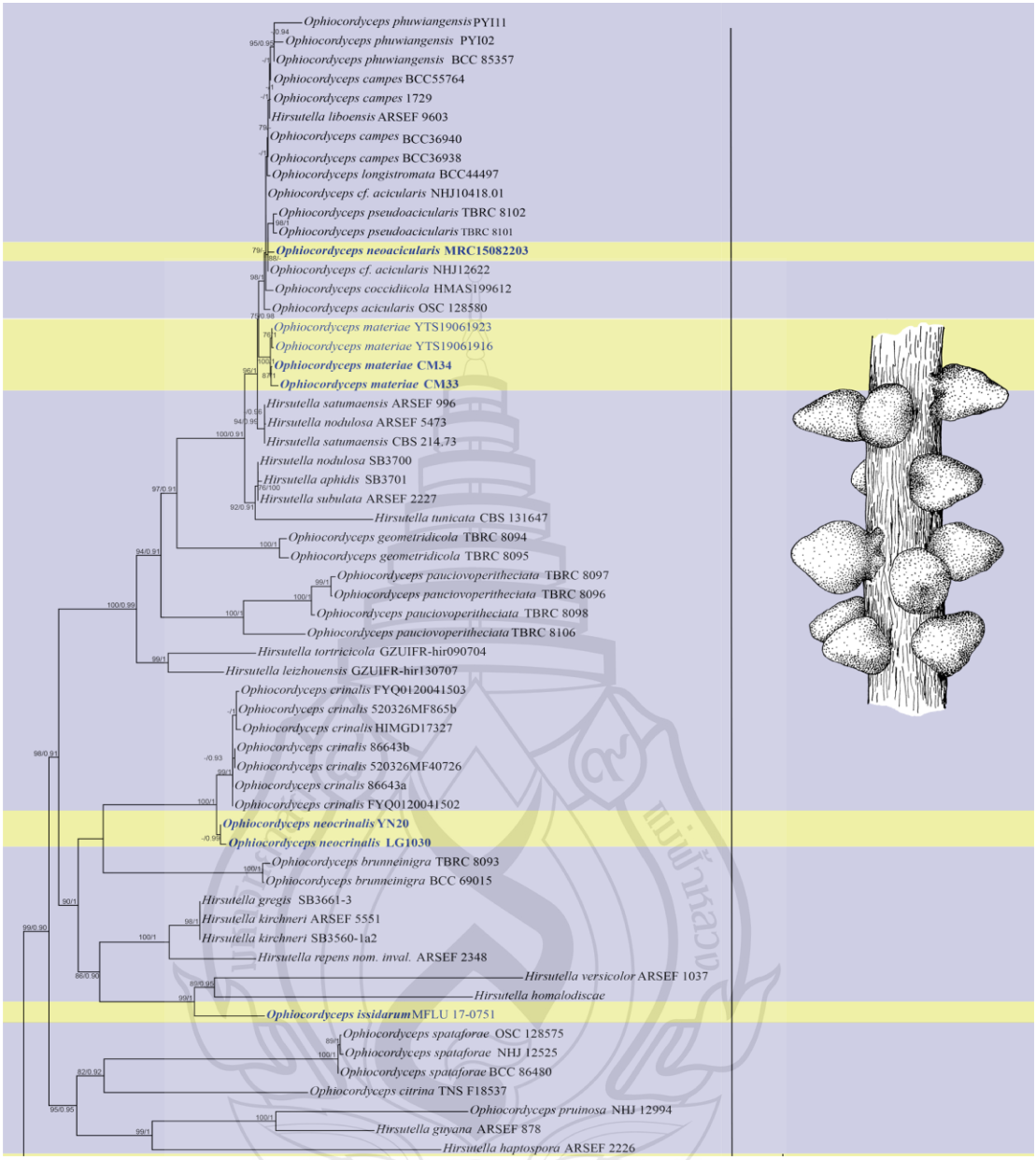


Figure 3.4 Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of *Ophiocordyceps*

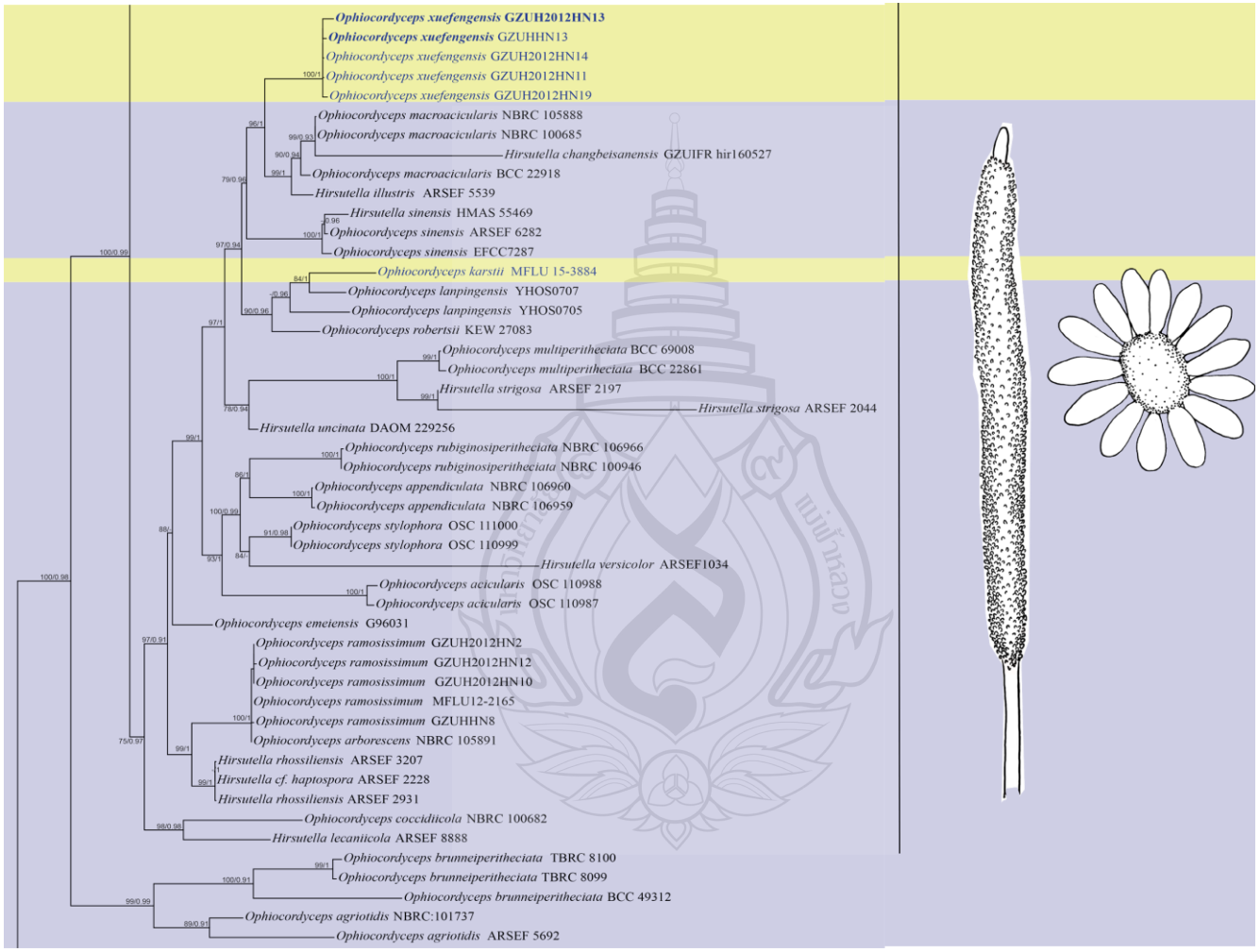


Figure 3.4 (continued)

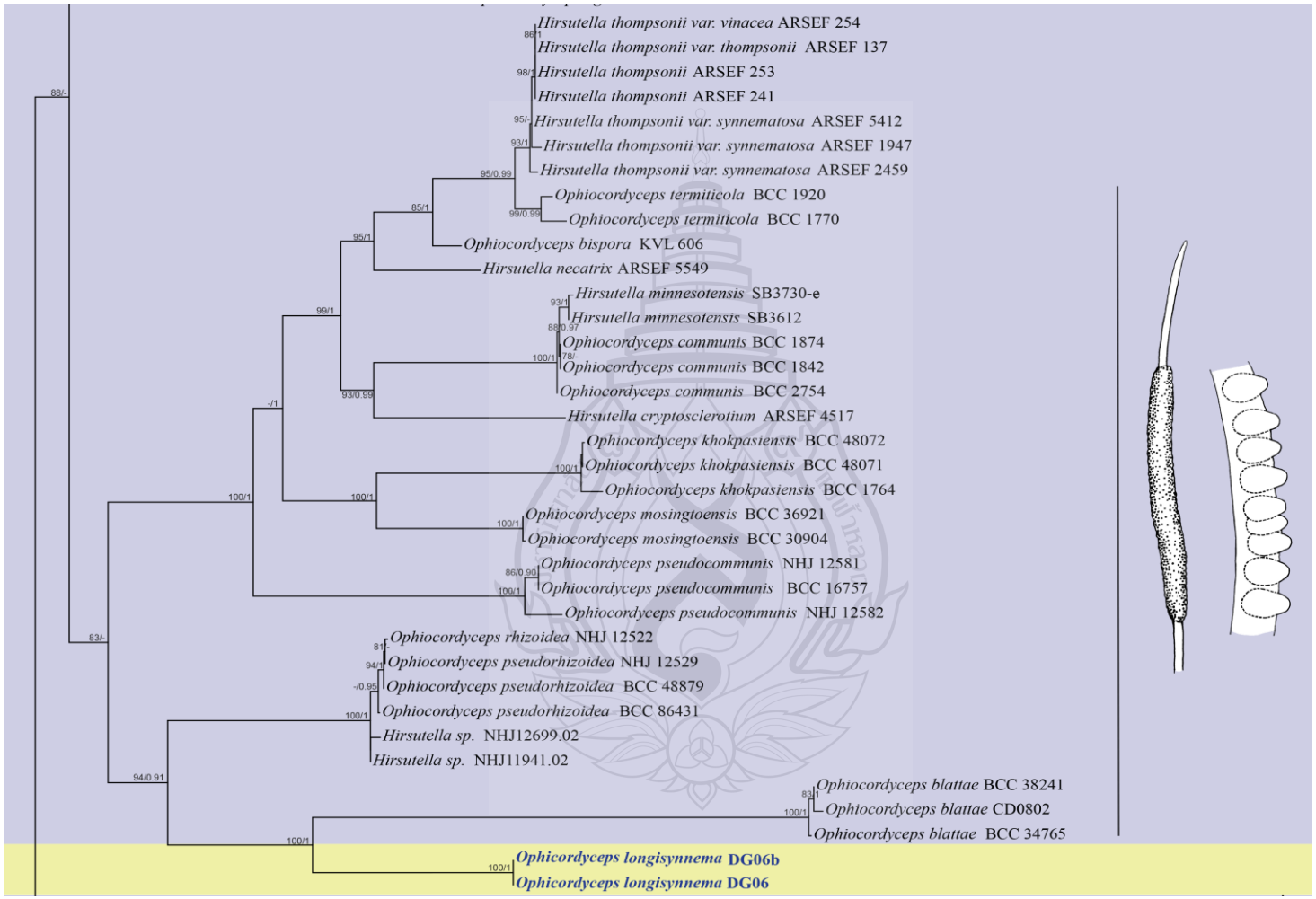


Figure 3.4 (continued)

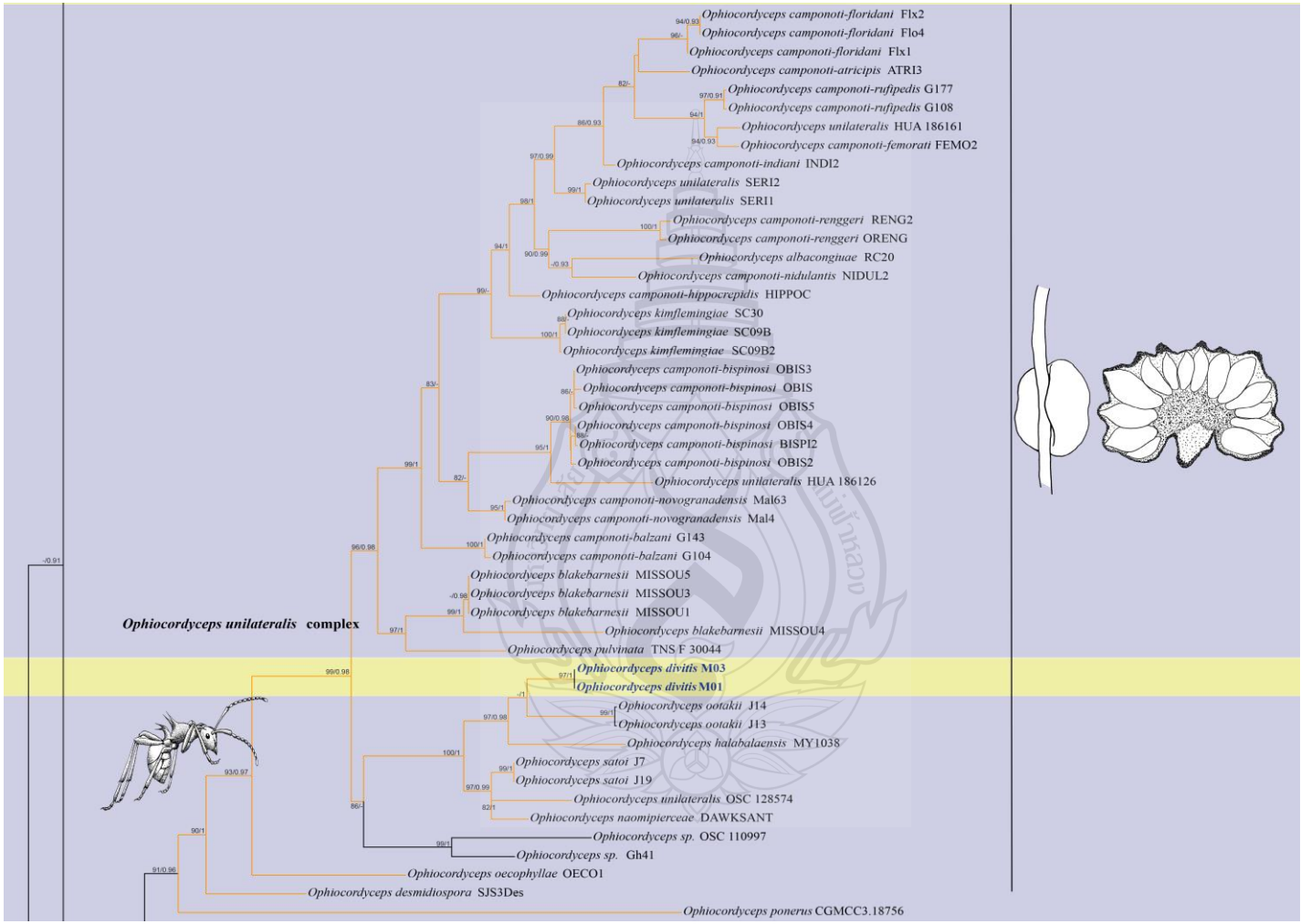


Figure 3.4 (continued)

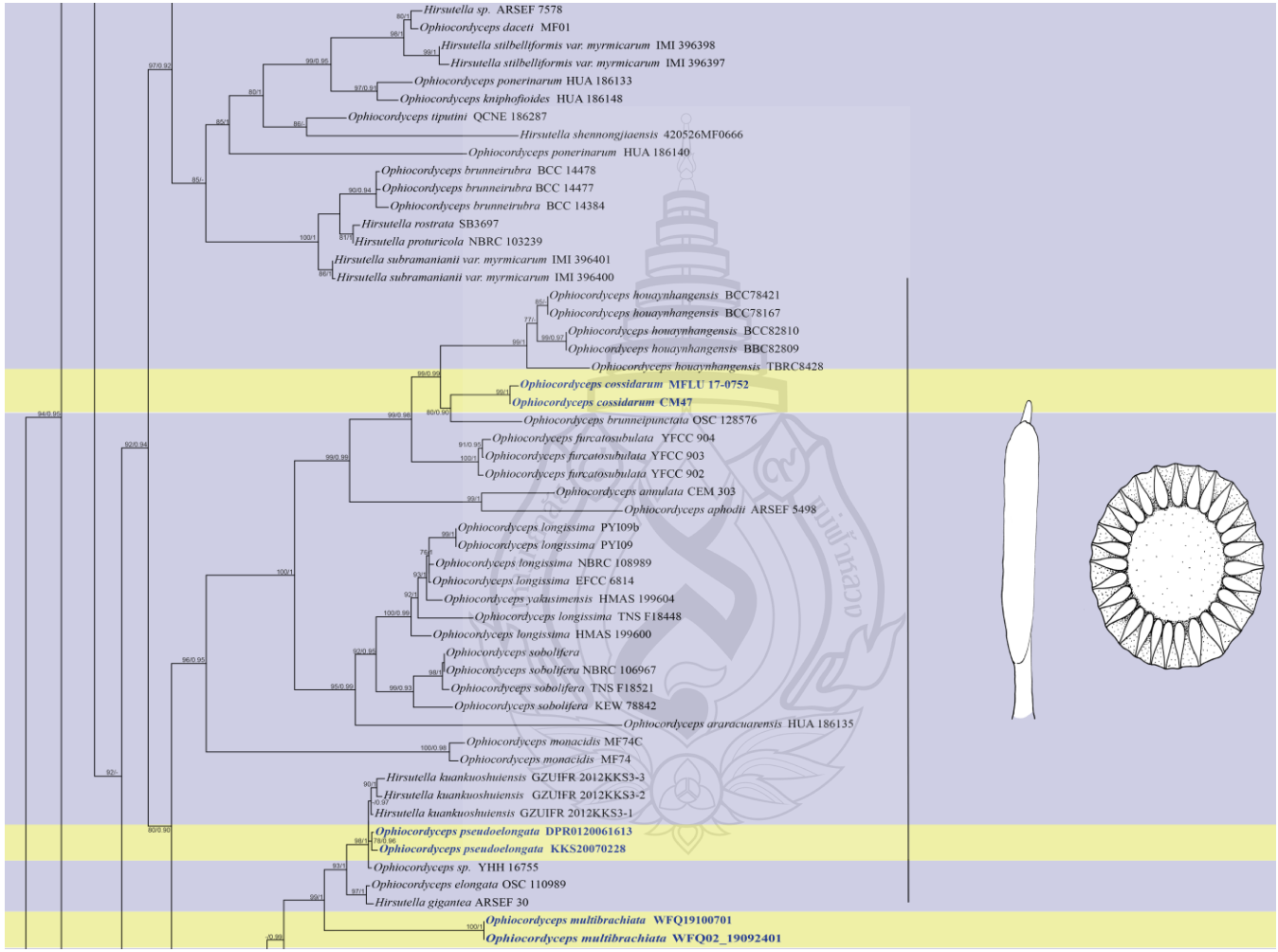


Figure 3.4 (continued)

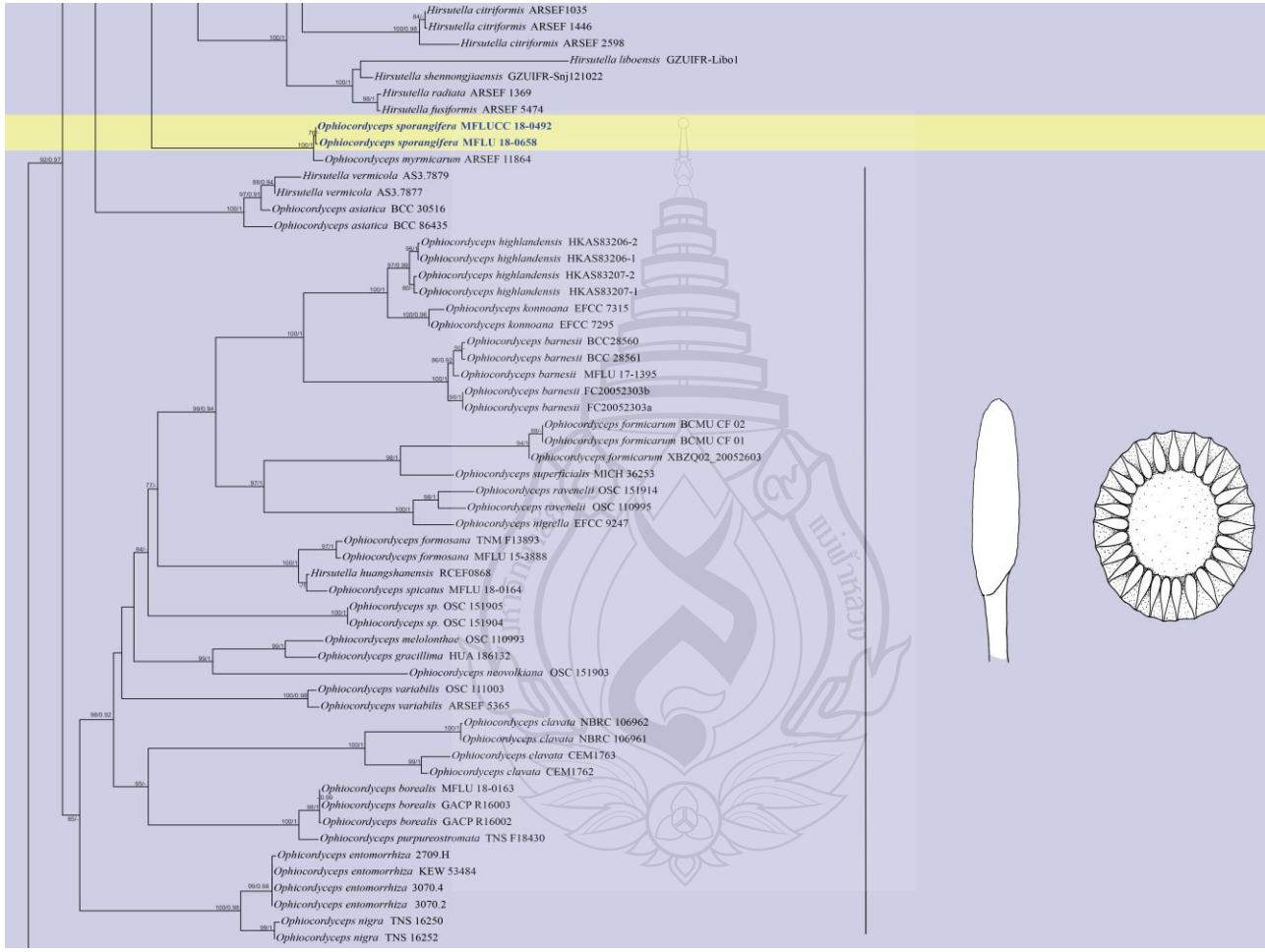


Figure 3.4 (continued)

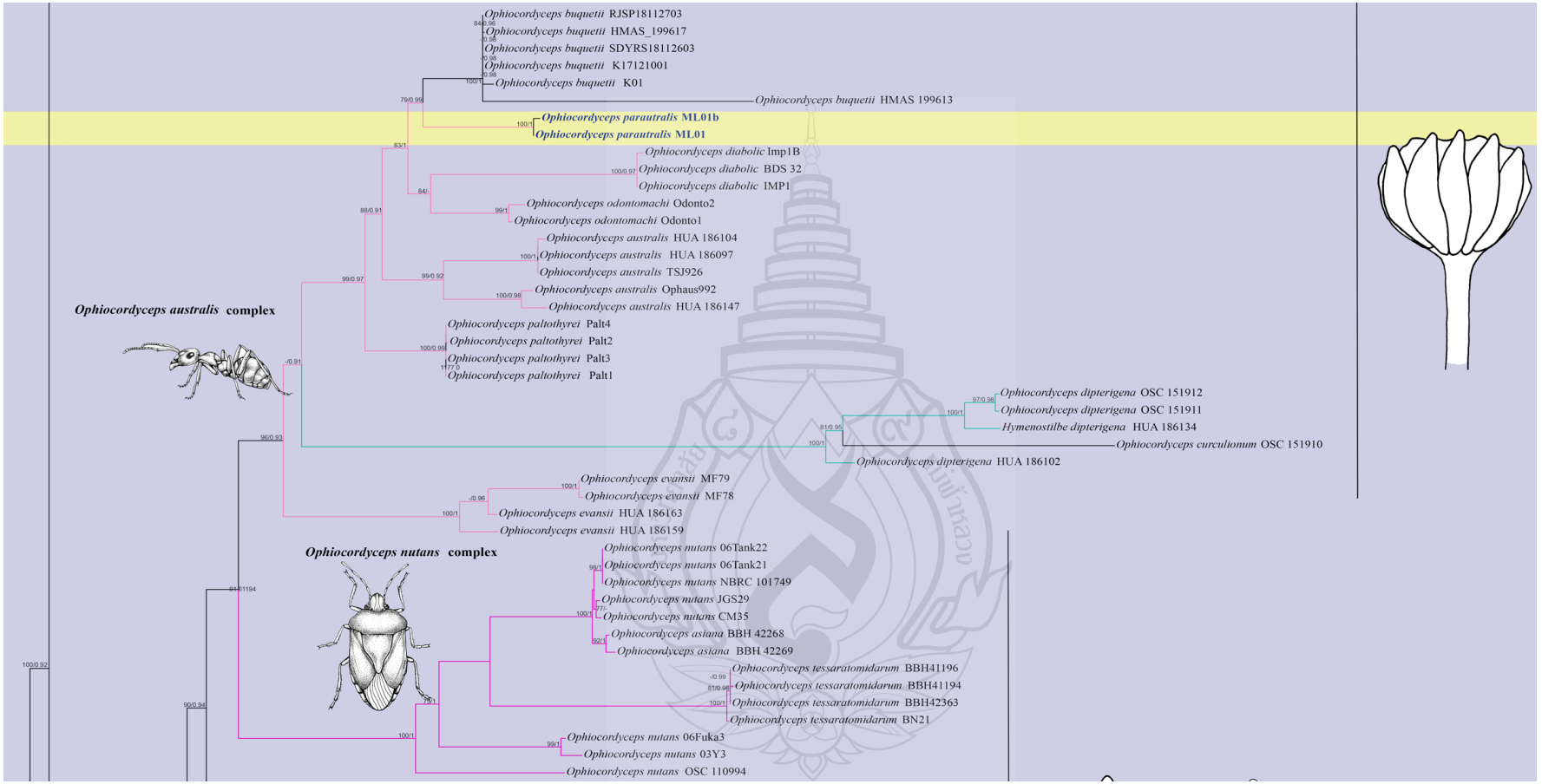


Figure 3.4 (continued)

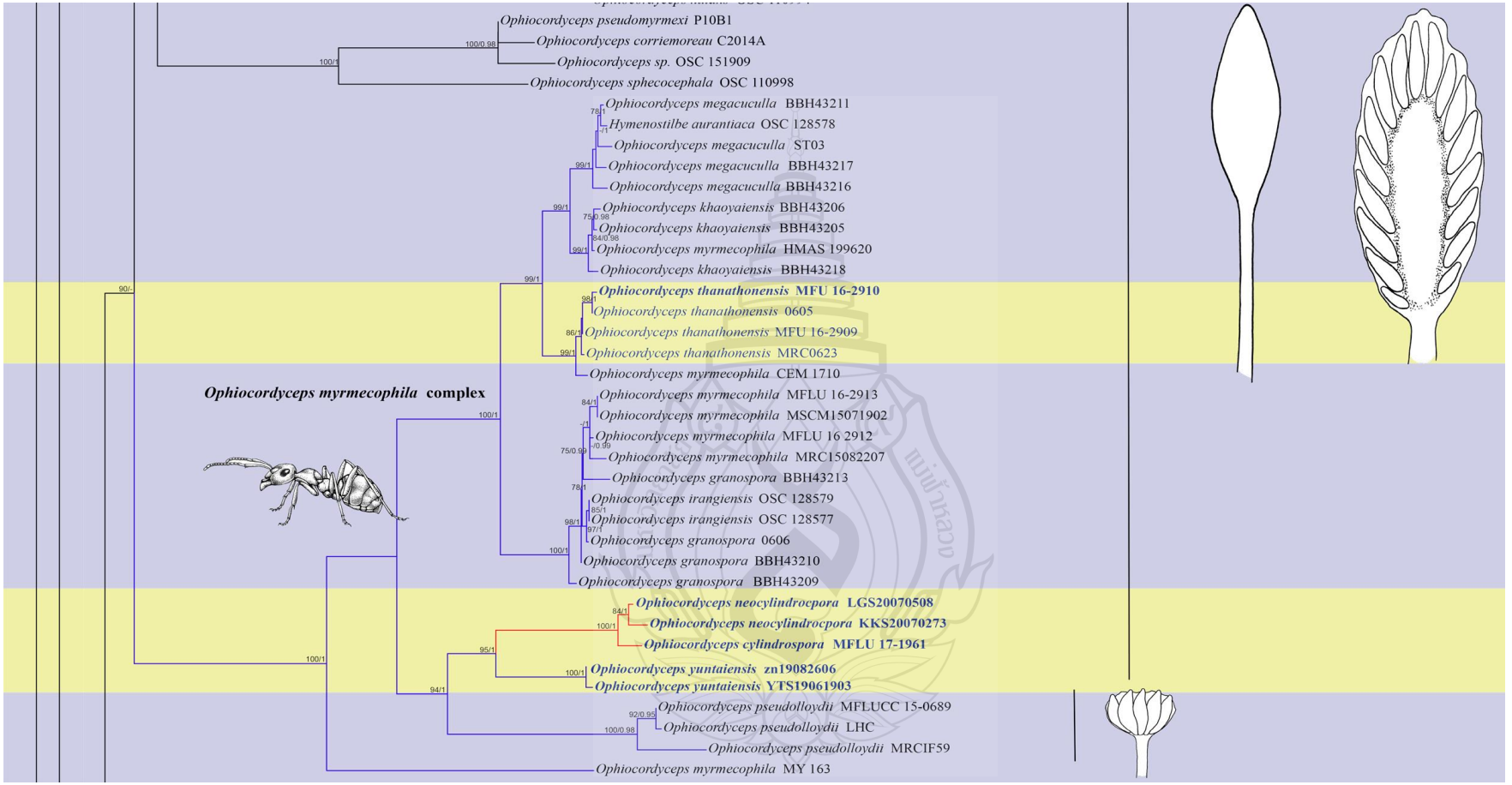
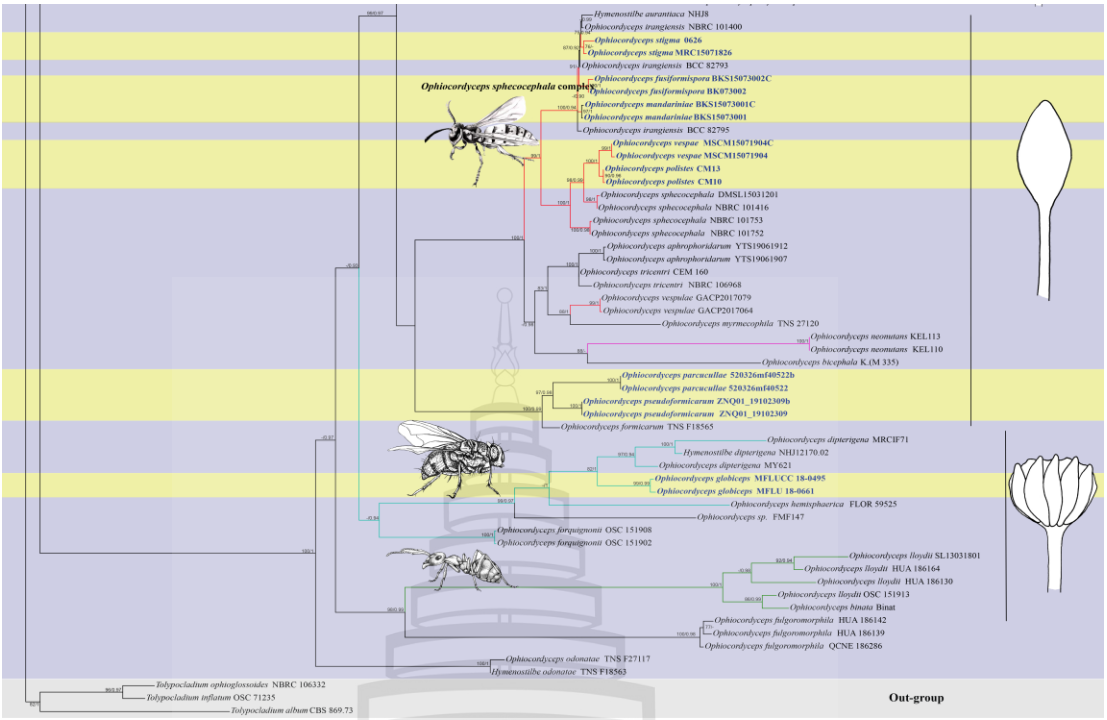


Figure 3.4 (continued)



Note Phylogenetic tree generated from a maximum likelihood analysis based on LSU, SSU. ITS, TEF, RPB1 and RPB2 sequences data of *Ophiocordyceps*. This phylogenetic tree of *Ophiocordyceps*, *Hirsutella* and *Hymenostilbe* comprises 440 taxa (including the 80 newly collected taxa) analyzed. Bayesian Posterior Probabilities (BYPP) equal to or great than 0.90 were given below each node. The new species were indicated in blue. The type strains were indicated in bold.

Figure 3.4 (continued)

Ophiocordyceps karstii T.C. Wen, Y.P. Xiao & K.D. Hyde, ***sp.nov.***

Index Fungorum number: IF 551814*; Faces of fungi number:* FoF 01795

Etymology: Name referring to the host genus on which the species occurs

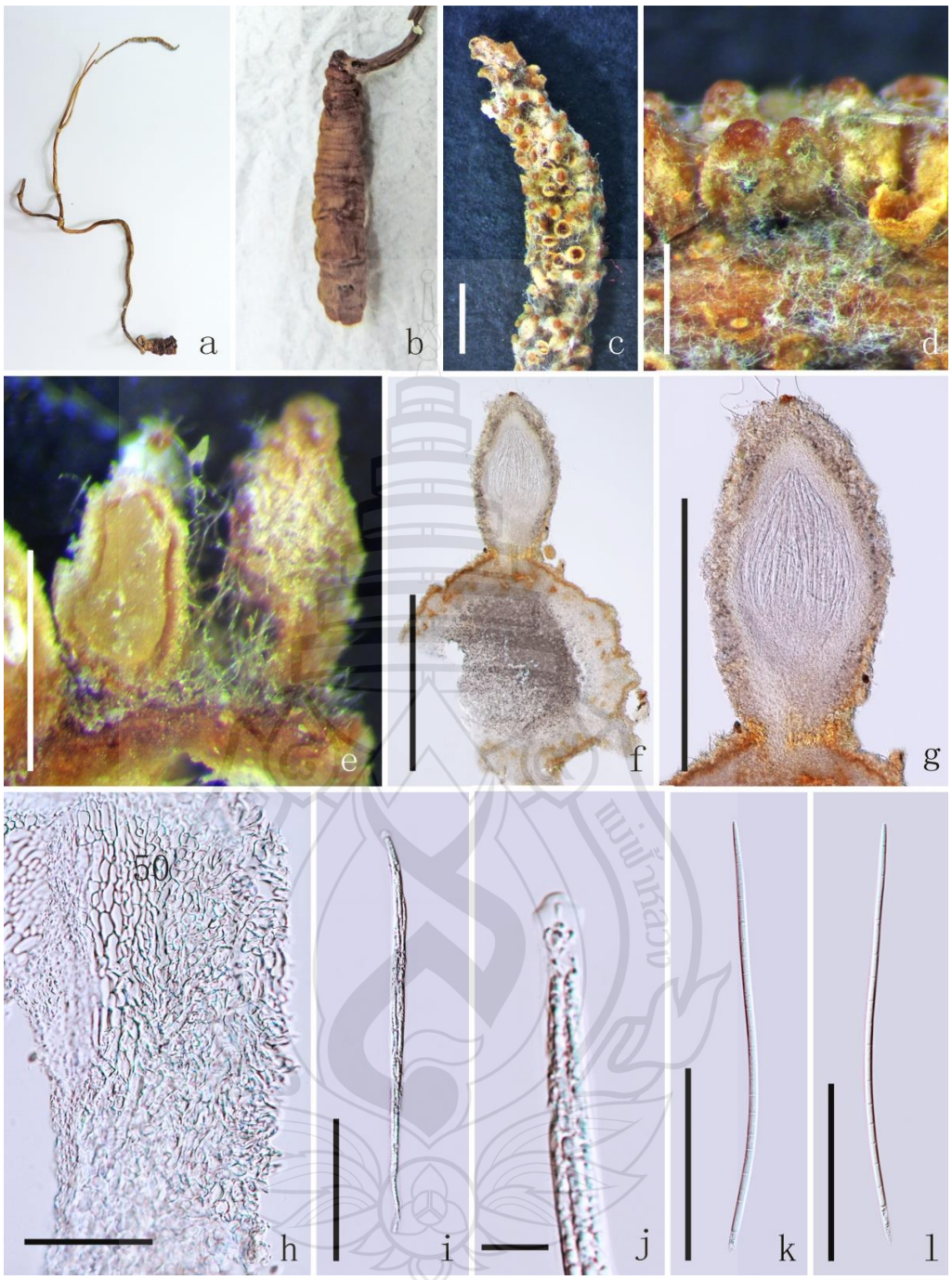
Holotype: MFLU 15–3884

Parasitic in larva of *Hepialus jianchuanensis*, brown to dark brown host, forming yellow to brownish stromata. **Sexual morph:** *Thallus* within host white, composed of intercalary hyphal bodies. *Stromata* mostly single, 140–145 × 2–4 mm, stipitate arising from head of the host. *Stipe* 12cm long, 2mm wide, clavate, with a

fertile apex, becoming golden yellow to brownish yellow when mature. *Fertile head* 20-25mm long, 2–4mm diam, clavate, light yellow to yellow-brown, upper surface roughened, coved with white incompact mycelium. *Ascomata* 600–765 × 247–323 μm ($\overline{x}$ = 683 × 285 μm, n = 30), superficial, yellow to brown, flask-shaped, thick-walled, ostiole on the top. *Peridium* 63–42 mm ($\overline{x}$ = 52 μm, n = 60) wide, three layers. *Asci* 186–228 × 8–12 μm ($\overline{x}$ = 207 × 10 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5–7 μm ($\overline{x}$ = 6 μm, n = 60) diam. *Ascospores* 173–202 × 3–5 μm ($\overline{x}$ = 188 × 4 μm, n = 60) fasciculate fusiform, smooth, as long as asci, hyaline, 10–18 septate, not break into secondly spores. **Asexual morph:** Undetermined.

Material examined: China, Guizhou Province, Chishui, On dead larva of *Hepialus jianchuanensis,* 23 October 2014, TingChi Wen CS2014102301 (MFLU 15–3884, **holotype**); CS2014102304 (MFLU 15–3885, MFLU 15–3886, MFLU 15–3887, **paratypes**).

Notes: Ophiocordyceps was introduced by Petch (1931) with *Ophiocordyceps blattae* (Petch) Petch as the type species and used by Sung et al. (2007) as the type genus of *Ophiocordycipitaceae*. According to morphological and phylogenetic analysis, *Ophiocordyceps karstii* closely matches *Ophiocordyceps lanpingensis* Hong Yu bis & Z.H. Chen bis and *Ophiocordyceps robertsii* (Hook.) G.H. Sung et al. This species is characterized by fusiform ascospores, which do not break into 173–202 × 3–5μm ($\overline{x}$ = 188 × 4μm, n = 60) secondly ascospores and superficial ascomata. Phylogenetic analysis of the multi-gene of combined TEF1, RPB1 and SSU sequence data confirms that *Ophiocordyceps karstii* clusters with *O. robertsii* in *Ophiocordyceps* with high bootstrap support. Therefore, we proposed *O. karstii* as a new species.



Note a Overview of the host and stromata. b Host: *Hepialus jianchuanensis*. c, d Stromata. e Vertical section of stroma. f Vertical sections showing the superficial perithecia. g Perithecia. h Peridium. i Asci. j Apical cap. k, l Ascospore. Scale Bars: c = 1 mm, d-g = 500 µm, i, k, l = 100 µm, h = 50 µm, j = 10 µm.

Figure 3.5 Morphology of *Ophiocordyceps karstii* (holotype MFLU 15-3884)

Ophiocordyceps xuefengensis T.C. Wen, R.C. Zhu, J.C. Kang & K.D. Hyde, Phytotaxa 123(1): 47 (2013).

Index Fungorum number: IF 803424

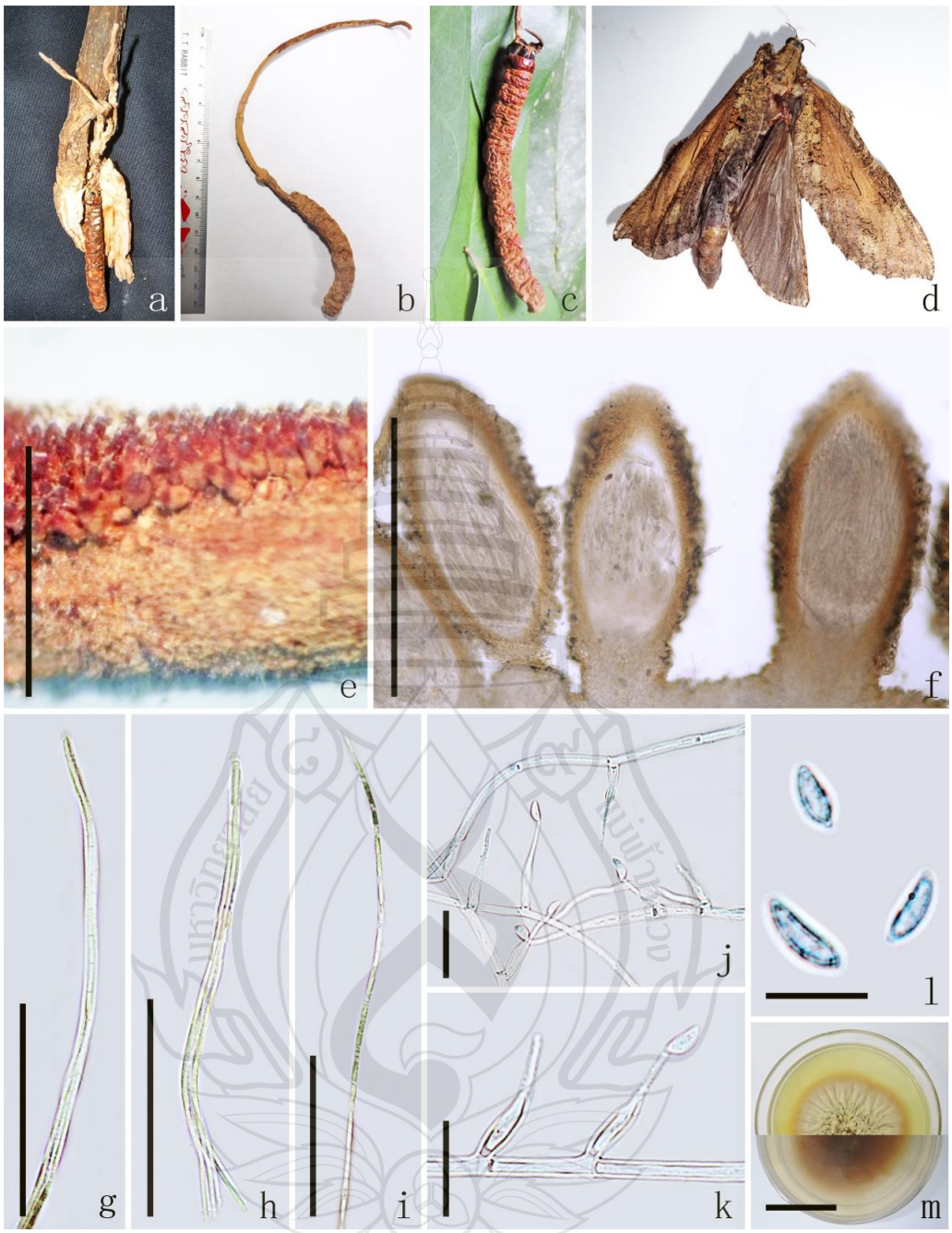
Holotype: MFLU 15–3884

Stromata, 20–42 cm long, 0.5–1 cm wide, growing from the head of Lepidoptera larva, usually simple, rarely branched, *Stipe*, 20–32 cm long, 0.5–0.8 mm wide, flexuous, yellow. *Fertile head*, 10–15 cm long, 1–1.1 cm wide cylindrical or obtuse, yellow. *Ascomata* 432.03–535.84 × 181.71–243.42 μm ($\bar{x}$ = 483.93 × 212.56, n = 30), completely immersed, elongated or ampuliform, with the ostiodes opening on the surface of the head. *Peridium* 25.67–40.95 μm wide ($\bar{x}$ = 33.31, n = 60), comprising three layers, *Asci* 260.81–340.71 × 6.24–8.61 μm ($\bar{x}$ = 300.76 × 7.43, n = 60), 8–spored, hyaline, cylindrical, possessing a prominent apical cap. *Ascospore* 260.81–340.71 × 6.24–8.61 μm ($\bar{x}$ = 330.76 × 7.43, n = 60). *Asci* 326.18–285.39 ×2.32–2.89μm ($\bar{x}$ = 305.78 ×2.60, n = 60), 8–spored, hyaline, cylindrical, possessing a prominent apical cap. *Apical cap* 3.98–7.62 μm wide ($\bar{x}$ = 5.80, n = 60).

Culture Characteristics: Colonies on PDA, 25 ℃, growing very slowly, up to a diam of 60–68mm after 3 weeks. Positive colonies were light brown, irregular edges, ridges, with raised, was fluffy, delicate mycelium sparse, no secretions. The back is dark brown, with radial folds, cracks. *Mycelium* 3.37–4.87 μm wide ($\bar{x}$ = 4.12, n = 60), colorless, septate, smooth. *Conidiophore* single 25.11–39.43 × 3.30–4.50 μm ($\bar{x}$ = 32.27 × 3.90, n = 60), at solitary, opposite or whorled from vegetative, monophialialidic or polyphialidic, hyaline, smooth, significantly swollen in basal portion, 3.30–4.50 um width ($\bar{x}$ = 3.90, n = 60), tapering to 1.17–1.76 μm ($\bar{x}$ = 1.47, n = 60) wide, twisting in four to six helices at the apex. Conidia 7.00–9.90 × 2.68–3.79 μm ($\bar{x}$ = 8.45 × 3.23, n = 100), hyaline, aseptata or with a septum, smooth, fusiform or like orange segments. No teleomorph observed.

Material examined: China, Hunan Province, Dongkou County, Xuefeng Mountains, on *Phassus nodus* in root of living *Clerodendrum cyrtophyllum*, 20 October 2012, Ru-Cai Zhu 2012HN14 (GZUH 2012HN14, **holotype**)

Notes: Ophiocordyceps xuefengensis was introduced by Wen et al. (2013). We would like to update the culture and asexual morph of this species.



Note a-m. *Ophiocordyceps xuefengensis*. a, b Overview of stromata and the host. c Larva of the host. d Adult of the host. e Ascomata on stroma. f. Cross sections showing the perithecia. g, h Asci. i Part of ascospore. j, k Conidiophore on vegetative. l Conidia. m Colonies on PDA after 3 weeks. Scale Bars: e = 5000 µm. f = 500 µm. g, h = 100 µm. i = 50 µm. l = 10 µm. m =5 cm.

Figure 3.6 Morphology of *Ophiocordyceps xuefengensis*

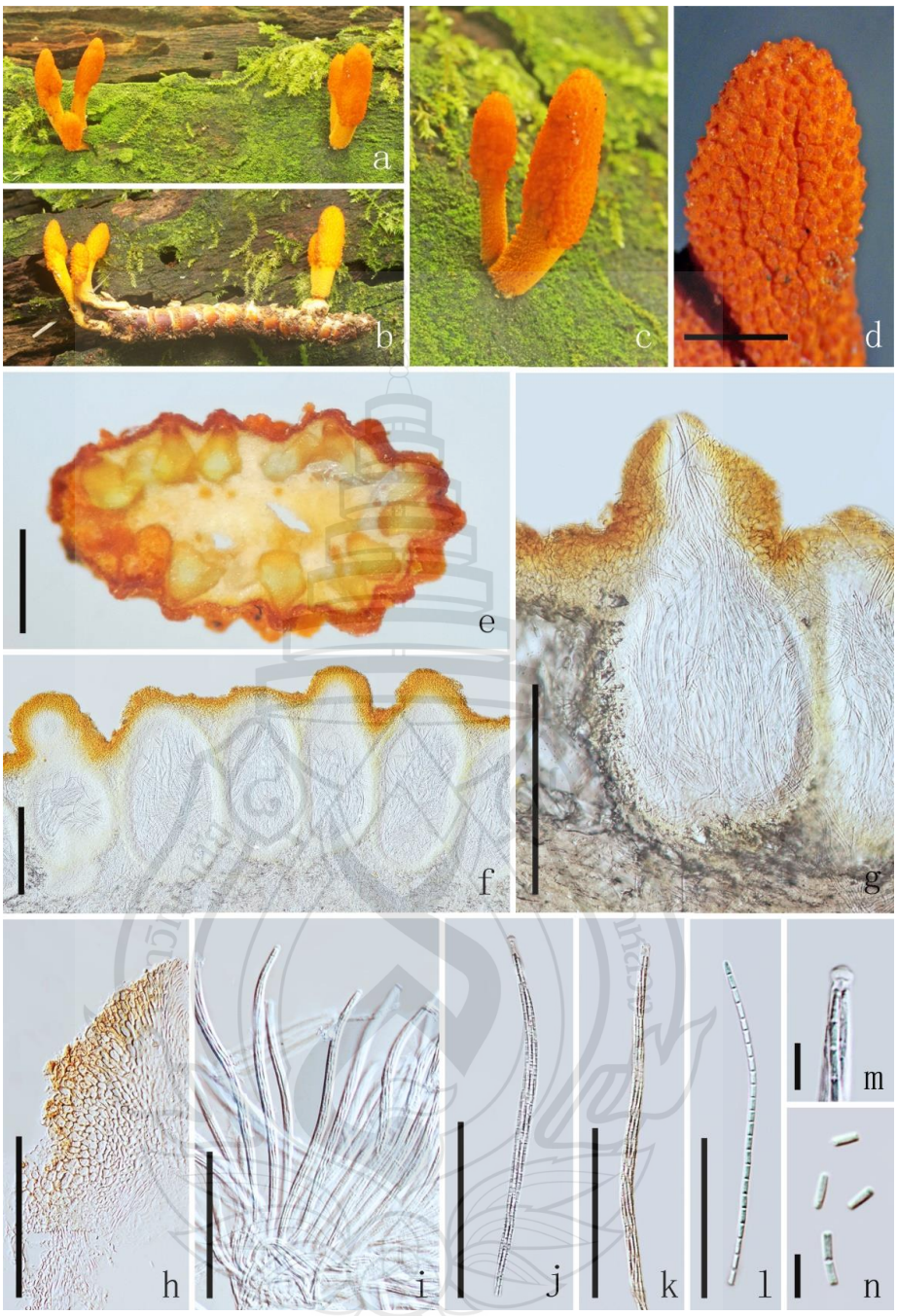
Ophiocordyceps formosana Y.W. Wang et al. in Wang et al., Evidence-Based Complementary and Alternative Medicine (no. 189891): 4 (2015).

Facesoffungi number: FoF 01796

Parasitic in larva of Coleoptera (Superfamily Tenebrionoidea), forming yellow to orange ascostromata. **Sexual morph:** Ascomycetous. Stromata 14 mm long, 2–5 mm wide, growing from the head and the tail of *Coleoptera* larva, simple or branched, yellow to orange, stipitate. *Stipe* 1.9–3.7 cm long, 2–4 cm wide, yellow, cylindrical, surface rough. *Fertile head* 30 mm long, 2–2.5 mm wide, orange, mostly elliptic barely branched, head like, with orange pseudoparenchymatous epidermal tissues, surface mastoid, differentiated from stipe. *Ascomata* 453–546 × 265–298 μm ($\bar{x}$ = 479 × 270, n = 30), completely immersed, orange, flask-shaped to oval shape, with the ostioles opening on the surface of the head. *Peridium* 26–38 μm wide ($\bar{x}$ = 30, n = 60), comprising three layers, *Asci* 366–498× 8–11 μm ($\bar{x}$ = 437 × 10, n = 60), 8-spored, hyaline, cylindrical, with apical cap, break into secondly ascospores. *Secondary ascospores* 2–6 × 1–3 μm ($\bar{x}$ = 4 × 2, n = 60), hyaline, cylindrical. **Asexual morph:** Undetermined.

Material examined: China, Hunan Province. On dead larva of Tenebrionoidea, 23 October 2014, Ping Zhang, ZP8282 (MFLU 15–3888); ZP828i (MFLU 15–3889, MFLU 15–3890, MFLU 15–3891).

Notes: Ophiocordyceps formosana Y.W. Wang et al. was introduced by Kobayashi (1979) as *Cordyceps formosana*. Wang et al. (2015) revised it as *Ophiocordyceps formosana*. This species is frequently used as a prestigious traditional Chinese medicine and has a long history of use as tonics and folk medicines that can be used as cancer and diabetes treatments and used as antioxidants among other uses (Wang et al. 2015). This species was found in Fujian and Taiwan (Wang et al. 2015). We collected this species in Hunan Province, China. As the phylogenetic and morphology analysis, these species were matched with *Ophiocordyceps formosana* Y.W. Wang et al. This species is a new record for Hunan Province, China. We also provide a colour figure for this species which includes asci and cap and the entire ascospore illustrated for the first time.



Note a, b Overview of stromata and the host. c, d Part of the stroma. e Vertical section of stroma. f, g Cross sections showing the perithecia. h Peridium. i-k Asci. l Part of ascospore. m Asci with apical cap. n Secondary ascospores. Scale Bars: d = 1000 µm. e = 500 µm. f, g = 200 µm. h-k = 100 µm. l = 50 µm. m, n = 10 µm.

Figure 3.7 Morphology of *Ophiocordyceps formosana*

Ophiocordyceps cossidarum Y.P. Xiao, T.C. Wen, L.S. Zha & K.D. Hyde, ***sp. nov.***

Index Fungorum number: IF553194*; Faces of fungi number:* FoF 3278

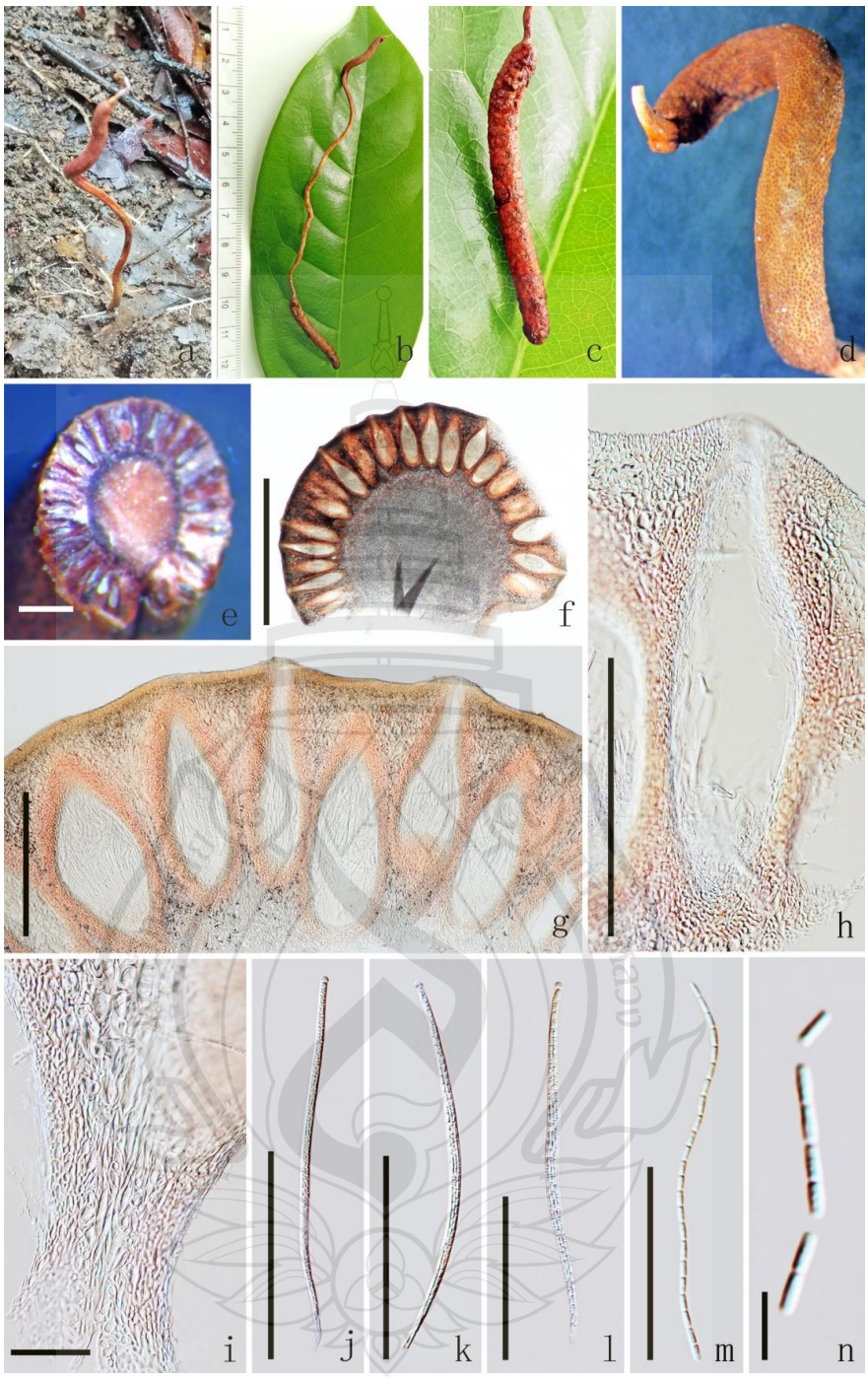
Etymology: Name referring to the host (Lepidoptera Cossidae).

Holotype: MFLU 17-0752

Parasitic in larvae of insect (Lepidoptera Cossidae), collected from buried in forest soils near root of the tree. **Sexual morph:** *Thallus* within host. *Stroma* reddish-brown or cinnamon to brown on one end of the insect larva, mostly erect. *Stroma* usually solitary, simple, 40-70 mm high. *Stipe* simple, cylindrical, 25−65 mm long, 1−2 mm wide, depending on the one side of the insect larva. *Fertile head* distinctly sub-terminal with asexual state at apex. *Ascomata* 355–454 × 136–171 µm ($\bar{x}$ = 405 × 153 µm, n = 30), immersed, red, ovate to phialide, red-walled. *Peridium* 26–35 mm ($\bar{x}$ = 31 µm, n = 60) wide, red, three layers. *Asci* 174–221 × 5.7–7 µm ($\bar{x}$ = 197 × 6.4 µm, n = 60) hyaline, cylindrical, 8-spored with a thickened apex. *Apical cap* 2.5–3.8 × 4.3–5.7 µm ($\bar{x}$ = 3.1 × 5 µm, n = 60), hyaline. *Ascospores* 131–153 × 1.8–2.2 µm ($\bar{x}$ = 142 × 2 µm, n = 60), hyaline, filiform, multiseptate breaking into 32 part-spores. *Part spores* 3.7–4.8 × 1.8–2.4 µm ($\bar{x}$ = 4.2 × 2.1 µm, n = 60), hyaline, cylindrical and truncated at the ends. **Asexual morph:** Undetermined.

Material examined: Thailand, Chiang Mai, The Mushroom Research Center, on larvae of insect (Lepidoptera Cossidae), 19 August 2015, YP Xiao, MRC 15082202. (MFLU 17-0752, **holotype**), MRC 15082202. (HKAS96377 **isotype**).

Notes: Phylogenetic analysis indicates that *Ophiocordyceps cossidarum* is closely related to *O. brunneipunctata* with high bootstrap support (100% ML, 1.0 PP). However, the new species differs from *O. brunneipunctata* in having shorter asci, one ascus breaking into 64 part-spores and longer part spores. Therefore, we proposed *O. cossidarum* as a new species.



Note a Habitat. b Overview of the host and stromata. c Host. d Stromata. e Cross sections showing the perithecia. f–h Perithecia. i Peridium. j–l Asci. m Part of ascospores. n Secondary ascospores. Scale Bars: f = 1000 µm, e = 400 µm, g, h = 200 µm, j–l = 100 µm, i, m = 50 µm, n = 10 µm.

Figure 3.8 Morphology of *Ophiocordyceps cossidarum* (holotype MFLU 17-0752)

Ophiocordyceps sporangifera Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Index Fungorum number: IF555324; *Facesoffungi number*: FoF 04865

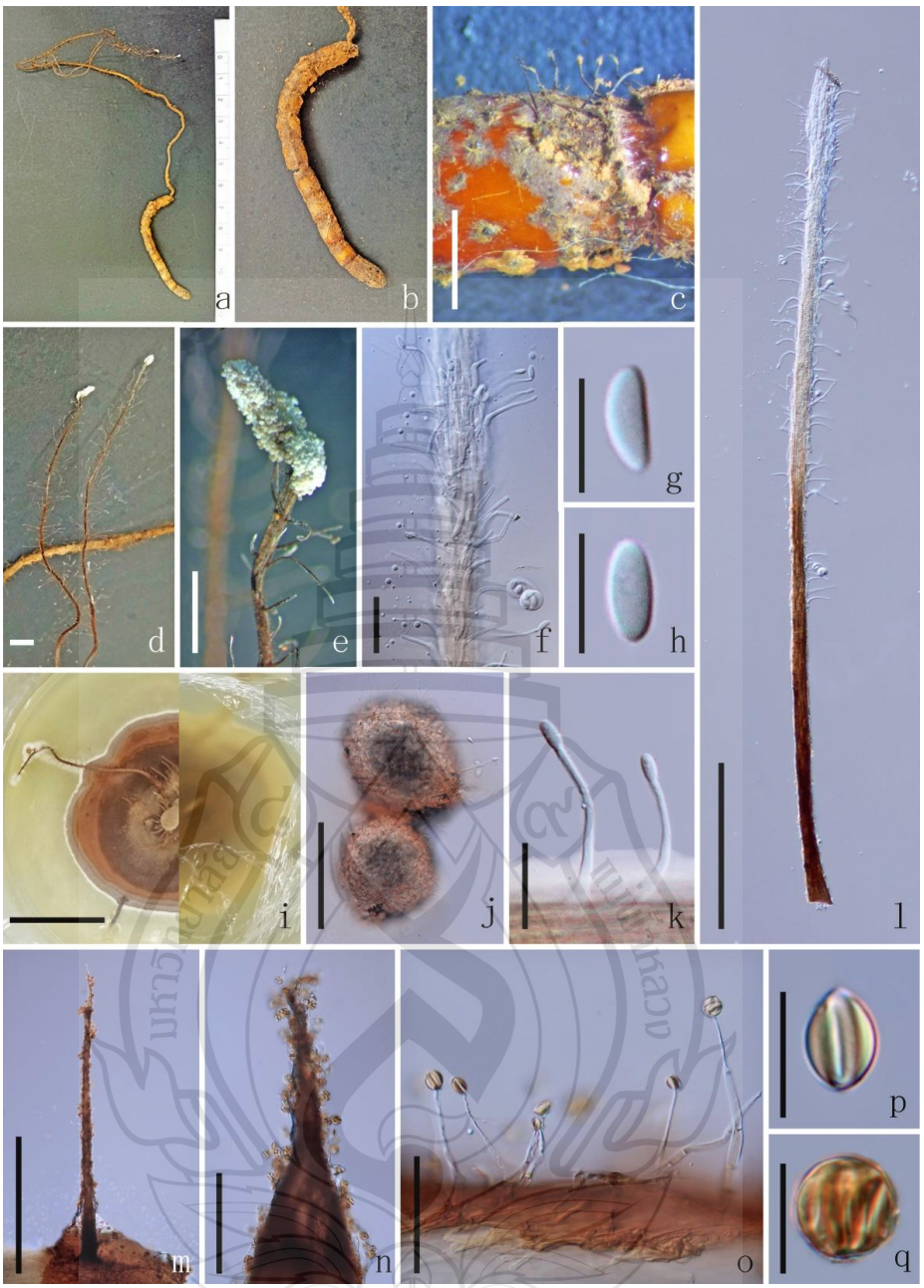
Etymology: The specific epithet refers to the feature of the sporangium-bearing.

Sexual morph: Unknown. **Asexual morph:** *Primary synnema* 9–18 cm high 1–2 mm diam., arising from the head region of the larva, branching into 2–5, cylindrical, brown to deep brown, with small white fertile head on the top, not smooth. *Fertile head* 500–2000 µm long., 400–1000 µm diam., globose to subglobose, capitulum, white to brown, arising from the apical end of primary synnema, mess of sporangium on the surface. *Sporangium* 78–121 µm diam. ($\bar{x}$ = 100 µm, n= 60), spherical, arising from the apical end of primary synnema, white color when immature, becoming brown to dark brown after mature, consisting of thick-walled cells. *Secondary synnemata* 1092–1937 × 21–34 µm, ($\bar{x}$ = 1515 × 27 µm, n= 60), laterally from the primary synnema, brown to white, cylindrical, not smooth. *Hyphae* 1.8–2.8 µm wide ($\bar{x}$ = 2.3 µm, n= 60), irregularly multi-septate, brown, cylindrical, smooth or rough, sometimes particularly expand. *Phialides* 25–40 × 1.3–2.5 µm ($\bar{x}$ = 33 × 1.9 µm, n= 60), hirsutella-like, hyaline, solitary, unbranched, narrow slender, smooth. *Conidia* 6.7–9.8 × 2.5–3.8 µm ($\bar{x}$ = 8.3 × 3.2 µm, n= 60), 1 cell, hyaline, subglobose to reniform, bound in mucilaginous spheres. *Mucilaginous spheres* 10.5–12.9 × 6.4–8.7 µm ($\bar{x}$ = 11.7 × 7.5 µm, n= 60), composed of 1–12 conidia, hyaline, at phialide apex.

Culture Characteristics: growing on PDA, reaching 2 cm diam., after 4 weeks at 25℃， with circular, dense mycelium on the surface. After 6 weeks, the colour of the colony was gradually deepened from white to dark brown from the periphery to the center, with complex fold as 4 circle rings, reverse white to yellow in colour, with ring. Synnemata was producing after 8 weeks. Most of the characters are the same as the fresh collection except phialides and mucilaginous spheres. *Phialides* 56–86 µm long ($\bar{x}$ = 71 µm, n= 60), 3–5 µm wide at base ($\bar{x}$ = 4 µm, n= 60), 1.4–2.2 µm at top ($\bar{x}$ = 1.8 µm, n= 60), hirsutella-like, hyaline, solitary, unbranched, narrow slender, smooth, 1–4 septa, not observed on host. *Mucilaginous spheres* 10.5–15.9 × 8.2–14.7 µm ($\bar{x}$ = 12.7 × 11.5 µm, n= 60), 1–4 conidia, hyaline to brown. Observing was stopped after 10 weeks.

Material examined: Thailand, Chiang Mai, The Mushroom Research Centre, on dead larva of Elateridae, Coleoptera, 6.5 cm long 0.38 cm diam., brown to dark brown, with thallus inside (larva), 18 July 2015, YuanPin Xiao, (MFLU 18–0658, **holotype**); Thailand, Chiang Mai, The Mushroom Research Centre, on dead larva of Elateridae, Coleoptera, 5.8 cm long 0.4 cm diam., brown to dark brown, with thallus inside (larva), 22 August 2015, YuanPin Xiao, (MFLU 18–0659, **paratypes,** ex-type living culture, MFLUCC 18–0492); Thailand, Chiang Mai, Samoeng on larva insect of Elateridae, Coleoptera, 5.5 cm long 0.32 cm diam., brown to dark brown, with thallus inside (larva), 18 June 2017, YuanPin Xiao, (MFLU 18–0660, **paratypes,** living culture, MFLUCC 18–0493, MFLUCC 18–0494).

Notes: *Ophiocordyceps sporangifera* is closely related to *O. myrmicarum* D.R. Simmons & Groden in our phylogenetic tree. The morphology of *O. sporangifera* is different from *O. myrmicarum* in having longer primary and secondary synnemata, a white to brown sporangium, shorter phialides, and it infects insect larvae (Lepidoptera, Cossidae), while *O. myrmicarum* was found on an ant (*Myrmica rubra*) (Simmons et al. 2015). The phylogenetic analysis does not have good support, but *O. sporangifera* is distinct from *O. myrmicarum*. In the phylogenetic tree, the relationships of *O. sporangifera* and *O. myrmicarum* are obscure because they share one clade wita h short branch length (100% ML/ 1 BYPP), while the two strains of *O. sporangifera* clustered together with low bootstrap support (88% ML/ 0.90 BYPP). The type strain of *O. sporangifera* has 0 bp in nr*SSU*, 3 bp in *tef-1α* and 5 bp in RPB1 that are different from *O. myrmicarum*. However, the morphological features of those two species are different, thus, they should be treated as two separate species.



Note a Synnemata on host surface. b Host. c Synnemata on host surface. d Synnemata. e Fertile head of primary synnema. f, l Secondary synnemata. g, h Conidia. i Culture. j Sporangium. k. Phialides. m, n Secondary synnemata on culture. o Phialides on culture. p, q. Conidia form mucilaginous spheres. Scale bars: i = 1 cm, c–e = 1000 µm, m = 500 µm, l = 200 µm, j, n = 100 µm, f, o = 50 µm, k = 20 µm, g, h, p, q = 10 µm.

Figure 3.9 Morphology of *Ophiocordyceps sporangifera* (holotype MFLU 18-0658)

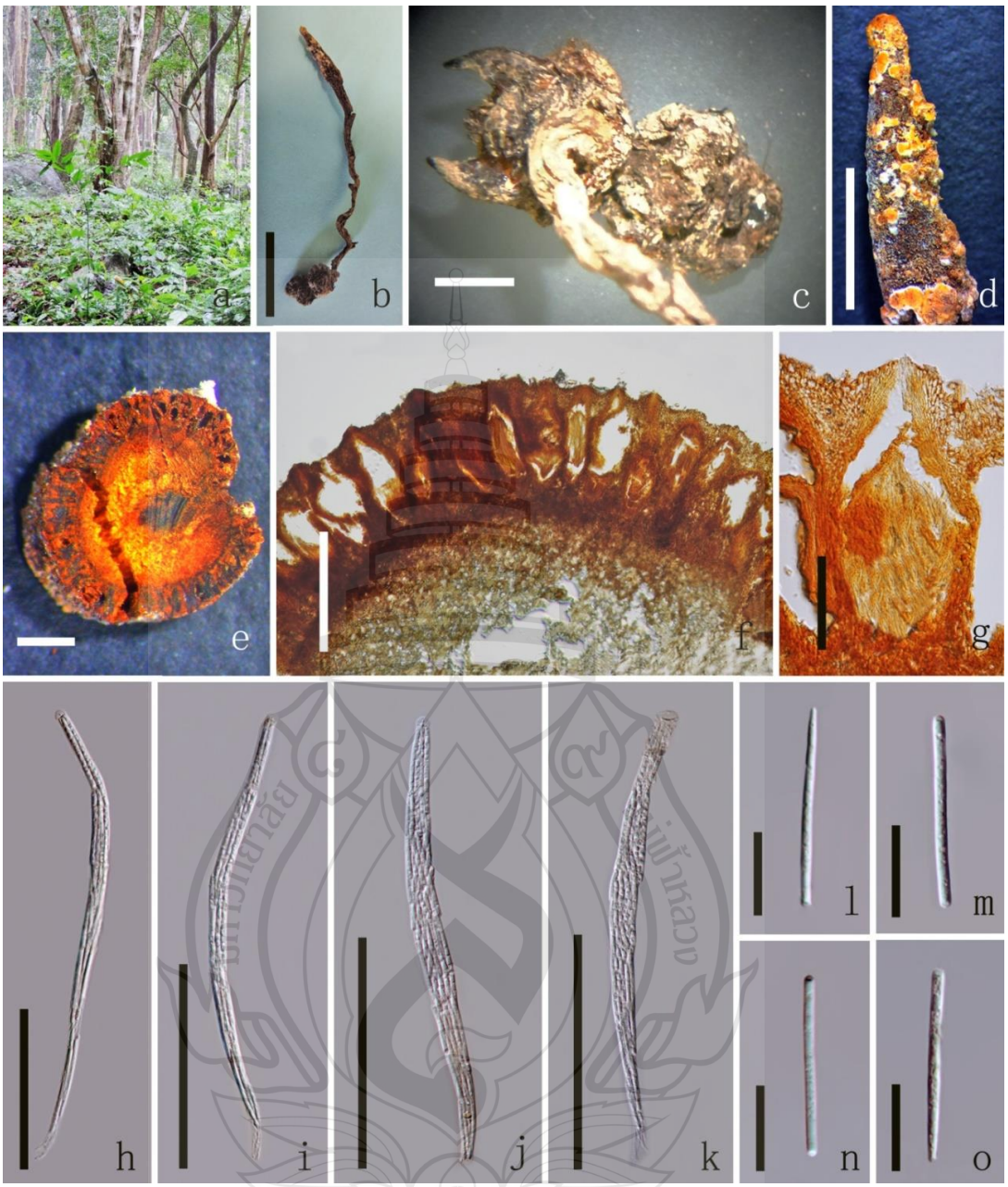
Ophiocordyceps barnesii (Thwaites) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 40 (2007)

Index Fungorum number: 504230; *Facesoffungi number*: FoF 03810

Parasitic on larvae (Coleopteran), buried in the soil. **Sexual morph:** *Host* 2–2.5 long, 0.5–1 cm wide, brown to dark brown without hyphae on the surface. *Stromata* 13–20 long, 0.5–1 cm diam., mostly single, stipitate, unbranched or branched into 2 or 3 fertile head, arising from between the head and thorax of larva (fusiformis), dark-brown, fleshy, cylindrical, often flexuous or angularly crooked. *Stipe* 1–2 cm long, 2–3 mm diam., brown, with a fertile apex. *Fertile head* 2–5 cm long, 1–3.5 mm diam., single or branched more than 2, cylindrical, apically tapered, brown with orange mycelium cover on the surface. *Perithecia* 308–389 × 98–132 µm ($\bar{x}$ = 349 × 115 µm, n = 60), immersed, brown, elongated pyriform or flask-shaped, thick-walled. *Peridium* 12–21 µm ($\bar{x}$ = 16 µm, n = 60) wide, brown, *textura angularis* to *textura globulosa* to *textura prismatica*. *Asci* 195–229 × 6–9 µm ($\bar{x}$ = 212 × 7.5 µm, n = 90), 8-spored, hyaline, filiform, with a thin apex. *Apical cap* 3.1–4.2 × 4.1–5.4 µm ($\bar{x}$ = 3.6 × 4.7 µm, n = 60), with a small channel in the center. *Ascospores* 155–200 × 2.2–2.7 µm ($\bar{x}$ = 178 × 2.5 µm, n = 60), 3-septate, easily breaking into 4 part-spores, filiform, tapered at each end. *Secondary ascospores* 31.6–41.6 × 2.2–2.7 µm ($\bar{x}$ = 36.6 × 2.5 µm, n = 90) cylindrical, thickening at each end or tapered at one end, straight, hyaline, smooth-walled. **Asexual morph:** undetermined.

Material examined: Thailand, Prachuap Khiri Khan. On dead larvae (Coleopteran), 29 July 2015, YuanPin Xiao, BK15072907 (MFLU 17-1393); BK15072902, BK15072906 (MFLU 17-1394, HKAS100693).

Notes: We collected *Ophiocordyceps barnesii* in this study which was colonized by an orange hyperparasite which we introduce below as *Polycephalomyces aurantiacus*. This species may be important in future industrial production of *Cordyceps* species, which are increasingly being produced because of their medicinal properties and biopesticides potential.



Note a Habitat. b Overview of the host and stromata. c Host. d Stroma. e Cross section of stroma. f Cross sections showing the immersed perithecia. g Perithecia. h–k Asci. l–o Secondary ascospores. Scale Bars: b = 5 cm, c = 5 mm, d = 2 cm, e, f = 500 µm, p = 200 µm, g–k = 100 µm, l–o, s = 20 µm, q = 10 µm, r = 5 µm.

Figure 3.10 Morphology of *Ophiocordyceps barnesii* (MFLU 17-1395)

Ophiocordyceps issidarum Y.P. Xiao, T.C. Wen, L.S. Zha & K.D. Hyde, ***sp. nov***.

Index Fungorum number: IF553193; *Faces of fungi number:* FoF 3277

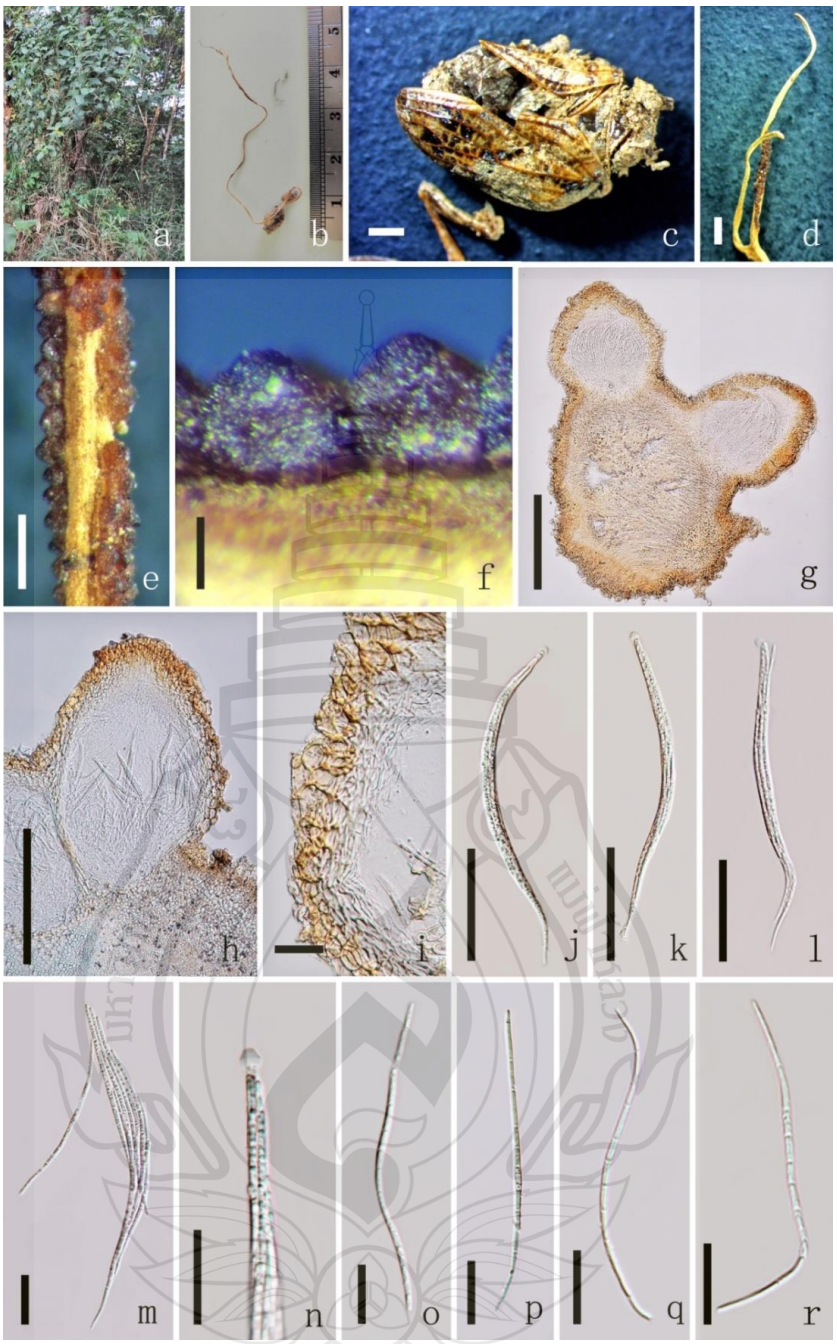
Etymology: Name referring to the host (Hemiptera Fulgoridae Issidae).

Holotype: MFLU 17-0751

Parasitic in adult of insect (Hemiptera Fulgoridae Issidae), yellow to dark brown host, forming yellow to brownish stromata. **Sexual morph:** *Thallus* within host. *Stromata* 60–75 mm long, 1.5–2 mm wide, mostly branched, stipitate arising from abdomen of the host. *Stipe* 6 cm long, 2 mm wide, clavate, with stromata on the side face, becoming brown when mature. *Ascomata* 600–765 × 247–323 μm ($\bar{x}$ = 683 × 285 μm, n = 30), superficial, brown to dark brown, oval shaped, thick-walled, ostiole absent. *Peridium* 42–63 mm ($\bar{x}$ = 52 μm, n = 60) wide, comprises three layer. *Asci* 186–228 × 8–12 μm ($\bar{x}$ = 207 × 10 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5–7 μm ($\bar{x}$ = 6 μm, n = 60) diam. *Ascospores* 173–202 × 3–5 μm ($\bar{x}$ = 188 × 4 μm, n = 60) cylindrical, smooth-walled, hyaline, 8–9-septate, not break into secondly spores. **Asexual morph:** Undetermined.

Material examined: Thailand, Chiang Mai, The Mushroom Research Center, on adult of insect (Hemiptera Fulgoridae Issidae), 19 July 2015, YuanPin Xiao, MSCM 15071901 (MFLU 17-0751, **holotype**), MSCM 15071901b (HKAS96376, **isotype**).

Notes: Phylogenetic result indicates that *Ophiocordyceps issidarum* is closely related to *O. unilateralis*, *O. cf. acicularis* and *O. acicularis*. The new species is however characterized by shorter asci and ascospores with 8–9-septate. Therefore, we proposed *O. issidarum* as a new species in *Ophiocordycpes*.



Note a Habitat. b Overview of the host and stromata. c Host. d–f Stroma. g Vertical section of stroma. h Vertical sections showing the superficial perithecia. i Perithecium. j–l Asci. m Asci with 8 ascospores. n Asci with apical cap. o–r Ascospores. Scale Bars: c–d = 1000 µm, e = 500 µm, g, h = 200 µm, f = 100 µm, j–l = 50 µm, j, m–r = 20 µm.

Figure 3.11 Morphology of *Ophiocordyceps issidarum* (holotype MFLU 17-0751)

Ophiocordyceps globiceps Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Index Fungorum number: IF555323; *Facesoffungi number*: FoF 04864

Etymology: The specific epithet refers to the feature of the secondary hemispherical to globoid fertile head.

Parasitic on fly (Muscidae, Diptera). **Sexual morph:** *Stromata* 4–8 mm long × 0.5–1 mm diam., one or several from the host, stipitate, capitate, unbranched, cinnamon to yellow. *Stipe* 3.5–7.5 mm long, 0.2–0.5 mm diam., yellow, cylindrical, with a fertile apex. *Fertile head* 1–1.5 mm long, 1–1.2 mm diam., cinnamon to yellow, single, hemispherical to globoid. *Perithecia* 538–663 × 182–247 μm ($\bar{x}$ = 600 × 214 μm, n= 60), immersed, ovoid to elongated pyriform, thick-walled, vertical with the ostioles opening on the upper surface of the head. *Peridium* 17–22 μm ($\bar{x}$ = 20 μm, n= 90) wide, hyaline, of *textura porrecta* to *textura prismatica* to *textura angularis*. *Asci* 373–454 × 5.7–8.2 μm ($\bar{x}$ = 413 × 7 μm, n= 90), 8-spored, hyaline, filiform, with a thick apex. *Apical cap* 4.4–6.4 × 4.9–5.7 μm ($\bar{x}$ = 5.4 × 5.3 μm, n= 60), thick, with a small channel in the center. *Ascospores* 240–303 × 1.8–2.3 μm ($\bar{x}$ = 272 × 2.1 μm, n= 60), filiform, hyaline, multiseptate. *Secondary ascospores* 4–5.4 × 1.2–1.9 μm ($\bar{x}$ = 4.7 × 1.6 μm, n= 90) cylindrical to fusoid, 1-celled, straight, hyaline, smooth-walled. **Asexual morph:** Undetermined.

Culture characteristics: growing on PDA, reaching 5 cm diam., after 6 weeks at 25℃, superficial cottony, whitened, loose, reverse yellow. After 10 weeks at 25℃, reaching 6 cm diam., no conidiogenous structures observed.

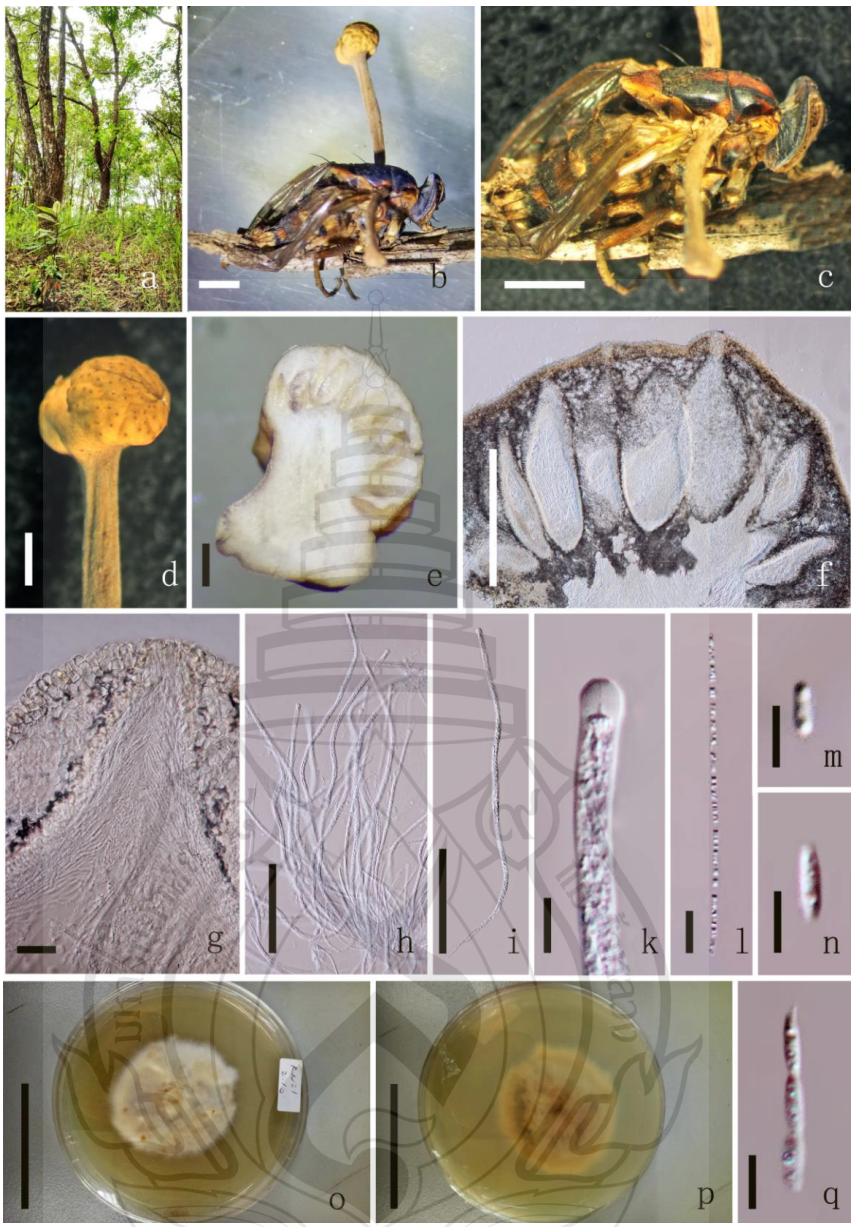
Material examined: Thailand, Ranong, Tambon Khao Niwet, parasitize on fly (Muscidae, Diptera) 7 mm long, 3 mm wide, brown to dark brown, without hyphae on the surface, collected on the grass stem, 19 July 2015, YuanPin Xiao, (MFLU 18–0661, **holotype**, ex-type living culture, MFLUCC 18–0495); Thailand, Chiang Mai, on adult fly (Diptera), 6.5 mm long, 2.7 mm wide, brown to dark brown, without hyphae on the surface, collected on the grass, 19 July 2017, YuanPin Xiao, (MFLU 18–0662, **paratypes**, living culture MFLUCC 18–0496).

Notes: In the phylogenetic tree, *Ophiocordyceps globiceps* is closely related to *O. dipterigena* (Berk. & Broome) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafor. (Thailand) and *O. hemisphaerica* Mafalda-Freire, Reck & Drechsler-Santos (Brazil), which infect flies (Luangsa-ard et al. 2008, Hyde et al. 2016).

Ophiocordyceps globiceps also groups with *Ophiocordyceps* sp. (FMF147) (106bp ITS differ), which was introduced by ITS sequence data and without any other detail (Freire 2015). *Ophiocordyceps globiceps* has 60 bp that differ from *O. dipterigena* (MY621) in ITS region, 19 bp in *tef-1α.* It has 87 bp that differ from *Hymenostilbe dipterigena* Petch (NHJ12170, asexual morph of *O. dipterigena*) in ITS region, and 20 bp in *tef-1α*. *Ophiocordyceps globiceps* also has 94 bp (ITS) that differ from *O. dipterigena* (MRCIF71, Thailand), which only has ITS and without any details. *Ophiocordyceps globiceps* has 104 bp that differ from *O. hemisphaerica* (FLOR 59525) in ITS region, and has 21 bp in nr*SSU*, 97 bp in nr*LSU*, 74 bp in *tef-1α* that differ from *O. dipterigena* (OSC 151913).

We compared the new species with other *Ophiocordyceps* species which infect flies (Diptera) or are morphological similar to *O. globiceps*. *Ophiocordyceps globiceps* differs from three records of *O. dipterigena* found in Sri Lanka, Japan and Thailand by producing single smaller stroma, smaller and shorter perithecia, shorter asci and smaller ascospores. *Cordyceps sakishimensis* Kobayasi & Shimizu, *Ophiocordyceps discoideicapitata* (Kobayasi & Shimizu) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, *Ophiocordyceps forquignonii* (Quél.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, *Ophiocordyceps hemisphaerica* Mafalda-Freire, Reck & Drechsler-Santos, *Ophiocordyceps lacrimoidis* Mafalda-Freire, Reck & Drechsler-Santos and *Cordyceps muscicola* Möller (= *Ophiocordyceps muscicola*) have been reported as fly infected taxa (Saccardo 1891, Möller 1901, Kobayasi and Shimizu 1982, Freire 2015, Hyde et al. 2016), and but their morphology is different from *O. globiceps*. *Cordyceps sakishimensis* is distinct from *O. globiceps* in having white, longer, cylindrical stromata and larger superficial perithecia. *Ophiocordyceps discoideicapitata* differs from *O. globiceps* by producing smaller stromata, pyriform, larger perithecia and longer part-spores (Kobayasi and Shimizu 1982). *Ophiocordyceps forquignonii* is distinct from *O. globiceps* in having a cylindrical fertile apex and oval secondary ascospores (Saccardo 1891). Molecular data indicate that the new species has 26 bp in nrSSU, 89 bp in nrLSU that are different from *O. forquignonii*. *Ophiocordyceps hemisphaerica* is different from *O. globiceps* in having longer stomata, larger obpyriform perithecia, longer asci and longer fusoid part-spores (Hyde et al. 2016). *Ophiocordyceps lacrimoidis* (Diptera infected species) was not

considered in our phylogenetic sampling as the DNA (ITS) sequence did not align well with other species, but its DNA sequence differed by 154 bp in the ITS region from the sequence of *O. globiceps*. However, *Ophiocordyceps lacrimoidis* is morphologically different from our new species in having producing longer stipe, obpyriform, slightly curved perithecia, longer asci and longer part spores. *Cordyceps muscicola* was revised as *Ophiocordyceps muscicola* by Freire (2015), while it is different from *O. globiceps* in having longer stromata, larger pyriform perithecia, longer asci and longer part-spores (Möller 1901, Freire 2015). We would like to introduce *Ophiocordyceps globiceps* as a new species based on the phylogenetic and morphological analyses.



Note a. Habitat. b. Ascostroma emerging from infected fly. c. Host. d. Fertile head of ascostroma. e. Vertical section of the stroma. f. Section of ascomata. g. Peridium. h, i. Asci. k. Apical cap of asci. l, q. Part of ascospores. m-n. Secondary ascospores. o. Upper side of the culture. p. Reverse side of the culture. Scale bars: b-d = 1000 *µm*, e, f = 500 *µm*, h, i = 100 *µm*, g = 20 *µm*, k, l = 10 *µm*, m, n, q = 5 *µm*, o, p = 5 cm.

Figure 3.12 Morphology of *Ophiocordyceps globiceps* (holotype MFLU 18-0661)

Ophiocordyceps cylindrospora Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Index Fungorum Number: IF553983; *Facesoffungi Number*: FoF 03878

Etymology: The specific epithet refers to the cylindrical secondary ascospores.

Holotype: MFLU 17-1961

Parasitic on wasps (Hymenoptera), collected from the underside of leaves litter. **Sexual morph:** *Host* 11 mm long, 3–5 mm wide, black wasp without hyphae on the surface. *Stromata* 50–90 mm long, 0.5–1.5 mm diam, mostly single, stipitate, rarely double, arising from between the head and thorax of adult wasps, pale yellow to yellow. *Stipe* 25–27 mm long, 0.5–2 mm diam, clavate, with a fertile apex, becoming pale to yellow. *Fertile head* 3–3.2 mm wide, 1–1.2 mm diam, fusiform, yellow, upper surface roughened, lateral surface, ridged and furrowed. *Ascomata* 551–638 × 261–327 µm ($\bar{x}$ = 594 × 294 µm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 20–25 mm ($\bar{x}$ = 23 µm, n = 60) wide. *Asci* 248–313 × 5–7 µm ($\bar{x}$ = 480 × 6 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5–12.5 × 8.5–10.4 µm ($\bar{x}$ = 8.7 × 9.5 µm, n = 60) thick, with a small channel in the center. *Ascospores* easily breaking into part-spores, filiform. *Secondary ascospores* 3.1–3.9 × 1.6–2 µm ($\bar{x}$ = 3.5 × 1.8 µm, n = 90) cylindrical, truncated at both ends, straight, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: Thailand, Chiang Mai, MRC. On dead wasp, 19 July 2015, YuanPin Xiao, MSCM15071905 (MFLU 17-1961, **holotype**); (MFLU 17-1962, MFLU 17-1963 **paratypes**).

Notes: *Ophiocordyceps cylindrospora* is proposed as pathogen on wasps and collected from ChiangMai, Thailand. The morphology the new species was similar to *Ophiocordyceps sphecocephala*, *O. myrmecophila*, *O. pseudolloydii*, *O. hemisphaerica*, *O. irangiensi*, which are showing in the table. The morphology of Ophiocordyceps *cylindrospora* differs from other species in the genus *Ophiocordyceps* in having cylindrical and shorter secondary ascospores. Phylogenetic analyses of combined SSU, LSU, ITS, RPB1 and RPB2 sequence data have shown the placement of *O. cylindrospora* is new species in the genus.

Note a Habitat of *Ophiocordyceps cylindrospora*. b Ascostroma emerging from infected wasps. c Overview of host. d Fertile head of ascostroma. g Ascomata. h, i Peridium. j-m Immature to mature asci. n Apical cap of asci. o-q Secondary ascospores. r Germinated secondary sacospores. Scale Bars: d, e = 500 µm, f = 200 µm, g = 20 µm, h–k = 100 µm, l = 10 µm, m, n = 2 µm.

Figure 3.13 Morphology of *Ophiocordyceps cylindrospora* (holotype MFLU 17-1961)

Ophiocordyceps multibrachiata Y.P. Xiao, J. Meng & K.D. Hyde ***sp. nov.***

Holotype: WFQ02-19092401

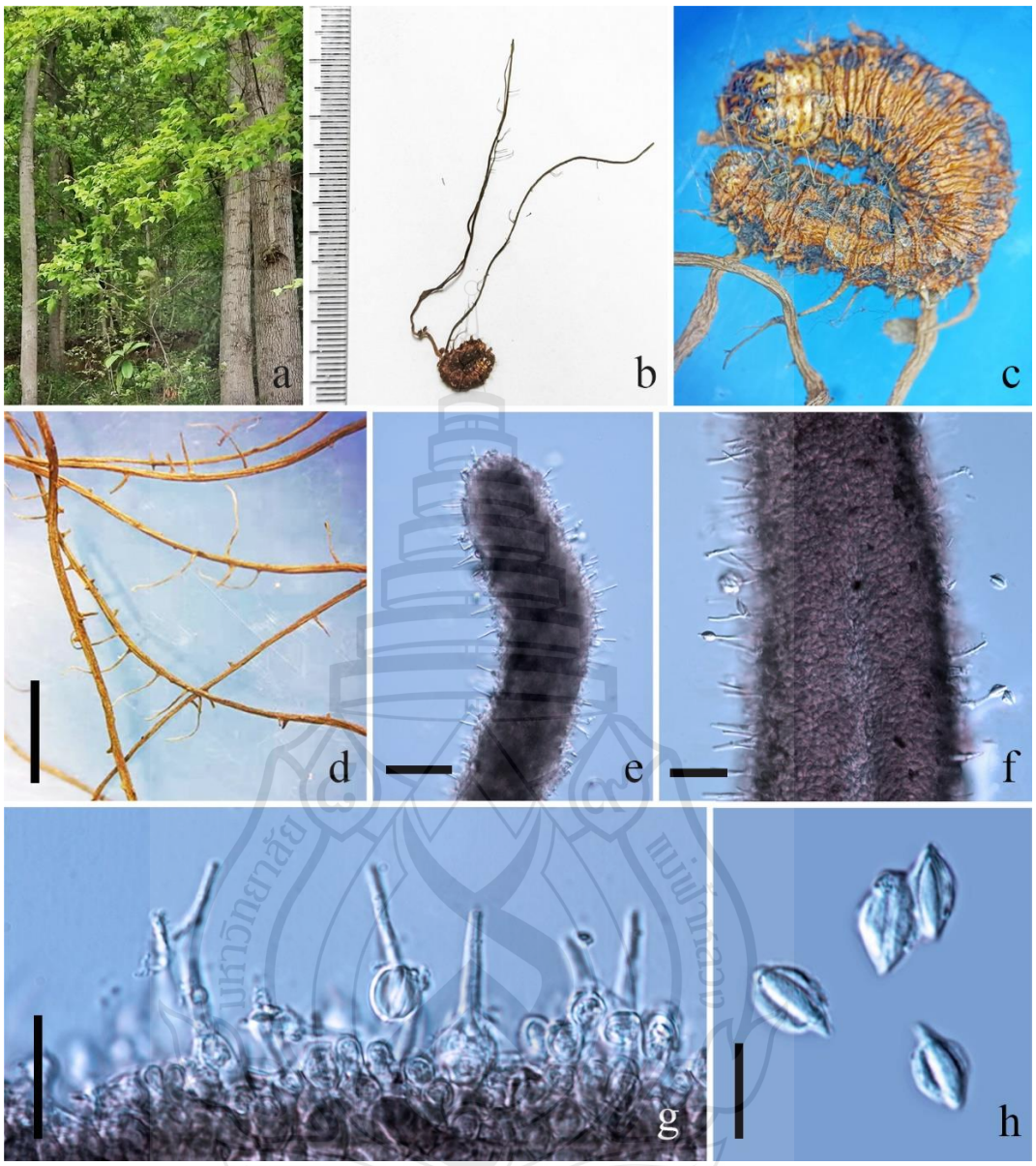
Etymology: The species name refers to the multiple branched synnemata.

Host: larvae of Coleoptera

Parasitic on the larvae of Coleoptera. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Primary synnemata* 4–6 cm long, 0.1–0.7 mm wide, arising from the insect body, solitary, or several, stipitate, multiply branched, brown to yellow brown, not smooth, cylindrical, or rhizoid, secondary synnemata observed, without an enlarged globose fertile head on the top. *Secondary synnemata* 1–5 mm long, 0.1–0.2 mm wide, laterally scattered along the primary synnemata, unbranched, yellow to yellowish, cylindrical with a tapering top, not smooth. *Phialides* 20–38 × 1–8 µm ($\overline{x}$ = 29 × 5.2 µm, n = 60), scattered, lower portions amygdaliform to ovoid, tapering abruptly, forming a long neck, 6–12 × 4–8 µm ($\overline{x}$ = 9 × 6 µm, n = 60) at the base, 15–26 × 1–2.1 µm ($\overline{x}$ = 20.5 × 1.5 µm, n = 60) neck, one-type, hyaline, smooth. *Conidia* 2–4 × 1–1.5 µm ($\overline{x}$ = 3 × 1.2 µm, n = 60), 1-celled, one-type, hyaline, fusiform to limoniform, usually bound in mucilaginous spheres. *Mucilaginous spheres* 10–16 × 8.2–15.8 µm ($\overline{x}$ = 13 × 12 µm, n= 60), composed of 1–6 conidia, hyaline.

Material examined: China, Guizhou Province, Zunyi City, parasitic on larvae of Coleoptera. in soil, 22 October 2020, Qingfeng Meng, WFQ02-19092401.

Notes: Two specimens were obtained from the same region of *Polycephalomyces formosus*, which had been not infected by *Polycephalomyces formosus*. Moreover, these two taxa belong to the *Ophiocordyceps* clade, which is distinct from the *Polycephalomyces* clade. However, they also obtain strong support that differs from other species of *Ophiocordyceps*. Morphologically, *Ophiocordyceps multibrachiata* is distinct from the other species by producing multiple-branched synnemata, fusiform to limoniform, typically bound in mucilaginous spheres conidia. Thus, a new species, *Ophiocordyceps multibrachiata* under *Ophiocordyceps*, is introduced.



Note a Habitat. b Synnemata emerging from infected insect. c Overview host. d, Secondary synnemata on the primary synnemata. e Synnemata. f, g Philidies. h Conidia. Scale Bars: d = 5000 µm, e = 100 µm, f, g = 20 µm, h = 10 µm.

Figure 3.14 Morphology of *Ophiocordyceps multibrachiata*

Ophiocordyceps neocrinalis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

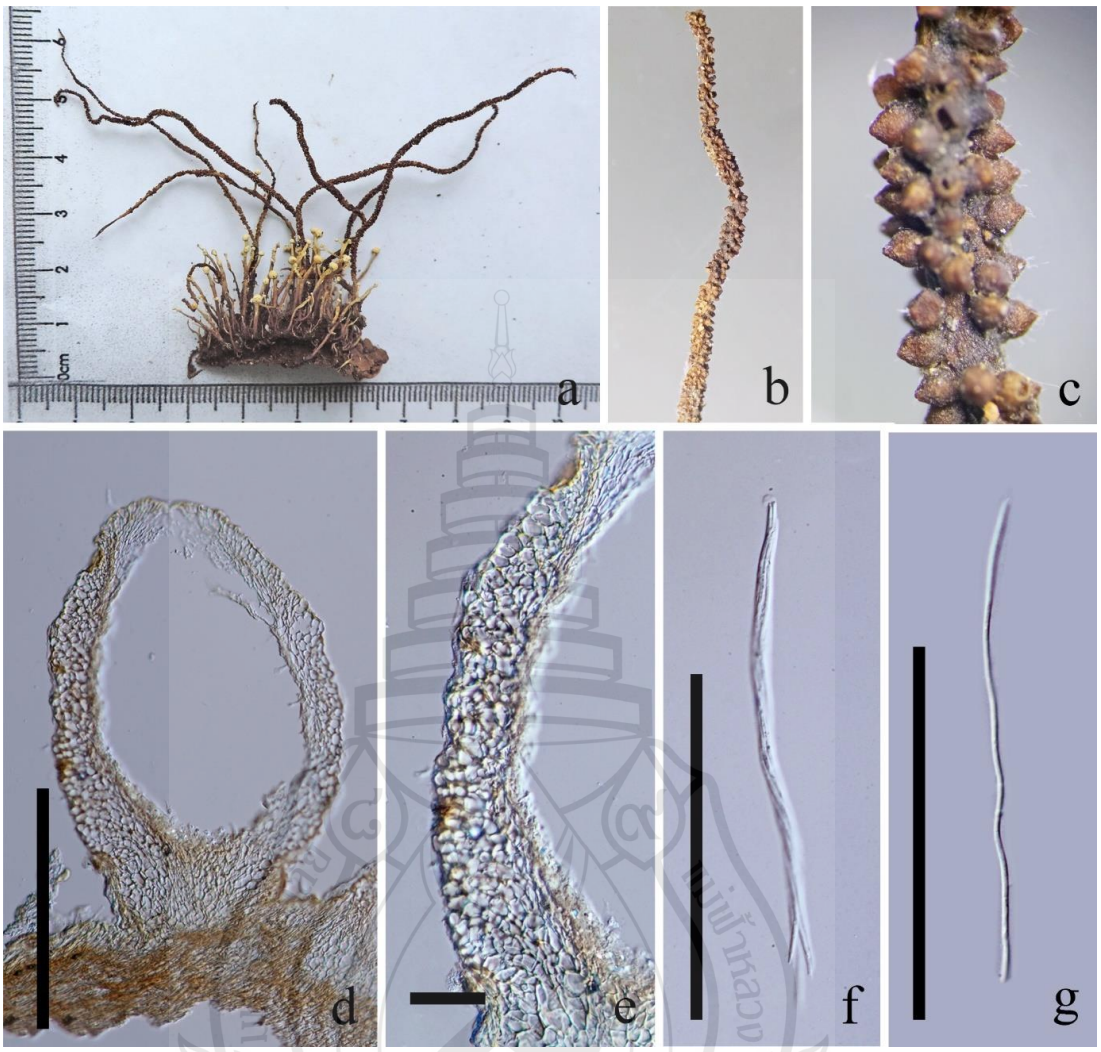
Etymology: Name referring to the similarity to *O. crinalis*.

Parasitic on Coleoptera larva, yellow to brown host, forming yellow to brownish ascostromata, insect in the leaf litter or in the soil, stromata erect in the air.

Sexual morph: Ascomycetes. *Thallus* within the insects host. *Host* 1.5 cm long, 0.5 cm wide, brown, without hyphae on the surface. *Ascostromata* 1.2–3 cm long, 0.5–1 mm wide, stromatic, stipitate, several, unilocular, loosely scattered at the abdomen of the host. *Stipe* 0.5–1 cm long, 0.4–0.7 mm wide, wiry, fibrous, cylindrical, brown. *Fertile head* 0.5–2 cm long, 0.6–1 mm wide, perithecia scattered from the lower part to the top of the stroma, distinct to the stipe. *Perithecia* 285–320 × 158–192 μm ($\bar{x}$ = 302 × 175 μm, n = 30), superficial, brownish to red-brown, amygdaliform to oval-shaped, thick-walled. *Peridium* 28–39 mm ($\bar{x}$ = 34 μm, n = 60) wide, two layers, *textura angularis* outer layer to *textura porrecta* inner layer, brownish. *Asci* 149–178 × 5.6–7.5 μm ($\bar{x}$ = 164 × 6.5 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.5–4.3 μm ($\bar{x}$ = 3.9 μm, n = 60) diam. *Ascospores* 116–139 × 1.9–2.5 μm ($\bar{x}$ = 128 × 2.2 μm, n = 60) cylindrical, smooth, hyaline, not breaking into secondary spores. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Kunming City, Yeya Lake. parasitic on Coleoptera larva, on the leaf litter, 30 September 2018, Juan Meng, YN20. China, Guizhou Province, Leigong moutain, Lake. parasitic on Coleoptera larva, on the leaf litter, 30 September 2018, Juan Meng, LG1030.

Notes: *Ophiocordyceps crinalis* is closest to the new species, which was reported as *Cordyceps crinalis*, collected from American and transferred to *Ophiocordyceps* (Sung et al., 2007). Morphologically, *Ophiocordyceps crinalis* is distinct from *Ophiocordyceps crinalis* by producing shorter asci and shorter secondary ascospores.



Note a Overview of *Ophiocordyceps neocrinalis*. b, c Stroma. d Perithecia. h Peridium. f Asci. g Ascospore. Scale Bars: d = 200 µm, f, g = 100 µm, e = 20 µm.

Figure 3.15 Morphology of *Ophiocordyceps neocrinalis*

Ophiocordyceps crinalis (Ellis ex Lloyd) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 41 (2007).

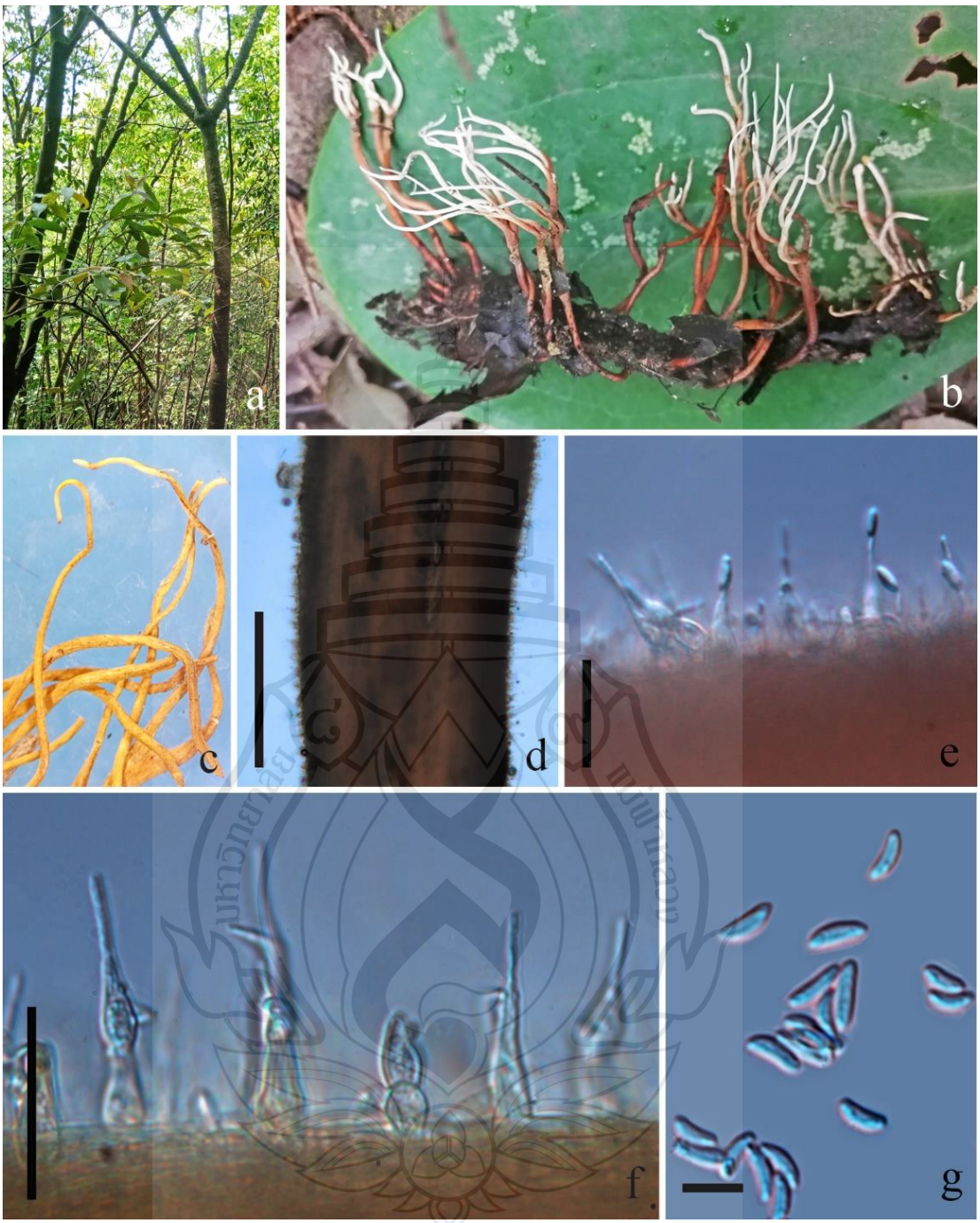
Index Fungorum Number: IF 504243

Parasitic on larvae of Lepidoptera, in leaf litter. **Sexual morph: Sexual morph:** Ascomycetes. *Thallus* within insect host. *Host* 3–6 cm long, 1–2 cm wide,

brown, without hyphae on the surface. *Stromata* 1–4 cm long, 0.5–1.6 mm wide, stromatic, stipitate, several, crowed scattered at the whole body of the host. *Stipe* 0.5–2 cm long, 0.2–1 mm wide, cylindrical, brown. *Fertile head* 1–3 cm long, 0.7–1.6 mm wide, perithecia scattered from the middle part to the upper of the stroma, distinct to the stipe, with a short infertile part. *Perithecia* 340–500 × 228–302 µm ($\bar{x}$ = 420 × 265 µm, n = 30), superficial, brownish to red-brown, oval-shaped, thick-walled. *Peridium* 28–40 mm ($\bar{x}$ = 34 µm, n = 60) wide, two layers, *textura angularis* outer layer to *textura porrecta* inner layer, brownish. *Asci* 110–138 × 4.4–6.8 µm ($\bar{x}$ = 124 × 5.6 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.7–5 µm ($\bar{x}$ = 4.1 µm, n = 60) diam. *Ascospores* 108–129 × 1.8–2.6 µm ($\bar{x}$ = 119 × 2.2 µm, n = 60) cylindrical, smooth, hyaline, 3–5-sepeta, not breaking into secondary spores. **Asexual morph:** Hyphomycetous. *Synnemata* 1–2.8 cm long, 0.5–2 mm wide, cylindrical with tapering tip, stipitate, usually branched into 2 or 3 in the middle of synnemata, bicolored, red on the lower portion, gradually became to white or yellowish to the upper portion, scattered on the insect body, without fertile head. *Conidiophores* 18.2–32.4 × 2.1–4.6 µm wide ($\bar{x}$ = 25.3 × 3.3 µm, n = 60), solitary, unbranched, growing along the white or yellowish upper portion. *Metulae* 4–9.4 × 2.1–4.5 µm ($\bar{x}$ = 6.7 × 3.3 µm, n = 90), smooth-walled, hyaline. *Phialide* 15.6–23.9 µm long ($\bar{x}$ = 19.8 µm, n = 60), directly growing from hyphae, solitary, acute at the base 5.2–8.3 × 2.2–4.6 µm ($\bar{x}$ = 6.7 × 3.4 µm, n = 90), tapering into a long neck. *Conidia* 5.1–7.1 × 1.9–2.8 µm ($\bar{x}$ = 6.1 × 2.4 µm, n = 60), allantoid, 1-celled, hyaline.

Material examined: China, Guizhou Province, Zunyi City, parasitic on *Ophiocordyceps crinalis* (Ophiocordycipitaceae), on the leaf litter, 25 July 2010, HKAS 86643 (sexual morph). China, Guizhou Province, Zunyi City, parasitic on larvae of Lepidoptera, on the leaf litter, 30 September 2020, Yu Yang, 520326MF40865 (asexual morph).

Notes: This study provides both of the sexual morph and asexual morph of *Ophiocordyceps crinalis* with molecular data.



Note a Habitat. b Overview of *Ophiocordyceps crinalis*. c, d Synnemata. e, f Conidiophores with phialides. g Conidia. Scale Bars: d = 200 µm, e, f = 200 µm, g = 5 µm.

Figure 3.16 Morphology of *Ophiocordyceps crinalis* (asexual morph)

Note a Herbarium record. b Overview of *Ophiocordyceps crinalis*. c, d Stromata. e, g Section of stroma with perithecia. f Peridium. h, i Asci. j, k Ascospores. Scale Bars: e, g = 200 µm, f = 20 µm, h–k = 50 µm.

Figure 3.17 Morphology of *Ophiocordyceps crinalis* (sexual morph)

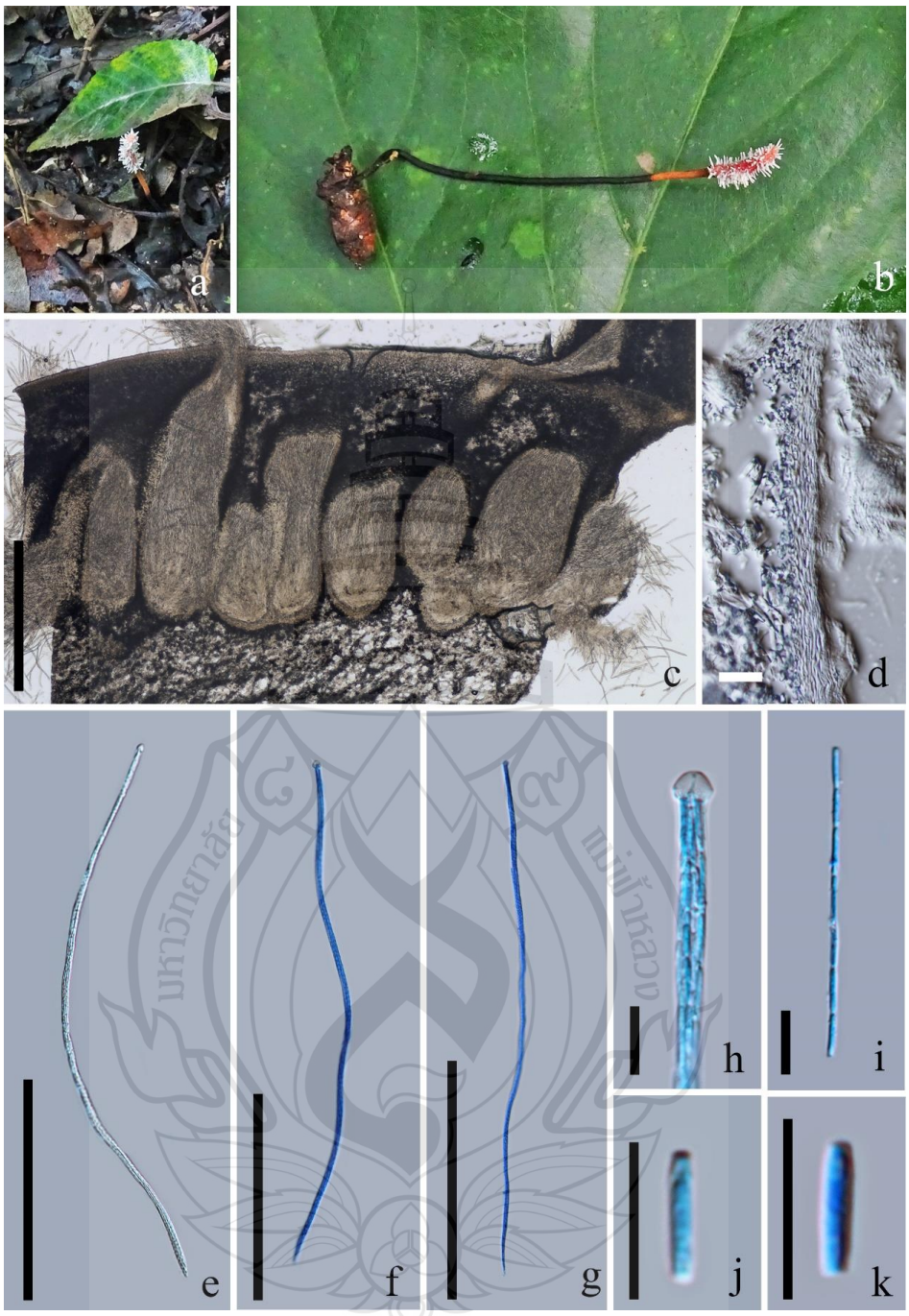
Ophiocordyceps tessaratomidarum Mongkols., Noisrip., Pooissarakul, Rungjind. & Luangsa-ard, in Khao-ngam, Mongkolsamrit, Rungjindamai, Noisripoom, Pooissarakul, Duangthisan, Himaman & Luangsa-ard, Mycol. Progr. 20(3): 348 (2021).

Index Fungorum number: IF 838745

Parasitic on stink bug (Hemiptera), on insect buried in the soil, the stromata erect in the air. **Sexual morph:** *Host* 1.2–2.5 cm diam, brown to dark brown, without mycelium coved the surface. *Stromata* 6–12 cm long, 1.5–3 mm wide., solitary, unbranched, bi-colored, dark on lower part, orange to red on the upper part, hard, cylindrical or clavate. *Stipe* 4–10 cm long, 0.1–0.3 cm wide., dark to red, unbranched, differ with the fertile head. *Fertile head* 1.3–3 cm long, 2–3 mm wide, red, cylindrical with a terminal tip, single, smooth. *Perithecia* 760–1150 × 216–319 µm ($\bar{x}$ = 955 × 237 µm, n = 60), oblique immersed, ovoid to obpyriform, curved in the middle. *Peridium* 20–30 µm ($\bar{x}$ = 25 µm, n = 90) wide, hyaline, of three layers, *textura prismatica* out layer, *textura epidermoidea* middle layer, *textura porrecta* inner layer. *Asci* 610–800 × 6–9.6 µm ($\bar{x}$ = 705 × 7.8 µm, n = 90), 8-spored, hyaline, filiform, with a thick apex. *Apical cap* 4.5–5.1 µm ($\bar{x}$ = 4.8 µm, n = 60) thick, hyaline. *Ascospores* as long as asci, filiform, hyaline, multiseptate, easy to break into secondary ascospores. *Secondary ascospores* 9.2–11.4 × 1.6–2.3 µm ($\bar{x}$ = 10.3 × 2.0 µm, n = 90) cylindrical, one-celled, straight, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Yunnan Province, Kunming City, Yeya lake. Parasitic on stink bug (Hemiptera), insect buried in the soil, the stromata erect in the air. 02 December 2018, Juan Meng, YYH18093019. China, Guizhou Province, Yuntai Mountain. Parasitic on stink bug (Hemiptera), insect buried in the soil, the stromata erect in the air. 16 June 2019, Yu Yang, YTS19061906Z, BN21

Notes: The new collection is sister with *Ophiocordyceps tessaratomidarum* in the phylogenetic tree with high support value (100/1). Themorphologyy similar to *Ophiocordyceps tessaratomidarum*. Thus, the new collections are identified as *Ophiocordyceps tessaratomidarum* in this study. However, *Ophiocordyceps tessaratomidarum* was reported as the host of *Pleurocordyceps nutantis* in this study, and also a new record in Thailand.



Note a Habitat of *Ophiocordyceps tessaratomidarum*. b Overview of *Pleurocordyceps sinensis* and *Ophiocordyceps nutans*. c Cross section shows the ascomata of *Ophiocordyceps nutans*. d Peridium. e–g Asci. h Apical cap. i Part of the ascospores. j, k Secondary spores. f–k Dyed by cotton blue. Scale Bars: c = 500 µm, e–g = 200 µm, d = 20 µm, h–k = 10 µm.

Figure 3.18 Morphology of *Ophiocordyceps tessaratomidarum*

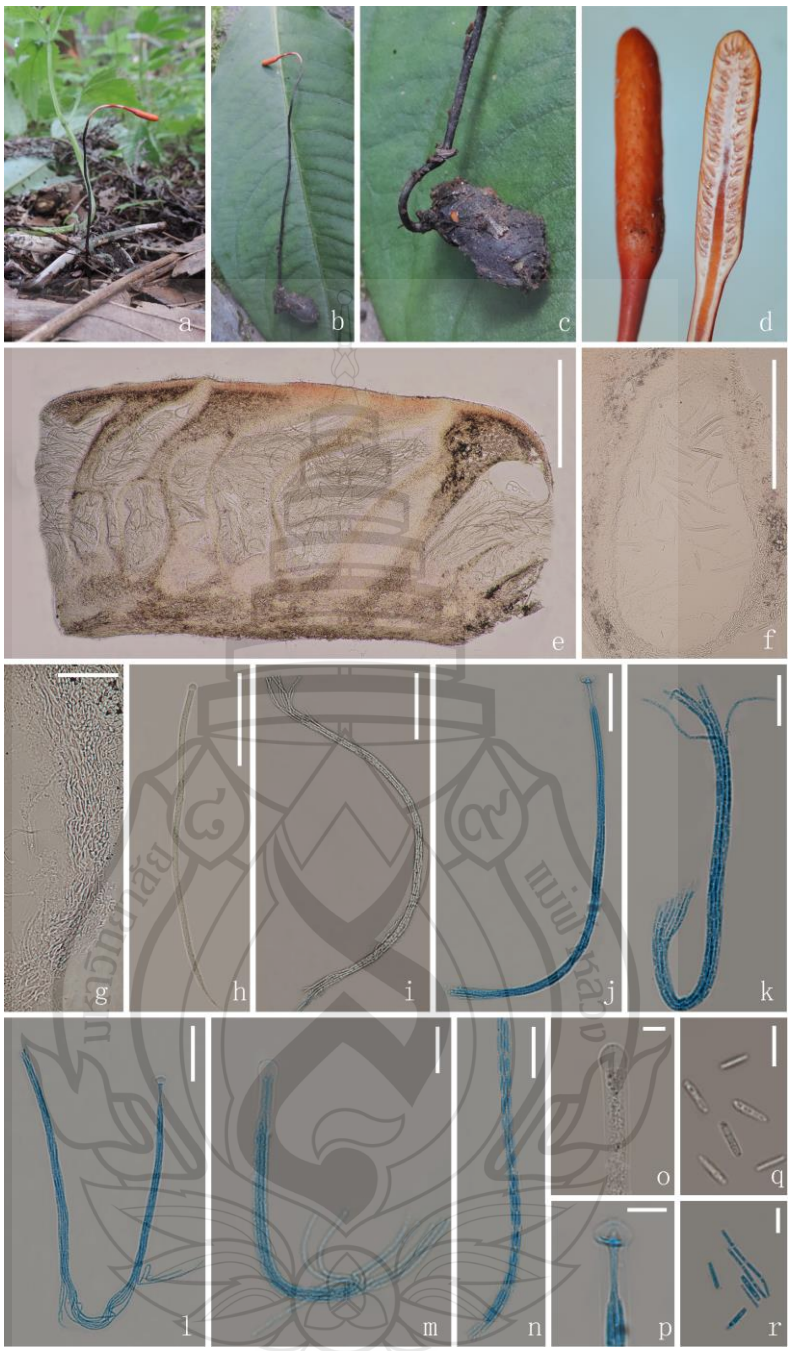
Ophiocordyceps nutans (Pat.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 45 (2007).

Index Fungorum number: IF 504313

Parasitic on stink bug (Hemiptera), on insect buried in the soil, the stromata erect in the air. **Sexual morph:** *Host* 0.8–1.4 cm diam, dark brown to dark, without mycelium coved the surface. *Stromata* 6–8 cm long, 1–3 mm wide., solitary, unbranched, bi-colored, dark on lower part, orange to red on the upper part, hard, cylindrical. *Stipe* 4–7 cm long, 0.1–0.3 cm wide., dark to red, unbranched, differ with the fertile head. *Fertile head* 1–2 cm long, 2–3 mm wide, red, fusiform, single, smooth. *Perithecia* 760–890 × 216–269 µm ($\bar{x}$ = 825 × 243 µm, n = 60), oblique immersed, ovoid to obpyriform, curved in the middle. *Peridium* 22–28 µm ($\bar{x}$ = 25 µm, n = 90) wide, hyaline, of three layers, *textura prismatica* out layer, *textura epidermoidea* middle layer, *textura porrecta* inner layer. *Asci* 510–673 × 6.7–8.1 µm ($\bar{x}$ = 592 × 7.4 µm, n = 90), 8-spored, hyaline, filiform, with a thick apex. *Apical cap* 3.9–4.8 × 6.7–7.2 µm ($\bar{x}$ = 4.4 × 7.0 µm, n = 60), thick, hyaline. *Ascospores* as long as asci, filiform, hyaline, multiseptate, easy to break into secondary ascospores. *Secondary ascospores* 8.7–11.4 × 1.8–2.2 µm ($\bar{x}$ = 10.1 × 2.0 µm, n = 90) cylindrical, one celled, straight, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Jiangxi Province, Jinggang City, Jinggang Mountain. on stink bug (Hemiptera), insect buried in the soil, the stromata erect in the air. 02 December 2018, Juan Meng, JGS29, CM35 (Reference specimen).

Notes: *Ophiocordyceps nutans* was indicated as a reference specimen with molecular data in this study.



Note a Habitat of *Ophiocordyceps nutans*. b Overview of *Ophiocordyceps nutans*. c Host. d, e Cross section shows the ascomata of *Ophiocordyceps nutans*. f Perithecia. g Peridium. h–n Asci. o, p Apical cap. q, r Secondary spores. j–n. p, r Dyed by cotton blue. Scale Bars: e, f = 200 µm, g = 20 µm, h–m = 50 µm, o, p = 5 µm, q, r = 10 µm.

Figure 3.19 Morphology of *Ophiocordyceps nutans*

Ophiocordyceps buquetii (Mont. & C.P. Robin) Spatafora, Kepler & C.A. Quandt, in Spatafora, Quandt, Kepler, Sung, Shrestha, Hywel-Jones & Luangsa-ard, IMA Fungus 6(2): 359 (2015).

Index Fungorum number: IF 814734

Parasite in the queen and worker of green tree ant species of *Oecophylla smaragdina* (Formicidae, Hymenoptera). **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 1–2.5 cm long, 1–3 mm wide, clavate with long stipe, solitary or branched, numerous grow from the joint of the ant body, bicolored, upper portion brown to cream to red colored, lower portion brown to black colored. *Fertile head* 2–4 mm long, 1–3 mm wide, cream to red colored, capitate, coved with mess conidia. *Stipe* 1–2 cm long, 1–2 mm wide, flexuous, black to brown colored, hard. *Hyphae* 3.0–4.5 µm wide ($\bar{x}$ = 3.7 µm, n = 60), irregularly multi-septate, hyaline, filiform, smooth. *Conidiophore* 30–45 µm long ($\bar{x}$ = 37 µm, n = 60), concentrated in head, mono-, bi- or terverticillate. *Phialide* 12.8–18.3 × 2.0–2.8 µm ($\bar{x}$ = 16 × 2.4 µm, n = 60), hyaline, smooth, forming a hymenial layer, cylindrical, rarely branched into 2, sometimes tapering into a short neck, 1–3 phialides in one forming from the same node. *Conidia* 4.1–5.6 × 2.7–3.6 µm ($\bar{x}$ =4.9 × 3.1 µm, n=60), 1-cell, hyaline, globose to obovoid to obclavate.

Material examined: Thailand, Chiang Rai Province, on the queen of green tree ant of *Oecophylla smaragdina*, 10 December 2017, Saranyaphat Boonmee, K01.

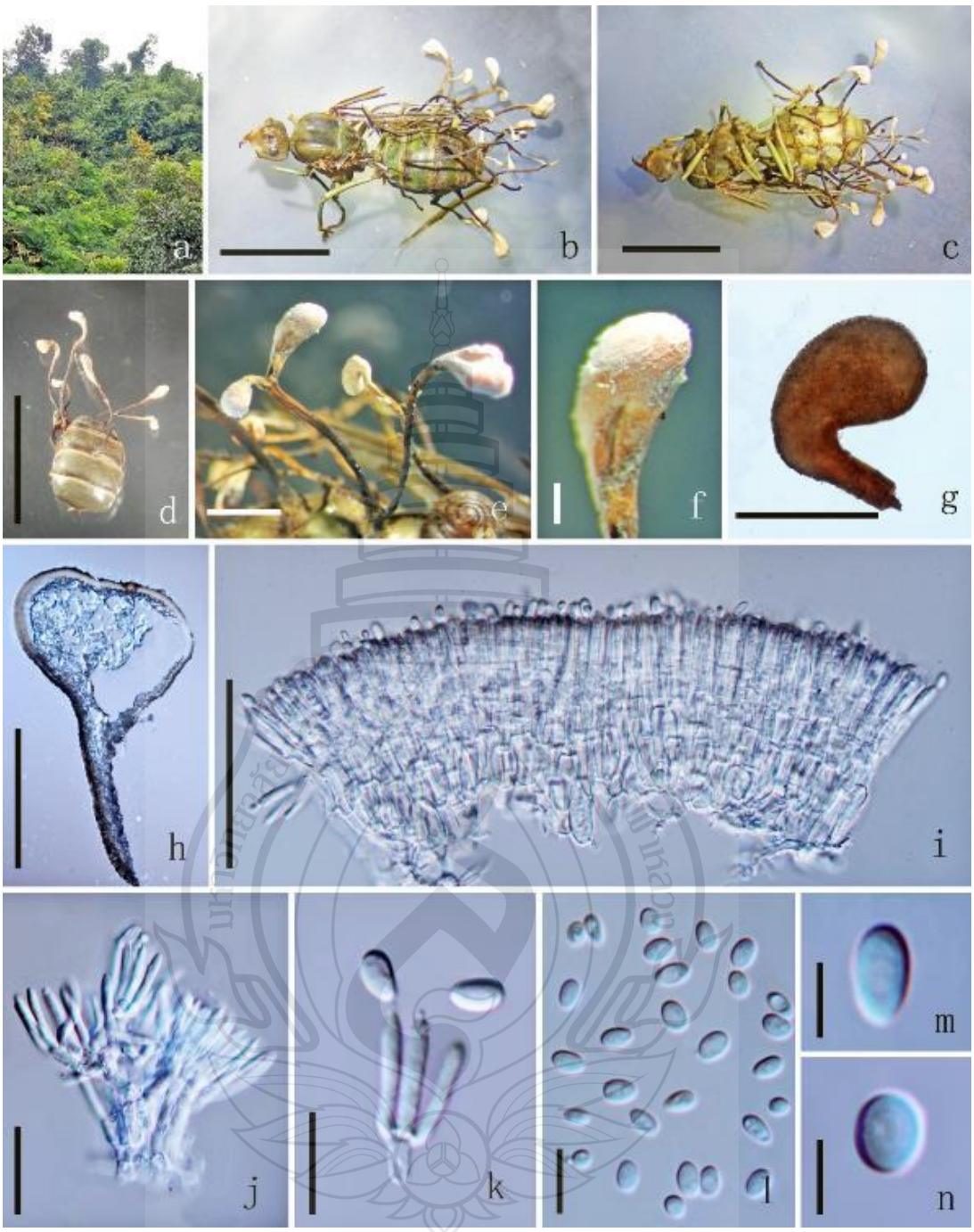
Notes: The new collections from China and Thailand shared the same clade with *O. buquetii* (HMAS 199613) in the phylogenetic tree. Morphologically, *O. oecophyllae* was close to *O. buquetii* and *Stilbum burmense* but distinct to *Stilbum burmense* by producing capitate synnemata, bicolored stipe without rigid hairs, shorter phialides and smaller conidia without mucus.

Ophiocordyceps buquetii was first reported as *Stilbum buquetii*, which parasitized *Hypsonotus clavulus* (Curculionidae, Coleoptera) and *Pycnopus bufo* (Curculionidae, Coleoptera), and produced many capitate synnemata, with rigid hairs on the stipe (Robin, 1853). Cooke (1892) proposed that *Stilbum buquetii* infected various insects, collected from many tropical countries. Petch (1934) reported an immature specimen of *Stilbum buquetii*, which parasitized a weevil (*Anchonus sp.*) and produced only one synnemata between the abdomen and the thorax. *Stilbum*

buquetii was synonymized under *Isaria briquetii* (Lloyd, 1922). Main (1951) redescribed the specimens of *Stilbum buquetii* collected from Brazil and Bolivia and emended the name *Isaria briquetii* to *Stilbum buquetii*. Two species, *Stilbella buquetii var. formicarum* (Current name: *Ophiocordycpes australiensis*) and *Stilbella buquetii var. buquetii* infected to ants (*Paltothyreus tarsatus*) and tropical beetles, have been transferred from *Stilbum* by Samson et al. (1981). *Stilbella buquetii* was moved to *Ophiocordyceps* based on morphological analyses (Spatafora et al. 2015). *Stilbella buquetii* is an entomopathogen, which parasites weevil and ants (Araújo et al., 2020), since *Stilbella buquetii var. formicarum* was reported by Samson and Evans (1981). Additionally, the strains (HMAS 199613, HMAS 199617) named *O. buquetii* were reported without morphological information (Quandt et al., 2014). The strains (Gh 24) named *O. buquetii* and parasite on ant were reported with limited morphological illustrations (Araújo et al., 2020). However, the rigid hairs of the original description of *Stilbum buquetii* were not present the illustrations of specimens CEM 1706, CEM 1703 and Gh 24.

Stilbum burmense was first reported as an ant pathogen, collected from Myanmar, similar as the species *Stilbum buquetii* (Mains, 1948). Luangsa-ard et al. (2008) reported a new collection of *Stilbum burmense* from Thailand with description and illustration. However, the description and illustration of the new collection differ with the original description of *Stilbum burmense* in having shorter phialides and smaller conidia without a mucus covering (Mains, 1948, Luangsa-ard et al., 2008).

In this study, we identify the new samples paracticed on different kinds of ants (queen and worker of green tree ants species of *Oecophylla smaragdina*, queen and worker of ants species of *Polyrhachis* sp.) as *Ophiocordyceps buquetii*, collected from China and Thailand. These new collections confirm that the *Ophiocordyceps buquetii* associated with ants are not a complex of species. And this conclusion was also confirmed by Araújo et al. (2020) with new samples collected from Ghana, Thailand and the Brazilian Amazon. Meanwhile, *Oecophylla smaragdina* is recorded as a new host for *Ophiocordyceps buquetii*.



Note a Habitat. b, c Overview of the fungus. d-g Synnemata. h Vertical section of synnema. i, j Conidiophores. k Phialides. l-o Conidia. Scale bars: b-d = 1 cm, e = 2000 µm, g-h = 1000 µm, f = 200 µm, i = 50 µm, j = 20 µm, k, l = 10 µm, m, n = 5 µm.

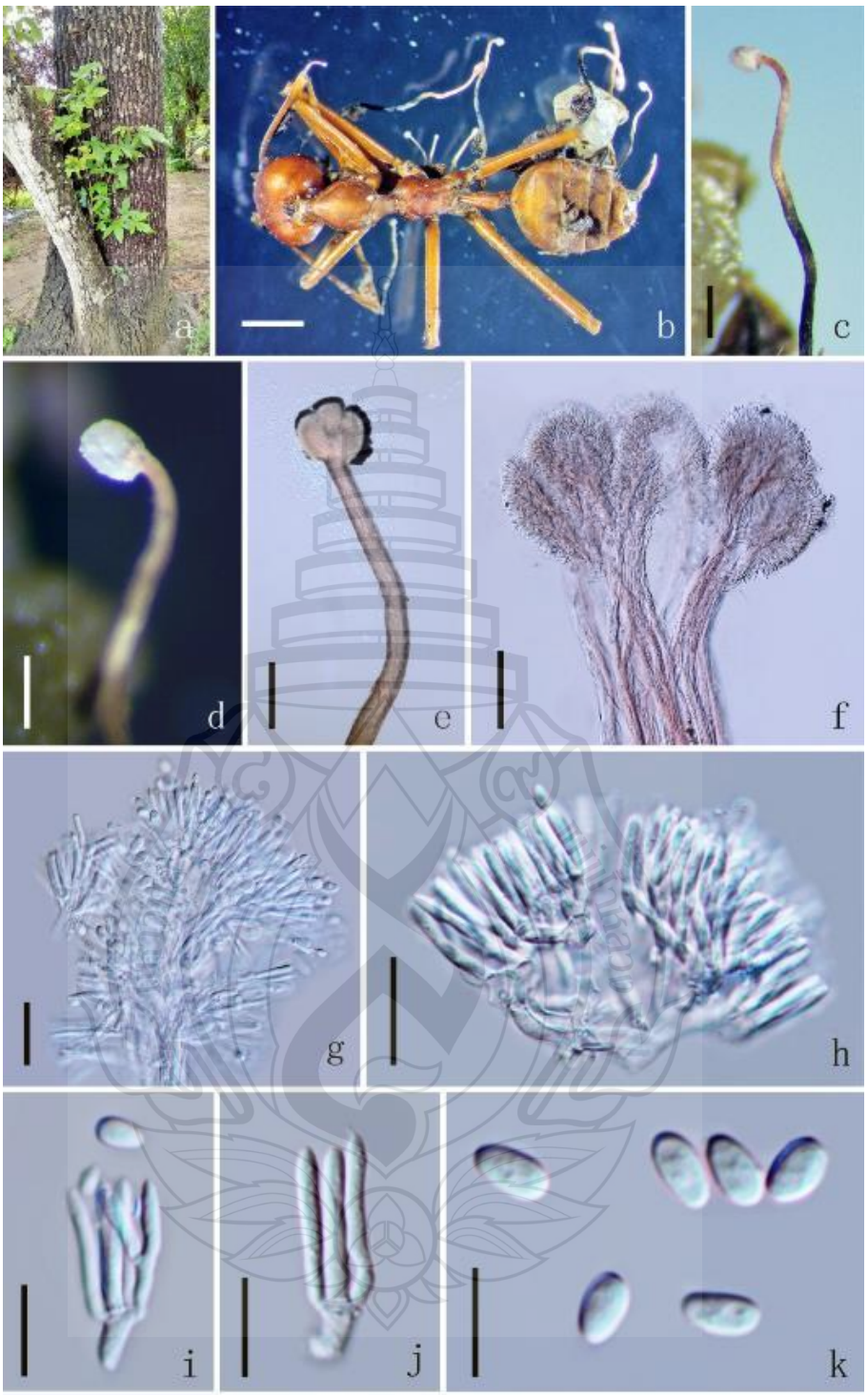
Figure 3.20 Morphology of *Ophiocordyceps buquetii* (New host K01)

Ophiocordyceps buquetii (Mont. & C.P. Robin) Spatafora, Kepler & C.A. Quandt, in Spatafora, Quandt, Kepler, Sung, Shrestha, Hywel-Jones & Luangsa-ard, IMA Fungus 6(2): 359 (2015)

Parasitism in the of green tree ant (Formicidae, *Oecophylla sp.*). **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 1–2.2 cm long, 0.05 mm wide, clavate with long stipe, solitary or branched, numerous grow from the joint of the ant body, bicolored, upper portion dark to cream to red colored, lower portion brown to dark colored. *Fertile head* 0.2–0.5 mm long, 0.1–0.2 mm wide, cream to red colored, capitate, coved with mess conidia. *Stipe* 1–2.2 cm long, 0.02–0.05 mm wide, flexuous, black to brown colored, hard. *Hyphae* 1.8–2.7 µm wide ($\bar{x}$ = 2.2 µm, n= 60), irregularly multi-septate, hyaline, filiform, smooth. *Conidiophore* 22–33 µm wide ($\bar{x}$ = 27 µm, n = 60), concentrated in head, mono-, bi- or terverticillate. *Phialide* 13.8–17.9 × 1.8–2.5 µm ($\bar{x}$ = 15.8 × 2.2 µm, n = 60), hyaline, smooth, forming a hymenial layer, cylindrical or subulate, tapering into a short neck. *Conidia* 5.6–6.9 × 3.2–4.0 µm ($\bar{x}$ = 6.3 × 3.6 µm, n = 60), 1-cell, hyaline, globose to obovoid to obclavate.

Culture characters: growing on PDA, reaching 7 cm diam., after 4 weeks at 20–25℃， with circular, whitened, loosely, aerial mycelium on the surface, with complex fold as a ring, reverse similar in colour, with ridge fold.

Material examined: Thailand, Chiang Rai, on queen of green tree ant of *Oecophylla smaragdina*, 17 August 2017, Yuanpin Xiao, PY0805.



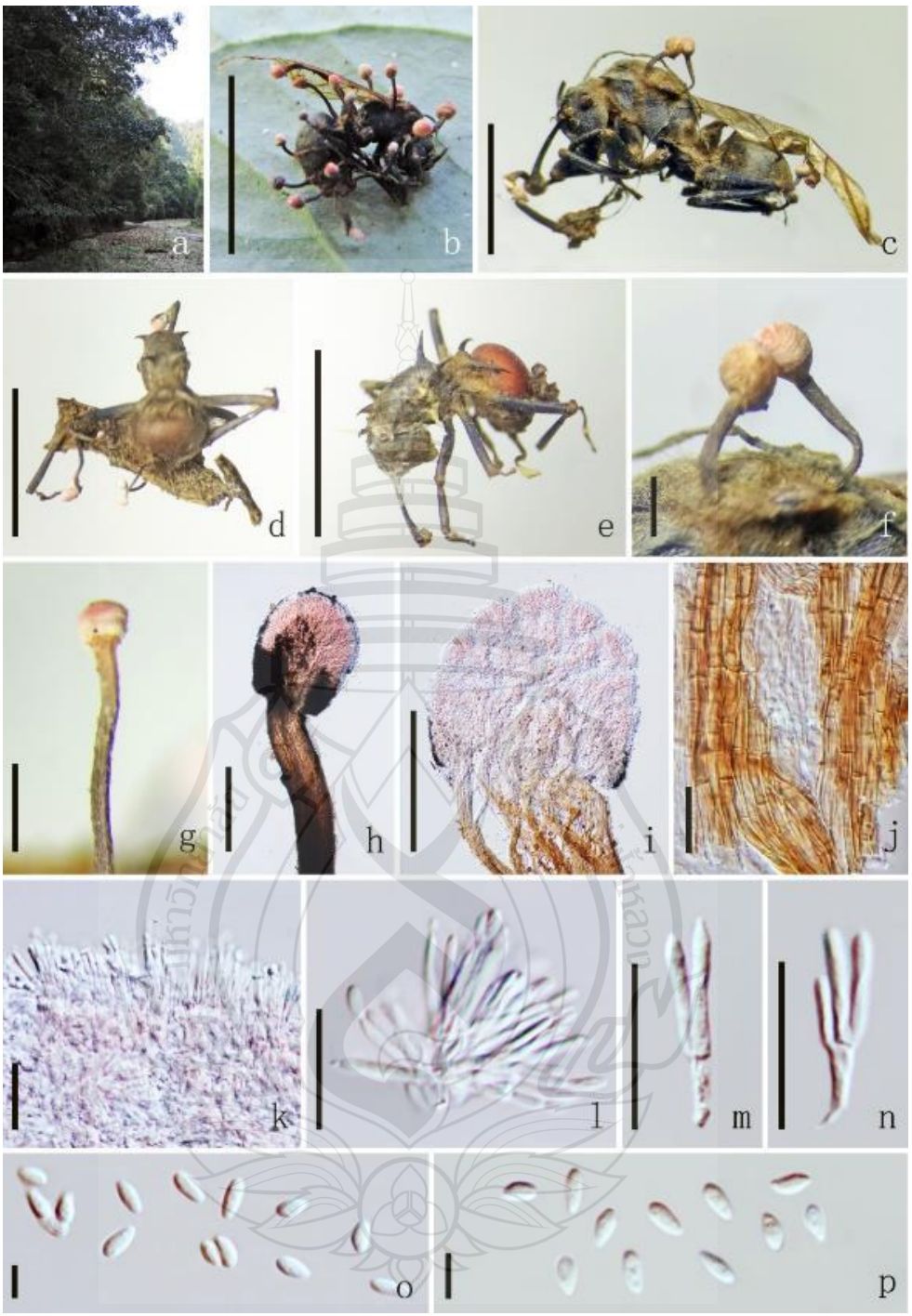
Note a Habitat. b Overview of the fungus. c-f Synnemata. g, h Conidiophores. i, j Phialides. k Conidia. Scale bars: b = 1000 µm, c = 500 µm, d, e = 200 µm, f = 100 µm, g, h = 20 µm, i–k = 10 µm.

Figure 3.21 Morphology of *Ophiocordyceps buquetii* (new host PY0805)

Ophiocordyceps buquetii (Mont. & C.P. Robin) Spatafora, Kepler & C.A. Quandt, in Spatafora, Quandt, Kepler, Sung, Shrestha, Hywel-Jones & Luangsa-ard, IMA Fungus 6(2): 359 (2015).

Parasite on the worker and queen of *Polyrhachis* sp. (Formicidae). *Host* 4 mm-6 mm long, 1 mm-2 mm diam., **Sexual morph:** Undertermined**. Asexual morph:** *Synnemata* 0.6–1.8 cm long, 0.6–1.7mm diam., arising from body joint, clavate, black to cinnamon gradually, with small pink or white fertile head on the topical. *Fertile head* 0.5–2 mm long, 0.5–1 mm wide., globose to subglobose, pale pink to white, with mess of conidia covered. *Stipe* 0.5–1.5 cm, long, 0.5–1.0 mm diam., cylindrical, black to cinnamon, branched or unbranched. *Hyphae* 2.4–4.7 µm ($\bar{x}$ = 3.4 µm, n = 50) wide, hyaline. *Phialides* 13–33 × 1.7–3.3 µm ($\bar{x}$ = 19.1 × 2.5, n = 30), hyaline, cylindrical, branched, with a tiny neck on the top, smooth. *Conidia* (5.1–7.3 × 2.1–3.8, $\bar{x}$ =6.2 × 3.1, n = 90) hyaline, ovoid to subglobose, smooth.

Material examined: China, Guizhou Province. On the worker and queen of *Polyrhachis* sp., 17 June 2019, JuanMeng, YRS05



Note a Habitat. b-e Overview of the fungus. f-i Synnemata. j Stipe. k Conidiophores. l-n Phialides. o, p Conidia. Scale bars: b = 1 cm, c-e = 5000 µm, f = 1000 µm, g, i = 500 µm, h = 200 µm, j–n = 20 µm, o, p = 5 µm.

Figure 3.22 Morphology of *Ophiocordyceps buquetii* (new host YRS05)

Ophiocordyceps neoacicularis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

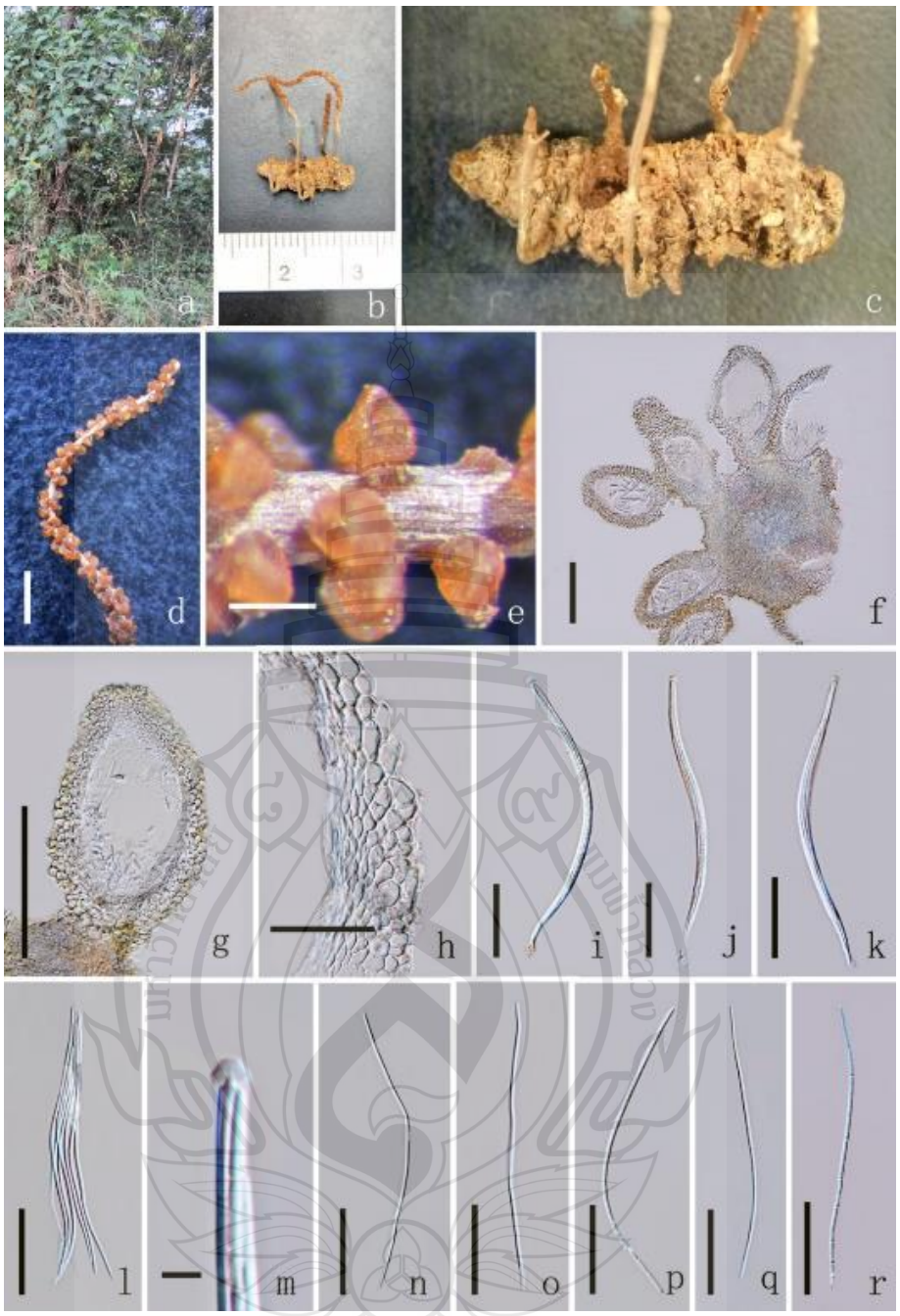
Etymology: Name referring to the similarity to *O. acicularis*.

Parasitic on Coleoptera larva, yellow to brown host, forming yellow to brownish ascostromata, insect in the leaf letter, ascostromata up in the air. **Sexual morph:** Ascomycetes. *Thallus* within insect host. *Host* 1.5 cm long, 0.5 cm wide, brown, without hyphae on the surface. *Ascostromata* 1.2–3 cm long, 0.5–1 mm wide, stromatic, stipitate, several, unilocular, loosely scattered at the abdomen of the host. *Stipe* 0.5–1 cm long, 0.4–0.7 mm wide, wiry, fibrous, cylindrical, brown. Fertile head 0.5–2 cm long, 0.6–1 mm wide, perithecia scattered from the thirds to the top of the stroma, distinct to the stipe. *Perithecia* 285–320 × 158–192 μm ($\overline{x}$ = 302 × 175 μm, n = 30), superficial, brownish to red brown, amygdaliform to oval shaped, thick-walled. *Peridium* 32–44 μm ($\overline{x}$ = 38 μm, n = 60) wide, two layers, *textura angularis* outer layer to *textura porrecta* inner layer, brownish gradually change to hyaline from outer layer to inner layer. *Asci* 149–178 × 5.6–7.5 μm ($\overline{x}$ = 164 × 6.5 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.5–4.3 μm ($\overline{x}$ = 3.9 μm, n = 60) diam. *Ascospores* 116–139 × 1.9–2.5 μm ($\overline{x}$ = 128 × 2.2 μm, n = 60) cylindrical, smooth, hyaline, 12–14 septate, not breaking into secondary spores. **Asexual morph:** Undetermined.

Material examined: Thailand, Chiang Mai Province, Mushroom Research Center, on Coleoptera larva, 22 August 2015, Yuanpin Xiao, MRC 15082203.

Notes: *Ophiocordyceps acicularis* is the closest species of the new species, which was reported as *Cordyceps acicularis* (Berkeley, 1857), collected from American and transferred to *Ophiocordyceps* based on morphology analyses (Petch, 1933). However, Petch (1933) redescribed *O. acicularis* after detecting the herbarium specimens of Ravenel 1276, which was deposited in Kew and the British Museum. The host of *O. acicularis* was changed from Lepidoptera larvae to beetle (Coleoptera) larvae (Petch, 1933). The main characteristics of *O. acicularis* were changed to narrow clavate asci, 4–6 septate ascospores that not dividing into secondary spores (Petch, 1933). The strain OSC 128580 had been proposed as *Cordyceps cf. acicularis* without morphology information (Spatafora et al., 2007) and it has been used to represent *O. acicularis* in many publications (Kepler et al., 2011; Sanjuan et al., 2015; Qu et al., 2018; Araújo et al., 2018). And the other two strains, OSC 110987, 0SC

110988, had been proposed as *O. acicularis* without morphology information and they have been used to represent *O. acicularis* (Evans et al., 2010; Chen et al., 2013; Sanjuan et al., 2015; Conlon et al., 2017; Luangsa-Ard et al., 2018; Thanakitpipattana et al., 2020). Another two strains (NHJ12622, NHJ10418.01), were collected from Thailand and named as *O. cf. acicularis* without morphology information (Luangsa-Ard et al., 2011). In addition, these strains cluster in distinct clades in the phylogenetic tree. Thus, *O. acicularis* requests more information. *Ophiocordyceps pseudoacicularis* was similar with *O. acicularis* in having similarity stromata similarand perithecia and differ from *O. acicularis* by producing slightly smaller ascospores (Luangsa-Ard et al., 2018). *Ophiocordyceps neoacicularis* is distinct to *O. acicularis* and *O. pseudoacicularis* by producing red brown perithecia, shorter asci and shorter ascospores with 12–14 septate. The strains NHJ12622 and NHJ10418.01 named *O. cf. acicularis* should be emend to *Ophiocordyceps neoacicularis*.



Note a Habitat. b Overview of the host and stromata. c Host. d, e Part of stroma. f Vertical section of stroma. g Vertical sections showing the superficial perithecia. h Perithecium. i–k Asci. l Asci with 8 ascospores. m Asci with apical cap. n–r Ascospores. Scale Bars: d = 1000 µm, e–g = 200 µm, h–l, n–r = 50 µm, m = 5 µm.

Figure 3.23 Morphology of *Ophiocordyceps neoacicularis* (holotype MRC 15082203)

Ophiocordyceps unicistroma Y.P. Xiao, J. Meng, T.C. Wen & K.D. Hyde, *sp. nov.*

Etymology: Name referring to the single ascostromata.

Parasitic on Lepidoptera larva, dark brown host, forming brown to dark brown ascostromata, insect buried in the soil, ascostroma up in the air. **Sexual morph:** Ascomycetes. *Thallus* within insect host. *Host* 3 cm long, 0.2 cm wide, dark brown, without hyphae on the surface. *Stromata* 10–12 cm long, 2–4 mm wide, stipitate, single, unilocular, erect, dark brown, growing from the head of the insect. *Stipe* 1.8–2 cm long, 3–4 mm wide, wiry, fibrous, cylindrical, dark brown. *Fertile head* 7–7.5 cm long, 2–4 mm wide, perithecia dense scattered from lower part to the top of the stroma, dark brown, not distinct to the stipe. *Perithecia* 372–458 × 202–247 μm ($\bar{x}$ = 415 × 224 μm, n = 30), superficial, dark brown, amygdaliform to ovoid shaped, thin-walled. *Peridium* 23–31 μm ($\bar{x}$ = 27 μm, n = 60) wide, two layers, *textura angularis* outer layer to *textura porrecta* inner layer, outer layer brownish, inner layer hyaline. *Asci* 194–243 × 5–6.7 μm ($\bar{x}$ = 218 × 5.8 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.2–5.4 μm ($\bar{x}$ = 4.4 μm, n = 60) diam. *Ascospores* 179–217 × 1.6–2.3 μm ($\bar{x}$ = 198 × 2 μm, n = 60) cylindrical, smooth, hyaline, 10–12 septate, not breaking into secondary spores. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Kunming City, Yeya Lake, on Lepidoptera larva, 02 October 2018, Juan Meng, YYH18100207.

Notes: *Ophiocordyceps unicistroma* is sister with *O. longistromata* in the phylogenetic tree and morphological similar with the *O. acicularis* and *O. longistromata* by producing stipitate ascostromata, superficial perithecia and multiseptate ascospores. Morphologically, *Ophiocordyceps neoacicularis* distincts with closed species by producing long and single stromatic ascostromata and 10–12 septate ascospores.

Note a, b. Habitat. c Overview of *Ophiocordyceps unicistroma* d, e Ascostroma emerging from infected insect. f Vertical section of the stroma. g Perithecia. h Peridium. i, j. Asci. k Apical cap. l, m Ascospores. Scale Bars: c = 2 cm, d = 5000 µm, e = 1000 µm, f = 500 µm, g = 200 µm, i, j, l, m = 100 µm, h, k = 20 µm.

Figure 3.24 Morphology of Ophio*cordyceps unicistroma* (holotype YYH18100207)

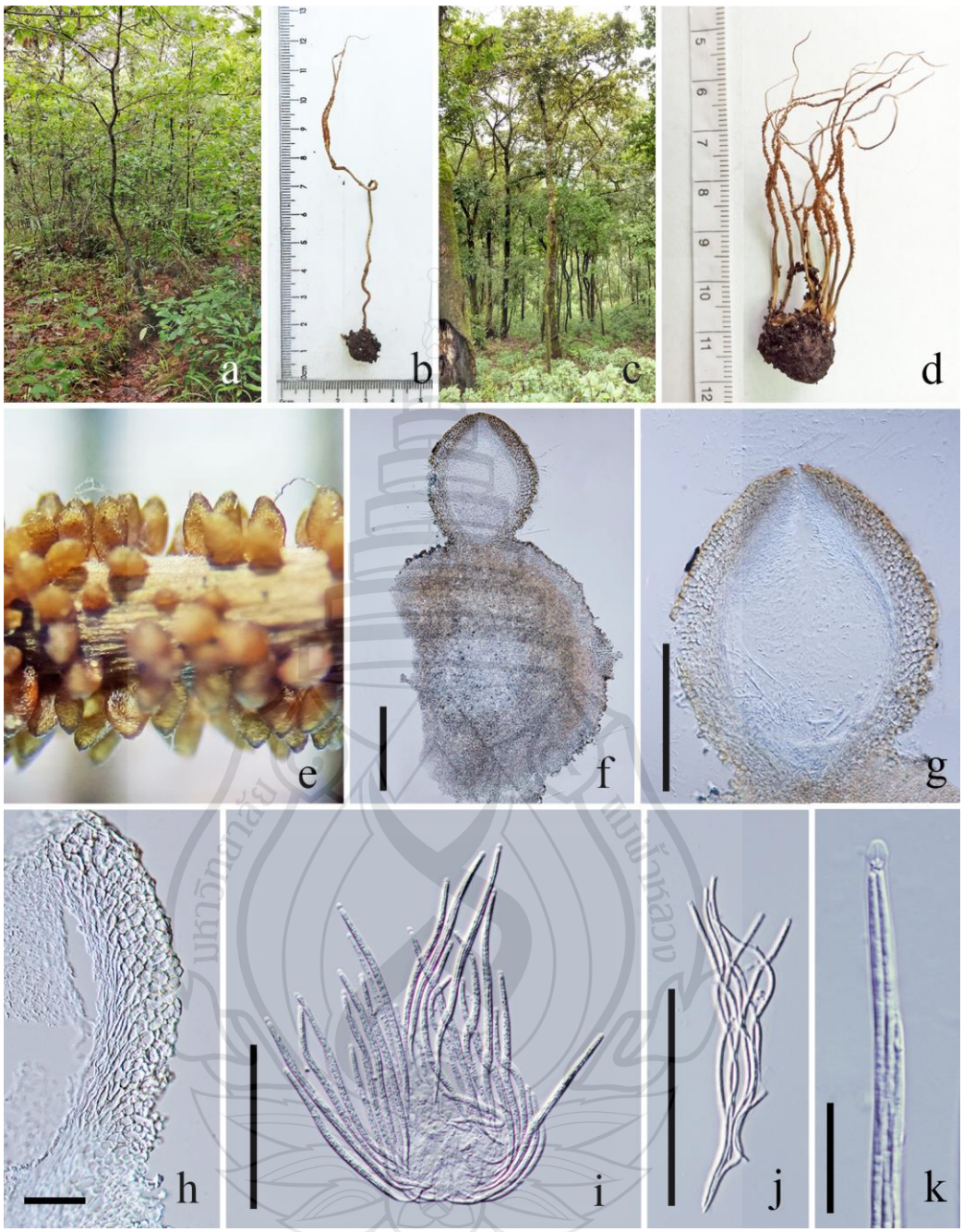
Ophiocordyceps materiae Y.P. Xiao, J. Meng, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: Name referring to the several stipes.

Parasitic on Lepidoptera larva, dark brown host, forming brown to dark brown ascostromata, insect buried in the soil, ascostroma up in the air. **Sexual morph:** Ascomycetes. *Thallus* within insect host. *Host* 0.8–1.2 cm wide, globose, dark brown, without hyphae on the surface. *Stromata* 5–12 cm long, 1–3 mm wide, stipitate, single, unilocular, erect, dark brown, growing from the whole body of the insect. *Stipe* 2–6 cm long, 1–2 mm wide, wiry, fibrous, cylindrical, brown. *Fertile head* 3–4 cm long, 2–3 mm wide, perithecia dense scattered from middle part, with 1–3 cm long infertile apex, brown, not distinct to the stipe. *Perithecia* 320–380 × 208–250 μm ($\overline{x}$ = 350 × 229 μm, n = 30), superficial, brown, ovoid shaped, thin-walled. *Peridium* 25–38 μm ($\overline{x}$ = 27 μm, n = 60) wide, two layers, *textura angularis* outer layer to *textura porrecta* inner layer, outer layer brownish, inner layer hyaline. *Asci* 206–280 × 6–7.2 μm ($\overline{x}$ = 243 × 6.6 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5.2–6.1 μm ($\overline{x}$ = 5.7 μm, n = 60) diam. *Ascospores* 200–268 × 1.4–2.2 μm ($\overline{x}$ = 234 × 1.8 μm, n = 60) cylindrical, smooth, hyaline, not breaking into secondary spores. **Asexual morph:** Undetermined.

Material examined: Thailand, Chiang Mai Province, on Lepidoptera larva, 14 July 2017, Yuanpin Xiao, CM33, CM34; China, Yunnan Province, Kunming City, Yeya Lake, on Lepidoptera larva, 19 June 2019, Yu Yang, YTS 19061923.

Notes: *Ophiocordyceps materiae* is sister with *O. acicularis* and *O. coccidiicola* in the phylogenetic tree. Morphologically, the new species *O. materiae* differs with the *O. acicularis* and *O. coccidiicola* by brown stromata, longer perithecia and longer ascospores.



Note a, Habitat in China. b, d Overview of *Ophiocordyceps materiae*. c Habitat in Thailand. e Part of stroma. f Vertical section of the stroma. g Perithecia. h Peridium. i Asci. j Ascospores. k Apical cap. Scale Bars: f, g, i, j = 200 µm, h, k = 20 µm.

Figure 3.25 Morphology of Ophio*cordyceps materiae*

Ophiocordyceps longissima (Kobayasi) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007

Index Fungorum number: IF 504298

Basionym: *Cordyceps longissima* Kobayasi, in Kobayasi & Shimizu 1963

Parasitic on Nymph of Cicadidae (Hemiptera), burin in the soil. **Sexual morph:** *Host* 2.1 cm long, 0.8 cm wide, brown, with brown hyphae on the surface. *Thallus* within insect host. *Stromata* 7–10 cm long, 0.1–0.3 cm wide., stromataic, stipitate, mostly single, multilocular, unbranched, arising from the joint between the head of larva, orange to red brown, fleshy, cylindrical. *Stipe* 5.5–6 cm long, 0.1–0.2 cm wide, red brown, with a fertile apex. *Fertile head* 1.5–2 cm long, 1–3 mm wide, red brown, single, unbranched, cylindrical, surface roughened, with a thin infertility channel unilateral, ostiole observed, with pseudoparenchymatous epidermal cortex on the surface. *Perithecia* 382–445 × 106–163 µm ($\bar{x}$ = 414 × 134 µm, n = 60), immersed, red, elongated ovoid, thick-walled. *Peridium* 16–23 µm ($\bar{x}$ = 19 µm, n = 90) wide, hyaline, *textura epidermoidea* to *textura angularis* to *textura porrecta* from outer layer to inner layer. *Asci* 233–302 × 5–6.5 µm ($\bar{x}$ = 267 × 5.7 µm, n = 90), 8-spored, hyaline, filiform, with a thin apex. *Apical cap* 2.7–3.6 × 4.7–5.9 µm ($\bar{x}$ = 3.1 × 5.3 µm, n = 60), thin, with a small channel in the center. *Ascospores* 240–303 × 1.8–2.3 µm ($\bar{x}$ = 272 × 2.1 µm, n = 60), filiform, hyaline, multiseptate. *Secondary spores* 7.6–10.9 × 1.6–2.3 µm ($\bar{x}$ = 9.3 × 1.9 µm, n = 90) cylindrical, one celled, straight, hyaline, smooth. **Asexual morph:** Undetermined

Material examined: Chiang Rai, Thailand. On nymphs of Cicada (Cicadidae, Homopter), 18 August 2017, Yuanpin Xiao, PY0809.

Notes: According to the morphology and phylogenetic comparison, two new collections from Phayao of Thailand are identified as *Ophiocordyceps longissima.* It is the first time that describe the characters of peridium for this species. This species has been frequently reported in south Asia including Japan, China, Thailand and Korea (Kobayasi & Shimizu, 1963; Li et al., 1999; Aung et al., 2008; Sung et al., 2011; Jaihan et al., 2021). Our study may help for the future investigation of this species.

Note a Habitat. b Ascostroma emerging from infected cicada. c. Overview of host. d, e. Fertile head of ascostroma. f, g. Ascostroma. h. Peridium. i. Part of ascospores. j, k. Secondary ascospores l, m. Asci. Scale bars: b, c = 1 cm, d = 5000 µm, e, f = 500 µm, g = 200 µm, l, m = 100 µm, h = 20 µm, i–k = 10 µm.

Figure 3.26 Morphology of *Ophiocordyceps longissima*

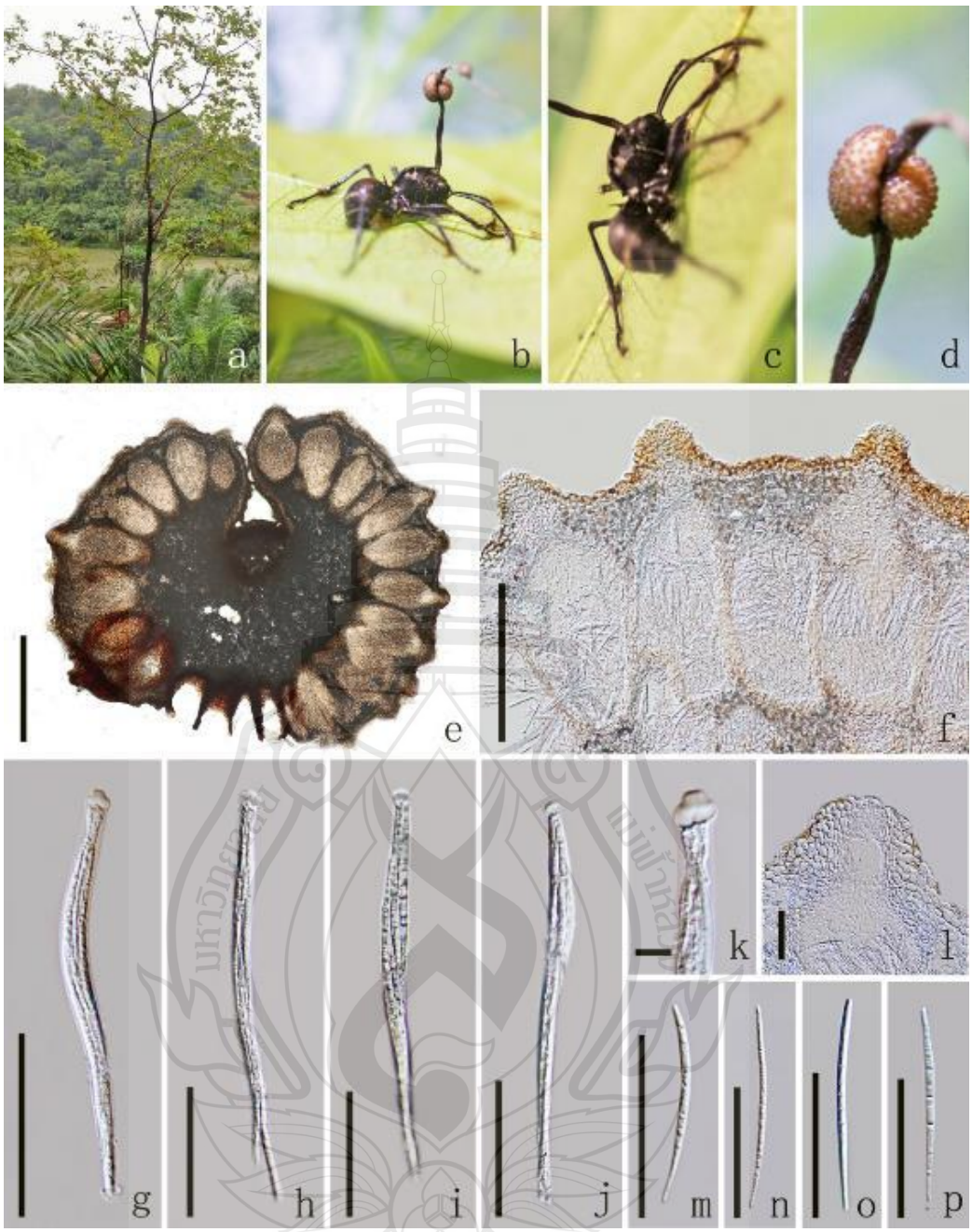
Ophiocordyceps divitis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the host species.

Parasitic on ant of *Polyrhachis dives* (Hymenoptera, Formicidae), collected from the lower surface of leave. **Sexual morph:** *Host* 4 mm long, 1–2 mm wide, without hyphae on the surface. *Stromata* 10–30 mm long, 0.2–3 mm wide, mostly single, disc-shaped, stipitate, arising from the joint between the head and trunk of ant, brown to dark brown. *Stipe* 10–29 mm long, 0.2–2 mm diam, clavate, with one or two lateral ascostroma. *Fertile head* 2–5 mm long, 2–4 mm wide, hemispherical to globose, lateral, brown, with papillae or conical ostiole. *Perithecia* 282–359 × 114–147 µm ($\bar{x}$ = 321 × 131 µm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 12–22 mm ($\bar{x}$ = 17 µm, n = 60) wide, hyaline, two layers, *textura angularis* outer layer to *textura prismatica* inner layer. *Asci* 132–154 × 5–7 µm ($\bar{x}$ = 143 × 6.2 µm, n = 60), 8-spored, hyaline, narrow cylindrical to fusiform, with a thickened apex. *Apical cap* 3.4–5.0 × 5.4–6.9 µm ($\bar{x}$ = 4.2 × 6.2 µm, n = 60) thick, with a small channel in the center. *Ascospores* 66.8–74.5 × 2.5–3.3 µm ($\bar{x}$ = 70.6 × 2.9 µm, n = 90), 3–5 septate, slender fusiform, not breaking into part-spores. **Asexual morph:** undetermined.

Material examined: Thailand, Ranong. On dead ant attached the lower surface of leave (Hymenoptera), 03 December 2016, YuanPin Xiao, RN03 (MFLU -, **holotype**); (MFLU 17-1962, MFLU 17-1963 **paratypes**).

Notes: *Ophiocordyceps divitis* is sister with *O. ootakii* and clust in the ant-associated clade in the phylogenetic tree. *Ophiocordyceps divitis* distinct to *O. ootakii* by infecting *Polyrhachis dives* and producing shorter asci.



Note a Habitat of *Ophiocordyceps divitis*. b Ascostroma emerging from infected ant host. c Host. d. Fertile head. e Vertical sections showing the completely embedded obliquely aligned perithecia. f Perithecia. g–j Asci. k Apical cap of ascus. l Ostiole. m–p Ascospore. Scale Bars: e = 500 µm, f = 200 µm, g–j, l–p = 50 µm, k = 5 µm.

Figure 3.27 Morphology of *Ophiocordyceps divitis*

Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 46 (2007)

Index Fungorum Number: IF 198070

Synonymy: Cordyceps sinensis (Berk.) Sacc., Michelia 1(no. 3): 320 (1878)

Hirsutella sinensis X.J. Liu, Y.L. Guo, Y.X. Yu & W. Zeng, Acta Mycol. Sin. 8(1): 37 (1989)

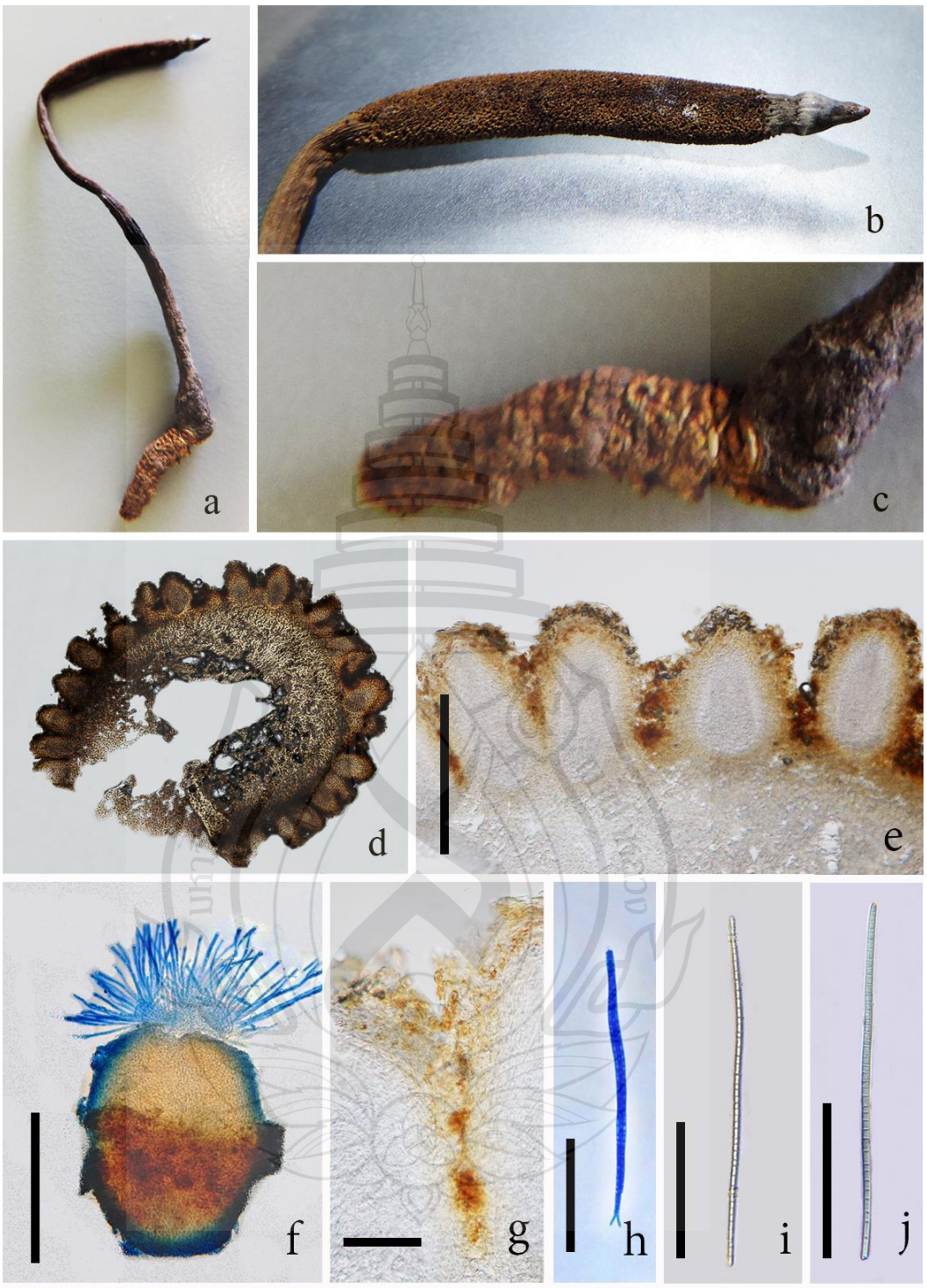
Hirsutella sinensis X. Fang, Mycological Society of China, Academic Annual Meeting Summary: 203 (2013)

Sphaeria sinensis Berk., London J. Bot. 2: 207 (1843)

Parasitic on larva of *Hepiaua larva* (Lepidoptera, Hepialidae), burin in the soil. **Sexual morph:** *Host* 3–5 cm long, 4–10 mm wide, without hyphae on the surface. *Stromata* 4–8 cm long, 2–5 mm wide, mostly single, cylindrical to lanceolate, stipitate, arising from the head of the host, brown to dark brown. *Stipe* 3–6 cm long, 2–5 mm wide, clindrical, with a slightly different fertile head. *Fertile head* 1–3 cm long, 4–7 mm wide, long lanceolate, dark brown, with a short infertility tip. *Perithecia* 340–460 × 145–260 μm ($\bar{x}$ = 400 × 221 μm, n = 30), superficial, subglobose, thick-walled. *Peridium* 28–40 mm ($\bar{x}$ = 34 μm, n = 60) wide, hyaline, two layers, *textura angularis* yellow outer layer to *textura prismatica* hyaline inner layer. *Asci* 260–340 × 8–12 μm ($\bar{x}$ = 300 × 10 μm, n = 60), 8-spored, hyaline, narrow cylindrical to fusiform. *Apical cap* 4.6–5.2 μm ($\bar{x}$ = 4.9 μm, n = 60) thick, with a small channel in the center. *Ascospores* 210–280 × 4–6 μm ($\bar{x}$ = 245 × 5 μm, n = 90), multi-septate, slender fusiform, not breaking into part-spores. **Asexual morph:** undetermined.

Material examined: China, Qinghai Province. On dead *Hepiaua larva* (Lepidoptera, Hepialidae), 05 June 2015, Ting-chi Wen, GZ2015060501 (reference specimen); China, Qinghai Province. On dead ant attached the lower surface of leave (Hymenoptera), 03 November 2021, Guangrong Li, L01 (reference specimen).

Notes: The new collection of *Ophiocordyceps sinensis* was described with photo plate and updated molecular data in this study.



Note a Overview of *Ophiocordyceps sinensis*. b Fertile head. c Host. d. e Vertical sections showing perithecia. f Perithecia. g Peridium. h Asci. i, j Ascospore. Scale Bars: f = 200 µm, g = 20 µm, h–j = 100 µm.

Figure 3.28 Morphology of *Ophiocordyceps sinensis*

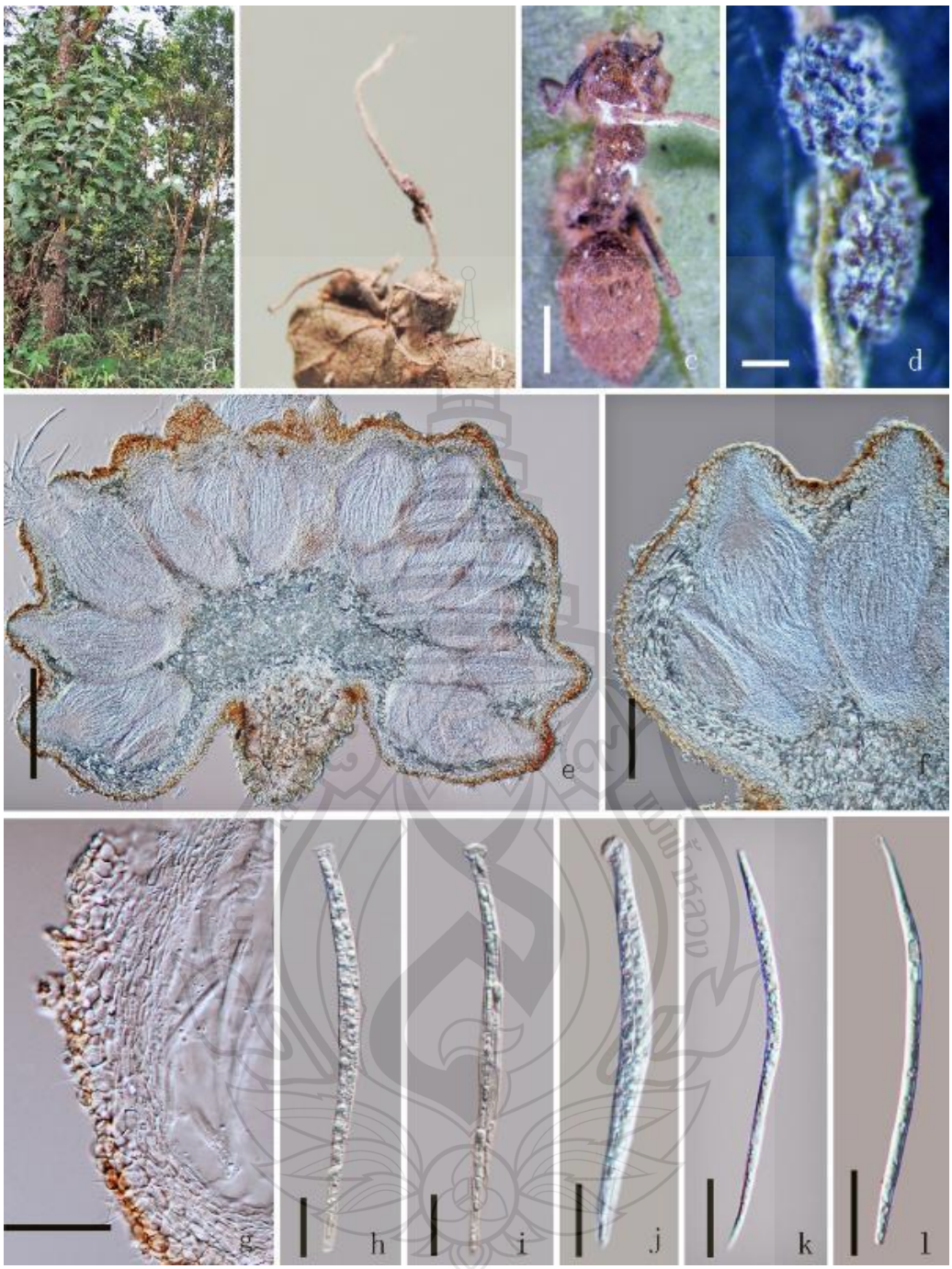
Ophiocordyceps unilateralis (Tul. & C. Tul.) Petch, Trans. Br. mycol. Soc. 16(1): 74 (1931).

Index Fungorum Number: IF 281145

Parasitic on ant (Hymenoptera, Formicidae), collected from the lower surface of leave. **Sexual morph:** *Host* 6 mm long, 1–2 mm wide, with dark brown hyphae on the surface. *Ascostromata* 8–17 mm long, 0.2–2 mm wide, stromatic, mostly single, stipitate, arising from the joint between the head and trunk of ant, brown to dark brown. *Stipe* 8–17 mm long, 0.2–2 mm diam, clavate, with one or two lateral ascomata. *Fertile head* 1–2 mm long, 1–2 mm wide, hemispherical, lateral, brown, with papillae or conical ostiole. *Ascomata* 234–306 × 112–149 µm ($\bar{x}$ = 270 × 131 µm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 10–17 mm ($\bar{x}$ = 14 µm, n = 60) wide, hyaline, three layers, *textura globulosa* outer layer to *textura angularis* to *textura prismatica* inner layer. *Asci* 129–152 × 7–10 µm ($\bar{x}$ = 141 × 8.5 µm, n = 60), 8-spored, hyaline, narrow cylindrical to fusiform, with a thickened apex. *Apical cap* 2.4–3.4 × 5.9–8.1 µm ($\bar{x}$ = 2.9 × 7.0 µm, n = 60) thin, with a small channel in the center. *Ascospores* 99.5–116.4 × 3.1–4.9 µm ($\bar{x}$ = 108 × 4 µm, n = 90), slender fusiform, not breaking into secondary spores. **Asexual morph:** undetermined.

Material examined: Thailand, Chiang Mai, MRC. On dead ant (Hymenoptera) biting the lower surface of leave, 10 February 2015, YuanPin Xiao, MRC15021026-2; MRC15021026-3.

Notes: Ten new collections from MRC of Thailand are identified as *Ophiocordyceps unilateralis*, which was frequently reported from Thailand (Wongsa et al., 2005; Luangsa-Ard et al., 2011). It is the first time that describe the characters of peridium for this species. The strain OSC 128574 was the first molecular records for the species *O. unilateralis* (Sung et al., 2007). Later, HUA 186161, SERI1, SERI2, HUA 186126, KT3307 and KT3308 have been published to represent to *O. unilateralis* (Luangsa-Ard et al., 2011). However, these strains are forming four distinct clades in the phylogenetic tree. KT3307 and KT3308 were reported molecular data with morphology analyses among these strains. We identified these samples as *O. unilateralis* by comparing the morphology of KT3307 and KT3308.



Note a Habitat of *Ophiocordyceps unilateralis*. b Ascostroma emerging from infected ant host. c Host. d. Fertile head. e Vertical sections showing the completely embedded obliquely aligned perithecia. f Perithecia. g Peridium h–j Asci. k, l Ascospore. Scale Bars: c = 1000 µm, d, e = 200 µm, f = 100 µm, g = 50 µm, h–l = 20 µm.

Figure 3.29 Morphology of *Ophiocordyceps unilateralis*

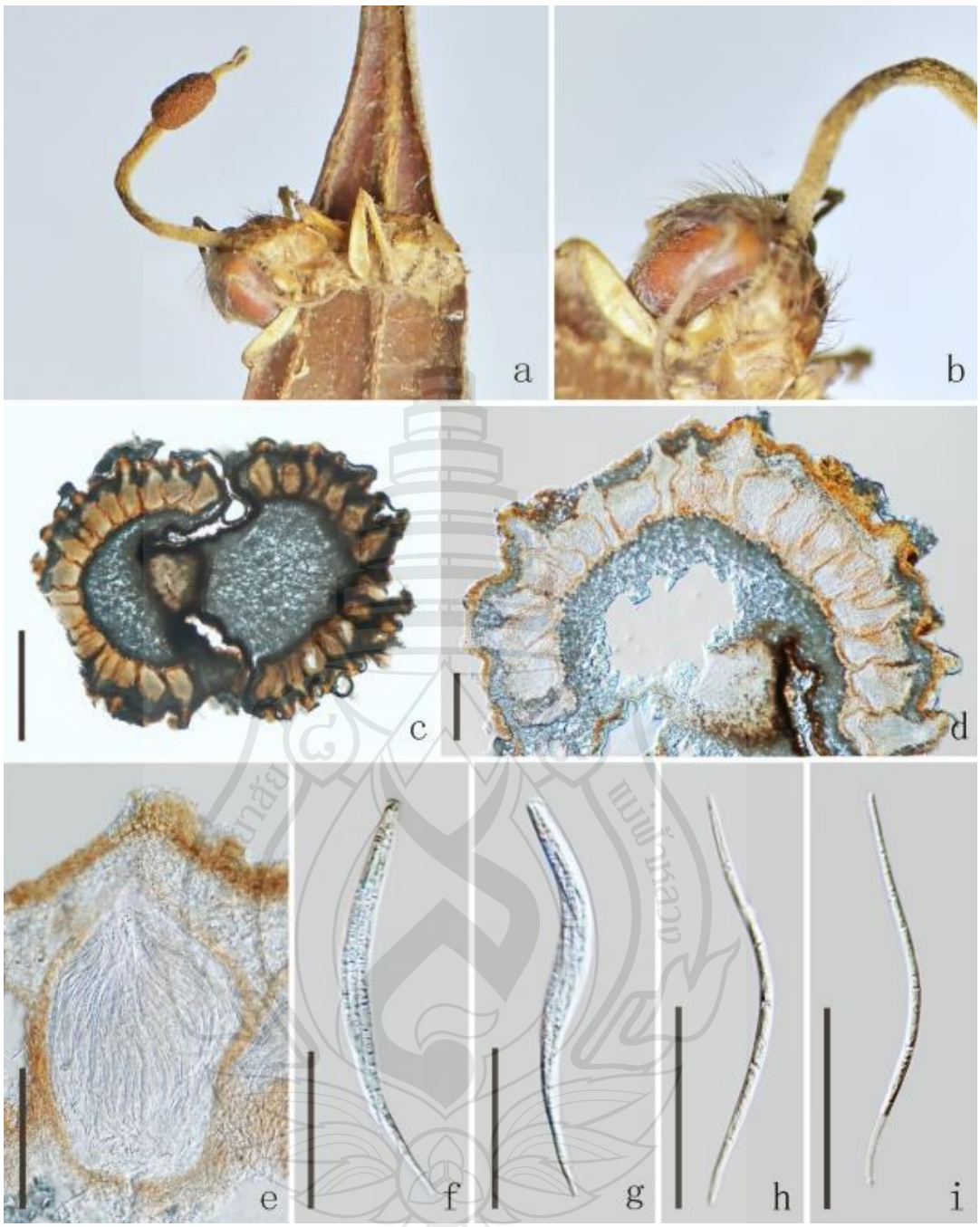
Ophiocordyceps biculcitulistipita Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to two lateral cushions opposite growing at the stipe.

Parasitic on ant (Hymenoptera), collected from the upper and lower surface of leaves. **Sexual morph:** *Host* 3.5–4 mm long, 0.5–1.2 mm wide, brown ant without hyphae on the surface. *Stromata* 5–9 mm long, 0.2–0.5 mm wide., mostly single, stipitate, unbranched, arising from the joint between the head and thorax of adult ant, yellow to brown. *Stipe* 4–8 mm long, 0.2–0.3 mm wide, cylindrical, yellow, with fertile part below the topical. *Fertile part* 12–13 mm wide, 0.4–0.5 mm diam, two lateral cushions opposite growing, dark brown, upper surface roughened. *Perithecia* 213–280 × 106–136 µm ($\overline{x}$ = 247 × 121 µm, n = 30), immersed, flask-shaped, thin-walled. *Peridium* 7–13 mm ($\overline{x}$ = 10 µm, n = 60) wide, two layers, textura angularis outer layer to textura prismatica inner layer. *Asci* 133–165 × 5–8 µm ($\overline{x}$ = 149 × 7 µm, n = 60), 8-spored, hyaline, narrow fusiform, with a thin apex. *Apical cap* 1.7–2.8 × 3.6–4.9 µm ($\overline{x}$ = 2.2 × 4.2 µm, n = 60). *Ascospores* 87–102 × 2–3 µm ($\overline{x}$ = 95 × 2.7 µm, n = 60), cylindrical, slightly curved in "S", tapering at both ends, 5–7 septate, hyaline, smooth, not breaking into part-spores. **Asexual morph:** undetermined.

Material examined: Ecuador, Amazonia, Orellana, NP Yasuni, rainforest. On dead ant (Hymenoptera), 18 March 2013, Kautmanova, V. Kautman, SL13031805 (MFLU, **holotype**); (MFLU, MFLU, MFLU **paratypes**).

Notes: *Ophiocordyceps biculcitulistipita* shares the same characters with the other ant pathogen species in *Ophiocordyceps* by producing stipitate stromata, lateral fertile region, narrow fusiform asci and cylindrical ascospores. And it is distinct to closed species in having two lateral cushions opposite growing at the stipe and (87–102 × 2–3 µm) cylindrical, slightly curved in "S" ascospores. Even though we did not get the molecular data of the collections, the new species *Ophiocordyceps biculcitulistipita* is established based on its distinguished characters.



Note a. Overview of *Ophiocordyceps biculcitulistipita* b. Ascostroma emerging from infected ant. c, d. Vertical section of the stroma. e. Perithecia. f, g. Asci. h, i. Ascospores. Scale Bars: c = 500 µm, d = 200 µm, e = 100 µm, f–i = 50 µm.

Figure 3.30 Morphology of *Ophiocordyceps biculcitulistipita*

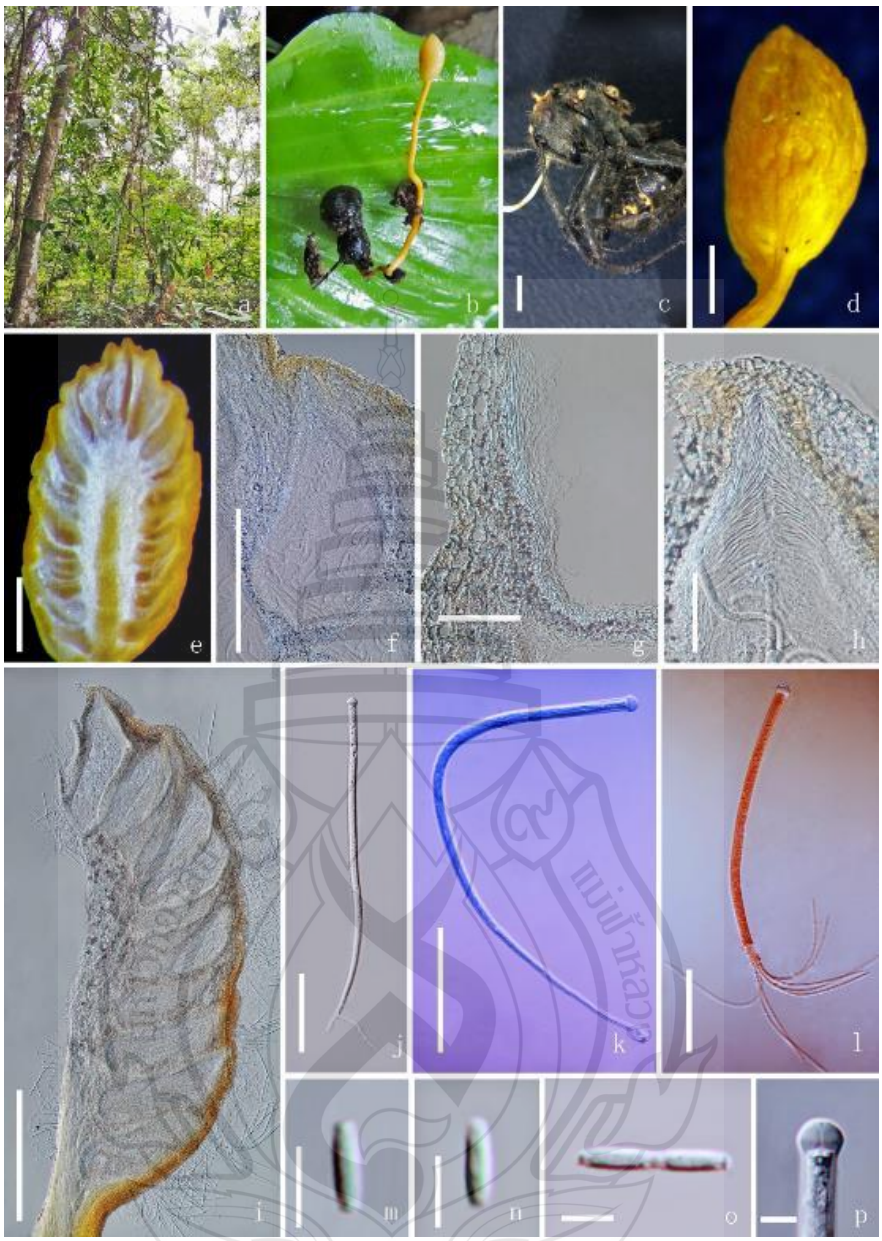
Ophiocordyceps myrmecophila (Ces.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007.

Index Fungorum number: IF 504307

Parasitic on ant. **Sexual morph:** *Host* 1–1.4 long × 0.4–0.6 cm wide, without hyphae on the surface. *Stromata* 2–8 cm long, 0.2–1 mm diam, mostly single, stipitate, arising from abdomen region or head of the ant. *Stipe* 2–7.5 cm long × 0.5–1.2 mm diam., clavate, with a fertile apex, becoming pale to yellow. *Fertile head* 1–2 mm wide, 1–1.2 mm diam, oblate globoid or fusiform, yellow, upper surface roughened, lateral surface ridged and furrowed. *Ascomata* 590–711 × 239–300 μm ($\bar{x}$ = 654 × 269 μm, n = 30), immersed, oblique flask-shaped, thick-walled. *Peridium* 16–26 mm ($\bar{x}$ = 21 μm, n = 30) wide. *Asci*, 320–430 × 5–7.4 μm ($\bar{x}$ = 375 × 6 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap*, 3.8–5.7 × 6.6–8.4 μm ($\bar{x}$ = 4.8 × 7.5 μm, n = 30), with a small channel at the center. *Ascospores* 310–390 × 1–2 μm ($\bar{x}$ = 340 × 1.5 μm, n = 30), filiform, hyaline, cylindrical, hyaline, smooth, easily break into part-spores. *Secondary spores* 5.5–7.4 × 1.5–2.3 μm ($\bar{x}$ = 6.5 × 1.8 μm, n = 60), cylindrical, truncated at both ends, straight, hyaline, smooth-walled. **Asexual morph:** Undetermined.

Material examined: Thailand, Chiang Rai, on dead ant, 18 July 2015, YuanPin Xiao, MRC1806101.

Note: The species *Ophiocordyceps myrmecophila* was proved with morphology and molecular data in this study.



Note a. Habitat of *Ophiocordyceps myrmecophila*. b. Stromata emerging from infected ant host. c. Overview of host. d. Fertile head of stromata. e. Vertical sections of the stromata. f. Perithecia. g. Peridium. h. Periphyses around the ostiole. i. Vertical sections of the stromata showing the completely embedded obliquely aligned perithecia. j–l. Asci. m–o. Part spores. p. Apical cap of ascus. Scale Bars: c = 1000 µm, d–f, i = 500 µm, j–l = 100 µm, g, h = 50 µm, m–p = 5 µm.

Figure 3.31 Morphology of *Ophiocordyceps myrmecophila*

Ophiocordyceps irangiensis (Moureau) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 43 (2007)

Index Fungorum number: IF 504283

Parasitic on ant (Hymenotera), collected from the underground. **Sexual morph:** *Host* 4–7 mm long, 1–3 mm wide, black ant without hyphae on the surface. *Stromata* 4–8 mm long, 0.2–1.2 mm diam, mostly single, stipitate, arising from between the petiole and gaster of adult worker ants (Hymenotera), pale yellow to yellow. *Stipe* 3–6 mm long, 0.2–0.4 mm diam, clavate, with a fertile apex, pale yellow. *Fertile head* 1–2 mm long, 0.5–1.2 mm diam, fusiform to ovoid, yellow, upper surface roughened, ridged and furrowed. *Perithecia* 689–814 × 149–205 µm ($\bar{x}$ = 752 × 177 µm, n = 30), immersed, oblique flask-shaped to flask-shaped, thick-walled. *Peridium* 13–25 mm ($\bar{x}$ = 19 µm, n = 60) wide, two layers, textura oblita out layer to textura porrecta inner layer. *Asci* 520–590 × 5–7 µm ($\bar{x}$ = 555 × 6 µm, n = 60), 8-spore, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.3–5.1 × 3.7–5.2 µm ($\bar{x}$ = 4.2 × 4.5 µm, n = 60) thick, with a small channel in the center. *Ascospores* as long as asci, easily breaking into part-spores, filiform. *Secondary ascospores* 7.1–9.2 × 1.3–2.0 µm ($\bar{x}$ = 8.2 × 1.6 µm, n = 90), fusiform, hyaline, smooth. **Asexual morph:** Undetermined.

Material examined: Slovakia, On dead ant (Hymenotera), 18 July 2015, SL1709.

Notes: The new species was identified as *Ophiocordyceps irangiensis* based on morphological comparing. *Ophiocordyceps irangiensis* was a new record in Slovakia.

Note a. Habitat of *Ophiocordyceps irangiensis*. b. Ascostroma emerging from infected ant host. c. Fertile head of ascostroma. d. Vertical sections of the stromata. e. Perithecia. f-h. Asci. i. Apical cap. j. Parts of ascospores. k-m. Secondary ascospores. Scale Bars: d = 500 µm, e-h = 200 µm, i = 10 µm, j-m = 5 µm.

Figure 3.32 Morphology of *Ophiocordyceps irangiensis*

Ophiocordyceps thanathonensis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Index Fungorum number: IF552731; *Facesoffungi number*: FoF 02827

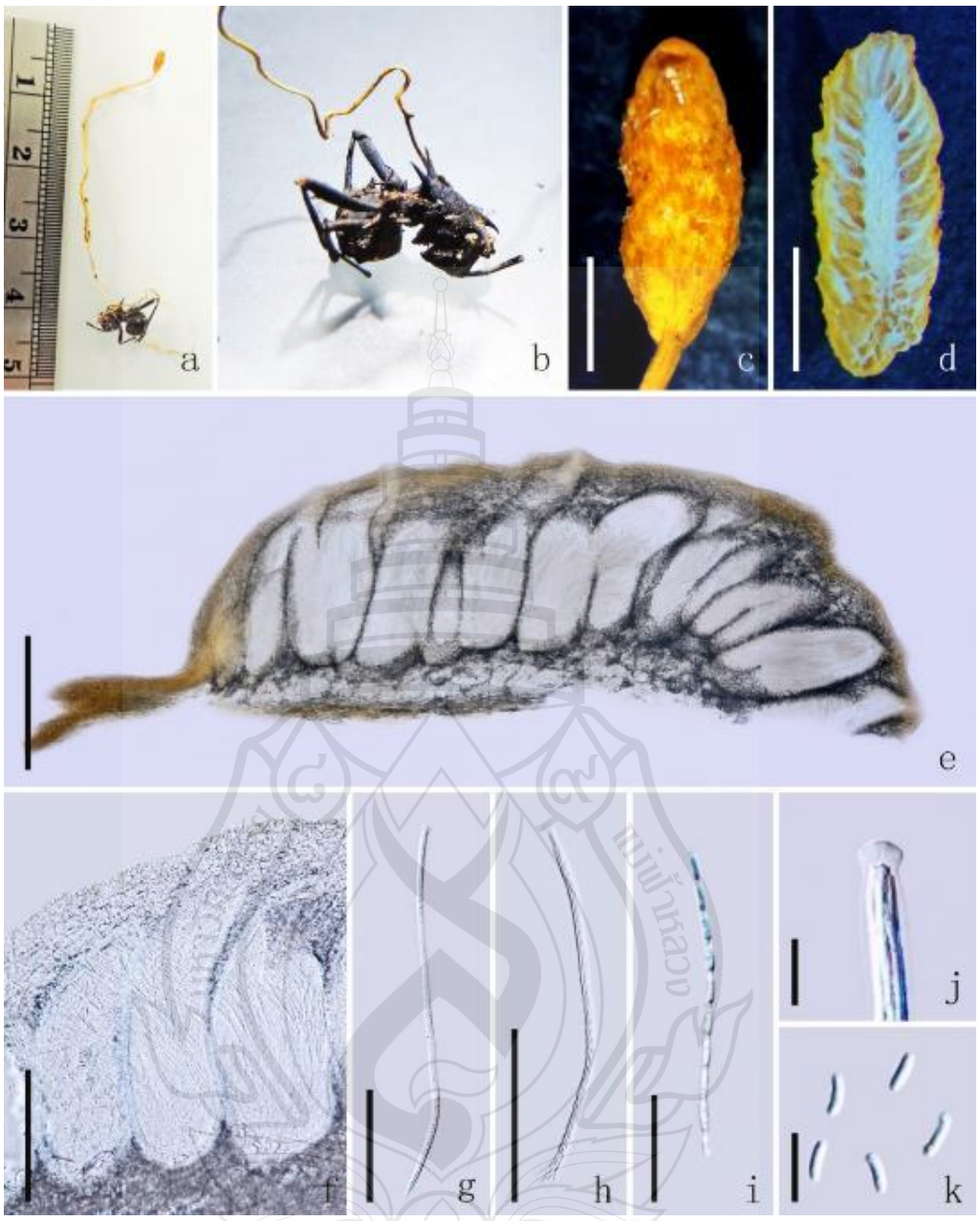
Etymology: The specific epithet refers to Thanathon in north Thailand, the collection location

Holotype: MFLU 16–2908

Parasitic on ant (Hymenotera), collected from the underside of leaves litter. **Sexual morph:** *Host* 8–12 mm long, 4–6 mm wide, black ant without hyphae on the surface. *Stromata* 50–90 mm long, 0.5–3 mm diam, mostly single, stipitate, rarely double, arising from between the head and thorax of adult worker ants (Hymenotera), pale yellow to yellow. *Stipe* 40–90 mm long, 0.5–2 mm diam, clavate, with a fertile apex, becoming pale to yellow. *Fertile head* 0.8–1.3 mm wide, 2.5–3.2 mm diam, fusiform, yellow, upper surface roughened, lateral surface, ridged and furrowed. *Ascomata* 546–692 × 193–254 µm ($\bar{x}$ = 619 × 224 µm, n = 30), immersed, oblique flask-shaped, thick-walled. *Peridium* 12–19 mm ($\bar{x}$ = 16 µm, n = 60) wide. *Asci* 369–496 × 5–7 µm ($\bar{x}$ = 432 × 6 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5–6.6 × 5.5–7.5 µm ($\bar{x}$ = 6 × 6.5 µm, n = 60) thick, with a small channel in the center. *Ascospores* 365–490 × 1–2 µm ($\bar{x}$ = 428 × 1.5 µm, n = 60), easily breaking into part-spores, filiform. *Secondary ascospores* 5.1–6.4 × 1.6–2.0 µm ($\bar{x}$ = 5.7 × 1.8 µm, n = 90) fusiform to cylindrical, truncated at both ends, mostly curved, rarely straight, hyaline, smooth. **Asexual morph:** Undetermined.

Material examined: Thailand, ChiangMai City, MRC. On dead ant (Hymenotera), 11 June 2018, Yuanpin Xiao, (MFLU 16–2908).

Notes: The new collection were grouped with *Ophiocordyceps thanathonensis* with high support value in the phylogenetic tree. And the morphology of the new collection was similar to the species *Ophiocordyceps thanathonensis* as well.



Note a Overview of *Ophiocordyceps thanathonensis*. b Host. c Fertile head. d Vertical section of the stroma. e, f Perithecia. g, h Asci. i Parts of ascospores. j Apical cap of asci. k Secondary ascospore. Scale Bars: c, d = 1000 µm, e = 500 µm, f = 200 µm, g, h = 100 µm, i = 20 µm, j, k = 10 µm.

Figure 3.33 Morphology of *Ophiocordyceps thanathonensis*

Ophiocordyceps pseudolloydii (H.C. Evans & Samson) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora 2007.

Basionym: *Cordyceps pseudolloydii* H.C. Evans & Samson, Trans. Br. mycol. Soc. 82(1): 133 (1984)

Index Fungorum number: IF 504324*; Facesoffungi number:* FoF 02828

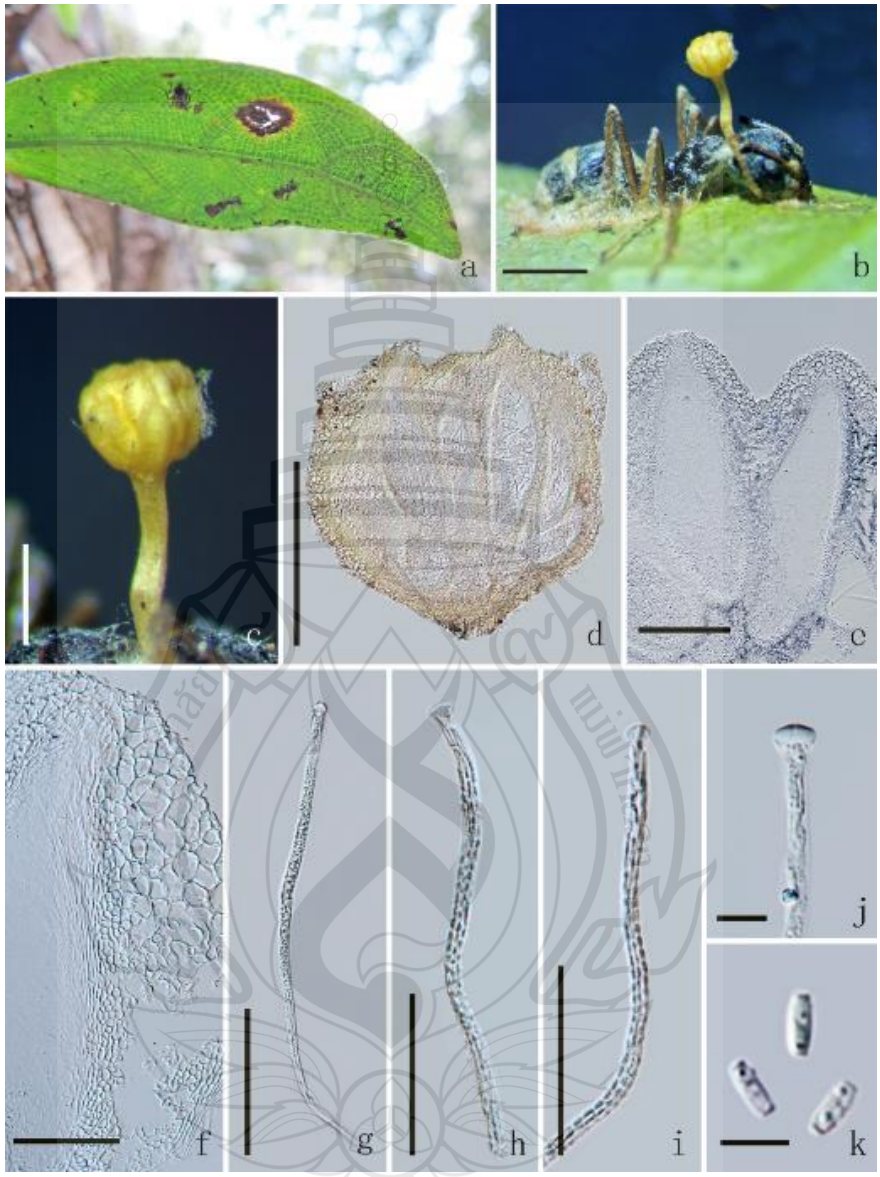
Parasitism in adult ant (Formicidae: Dolichoderinae), thallus, white to yellow, covered with white dense mycelium, attached to head and forming conspicuous, particularly at site attached to substratum, greyish yellow to light yellow. *Thallus* within host white, composed of intercalary hyphal bodies, covered with yellowish mycelium. *Stromata* mostly single, stipitate, arising from dorsal neck region of the ant, capitate. *Stipe* 2–4 mm long, 0.5–1.2 mm wide, clavate, with a fertile apex, becoming golden yellow to brownish yellow. *Fertile head* 1–2 mm wide, 0.5–2 mm diam, hemispherical or oblate globoid, sometimes slightly flattened, light orange to yellow, upper surface roughened, lateral surface, ridged and furrowed. *Ascomata* 374–455 × 125–182 µm ($\bar{x}$ = 414 × 154 µm, n = 30), immersered, flask-shaped, thick-walled, ostiole prominent. *Peridium* 16–28 mm wide. *Asci* 251–314 × 7–10 µm ($\bar{x}$ = 283 × 8.7 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 7.3–9.7 µm ($\bar{x}$ = 8.5 µm, n = 60) thick. *Ascospores* filiform, as long as asci, hyaline, multiseptate into secondary ascospores. *Secondary ascospores* 4.5–6.3 × 1–2.5 µm ($\bar{x}$ = 5.4 × 1.8 µm, n = 150), cylindrical, hyaline, smooth.

Culture characters: growing on PDA, reaching 7 cm diam., after 3 weeks at 20–25 °C，with whitened, dense, aerial mycelium on the surface, irregular at the edge, reverse dark brown to white at the edge, with folded ridge in the central.

Material examined: Thailand, Chiang Rai. On dead ant (Formicidae: Dolichoderinae), 10 February 2015, YuanPin Xiao, (MFLU 16–2914 (reference specimen designated here), MFLU 16–2915, MFLU 16–2916, MFLU 16–2917); *ibid*; living culture, MFLUCC 15–0689, MFLUCC 15–0690.

Notes: The new collections were grouped with *Ophiocordyceps pseudolloydii* with high support value in the phylogenetic tree. And the morphology of the new collection was similar to the species *Ophiocordyceps pseudolloydii* as well. Thus, this species was identified as *Ophiocordyceps pseudolloydii* with morphology

and molecular data in this study. In addition, this species was provided as a reference specimen for other species identification.



Note a Habitat of *Ophiocordyceps pseudolloydii*. b Overview of ascostroma and host. c Fertile head of ascostroma. d Vertical sections showing the completely embedded obliquely aligned perithecia. e Perithecia. f Peridium. g–i Immature to mature asci. j Apical cap of ascus. k Secondary ascospore. Scale Bars: b = 1000 µm, c, d = 500 µm, e, g = 100 µm, h, i = 50 µm, f = 20 µm, j = 10 µm, k = 5 µm.

Figure 3.34 Morphology of *Ophiocordyceps pseudolloydii*

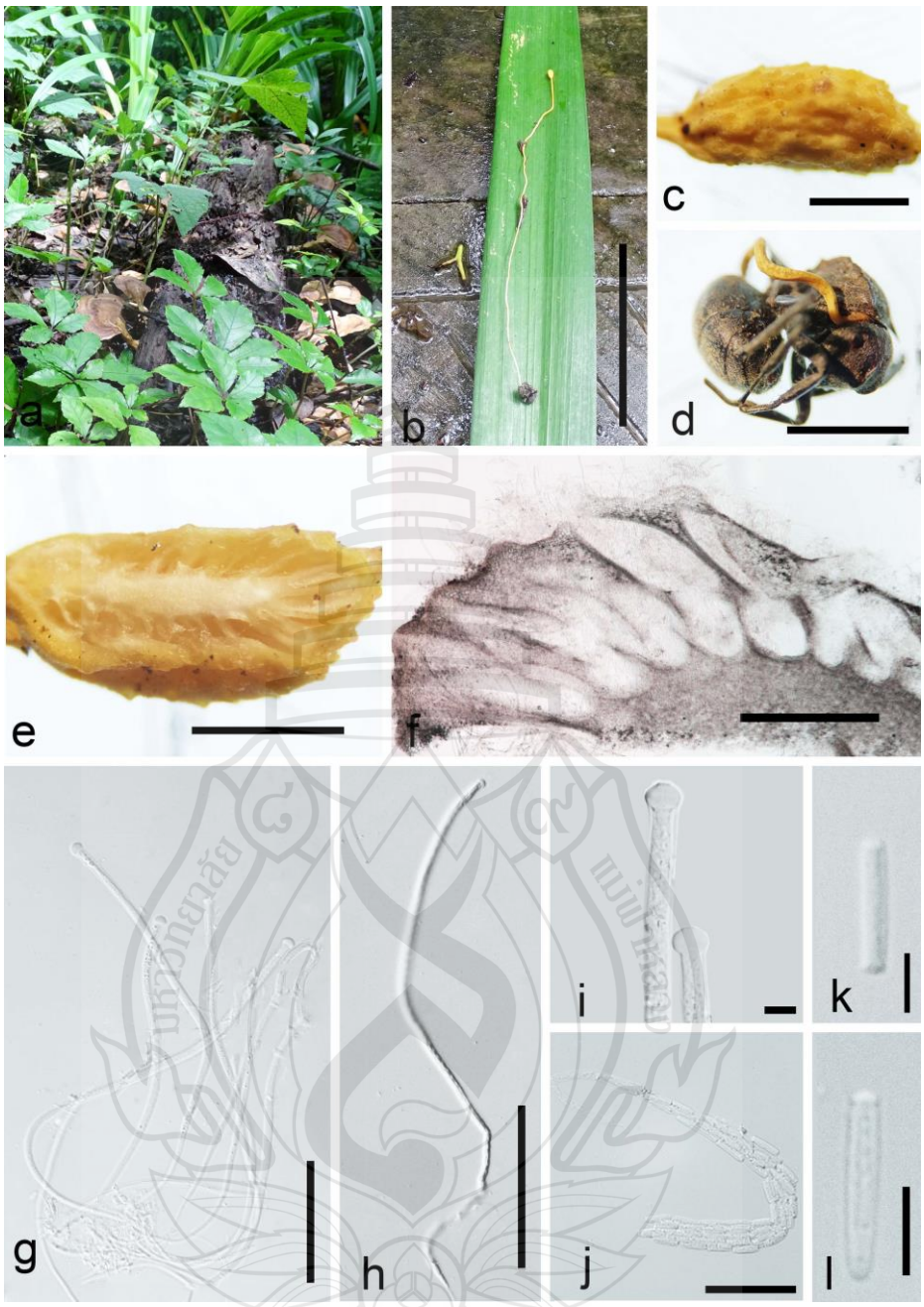
Ophiocordyceps yuntaiensis Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov***.

Etymology: The specific epithet refers to the fertile head.

Parasitism on ant (Formicidae: Dolichoderinae), bruin in the leaf litter. **Sexual morph:** *Stromata* 6–11 cm long, 1–4 mm wide, arising from the joint of ant, solitary, pale yellow to yellow, slender clavate, fibrous, unbranched, stipitate, with a fertile head on the top. *Stipe* 6–10 cm long, 1–2 mm wide, slender, unbranched, pale yellow to yellow, gradually changed to deep color, with a fertile head. *Fertile head* 3–5 mm long, 2.1–4 mm wide, distinctly different from the stipe, obovioid, yellow, upper surface roughened, ridged and furrowed. *Perithecia* 570–740 × 110–230 μm ($\bar{x}$ = 655 × 170 μm, n = 30), obliquely embedded, slender pyriform. *Peridium* 16–28 mm wide, three layers, textura prismatica yellowish outer layer covered over the whole ascomata, textura angularis hyaline middle layer, textura porrecta hyaline inner layer. *Asci* 310–370 × 6.4–7.1 μm ($\bar{x}$ = 340 × 6.8 μm, n = 30), slender cylindrical, with a thick apical cap. *Apical cap* 7.3–8.1 μm ($\bar{x}$ = 7.7 μm, n = 30) thick, hyaline. *Ascospores* as long as asci, filiform, easily breaking into secondary spores. *Secondary spores* 8.3–12.1 × 1.4–1.9 μm ($\bar{x}$ = 10.2 μm × 1.7 μm, n = 60), fusiform, aseptate, one-cell, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Guizhou Province, Qiandongnan Miao and Dong Autonomous Prefecture, Shibing County, Yuntai Mountain. On dead wasps (Hymenoptera) burin in the leaf litter, 19 June 2019, Yu Yang, YTS19061903, ZN19082606.

Notes: This new species was grouped with *Ophiocordyceps ovum*, *Ophiocordyceps cylindrospora* and *Ophiocordyceps pseudolloydii* in the phylogenetic tree. *Ophiocordyceps ovum* was parasitic on ants (Formicidae: Dolichoderinae), while *Ophiocordyceps ovum* and *Ophiocordyceps cylindrospora* were parasites on wasps (Hymenoptera). *Ophiocordyceps ovum* and *Ophiocordyceps pseudolloydii* were parasite on different kinds of ants. However, *Ophiocordyceps ovum* differs with *Ophiocordyceps pseudolloydii* in producing much longer stipe, obovoid fertile head, obliquely embedded perithecia and fusiform secondary spores. *Ophiocordyceps ovum* distinct from other species of *Ophiocordyceps* by parasitizing ants and producing long stipe and long fusiform secondary spores.



Note a Habitat of *Ophiocordyceps yuntaiensis*. b Overview of stroma and host. c Fertile head of stroma. d Host. e, f Vertical sections showing the completely embedded obliquely aligned perithecia. g, h Asci. i Apical cap of ascus. j–l Secondary ascospore. b = 5 cm, c–d = 0.5 cm, e = 0.2 cm, f = 500 µm, g, h, = 100 µm, j = 20 µm, i = 10 µm, k, l = 10 µm

Figure 3.35 Morphology of *Ophiocordyceps yuntaiensis*

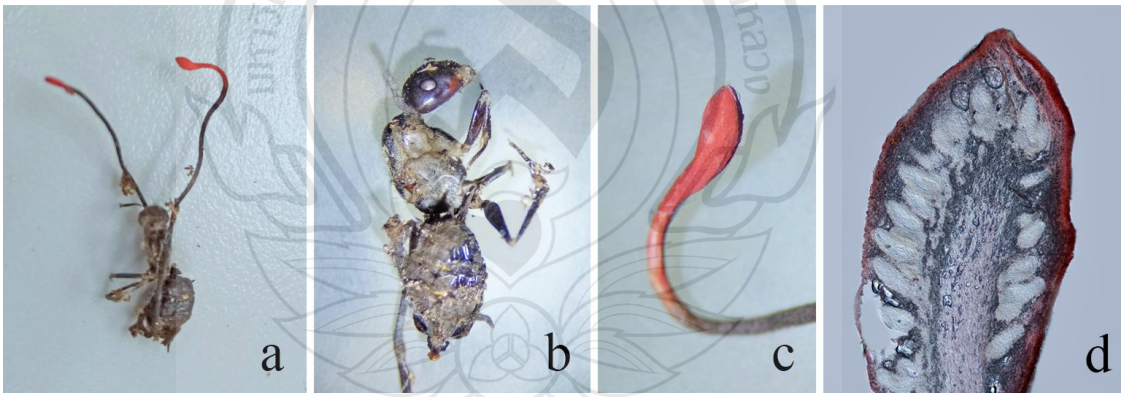
Ophiocordyceps parautralis Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov.***

Etymology: The specific epithet refers to the double fertile head.

Parasitism on ants (Formicidae: Dolichoderinae), bruin in the leaf litter. **Sexual morph:** *Stromata* –11 cm long, 1–4 mm wide, arising from the joint of ant, solitary, bicolor, dark lower part, red upper part, slender clavate, fibrous, unbranched, stipitate, with a fertile head on the top. *Stipe* 2–10 mm long, 0.5–1.4 mm wide, cylindrical, unbranched, dark lower part, becoming red upper part, with a red fertile head. *Fertile head* 2–4 mm long, 1–2 mm wide, distinctly different from the stipe, ovoid, red. *Perithecia* obliquely embedded, slender pyriform, immature. **Asexual morph:** undetermined.

Material examined: Thailand, Chiangrai Province. On dead ants (Formicidae: Dolichoderinae) burin in the leaf litter, 02 September 2017, Milan C. Samarakoon, ML01.

Notes: This new species sister to *Ophiocordyceps buquetii* in the phylogenetic tree. However, *Ophiocordyceps buquetii* differs with other species in producing double bicolor stromata, ovoid embedded perithecia.



Note a Overview of *Ophiocordyceps parautralis*. b Host. c Fertile head of ascostroma. d Vertical sections showing the completely embedded obliquely aligned perithecia.

Figure 3.36 Morphology of *Ophiocordyceps parautralis*

Ophiocordyceps pacucullae Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov***.

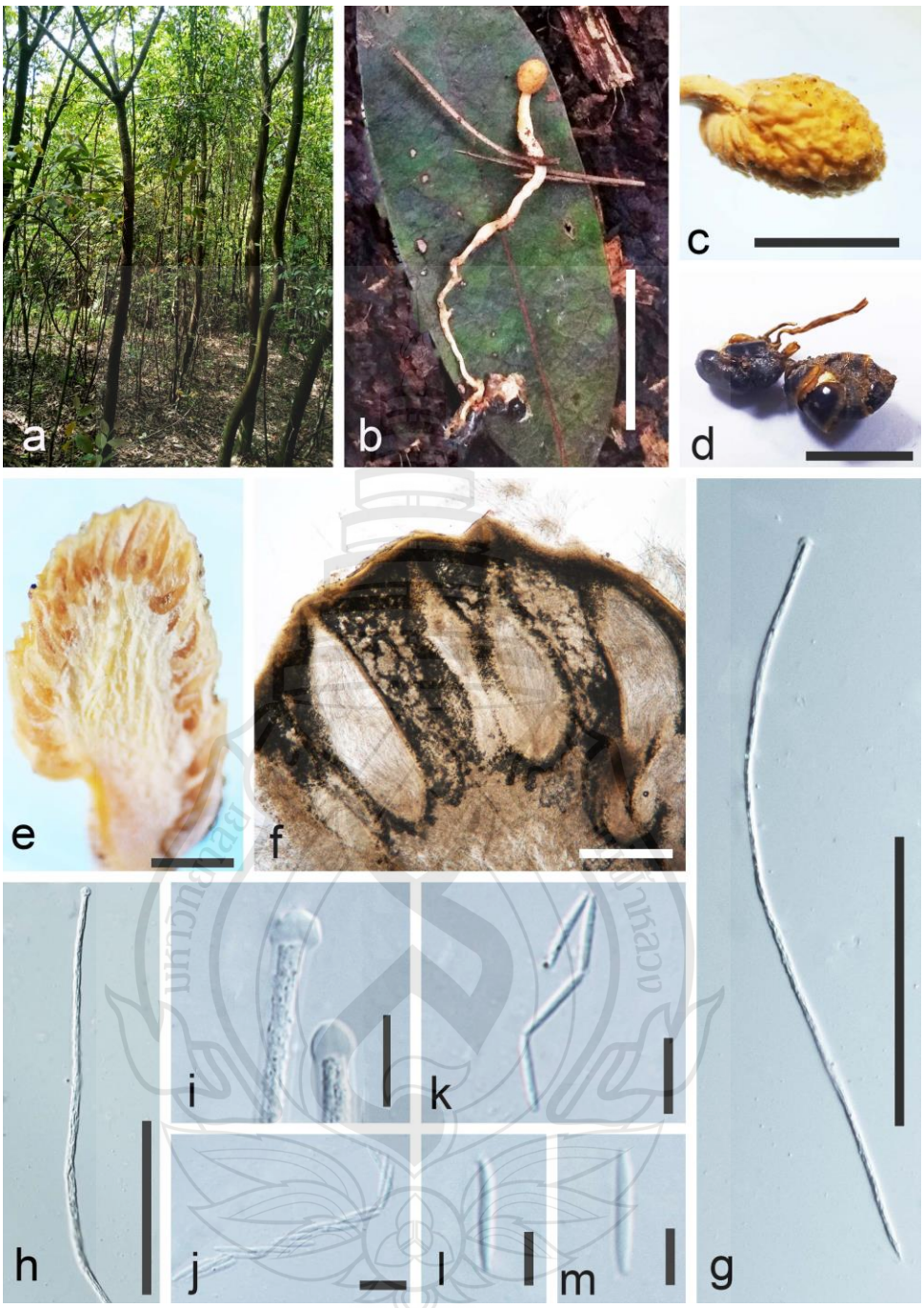
Etymology: The specific epithet refers to the double fertile heads.

Holotype: 520326MF40522

Parasitism on ant (Formicidae: Dolichoderinae), bruin in the leaf litter. **Sexual morph:** *Stromata* 4–5 cm long, 1–3 mm wide, arising from the joint of ant, solitary, yellowish to yellow, slender, fibrous, unbranched, stipitate. *Stipe* 4–4.7 cm long, 1–2 mm wide, slender, unbranched, yellowish, with a fertile head. *Fertile head* 4–6 mm long, 2–4 mm wide, distinctly different with the stipe, ellipsoid, yellowish to yellow, upper surface roughened, ridged and furrowed. *Perithecia* 790–970 × 210–250 μm ($\bar{x}$ = 880 × 230 μm, n = 30), obliquely embedded, pyriform to ovoid. *Peridium* 14–26 mm wide, three layers, textura prismatica yellowish outer layer covered over the whole ascomata, textura angularis hyaline middle layer, textura porrecta hyaline inner layer. *Asci* 420–530 × 6–8 μm ($\bar{x}$ = 475 × 7 μm, n = 30), slender cylindrical, with a thick apical cap. *Apical cap* 3.8–5.1 μm ($\bar{x}$ = 4.45 μm, n = 30) thick, hyaline. *Ascospores* as long as asci, filiform, easily breaking into secondary spores. *Secondary spores* 9.2–11.6 × 1.6–2.3 μm ($\bar{x}$ = 10.4 μm × 1.95 μm, n = 60), fusiform, aseptate, one-cell, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Guizhou Province, Zunyi City, Wuchuan County. On dead ant (Formicidae: Dolichoderinae), 23 October 2019, Yu Yang, 520326MF40522, 520326MF40522b.

Notes: The new species *Ophiocordyceps pacucullae* was sister to *Ophiocordyceps formicarum* in the phylogenetic tree. *Ophiocordyceps pseudoformicarum* was differ with *Ophiocordyceps formicarum* by producing long stipe, ellipsoid fertile head and longer fusiform secondary spores.



Note a Habitat of *Ophiocordyceps pacucullae*. b Overview of ascostromata and host. c Fertile head. d Host. e, f Vertical sections showing the completely embedded obliquely aligned perithecia. g, h Asci. i Apical cap of ascus. j–m Secondary spores. Scale Bars: b = 2 cm, c = 0.3 cm, d = 1 cm, e = 1000 mm, f–g = 200 μm, h = 100 μm, i–k = 10 μm, l–m = 5 μm

Figure 3.37 Morphology of *Ophiocordyceps pacucullae*

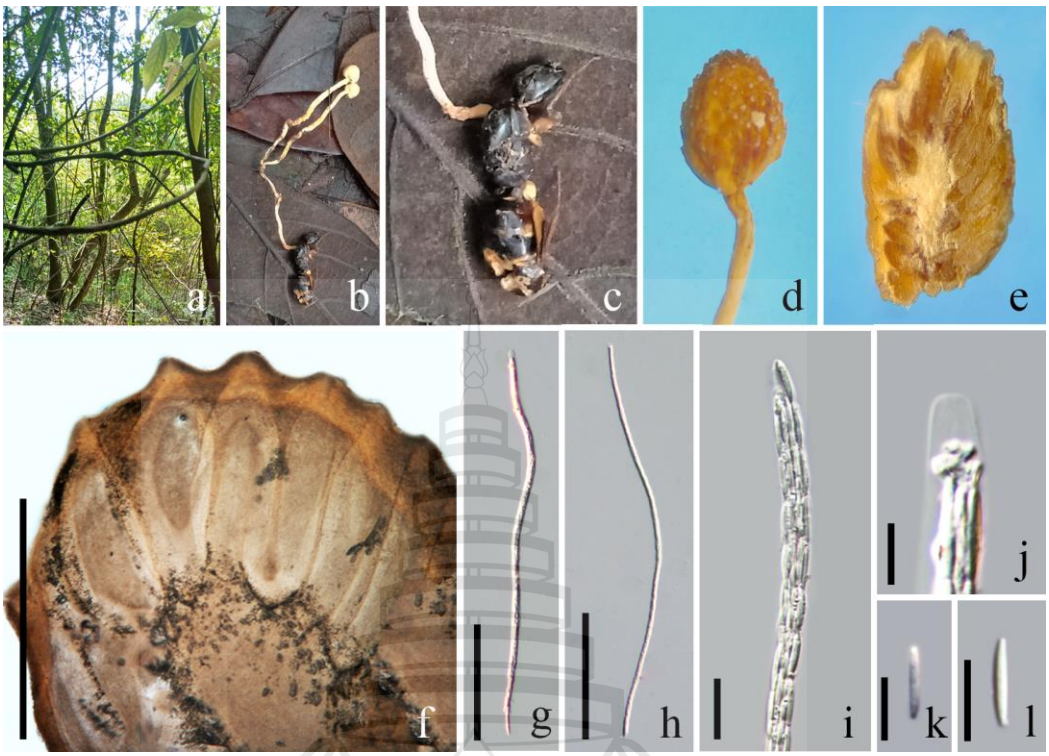
Ophiocordyceps pseudoformicarum Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov.***

Etymology: The specific epithet refers to the similar species *Ophiocordyceps formicarum*.

Parasitism on ant (Formicidae: Dolichoderinae), bruin in the leaf litter. **Sexual morph:** *Stromata* 3–6 cm long, 1–3.5 mm wide, arising from the joint of ant, single or double, brunched into 2, yellowish to yellow, slender, fibrous, stipitate. *Stipe* 3–5 cm long, 1–2 mm wide, slender, branched into 2, yellowish, with a fertile head. *Fertile head* 3–7 mm long, 2–3.5 mm wide, distinctly different with the stipe, ovoid, yellowish to yellow, upper surface roughened, ridged and furrowed. *Perithecia* 490–570 × 190–240 μm ($\bar{x}$ = 530 × 215 μm, n = 30), obliquely embedded, pyriform to ovoid. *Peridium* 16–36 mm wide, three layers, *textura prismatica* yellowish outer layer covered over the whole ascomata, *textura angularis* hyaline middle layer, *textura porrecta* hyaline inner layer. *Asci* 448–569 × 4.8–5.6 μm ($\bar{x}$ = 509 × 5.2 μm, n = 30), slender cylindrical, with a thick apical cap. *Apical cap* 5.2–7.9 μm ($\bar{x}$ = 6.6 μm, n = 30) thick, hyaline. *Ascospores* as long as asci, filiform, easily breaking into secondary spores. *Secondary spores* 10.4–12.3 × 1.5–2.2 μm ($\bar{x}$ = 10.4 μm × 1.9 μm, n = 60), fusiform, aseptate, one celled, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Guizhou Province, Zunyi City, Wuchuan County. On dead ant (Formicidae: Dolichoderinae), 23 October 2019, Yu Yang, ZNQ0119102309, ZNQ0119102309b.

Notes: The new species *Ophiocordyceps pseudoformicarum* was sister to *Ophiocordyceps formicarum* and *Ophiocordyceps pacucullae* in the phylogenetic tree. *Ophiocordyceps pseudoformicarum* was differ with them by double stromate, branched stipe, ovoid fertile head longer apical cap and longer secondary spores.



Note a Habitat of *Ophiocordyceps pseudoformicarum*. b Overview of ascostromata and host. c Host. d Fertile head. e, f Vertical sections showing the completely embedded obliquely aligned perithecia. f Peridium. g–i Asci. j Apical cap of ascus. k, l Secondary spores. Scale Bars: f = 500 μm, g, h = 100 μm, i, k, l = 10 μm, j = 5 μm

Figure 3.38 Morphology of *Ophiocordyceps pseudoformicarum*

Ophiocordyceps polistes Y.P. Xiao, T.C. Wen, & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the host species, *Polistes* sp.

Parasitism on wasps *Polistes* sp. (Hymenoptera), collected from the underground. **Sexual morph:** *Host* brown wasps without hyphae on the surface. *Stromata* 5–45 mm long, 0.1–0.5 mm wide., mostly single, stipitate, rarely double, arising from between the head and thorax of adult wasps, yellow. *Stipe* 4–43 mm long, 0.1–0.3 mm diam, clavate, with a fertile apex, becoming pale yellow to yellow. *Fertile head* 2–8 mm wide, 0.3–0.5 mm diam, fusiform, yellow, upper surface roughened, lateral surface, ridged and furrowed. *Perithecia* 510–720 × 200–340 μm ($\bar{x}$ = 615 × 271 μm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 20–58 mm

($\bar{x}$ = 39 µm, n = 60) wide, three layers. *Asci* 460–570 × 5–7 µm ($\bar{x}$ = 515 × 6 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 5.2–7.2 × 5.3–7.5 µm ($\bar{x}$ = 6.2 × 6.4 µm, n = 60) thick, with a small channel in the center. *Ascospores* easily breaking into part-spores, filiform. *Secondary ascospores* 11.8–13.2 × 1.8–2.8 µm ($\bar{x}$ = 12.5 × 2.3 µm, n = 90) fusiform, straight, hyaline, smooth. **Asexual morph:** Undertermined.

Material examined: Thailand, Chiang Mai. On dead wasp, *Polistes* sp. (Hymenoptera), 13 Junly 2017, YuanPin Xiao, CM10, CM11, CM12, CM13.

Notes: The new species, *Ophiocordyceps polistes*, sister with *Ophiocordyceps vespae* with strong support value. *Ophiocordyceps polistes* differs with *Ophiocordyceps vespae* by parasitizing on different species of wasp and producing shorter stromata, smaller fertile head and fusiform, straight secondary ascospores.

Note a Habitat of *Ophiocordyceps polistes* b Ascostroma emerging from infected wasps. c Overview of host. d Fertile head of ascostroma. e Vertical section of the stroma. f, g Ascomata. h, i Peridium. j–m Immature to mature asci. n Apical cap of asci. o–q Secondary ascospores. r Germinated secondary sacospores. Scale Bars: d = 1000 µm, e, f = 500 µm, g, j–m = 200 µm, h, i = 50 µm, n = 20 µm, o–r = 10 µm.

Figure 3.39 Morphology of *Ophiocordyceps polistes*

Ophiocordyceps neocylindrocpora Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov.***

Etymology: The specific epithet refers to the similar species, *Ophiocordyceps cylindrocpora*.

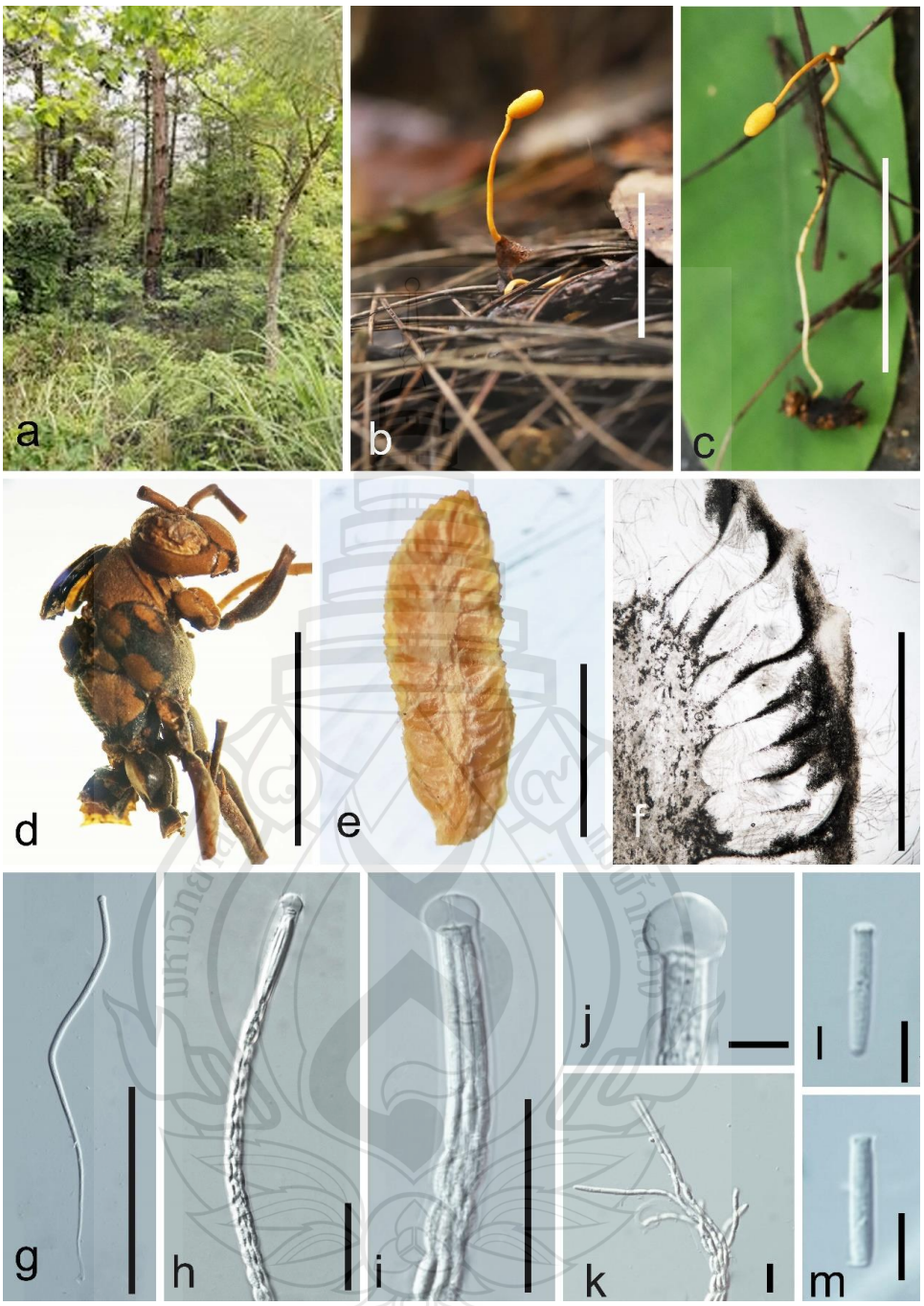
Holotype: ZNQ0119102309

Parasitism on wasps (Hymenoptera), burin in the leaf litter. **Sexual morph:** *Stromata* 3.5-4.5 cm long and 0.3–0.7 mm, arising from the joint of wasps, solitary, yellowish to yellow, slender, fibrous, unbranched, stipitate. *Stipe* 3–4.1 cm long, 1–2 mm wide, slender, unbranched, yellowish to yellow, gradually becoming deep color, with a fertile head. *Fertile head* 4–6 mm long, 2–3 mm wide, distinctly different from the stipe, subglobose, yellow, upper surface roughened. *Perithecia* 651–758 × 191–257 μm ($\bar{x}$ = 704.5 × 224 μm, n = 30), obliquely embedded, pyriform. *Peridium* 12–28 mm wide, three layers, yellowish textura prismatica outer layer covered over the whole ascomata, textura angularis hyaline middle layer, textura porrecta hyaline inner layer. *Asci* 288–403 × 5–8 μm ($\bar{x}$ = 345.5 × 6.5 μm, n = 60), 8-spore, slender cylindrical, with a thick apical cap. *Apical cap* 6.8–9.5 × 4–5.4 μm ($\bar{x}$ = 8.15 × 4.7 μm, n = 60) thick, hyaline. *Ascospores* as long as asci, filiform, easily breaking into secondary spores. *Secondary spores* 10.8–12.4 × 1.3–2.1 μm ($\bar{x}$ = 11.6 × 1.7 μm, n = 60), cylindrical, truncated at both ends, straight, aseptate, one-cell, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Guizhou Province, Qiandongnan Miao and Dong Autonomous Prefecture, Leishan County, Leigongshan Mountain. On dead wasps (Hymenoptera) burin in the leaf litter, 23 October 2019, Yu Yang, KKS20070273; China, Guizhou Province, Qiandongnan Miao and Dong Autonomous Prefecture, Leishan County, Leigongshan Mountain. On dead wasps (Hymenoptera) burin in the leaf litter, 05 July 2020, Yu Yang, LGS20070508. China, Guizhou Province, Qiandongnan Miao and Dong Autonomous Prefecture, Leishan County, Leigongshan Mountain. On dead wasps (Hymenoptera) burin in the leaf litter, 05 July 2020, Yu Yang, LGS20070510.

Notes: The new species *Ophiocordyceps neocylindrocpora* was sister to *Ophiocordyceps cylindrospora* in the phylogenetic tree with high support value. The species grouped with *Ophiocordyceps cylindrospora* and *Ophiocordyceps ovum*.

Ophiocordyceps cylindrospora were parasite on different species of wasps (Hyde et al., 2018), while *Ophiocordyceps neocylindrocpora* was parasite on species of ants. *Ophiocordyceps ovum* differs with *Ophiocordyceps cylindrospora* in having bigger perithecia, longer asci and much longer secondary spores. *Ophiocordyceps ovum* distinct with other species of *Ophiocordyceps* by parasitizing on wasp and producing cylindrical, long secondary spores. Thus, a new species, *Ophiocordyceps ovum*, is introduced in this study.



Note a, b Habitat of *Ophiocordyceps neocylindrocpora*. c Overview of ascostroma and host. d Host. e, f Vertical sections showing the completely embedded obliquely aligned perithecia. g–i Asci. j Apical cap of ascus. k Asci breaking into secondary spores. l, m Secondary spores. Scale Bars: b = 2 cm, c = 0.2 cm, d = 1 cm, e = 0.2 cm, f = 1000 μm, g = 200 μm, h, i = 20 μm, j–m = 5 μm.

Figure 3.40 Morphology of *Ophiocordyceps neocylindrocpora*

Ophiocordyceps mandariniae Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov.***

Etymology: The specific epithet refers to the host species.

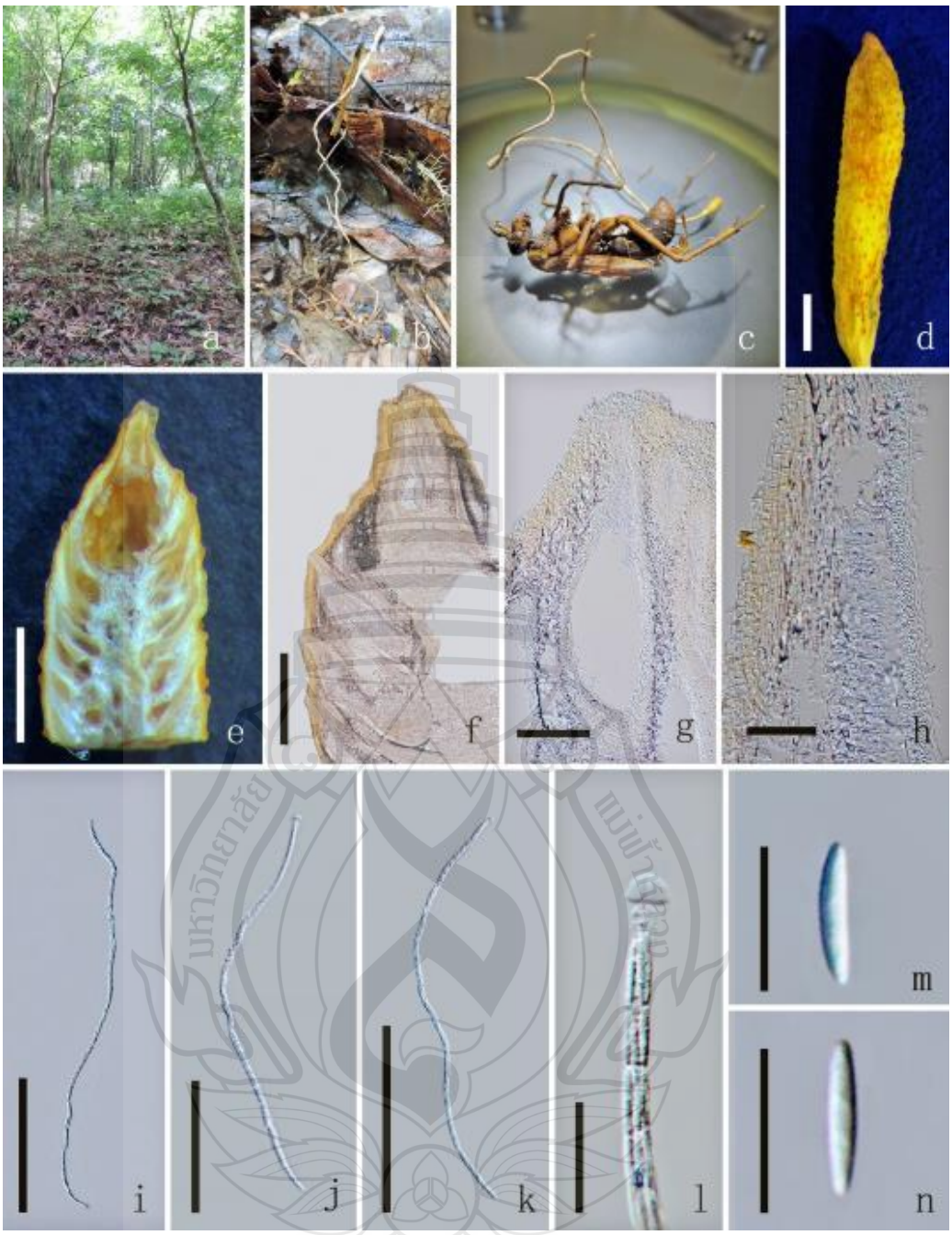
Holotype: BK15073001

Parasitic on wasp (Hymenoptera), collected from the underside of leaves litter. **Sexual morph:** *Host* 120–200 mm long, 6–10 mm wide, without hyphae on the wasp surface. *Stromata* 110–190 mm long, 0.5–1.2 mm diam, mostly single, stipitate, rarely double, arising from between the head and thorax of wasps, pale yellow to yellow. *Stipe* 100–90 mm long, 0.5–1.2 mm diam, clavate, with a fertile apex, becoming pale yellow to yellow. *Fertile head* 0.8–1.2 mm wide, 4–7 mm diam, fusiform, yellow, upper surface roughened, lateral surface, ridged and furrowed. *Ascomata* 616–800 × 267–315 µm ($\bar{x}$ = 708 × 291 µm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 18–28 mm ($\bar{x}$ = 23 µm, n = 60) wide. *Asci* 520–710 × 4.5–5.9 µm ($\bar{x}$ = 615 × 5.2 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.5–4.7 × 6.4–7.7 µm ($\bar{x}$ = 4.1 × 7.1 µm, n = 60) thick, with a small channel in the center. *Ascospores* 510–714 × 1.6–2.3 µm ($\bar{x}$ = 610 × 1.9 µm, n = 60), easily breaking into part-spores, filiform. *Secondary ascospores* 8.6–11.3 × 1.6–2.3 µm ($\bar{x}$ = 10 × 1.9 µm, n = 90) fusiform, mostly straight, hyaline, smooth. **Asexual morph:** undetermined.

Culture characters: growing on PDA, reaching 7 cm diam., after 6 weeks at 20–25 °C, with brown, dense, aerial mycelium on the surface, regular at the edge, reverse dark brown, with a folded ridge in the central.

Material examined: Thailand, Chiang Rai. On dead wasp (Hymenotera), 30 Junly 2015, YuanPin Xiao, BK15073001.

Notes: The *Ophiocordyceps sphecocephala* complex is forming one independent clade in the phylogenetic tree. We could not identify the species by micromorphology analysis. However, the four clades were clear isolated in the phylogenetic tree. These species of *Ophiocordyceps sphecocephala* could be identified by host species and phylogenetic analysis. The *Ophiocordyceps sphecocephala* complex is host-specific.



Note a Habitat of *O. mandariniae*. b Ascostroma emerging from infected wasps. c Overview of host. d Fertile head of ascostroma. e Vertical section of the stroma. f, g Ascomata. h Peridium. i–k Asci. l Apical cap of asci. m, n Secondary ascospores. Scale Bars: d, e = 1000 µm, f = 500 µm, g = 100 µm, h = 50 µm, i–k = 200 µm, l = 20 µm, m, n = 10 µm.

Figure 3.41 Morphology of *Ophiocordyceps mandariniae*

Ophiocordyceps fusiformispora Y. Yang, Y.P. Xiao & T.C. Wen, ***sp. nov.***

Etymology: The specific epithet refers to the shape of the secondary spores.

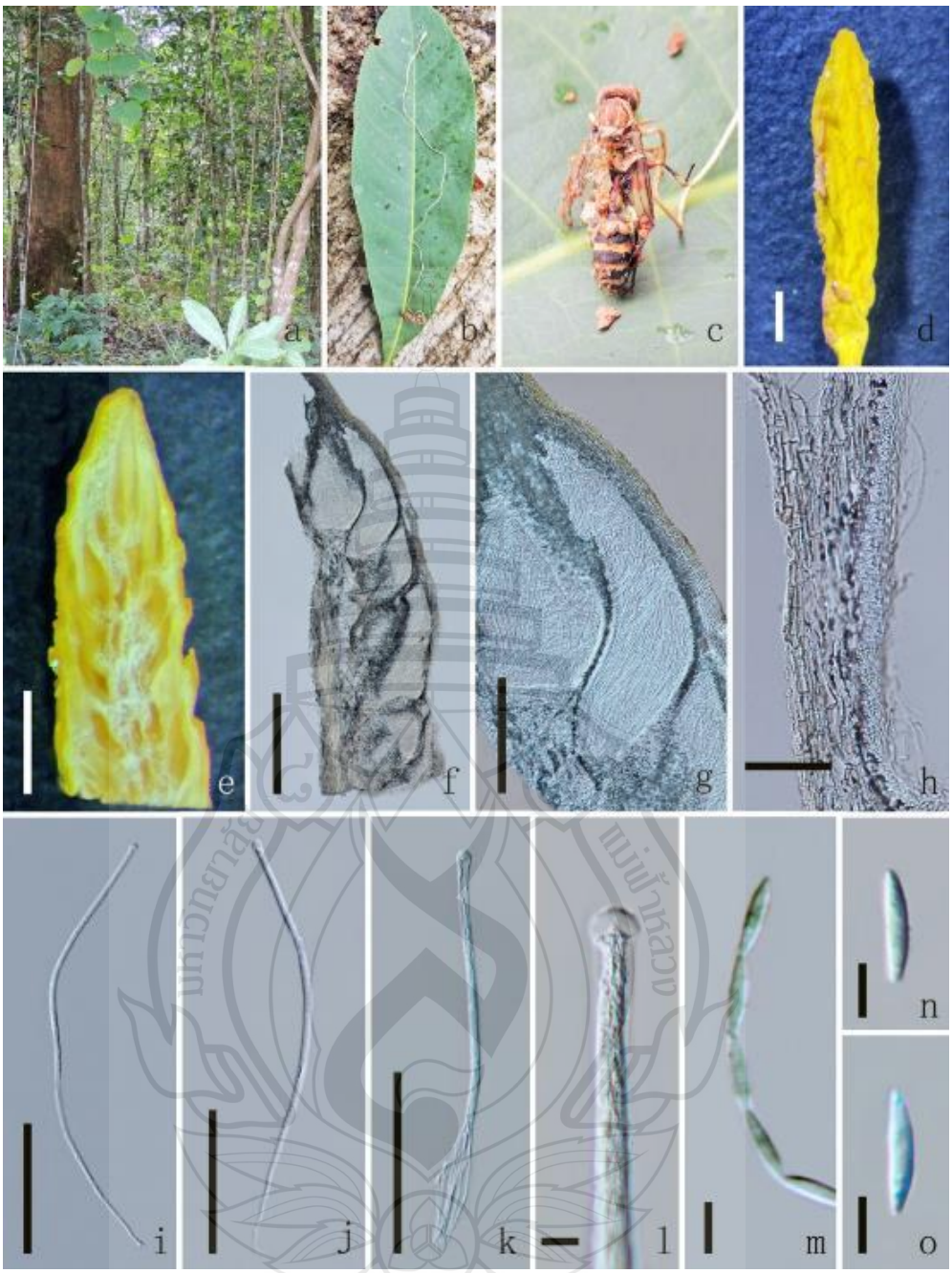
Holotype: ZNQ0119102309

Parasitic on wasp (Hymenoptera), collected from the underside of leaves litter. **Sexual morph:** *Host* 140–180 mm long, 2–3 mm wide, without hyphae on the wasp surface. *Stromata* 12–20 cm long, 0.2–1.1 mm diam, single, stipitate, clavate, arising from between the head and thorax of wasps, pale yellow to yellow. *Stipe* 130–175 mm long, 0.2–0.3 mm diam, cylindrical, hard, with a fertile apex, pale yellow to yellow. *Fertile head* 2–2.5 mm wide, 0.5–1 mm diam, fusiform, yellow, upper surface roughened, ridged and furrowed. *Perithecia* 730–855 × 190–270 μm ($\bar{x}$ = 792 × 230 μm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 16–23 mm ($\bar{x}$ = 19 μm, n = 60) wide, three layers, *textura prismatica* outer layer, *textura intricata* middle layer, *textura angularis* inner layer. *Asci* 450–585 × 5.0–7.1 μm ($\bar{x}$ = 518 × 6.1 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 4.0–5.1 × 5.1–6.9 μm ($\bar{x}$ = 4.5 × 6.0 μm, n = 60) thick, with a small channel in the center. *Ascospores* as long as asci, easily breaking into part-spores, filiform. *Secondary ascospores* 8.5–11.4 × 1.8–2.3 μm ($\bar{x}$ = 10 × 2.1 μm, n = 90), fusiform, hyaline, smooth. **Asexual morph:** Undetermined.

Culture characters: growing on PDA, reaching 7 cm diam., after 6 weeks at 20–25 °C， with brown, dense, aerial mycelium on the surface, regular at the edge, reverse dark brown, with folded ridge in the central.

Material examined: Thailand, Chiang Mai City, MRC. On dead wasp (*Hymenotera*), 18 July 2015, YuanPin Xiao, MRC17091826, 0626.

Notes: The new species, *Ophiocordyceps fusiformispora*, sister with *Ophiocordyceps pseudoformicarum* with strong support value. *Ophiocordyceps fusiformispora* differs with *Ophiocordyceps pseudoformicarum* by parasitizing on different species of wasp and producing longer, fusiform to falcate secondary ascospores.



Note a Habitat of *Ophiocordyceps fusiformispora*. b Ascostroma emerging from infected wasps. c Overview of host. d Fertile head of ascostroma. e Vertical section of the stroma. f, g Ascomata. h Peridium. i–k Asci. l Apical cap of asci. m–o Secondary ascospores. Scale Bars: d–f = 500 µm, g = 200 µm, h = 50 µm, i–k = 100 µm, l–o = 5 µm.

Figure 3.42 Morphology of *Ophiocordyceps fusiformispora*

Ophiocordyceps vespae *Y*.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov***

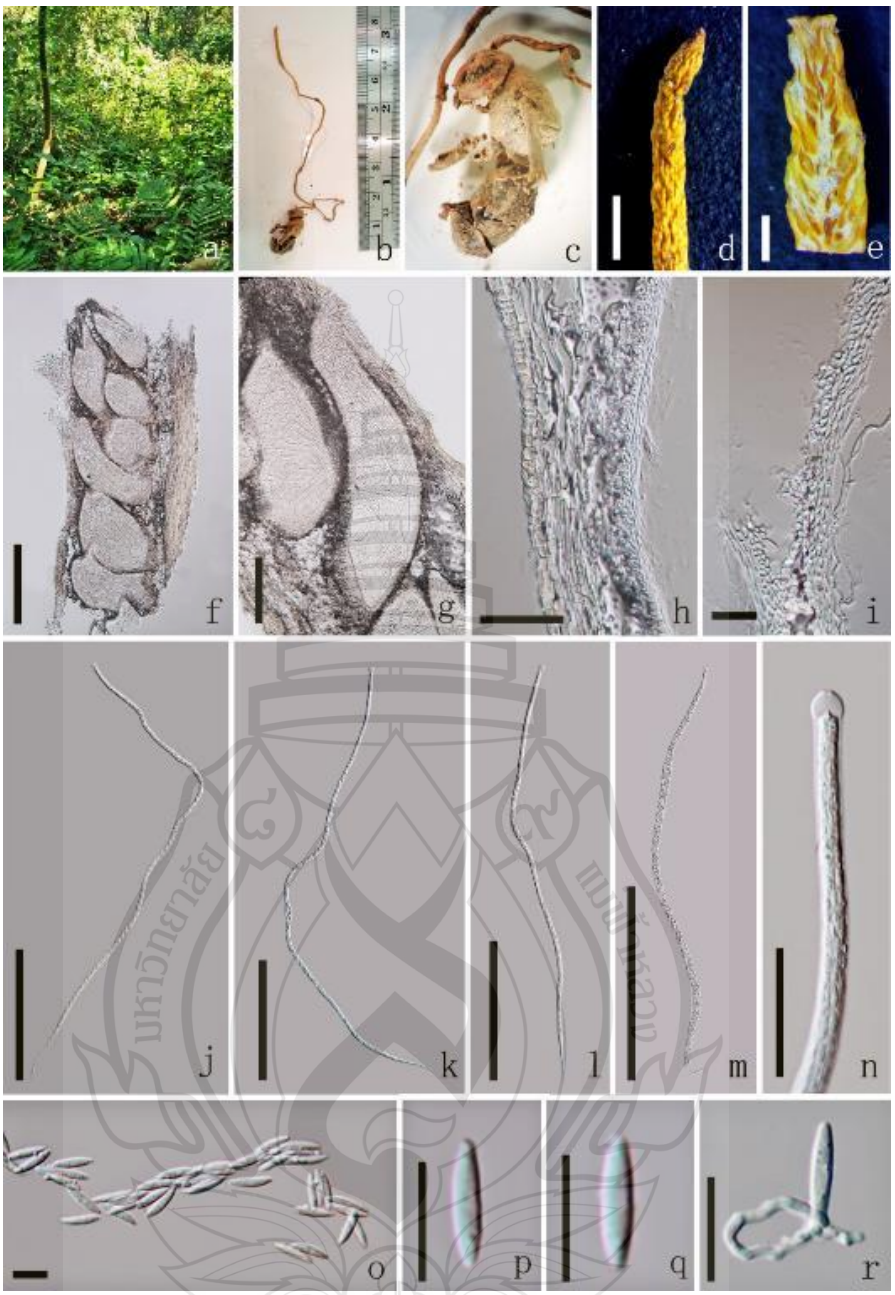
Etymology: The specific epithet refers to the host species.

Parasitic on wasps (Hymenoptera), collected from the underside of leaves litter. **Sexual morph:** *Host* 17 mm long × 6 mm wide, brown wasps without hyphae on the surface. *Stromata* 85–98 mm long, 0.3–0.5 mm diam., mostly single, stipitate, rarely double, arising from between the head and thorax of adult wasps, pale yellow to yellow. *Stipe* 90–110 mm long, 0.3–0.5 mm diam, clavate, with a fertile apex, becoming pale yellow to yellow. *Fertile head* 12–13 mm wide, 0.4–0.5 mm diam, fusiform, yellow, upper surface roughened, lateral surface, ridged and furrowed. *Perithecia* 600–821 × 235–318 μm ($\bar{x}$ = 711 × 276 μm, n = 30), immersed, oblique flask-shaped, thin-walled. *Peridium* 18–30 mm ($\bar{x}$ = 24 μm, n = 60) wide. *Asci* 527–668 × 6–8 μm ($\bar{x}$ = 597 × 7 μm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 4.2–5.9 × 5.6–7.9 μm ($\bar{x}$ = 5.1 × 6.8 μm, n = 60) thick, with a small channel in the center. *Ascospores* easily breaking into part-spores, filiform. *Secondary ascospores* 9.9–11.2 × 2.1–2.9 μm ($\bar{x}$ = 10.5 × 2.5 μm, n = 90) fusiform, truncated at both ends, straight, hyaline, smooth. **Asexual morph:** Undetermined

Culture characters: growing on PDA, reaching 7 cm diam., after 3 weeks at 20–25 °C，with brown, dense, aerial mycelium on the surface, irregular at the edge, reverse dark brown, with folded ridge in the central.

Material examined: Thailand, Chiang Mai City. On dead wasp, 19 Junly 2015, YuanPin Xiao, MSCM15071904.

Notes: The new species, *Ophiocordyceps longascoma*, sister with *Ophiocordyceps pseudoformicarum* with strong support value. *Ophiocordyceps fusiformispora* differs with *Ophiocordyceps pseudoformicarum* by parasitizing on different species of wasp and producing fusiform, truncated at both ends, straight secondary ascospores.



Note a Habitat of *Ophiocordyceps vespae* b Ascostroma emerging from infected wasps. c Overview of host. d Fertile head of ascostroma. e Vertical section of the stroma. f, g Ascomata. h, i Peridium. j–m Immature to mature asci. n Apical cap of asci. o–q Secondary ascospores. r Germinated secondary acospores. Scale Bars: d = 1000 µm, e, f = 500 µm, g, j–m = 200 µm, h, i = 50 µm, n = 20 µm, o–r = 10 µm.

Figure 3.43 Morphology of *Ophiocordyceps vespae*

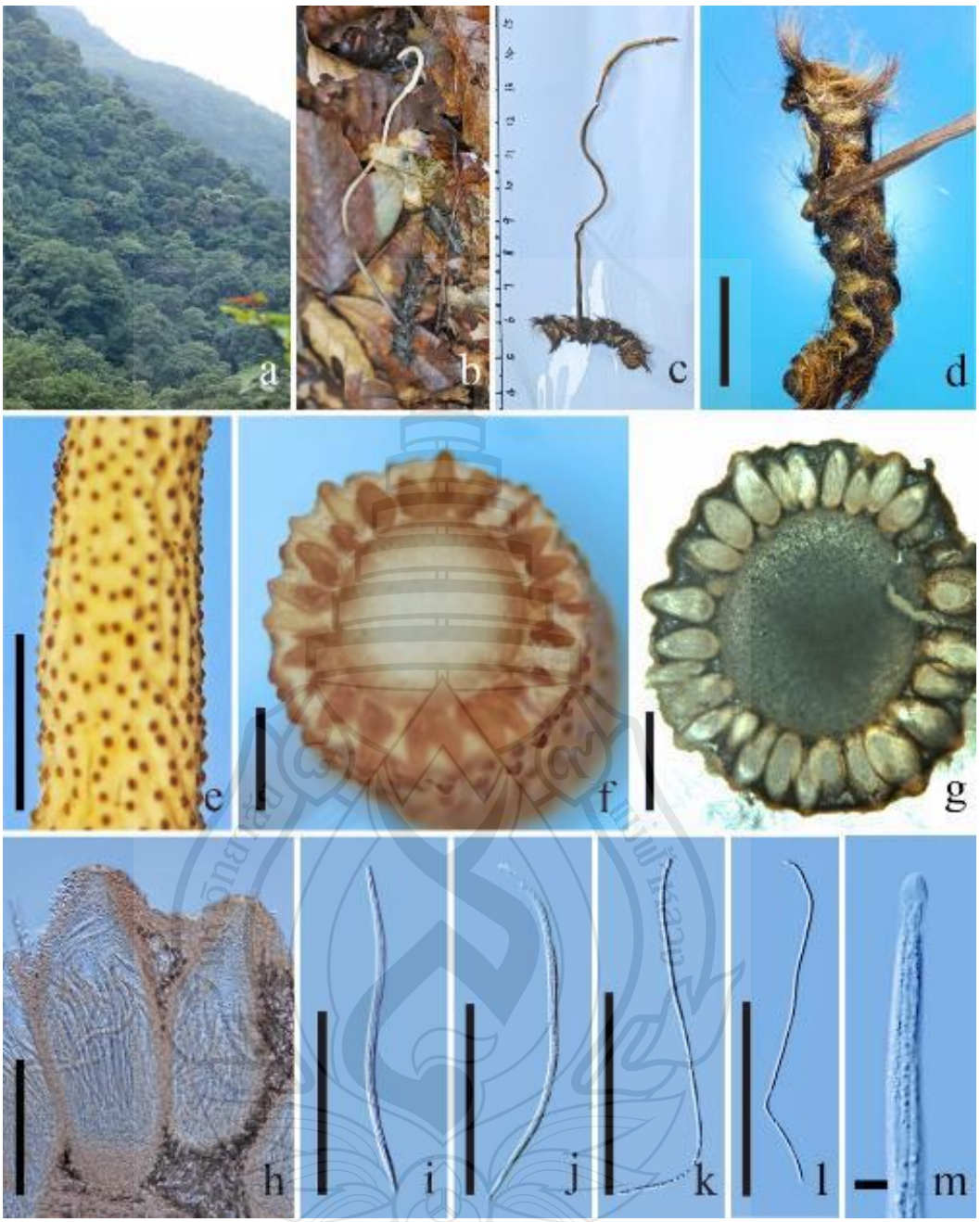
Ophiocordyceps pseudoelongata Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the similar species *Ophiocordyceps elongata*.

Parasitic on larva of Lepidoptera, burin in the underside of leaf litter. **Sexual morph:** Stromata 6–7 cm long, 2.2–3.2 mm wide, solitary, dark brown to pale yellow, gradually becoming light color from lower part to upper part, slender cylindrical, stipitate, with a slightly different fertile head. *Stipe* 4.5–6 cm long, 2.4 mm wide, slender cylindrical, dark brown to pale yellow, gradually becoming light color from lower part to upper part. *Fertile head* 1.1–1.4 cm long, 2.4–3.2 mm wide, pale yellow, cylindrical or cylindrical with a curve, with ostiole necks emerging straight to surface. *Perithecia* 360–440 × 170–240 μm ($\bar{x}$ = 400 × 205 μm, n = 30), vertical immersed to the axis within the fertile head, ovoid to pyriform, pale yellow to hyaline. *Peridium* 26–38 μm ($\bar{x}$ = 23 μm, n = 60) wide, three layers, textura angularis yellowish outer layer covered over the whole ascomata, textura intricata yellowish middle layer, textura porrecta hyaline inner layer. *Asci* 280–370 × 6.4–7.8 μm ($\bar{x}$ = 325 × 7.1 μm, n = 30), 8-spore, slender cylindrical, hyaline. Ascospores 280–370 × 6.4–7.8 μm ($\bar{x}$ = 325 × 7.1 μm, n = 30), hyaline, filiform, muti-septate, not breaking into secondary spores. **Asexual morph:** undetermined.

Material examined: China, Guizhou Province, Zunyi City, Xishui County. On larva of Lepidoptera, burin in the underside of leaf litter, 19 June 2020, Hongde Yang, KKS20072228, DPR0120061613.

Notes: *Ophiocordyceps pseudoelongata* was cluster with *Ophiocordyceps alboperitheciata* and *Ophiocordyceps elongate* in the phylogenetic tree with strong support value. The closest species was *Ophiocordyceps alboperitheciata* in the genus *Ophiocordyceps*. Morphologically, *Ophiocordyceps pseudoelongata* was distinct with *Ophiocordyceps alboperitheciata* by producing cylindrical fertile head with immersed perithecia (Fan et al., 2021). *Ophiocordyceps alboperitheciata* differs with other species of *Ophiocordyceps* by producing long stromata, cylindrical fertile head with immersed perithecia, ascospores not break into secondary spores and the fertile head slightly different with stipe. Thus, a new species, *Ophiocordyceps pseudoelongata* was introduced in this study.



Note a Habitat of *Ophiocordyceps pseudoelongata*. b, c Overview of fungi. d Host. e Part of fertile head. f, g Vertical section of the stroma. h Peridium. i, j Asci. k, l Ascopsore. m Apical cap of asci. Scale Bars: b = 5 cm, c = 0.5 cm, d = 1 cm, e = 0.2 cm, f = 500 μm, g–i = 200 μm, k–l = 100 μm, m=50 μm, j, n = 10 μm

Figure 3.44 Morphology of *Ophiocordyceps pseudoelongata*

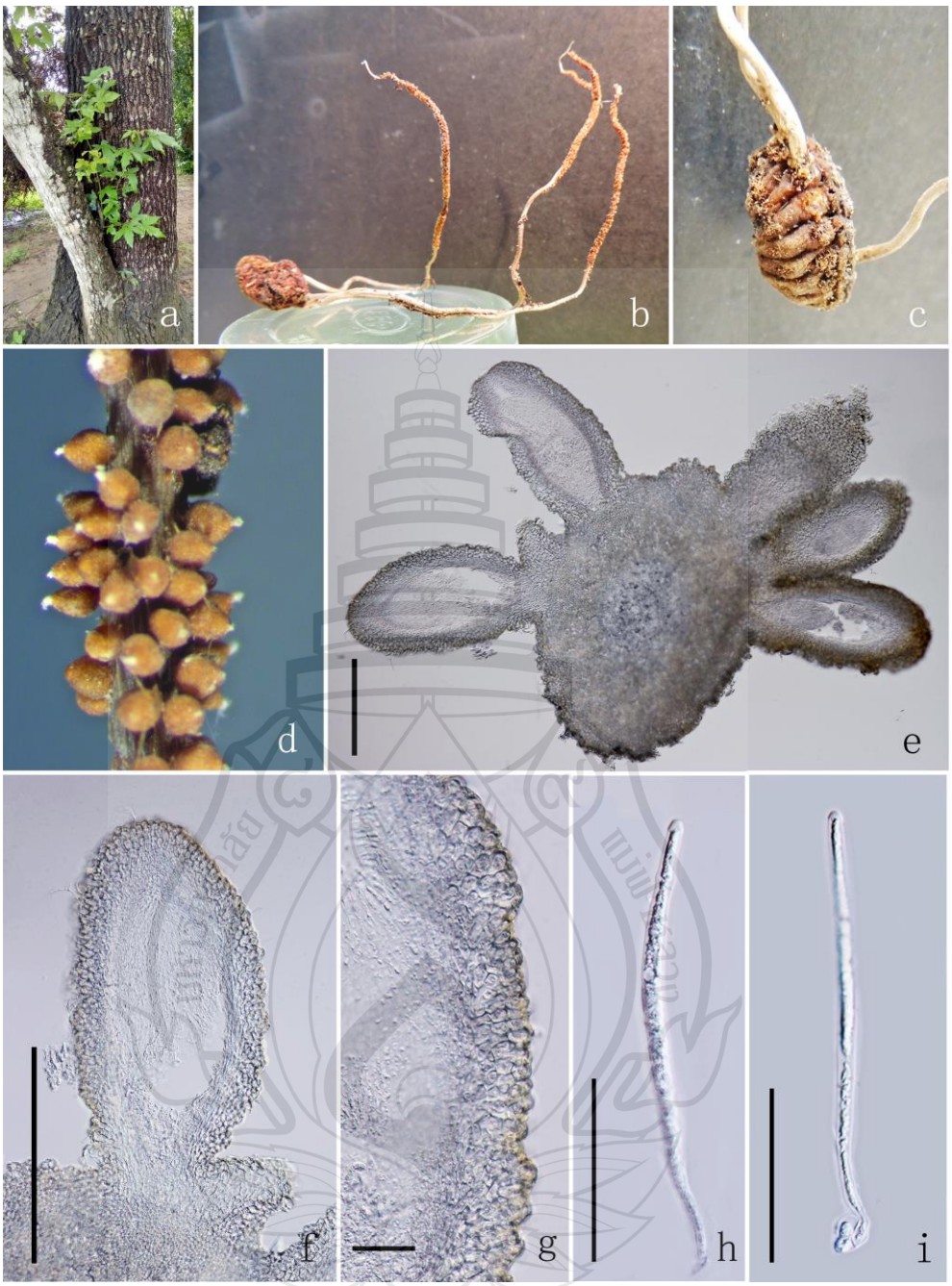
Ophiocordyceps phuwiangensis Tasan., Thanakitp., Phommavong & Luangsa-ard, in Tasanathai, Thanakitpipattana, Himaman, Phommavong, Dengkhhamounh & Luangsa-ard, Mycol. Progr. 19(10): 1052 (2020).

Index Fungorum number: IF 835587

Parasitic on larvae or pupa of *Monema sp.* (Lepidoptera, Limacodidae) in a tree hole. **Sexual morph:** *Stromata* 3–12 cm long, 1.2–2 mm wide, several, cylindrical, branched, brown, with a sterile tip. *Fertile part* 3–11 cm long, 1.8–2 mm wide, brown, with surperfical perithecia along the surface of stipe. Stipe 1–2 cm long, 1.2–1.4 mm wide, cylindrical, brown. *Perithecia* 250–400 × 180–220 um, surperfical on the surface of stipe, ovoid, pale yellow to hyaline. **Asexual morph:** Hyphomycetous. *Synnemata* filiform, erect, branched, 1–6 cm long, 0.2–0.5 mm wide, ligneous, yellow to brown, arising from all body of host. *Phialides* solitary along synnemata, 10.5–12.9 µm ($\bar{x}$ = 11.6 µm, n= 60) long, mostly with pyriform inflated basal portion, 3.8–6.9 × 4.0–5.6 µm ($\bar{x}$ = 5.2 × 4.8 µm, n= 60), with one slender, thin neck, 5.4–7.3 × 0.7–1.1 µm ($\bar{x}$ = 6.4 × 0.9 µm, n= 60). *Conidia* 6.5–8.2 × 1.7–2.5 µm ($\bar{x}$ = 7.3 × 2.1 µm, n= 60), fusiform, one-celled, smooth, mucous sheath absent.

Material examined: Thailand, Chiang Rai, on or pupa of *Monema sp.* (Lepidoptera, Limacodidae), gathered in the same tree hole, brown to dark brown, with thallus inside (larva), 18 August 2017, YuanPin Xiao, PY0801(asexual morph), PY0811 (sexual morph).

Notes: The new collections are clustered with the ex-type of *Ophiocordycpes phuwiangensis* (BCC85351). Although, the conidia of the new collection are different with *Ophiocordycpes phuwiangensis* by the fusiform shape. The conidia of *Ophiocordycpes phuwiangensis* is ellipsoid or lemon-shaped in the culture (Tasanathai et al., 2020). We identified the new collection as *Ophiocordycpes phuwiangensis*. This is the first time to report the asexual morph of *Ophiocordycpes phuwiangensis* from the fresh specimen.



Note a. Habitat. b. Overview of *Ophiocordyceps phuwiangensis*. c. Host. d. Stroma. e. Vertical section of the stroma. f. Perithecia. g. Peridium. h, i. Immeture asci. Scale bars: e, f = 200 *µm*, h, i = 100 *µm*, g = 20 *µm*.

Figure 3.45 Morphology of *Ophiocordyceps phuwiangensis* (new host PY0811)

Note a Habitat. b. Specimen in the tree hole. c. Synnemata on host surface. d, e. Host. f–h. Synnemata. i. Phialides with conidia. j, k. Conidia. Scale bars: c, d = 1 cm, e = 2000 *µm*, f = 1000 *µm*, g = 500 *µm*, h, i = 20 *µm*, j, k = 5 *µm*.

Figure 3.46 Morphology of *Ophiocordyceps phuwiangensis* (asexual morph)

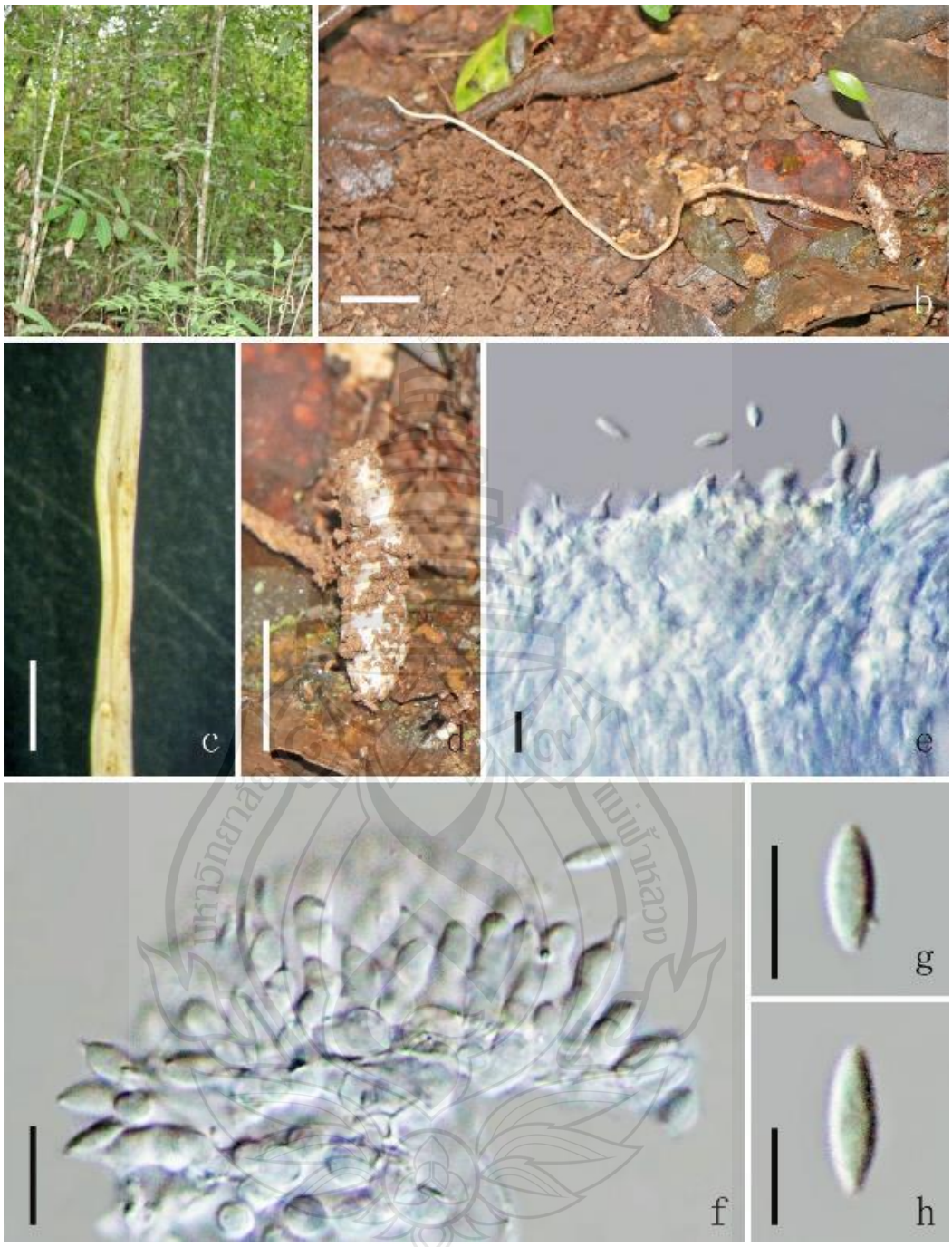
Ophiocordyceps longisynnema Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the color of the synnama.

Parasitic on termites (Blattodea, Termitidae) in the soil. **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* 18–20 cm long, 1–2 mm wide, fibrous, hard, wiry, erect, unbranched, pale. *Phialides* solitary along synnemata, 6.5–12.5 × 3.4–5.2 µm µm ($\bar{x}$ = 9.5 × 4.3 µm, n= 60) long, hyaline, inflated basal portion, with or without one short and thin neck, 1–2 µm ($\bar{x}$ = 1.5 µm, n= 60) long neck. *Conidia* 8.8–10.2 × 3.7–4.5 µm ($\bar{x}$ = 9.5 × 4.1 µm, n= 60), fusiform, hyaline, one-celled, smooth, mucous sheath absent.

Material examined: China, Yunnan Province, Xishuangbanna Dai Autonomous Prefecture. On termites (Blattodea, Termitidae) in the soil, 18 August 2017, YuanPin Xiao, DG06.

Notes: The new species, *Ophiocordyceps longisynnema*, was cluster with *Ophiocordyceps rhizoidea*, *Ophiocordyceps pseudorhizoidea*, *Hirsutella sp.* and *Ophiocordyceps asiatica* in the phylogenetic tree. Morphologically, *Ophiocordyceps longisynnema* differs from these close species in having quite long, pale synnemata, short neck phialides and fusiform conidia.



Note a Habitat. b Overview of specimen. c Part of synnemata. d Host. e Surface of the synnemata. f Conidiophore and phialides. g, h Conidia. Scale bars: b = 2 cm, d = 1 cm, c = 1000 *µm*, e–h = 10 *µm*.

Figure 3.47 Morphology of *Ophiocordyceps longisynnema*

Table 3.2 Sexual morph species of *Ophiocordyceps*

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. aciculariis	Cylindrical, brown	Perithecia, superfiacl	Long cylindrical, flexnous	Breaking into part spores	2.5–5	Berkeley (1857)
O. albacongiuae	Unbranched, dark brown, basal part velvety, tapering towards the apex; ascoma laterally	Semi–immersed, flask-shaped, 240–290 × 105–135	8–spored, cylindrical to clavate, 130–160 × 8–11	Cylindrical, slightly curved in "S",80–100 × 5, 5–6–septate		Araújo et al. (2018)
O. annulata		Completely immersed, ordinal in orientation.	250 × 5–7. ascus tip 4.5–6 × 5–6.	Approximatel y 200 × 1.5.	6–7 × 1.5	Sanjuan et al. (2015)
O. aphodii	Ochraceous–brown, 10–14 × 1–1.5, cylindrical, occasionally sterile at the tip, which is ovoid to cylindrical	Obliquely immersed, 367 ×110	200–225 × 3.8–5	90–151	Flattened at each end, 5.5–7.5 × 1.25–2	Mathieson (1949)
O. appendiculata	17 in height, stipitate cyclindrical to clavate	Pyriform, immersed, 340–360×150			5–10 × 1.5	Kobayasi and Shimizu (1983)
O. arachneicola	Solitary, cylindrical	Immersed, ellipsoidal				Kobayasi (1941)
O. araracuarensis	Solitary, simple, cylindrical, 83–97 mm long	Pyriform, 550–650 × 150–240, immersed in ordinal orientation	Cylindrical 300 × 5–6	Filiform, hyaline,	9–12 × 1	Sanjuan et al. (2015)
O. arborescens	Solitary or several, cylindrical, branched dendritic, 25–89.5 × 0.9–4.5	Superficial, ovoid, rubiginous to brown black, 320–570 × 270–350	Cylindrical, 225–250 long	Needleshaped , multiseptate, hyaline, 120–195×2.3–3.75		Ban et al. (2015)
O. arbuscula	Capitate, 5 long, the head hemispherical, reniform in section, reddish brown, the stipe slender, brownish yellow	Reddish brown, perithecia 450–650 × 220–250	Cylindric, 150–175 × 3–4	Ascospores filiform, immature		Teng (1936)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. asiatica	Solitary, simple, filiform, 150 × 10, orange brown	Superficial covering middle part of stroma, globose to subglobose, 261.5–302 × 205–240.5	8–spored, filiform, 104–143.5 × 5–6.5	Filiform, 100–122.5 × 1–2, with septate.		Tasan. et al. (2019)
O. asyuensis	Cylindrical, 7–15 × 0.5–1	Superficial ovoid 600–650 × 450	400–500 × 7–8		7–8 × 1.5, cylindrical	Kobayasi and Shimizu (1980)
O. barnesii	60 high, stipitate, fuscous or blackish brown	Immersed and thehead, rough, conoid 350 × 150	Cylindrical, capitate, 160–220 × 8–10	Filiform, as long as asci.	30–40 × 2 or 9–12 × 2	Petch (1924)
O. blakebarnesii	Single, unbranched, dark brown	Immersed to slightly erumpent, elongated, flask-shaped, 300–320 × 105–120	Cylindrical to clavate, 220–250 × 12–14	Hyaline, cylindrical, 140–160 × 4, 6–7-septate		Araújo et al. (2018)
O. blattae	Slightly clavate, 10 in height, dark red-brown with a lavender pruinose covering	Immersed, conoid, 200 × 150	Cylindrical to clavate, 100–130 × 8–12	Elongate, fusoid, 50–80 × 3–4, multiseptate		Petch (1924)
O. blattarioides	Solitary to gregarious, capitate,10–20 long	Ellipsoid, 760–800 × 220–300	Cylindrical, 250–300 × 5	Hyalines, filiform, multi-septate,	Cylindrical, 6–12 × 1.5	Sanjuan et al. (2015)
O. brunneinigra	Single, cylindrical and flexuous, brown-dark brown, 30–40 × 2	Superficial, aggregated, ovoid with a distinct base, dark brown-black, 560–650 × 200–240	Cylindrical, 250–320 × 10–15	Filiform,220–300 × 3–5, multiseptate		Luangsa-ard et al. (2018)
O. brunneiperithecia ta	Two to several, simple, wiry to pliant or fibrous,4–8 × 0.5–1	Superficial, ovoid, brown-dark brown,350–400 × 180–200	Cylindrical, 125–175 × 6–8	110–160 × 3–4, filiform, whole, multiseptate		Luangsa-ard et al. (2018)
O. brunneiunctata	Solitary, 40–90 in height	Immersed, ovate to pyriform, brown, 270–335 × 110–160	Cylindrical, 280–295 × 6–7	Filiform, flexuous	Truncate, 4–6 × 1–1.5	Hywel–Jones (1995)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. brunneirubra	Solitary, simple or branched, clavate, slender and wiry, 95 × 0.5	Immersed, ovoid, 334.5–400 × 138.5–178	Cylindrical, 176–214.5× 4.5–7	Filiform, 156.5–197.5 × 2–3, with septa		Tasanathai et al. (2019)
O. camponoti	Single, 15–20 × 25, cylindrical, velvety and ginger brown at the base, becoming cream–pinkish towards apex	Immersed to partially erumpent, flask-shaped, 240–280 × 100–150	Cylindrical to clavate,110–140 × 6–6.5	Vermiform 80–85 × 3, 5-septate, sinuous to curved		Araújo et al. (2015)
O. camponoti–balzani	Morphology similar to *O. camponoti–rufipedis*, but fertile region dark brown to black	Semi-erumpent, flask-shaped, 400–450 × 100–150	Cylindrical, 200–240 × 12–16	Cylindrical, 135–175 × 4.0–5.0, 14–22-septate		Evans et al. (2011)
O. camponoti–bispinosi	Single, 5–7 in length; cylindrical, black, with a cream-white swollen terminal part	Immersed to slightly erumpent, globose to flask-shaped, 250–290 × 150–170	Cylindrical to clavate, 110–130 × 8–8.5	Cylindrical, 70–75 × 4.5–5, 4–5 septate		Araújo et al. (2015)
O. camponoti–chartifices	Single, 10–15 mm in length, cylindrical, velvety and ginger brown, becoming cream-pinkish at the apical part	Immersed to partially erumpent, globose, 200–235 × 135–175	Cylindrical to clavate, 100–125 × 6	Vermiform 75–85 × 5, 9–13-septate, sinuous to curved, never straight at maturity		Araújo et al. (2018)
O. camponoti–femorati	Single, averaging 3.5 × 0.25, up to 6 in length, cylindrical to laterally compressed, ginger to dark-brown	Immersed to partially erumpent, flask-shaped, 200–230 × 135–165	Cylindrical to clavate, 110–130 × 8–9	Sinuous to curved, 75–90 × 3, 5–septate		Araújo et al. (2018)
O. camponoti–floridani	Single, 5–7 × 0.15 mm, cylindrical ginger to dark–brown, characteristically swollen terminal part, clavate	Immersed to partially erumpent, flask-shaped, averaging 225–250 × 135–165	Cylindrical to clavate,115–135 × 7–10	Cylindrical, robust, straight to gently curved, 75–85 × 4–5, 5–septate		Araújo et al. (2018)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. camponoti–indiani	Multiple, 8–10 × 0.3–0.4, ginger at the base becoming purplish-cream towards the apex	Immersed to semi–erumpent, ovoid to flask-shaped, 230–310 × 120–175	Cylindrical 170 × 8.5	Cylindrical, 75 × 4.5, 5-septate		Araújo et al. (2015)
O. camponoti–leonardi	Single, 20 long, dark brown at the base becoming light brown at the tip of the stroma	Fusoid-ellipsoid with rounded ostioles, 400–430 × 200–230	Cylindrical, 130–175 × 7–8	110–125 × 2–3, multiseptate		Kobmoo et al. (2012)
O. camponoti–melanotici	Morphology similar to *O. camponoti–rufipedis*, Fertill area dark brown to black, 1.3 × 0.8–1.0	Semi-erumpent, flask-shaped, 400–450 × 100–150	200–275 × 12–16	Cylindrical, 170–210 × 4–5,27–35–septate		Evans et al. (2011)
O. camponoti–nidulantis	Single, 10–15 × 0.2, cylindrical, black, covered with ginger velvety hyphae fading away towards the apex	Immersed to partially erumpent, flask-shaped, 200–240 × 100–150	Vermiform to clavate,110–145 × 6–8	Vermiform, 90–105 × 3–4, 5–septate, gently curved		Araújo et al. (2018)
O. camponoti–novograndensis	Morphology as for *O. camponoti–rufipedis*, fertile region brown, 0.8–1.0 × 0.5–0.6	Semi-erumpent, crowded, 225–250 × 125–155	Cylindrical, 95–120 × 9–10	Filiform, 75–95 × 2.5–3.5, 5–10–septate, mainly curved		Evans et al. (2011)
O. camponoti–renggeri	Single, up to 30, cylindrical, velvety and dark brown, tapering towards the apex	Immersed to partially erumpent, flask-shaped, 220–250 ×100–165	Cylindrical 130–145 × 8–10	Vermiform,90–120 × 4, 5–8-septate, straight to sinuous		Araújo et al. (2018)
O. camponoti–rufipedis	Single, up to 15 in length, cylindrical, ginger to dark brown at base, white to pinkish in fertile upper part	Immersed to partially erumpent, flask-shaped, 175–260 × 100–130	Cylindrical to clavate, 120–160 × 8–10	Multiserriate, vermiform, 80–95 × 2–3, 4–7-septate, sinuous to curved, rarely straight		Evans et al. (2011)
O. camponoti–saundersi	Single, up to 15 long, dark brown at the base becoming pale purple at the tip of the stroma	Fusoid-ellipsoid with rounded ostioles, 280–320 × 160–180	Cylindrical, 80–160 × 6–7	Lanceolate with tapering ends, 75–85 × 2–3, multiseptate		Kobmoo et al. (2012)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. camponoti–sexguttati	Single, unbranched, averaging 18–20 × 2, dark brown at the base turning lighter brown towards the apex	Immersed to partially erumpent, flask-shaped, 225–230 × 135 withshort neck.	Cylindrical, 150–160× 8–9	Multiguttulate, cylindrical, 120–140 × 3, 7–septate, straight or curved		Araújo et al. (2018)
O. cicadellidicola	Simple, cylindrcial, 45–50 long	Superfical, ovoid, 425–480 × 270–320			8–9 × l–1.5 truncate on both sides	Kobayasi and Shimizu (1983)
O. cicadicola	Clustered, gray when fresh, light bluish brown after drying, 15–25 long	450–600 × 180–250, obliquely immersed	Cylindrical, 200–260 × 5–6		5–6.5 × 1	Teng, (1935)
O. clavata	Clavate or corniform, 4–5 × 0.7–1.2, base irregularly verrucose, pale ochraceous (Light buf), pubescent	Aggregated, semi-superficial, ovoid420–550 × 230–330			5–9 × 1.5, truncate	Kobayasi and Shimizu (1980)
O. clavulata	Cylindrical 2–2. × 0.5, white	Black globose	90–100 × 9–10, cylindrical with narrowly spindle-shaped containing	Fusiform, 60–75 × 2.5–3		Schweinit (1832)
O. coccidiicola	4–6 cm long, fleshy, stipitate	250–270 × 150–160, ovoid	130–150 × 8.5–10	75–95 × 3–3.5, 9–16 septate		Kobayasi and Shimizu (1978)
O. cochlidiicola	Cylindrical, 45–50 cm long	Superfical, ovoid, 425–480 × 270–320	6 inches thick, 3.5–4 wide		8–9 × l–1.5, truncate	Kobayasi and Shimizu (1980)
O. coenomyiae	Solitary, stiptate, changing gradually to yellowish white at upper part, inside hollow	Lanceolate, alutaceous, 700–750 × 200–220, vertically immersed	Cylindrical, 500–750 long	Needle-shaped, divided into 32 part spores, 700–750 × 7.8–8.0	Cylindrical, 8–15 × 1.8–2.5	Ban et al. (2015)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. communis	Filiform, 50–100 × 0.3–0.6, whitish-grey, 70–130 emerging above leaf litter	Superficial subterminal, emerging through grey anamorph, tightly packed around the stipe, 285–675 × 195–390	With a short cap, 8–spored, filiform, 215–250 × 15	Stout, lightly pigmented 120–150 × 5–6		Sung et al. (2007)
O. cossidarum	Reddish-brown or cinnamon to brown on one end of the insect larva, mostly erect	136–171, immersed, red, ovate to phialide, red-walled	174–221 × 5.7–7, cylindrical	131–153 × 1.8–2.2, multiseptate breaking into 32 part–spores	3.7–4.8 × 1.8–2.4, hyaline, cylindrical, truncated	Hyde et al. (2017)
O. crassispora	Clavate, simple or occasionally 2 or 3, 45–65 × 45	Globoid or ovoid, 200–450 × 190–420,	Cylindric, 170–220 × 7.8–10.4	Hyaline or pale yellow, clavate, multiseptate, 120–196 × 5.2–6.2	1–celled segments 6.5–9.8 × 5.2–6.5	Zang et al. (1990)
O. crinalis	Several, long filiform, 50–80 × 0 .3–1, attenuated	Superficial, distributing unequally on upper half of stalk, ovoid, 300–330 × 225–250	150–200 × 5–6		4–5 × 1	Kobayasi and Shimizu (1982)
O. cuboidea	Cylindrical or sometimes flattened, wiry, hard, cream to pale yellow, 3.2–29.9 × 0.3–7.4	Superficial, pale orangish yellow, lemon-shaped, 350–550 × 230–400	250–570 × 3.0–5.0	Needle-shaped, hyaline, finely segmented into part spores	1.0–3.0 × 1.0–2.0	Ban et al. (2009)
O. cucumispora	Cylindrical, 15–20 × 0.3–0.4, fleshy, fresh sliver, gray or ochraceous dry	Perpendicular, whitish to pale ochraceous, 400 × 480 × 180–220	Cylindrical 230–280 × 5–7		7–9 × 1.8–2.5	Evans and Samso (1982)
O. curculionum	Stalked, 20 long, firm cylindrical, dark	Obliquely arranged, curved with long neck, 630–850 × 200–260			Long fusiform, 12–18 × 1.5	Kobayasi (1981)
O. cylindrospora	50–90 × 0.5–1.5, single, stipitate, rarely double, pale yellow to yellow	551–638 × 261–327, immersed, oblique flask-shaped	248–313 × 5–7, cylindrical	Easily breaking into part-spores, filiform	3.1–3.9 × 1.6–2, cylindrical, truncated	Hyde et al. (2018)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. cylindrostromata	Binate, cylindric, simple, 33–40 × 1–1.5, dark brown	Superficial, subpyriform, 255–405 × 150–225	Thread-like, 1600 × 4.2	Multiseptate, interval cells 6–8 × 1.5–2		Liang et al. (2003)
O. dayiensis	Single, filiform, simple, 140 × 2, brownish	Immersed, narrowly ovoid, 430–480 × 210–270	Slender cylindric, 225–345 × 6–7.5, with very thin cap of ascus, 1–1.5 high and 3 wide	Filiform, multiseptate, pointed at both ends, 300 × 1–1.8	7.2–12.8 long	Zong et al. (2003)
O. dermapterigena	Single, simple, emerging from host tail, slender, cylindric, pale brown, 15 × 1	Embedded to ovoid, 405–450 × 180–230	6–7.2 thick	Filiform, multiseptate	1–celled fragments 6–15 × 2–3	Liang et al. (2003)
O. dipterigena	One to several from the host, 2.5–8 long, capitate	Narrowly ovoid or conoid, 700–900 × 240–400, vertical embedded	Cylindric, 480–600 long	Filiform, multiseptate	Cylindric or fusoid fragments 6–12 × 1–1.5	Kobayasi (1978)
O. discoideicapitata	Binata, 3-4 cm long, simple, cylindrical shaft, 0.7–1 mm thick, orange	Immersed, pyriform, 620–700 × 200–250	Asci 5–6 wide		6–9 × 1, truncated	Kobayasi and Shimizu (1982)
O. ditmarii	Stipe more or less elongated, simple, 15–35 × 0.5–1	Claviform, inserted obliquely, 900–1000 × 290–325	Cylindrical, 150–170 × 6–7.5		Non rectangular, 8.2–10.6 × 1.5–2	Vooren and Audibert (2006)
O. elateridicola	70 cm long tailed appendage	Immersed, pyriform, 400–450 × 120–150	4 wide		3–4 × 1, truncated	Kobayasi and Shimizu (1982)
O. elongata	Clava, 110 long.; stipitate, pale brown	Immersed, scattered or congested, 400 × 300	Cylindrical, 220 × 8			Petch (1937)
O. elongatiperithecia ta	Single, cylindrical, 35–40 long	Superficial, gregarious part，elongate-fusiform, 620–700 × 270–280			14–15 × 2, truncate	Kobayasi and Shimizu (1982)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. elongatis tromata	Stromata filiformia, 140 long	Omnino immersa, 230–250 × 310–330, ovoidea, ostiolis conicis	80–90×6.0, capitibus 4–4.5 in diam		7–10 × 1.5, truncate	Kobayasi and Shimizu (1982)
O. emeiensi s	Singleor 1-2 branched, 100–160 × 1.5–3	Isolated or aggregated, brown surface to black ellipse, 280–320	Cylindrical, 173–213 × 7.5–8	Filiform, 45–60 × 1–1.5 multiseptate	9.8–16 long	Liu and Liang (1997)
O. engleria na	Disseminated, yellow–gray, 10–13 mm long, stalked	Superfical, 8–20, cylindrical, fusiform, obtuse-rounded	Elongated cylindrical 300–400 × 8–10		6–10 long, sometimes branched, with a curved	Hennings (1897)
O. evansii	Simple, capitate, slender, 20–30 long, filamentous, bicolored, stipe slender, cylindric, 18–28 × 0.7 glabrous, pliant, brownish black	Obclavate, 1600–1800 × 260–30, with a prominent reddish brown ostiole, 60–80 × 80–100, immersed	Cylindrical, 950–1200 × 8		Fusiform-ellipsoid, 17–20 × 1.5–2	Sanjuan et al. (2015)
O. evdogeor giae	Csespitose; cylindrical, swelling gradually into an oblique		Filiform, with an inflated	This differs from all known species in thecæspitose falcate heads, which are naked at the base on the convex side.		Berkeley (1854)
O. falcatoid es	Single, cylindrical, 17–24 × 0.8–1, brown	Superficial, ovoid, elongate, 350–400 × 200–250	150–175 × 7–8	125–150 × 2.5–3, multisepitate	9–11 × 3, truncate	Kobayasi and Shimizu (1980)
O. fascicula tistromat a	Tagregaria, cylindricafere filiformia, attenuata, 37–43 × 0.6–0.7	Superficial, ovoid, 370–430 × 250–300	3–4 wide		8 × 1.5, truncate	Kobayasi and Shimizu (1982)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. ferruginosa	Robust, rusty, club clubed or cylindrical, 11–13 mm long, glabrous; an appendix recurved with a gross corniform;	Immersered, ovoid, 600–650 × 250–300	5–6 wide		5–7 × 1, truncate	Kobayasi and Shimizu (1980)
O. filiformis	Stroma winding, filiform, slender, simple, first white then white-yellow or yellow-ochraceous	Unperficial, bare, conoolor stroma, solitary or often turfed, ovate or ovate–conical, 380–450 × 220	Cylindrical, gland-shaped head apiee, tapering to base on a pediculously, 220 150–280 × 2–4	Filiform, 170–260 × 0.5–1	5–10 truncate	Moureau (1949)
O. formosana	Stalks exhibited long–cylindrical shapes of 1–30 × 0.5–2 in size that were orange in color and bore short hairs	Embedded, brownish orange and ovoid shaped 360–480 × 240–320	Cylindrical shapes with attenuated bases 6.5–7.9 × 160–240	Cylindrical and filamentous	Truncated, 2.6–3.0 × 6.5–7.3	Wang et al. (2015)
O. fulgoromorphila	Solitary to gregarious, capitate, 87–110 long, perpendicularly branched in secondary bi-colored stromata	Conical to ellipsoid, 780–1100 × 280–380, immersed in slightly oblique	Cylindrical 300–600 × 5–6	Hyaline, filiform, multiseptate	9–12 × 1–2 with two oil drops, breaking irregularly into fusiform	Sanjuan et al. (2015)
O. furcicaudata	Cylindrical stem, simple, yellow, 30 mm long, 2 thick, cylindrical, fertile, pale yellow, 13 × 1.8	Immersed ovoid vel pyriformia, 390–420 × 180–225	Cylindrici, 114 × 4.8, capitibus 4.2 diam		3.6–4.8 × 1.5–1.8, truncate	Liang et al. (2003)
O. gansuensis	Solitary or rarely branched, fleshy, cylindrical or clavate, 50–80 long and 2.5–5 wide	Superficial, subglobose, 320–350 × 270–300, dark brown，tuberculate	Cylindric, hyaline, unitunicate, uniscriate, 6 or 8 ascospores, 212–284 × 8.5–13.5		Ellipsoidal to oblong，l-celled, hyaline, smooth, 12.8–21.3×6.3–8.5	Zhang et al. (1989)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. geniculata	Bina ex abdomnis lateraliter oriunda, cylindrica, simplicia vel geniculatim ramosa, 15–25 longa, 0.3–0.4 crassa	Superficialia, raro interspersa in partem superioram stipitis producta, 450–500 × 300–330, ovoidea, cum cellulis globosis omnino obsita, pallide aurantiaca	5 crassi, capitibus 3.5 in diam		5–6 × 1, truncate	Kobayasi and Shimizu (1980)
O. geometridicola	Numerous, up to 20, simple, wiry to flexuous, 5–8 × 1	Superficial, ovoid, brown to dark brown, 280–400 × 240–290	Cylindrical, 150–190 × 5–8	Cylindrical to vermiform, septate, 120–150 × 2–2.5		Luangsa-Ard et al. (2018)
O. globiceps	4–8 × 0.5–1, one or several from the host, stipitate, capitate, unbranched, cinnamon to yellow	538–663 × 182–247, immersed, ovoid to elongated pyriform	373–454 × 5.7–8.2, filiform	240–303 × 1.8–2.3, multiseptate	Truncate	Xiao et al. (2019)
O. gracilioides	Bursting out to the fleshy part of the stipitate		Cylindrical, 600–700 × 6–6.5		6.3–8.5 × 1.2–1.5	Kobayasi (1941)
O. granospora	Simple, solitary, cream yellow to yellow orange, 25–95 long, with ovoid fertile heads	Obliquely immersed, ovoid, obclavate, obpyriform, 595–746 × 153–208	Hyaline, cylindrical, capitate, 428–489 × 5–7	Filiform, multi-septate, 440–494 × 1–2	Truncate, 6–13 × 1–2	Khonsanit et al. (2018)
O. halabalaensis	Dark brown, 6.5–18 high, sprung up in the head and chest of an insect	Fusiform or ellipsoid, tightly contiguous350–420 × 180–210	Cylindrici, octo–sporis, 150–200 × 7–10	Cylindricae, multiseptatae, totae, quoque extremo angustato, 60–75 × 3–5		Luangsa–Ard et al. (2011)
O. hirsutellae		Semi-immersed, globose, 250 diameter, with a short, cylindric ostiolum, 50 high, apex obtuse	Spores biseriate above, uniseriate below, to linear clavate, 130 × 6	Fusoid, straight or slightly curved, ends obtuse, seven-septate, 22–27 × 5–6		Petch (1937)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. houaynhangensis	Solitary, 11 × 1.5–2.5, cylindrical, cream; stipe simple	Completely immersed, obclavate, 443–360 × 94–140	Cylindrical, 115–207 × 4–5	Cylindrical, breaking into 32 secondary spores,	4–7 × 1–2, truncate	Crous et al. (2018)
O. issidarum	60–75 long, 1.5–2 wide, mostly branched	600–765 × 247–323, superficial, brown to dark brown, oval shaped	186–228 × 8–12, 8–spored, hyaline, narrow cylindrical	173–202 × 3–5, cylindrical, 8-9–septate		Hyde et al. (2017)
O. japonensis	Solitary or cespitose，simple，flexuons, subcompressed, carnose，orange colored，11.5–25 × 1–1.5	Subimmersed, globose, ostiolate	Cylindrical or clavate，130–170 × 5–6	Fliform, multiseptate，1.5–2 wide		Hara (1914)
O. jiangxiensis	Single, caespitous or fasciculate, cylindrical, 40–90 × 5	Superficial, elongate-ovoid, 520–600 × 300	2.4–3.0 × 1.8–2.2	Cylindrical 1.0–1.2 thick, multiseptate		Liang et al. (2001)
O. jinggangshanensis	Solitary or caespitous, filiforms, not ramifying, pale ocherous, arising from whole host body, 13 × 0.5	Superficial, 320 × 230	Cylindrical, 165 × 9–10 × 4.5 × 4.5	Filiforms, 2.5–3 thick, multiseptate		Liang et al. (2001)
O. kangdingensis	Clavate, single, 62–75 × 2–4					Zang and Kinjo (1998)
O. karsti	Mostly single, 140–145 × 2–4, stipitate arising from head of the host	600–765 × 247–323, superficial, yellow to brown, flask-shaped	186–228 × 8–12, cylindrical	173–202 × 3–5, fasciculate, fusiform, 10–18 septate		Li et al. (2016)
O. khaoyaiensis	Simple, solitary, pale-yellow, yellow-orange to orange	Obliquely immersed, ovoid, obclavate, 660–796 × 207–257	Cylindrical, 466–532 × 5–7	Filiform, multiseptate,434–497 × 1–2	Barrel-shaped, allantoid, cylindrical, 6–14 × 1–2	Khonsanit et al. (2018)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. khokpasiensis	Solitary, simple, cylindrical, 160 long, 1 wide, brown	Pseudo-immersed, subglobose to broadly ellipsoidal, covering middle part of stroma, 214–248.5 × 140–186	8–spored, filiform, 86–115 × 4–5	Filiform, 51–74 × 2–3		Tasanathai et al. (2019)
O. khonkaenensis	Solitary to three, 20–30 × 2–3 wide. Rhizoids flexuous, pink to red	Perithecial, completely immersed, ovoid, 615–675 × 216–263	Cylindrical, 252–326 × 5–5.8	Filiform, 314–353 ×1.5–2	9–11.5 × 1.5–2	Crous et al. (2019)
O. kimflemingiae	Single, 11–17 × 0.3–0.45, cylindrical, ginger to light brown, basal part velvety	Immersed to partially erumpent, flask–shaped, 250–275 × 120–160	Cylindrical to clavate, 120–150 × 10–11	Cylindrical, 80–90 × 5, 5-6–septate		Araújo et al. (2018)
O. kniphofioides	On the side, first single and simple, but long-branched, pale to brownish, clavate, 5–6 × 0.7–1.0	Yellow, ovoid to lageniform,170–250 × 110–140	Cylindrical, 140–200 × 12	Filiform, 3–5 septatae, 110–150 × 1.5–3.0		Evans and Samson (1982)
O. kniphofioides var. dolichoderi	Single, simple, long and narrow, 40–50 × 0.2–0.3					Evans and Samson (1982)
O. kniphofioides var. kniphofioides	On the side, single and simple, pale to deep orange, then brownish brown, clavata to conical, 5–6 × 0.7–1.0	Yellow, slightly prominent, ovoid to lageniform, 170–250 × 110–140	Cylindrical, 140–200 × 12	Filiform, rounded up, down, narrowed, 3–5 septate, droplets		Evans and Samson (1982)
O. kniphofioides var. monacidis	Short, narrow, 8–12 × 0.2–0.3			95–110		Evans and Samson (1982)
O. kniphofioides var. ponerinarum	Stroma up to 8 cm long, usually 30–40 × 0.4–0.6	Late Lageniformia, 240–320 × 140–190				Evans and Samson (1982)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. kobayasii	Multiple, arising from the head region and body of the insect host, pale cream, cylindrical	Superficial, ovoid, 190–230 × 150–175	Cylindrical, 125 × 10–15	Filiform, aseptate, 52–72 × 2–2.5		Thanakitpipattana et al. (2020)
O. konnoana	Singly or in pairs, slightly tapering, 9–11.5 × 0.5–0.8	Superficial, ovoid, 400–425 × 300, farinaceous, pink or almost white	100–110 × 4–5		4–6 × 1	Kobayasi and Shimizu (1980)
O. koreana	Solitary or gregarious, cylindrical, 35–70 × 1.8–2	A very small straight and compact surface, arranged in ovoid 210–255 × 130–140	50–70 × 7–9	Cylindrical, tapering on both sides, 40–63 × 2–2.5, 7-8–septate		Kobayasi (1941)
O. krachonicola	Solitary, cylindrical, 37–40 × 1–1.5	Immersed, ovoid to obclavate, 474.5–539 × 193.5–258	Cylindrical, 286–377 × 4–5	Divided into 64 part-spores after maturity, 351–416.5 × 1	Cylindrical, 4.4–7 × 1	Thanakitpipattana et al. (2020)
O. lacrimoidis	4–5 × 1, simple, stipitate	Obpyriform, slightly curved, 650–700 × 200–250, completely immersed	Narrow cylindrical, 350–450× 5, apex thickened	Filiform, more than 56 septa, easily breaking into partspores	Cylindrical, 8–14 × 2, hyaline, smooth	Hyde et al. (2016)
O. paracuboidea	Cylindrical, nonramulose	Vertically, citriform, pale orange-brown, 400–600 × 290–400	Cylindrical, 225–400 × 3.0–6.25		1.3–2.5 × 1.0–2.0	Ban et al. (2009)
O. lanpingensis	Several or solitary, simple or more usually branched, 50–160 × 0.2–1.3, brown	Oval, 310–370 × 200–240, superficial	Cylindrical, 240–300 × 5.1–6.5	Cylindrical, 240–300 × 1.4		Chen et al. (2013)
O. laojunshanensis	Clavate, slender, simple, rarely 2 or 3, 47.0–93.0 × 1.0–3.9	Globosa, 200–300 × 200–350	Cylindrical, 165–275 × 11.5–14.5	Filiform, multiseptate, 130–250 × 5.0–6.0		Chen et al. (2011)
O. lloydii var. binata	Two, on either side-literally, yellow to brown, 0.8–1.4 × 0.4–0.7	400–600 × 140–160			7–8 × 1.5–2.0	Evans and Samson (1984)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. lloydii var. lloydii	Single, unbranched, cream to pale tan, cylindrical, 4–8 × 0.25–0.35	Semi-erumpent, flask-shaped to narrowly ovoid, 700–850 × 210–300	Cylindrical	Filiform	8–9.5 × 1.5–2.0, ellipsoidal, to truncate	Evans and Samson (1984)
O. longissima	Originating from the upper part of the head, singular with an elongate trunk	Embedded, ovoid, without hills, 600–650 × 280–310	Cylindrical 5–6 thick		Cylindrical, 9–11 × 1.1	Kobayasi and Shimizu (1963)
O. lutea	Single, yellow or pllido-golden, then cream or ociracea, 35–120 high	Immersed, clavate and curved, obliquely, long-shaped, 600–1200 × 200–300	Cylindrical, 1100 × 3–5	Cylindrical, 8–15 × 0.8–1.5		Moureau (1949)
O. macroacicularis	Several, cylindrical, unbranched, 97.2–166.1 × 1.3–2.4	Superficial, ovoid, alutaceous to brown, 410–760 × 260–420	Cylindrical, 235–310 long	Needle-shaped, multiseptate, 14–16 septa, hyaline, 200–300 × 2.3–3		Ban et al. (2014)
O. maculari s	Single or two, light ochraceous-salmon " or " vinaceous fawn," 20–35 × 1	Superficial, ovoid, 290–320 × 190–220	Narrowly clavate, 150–180 × 6–8	Fusoid, 60–90 × 2–3	Multi-septate, 6–14 long	Mains (1934)
O. megacucculla	Simple, solitary, yellow to yellow-orange, 50–95 long	Obliquely immersed, obclavate, obpyriform, elongate flask-shaped, 631–712 × 212–267	Hyaline, cylindrical, capitate, 499–581 × 5–9	Filiform, multi-septate and breaking into 64 part–spores, 458–521×1–2	Barrel-shaped, truncated, 7–14 × 1–2	Khonsanit et al. (2018)
O. michiganensis	Slender cylindric or filiform, 38 long, 0.8 thick	Semi-immersed, then emerging, separated or 2–3 fasciculated, ovoid, 350–500 × 310–420	Asci 250–270 × 9–10, cap hemi–globose, 5 u in diameter.		7–8 × 2–2.5	Kobayasi and Shimizu (1982)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. minutissima	Stroma arising laterally from the head or abdomen, singular, simple or rarely branched	Ovoid superficial,600–630 × 350–430	Asci 5–5.5 thick		4–6 × 1, truncate	Kobayasi and Shimizu (1982)
O. monacidis	Stroma originating from the side of the neck or pronotum of Monacids, the terminal part is fertile, small, 1.4–1.8 × 0.5–0.6			95–110		Evans and Samson (1982)
O. monticola	Head nails, 20–25 mm long, ashy stakes, 1.5–2	Immersis, fusoideo-ovoideis,600–660 × 200–240	Cylindriceis 420–510 × 5–6		6–8 × 1.5	Mains (1940)
O. mosingtoensis	Solitary, simple, cylindrical, up to 110 long, 1 wide, brown	Pseudo-immersed, broadly ovoid covering middle part of stroma, 414–469 × 208–263	8–spored, filiform, 217–265 × 4.5–6.5	Filiform, 291 × 1.5–3, with septa.		Tasanathai et al. (2019)
O. mrciensis	Stroma arising from the host's abdomen, branched, filiform, 5–12 cm long, the fertile part black. apical appendix filiform, 4 cm long	Superficial, elongated vel ellipsoidea, 210–375 × 150–180	135–306 × 9–15	185–435 × 3.5, multiseptatae		Aung et al. (2006)
O. multiaxialis	Stromata clavate, in clusters, occasionally 2, 3 or 4 from host, 40–52 long, 1.5–3 diam	Globoid, 100–300 × 100–320	Asci clavate, narrow at the base, 25–52 × 7.8–9.1	Ascospores hyaline, filiform, multiseptate, 7.8–20 × 0.6–1.2		Zang et al. (1998)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. multiperitheciata	Several, cylindrical, branched dentritic, 75–110 long,1–1.5 wide, dark brown to black	Superficial, gregarious, ordinal in arrangement, narrowly ovoid, brown to dark brown, 990–1200 × 350–450	400–600 × 6–7.5	Filiform, 470–660 × 1.5–2.5, remaining whole after discharge, multiseptate.		Luangsa–Ard et al. (2018)
O. myrmecophila	A single, simple clavus usually emerged from the host and terminated in a solitary, fertile head	Ascomata were packed with asci and there was no sign of a hamathecium	Asci did not mature simultaneously and could be found at all stages of development in a single ascoma		6.7–7.5 × 1.3–1.7	Hywel (1996)
O. naomipierceae	Stromata ginger to light-brown, commonly clavate, produced always from dorsal pronotum, frequently on leg joints, 1.5–2.25 × 0.45–0.75	Immersed, flask–shaped, 260–320 × 150–200	Vermiform, cylindrical, 150–180 × 7	Hyaline, straight to gently curved, vermiform,75–105 × 5–6, 4–6–septate; tapering at apex		Araújo et al. (2018)
O. neonutans	Stromata solitary, rarely two, simple or branched 32–170 × 1–2	Crowded, obliquely vertical in the head, completely immersed, piriform, 550–1200 × 130–360	Cylindrical, hyaline 220–900 × 3–8	Parallel, filiform, multiseptate, easily fragmenting into 64 part–spores	Cylindrical 6–15 × 1.2–3	Friedrich et al. (2018)
O. neovolkiana	Stroma from the abdominal joints of the larvae, breaking out solitary or in pairs at the base, clinging 13–18 feet deep, fleshy	Embedded and upright ovoid or ellipsoid, 340–460 × 140–165	230–300 × 9–10		Cylindrical 2.8–8 × 1.7–2	Kobayasi (1941)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. nepalensis	Stromata clavate, simple, 41–45 long, 2–3.5 diam., ascogenous portion almost one half of the length	Globoid or ovoid, 110–260 × 100–250. embedded	Clavate or cylindric, 102–120 × 5–9	Hyaline, filamentous, multiseptate, 20–70 × 0.5–1.3	15–35 × 0.5–1.3	Zang and Kinjo (1998)
O. novae–zelandiae	Arising irregularily from endosclerotium, usuallystlked, branched, often anastomosing	Perithecia gregarious, superfieial, obpyriform 350–400 × 500–600	Asci cylindrical, 250–340 × 3–5	Fliform, 250–300 × 0.5–1 multiseptate	0.5–3 × 0.5–1	Dingley (1953)
O. nutans	Solitary or in pairs, forming filiform 50–170 cm long	Perithecia deeply obliquely immersed, elongate ampulse densely arranged eurvated 530–570 × 145–185,	Asci cylindrical, tapering, 330–460 × 7–7.7		Cylindrical, 6.5–10 × 1.4–1.6	Kobayasi (1941)
O. obtusa	Stroma single, up to 60 long.	Immersed with irregularly protruding ostiola, ovoidor oblong, 480–550 × 200–230	Asci arcuate, attenuated toward both ends, 220–270 × 10–12	150–200 × 3–3.5, septate		Kobayasi and Shimizu (1980)
O. octospora		Immersed in a prominent, stalked stroma	8 spores per ascus, and these are 40–70 × 15–30	Ascospores have been described as ellipsoidal to cylindrical		Blackw and Gilb (1981)
O. odonatae	Stipitate, cylindrical, terminal				Clavat or globose 0.6–0.9	Kobayasi (1941)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. ootakii	Stroma single or branched, produced from dorsal pronotum, averaging 6.5 × 0.3, cylindrical, greyish to light brow	Immersed to partially erumpent, flask-shaped, 230–260 × 120–150	Cylindrical to clavate, 130–180 × 8–9	Vermiform, straight to gently curved, 85–100 × 3, 5–septate, tapering at both ends		Araújo et al. (2018)
O. owariensis	Solitary, fleshy, dark brown, straight, cylindric,57 long	Obliquely immersed, asymmetrical, ampullaceous, 460–530 × 200–270	4.3 wide		4.2–5.6 truncate.	Kobayasi (1939)
O. owariensis f. viridescens	Solitary, simple or 3–4 branched, greyish-green or dark herbage green straight	Obliquely inserted, ampullaceous,440–640 × 180–320	Cylindrical, 180–300 × 5–6.5	Filiform, 150–280 × 1–2		Uchiyama and Udagawa. (2002)
O. oxycephala	Stem simple filiform, about 40 feet long, equal to 1 in thick, tortuous curved, fibrillose, fleshy hairless rufescens ochrescent	Immersed, elongated-ampullaceadense aggregates, more or less curved, 700–1000 × 210–290	Filiform 550 long		3.5–4.2 × 1.5	Kobayasi (1941)
O. paracuboidea	Stromata isolated or, in some cases, cylindrical, nonramulose	Vertically, citriform, pale orange to brown, 400–600 × 290–400	Cylindraical, 225–400 × 3.0–6.25		1.3–2.5 × 1.0–2.0	Ban et al. (2009)
O. pauciovoperitheciata	Solitary, simple, wiry to pliant or fibrous,14 long, 1 wide	Superficial, sparse, up to 20, vertically placed, ovoid, brown, 300–400 × 210–300	Cylindrical, 140–220 × 5–7.5	135–215 × 2–3, filiform		Luangsa-Ard et al. (2018)
O. peltata	Stipitate, completely immersed with darker ostioles, scarcely or slightly prominent, dotted; 2–5 × 5–7	Immersered, 250 long	Clavat 100 × 10	Fusiform, multiseptate,72–91 × 3–3.54		Wakefield and Groves (1916)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. petchii	The stromata are brownish gray, slender, 1 thick, up to 70 long and with up to 6 lateral branches which are up to 20 long	Ovoid to ellipsoid, 300–420 × 156–280	Fusoid, 150–180 × 5–8	Filiform, up to 100 × 2, multiseptate		Mains (1959)
O. ponerinarum	Stromata ad 80 longa, layers and accordingly placed this species in a new plerumque 30–40 × 0.4–0.6	Lageniformia, 240–320 × 140–190				Evans and Samson (1982)
O. prolifica	Stromata with 1–2 branched and form 2–3 branches above the aerial part, 70.9–140.0 × 0.8–2.2	Superficial, oblong to lemon-shaped, 320–530 × 200–340, pale reddish-yellow	430–650 × 3.0–5.0		2.0–3.0 × 1.0–2.0	Ban et al. (2009)
O. pruinosa	Subjacent hyphac white	Semi-immersered, dark red, conoid, 100 wide	150 × 6–10, narrow-clavate	Fusoid, 7–septate, apex obtuse, 18–28 × 5–6		Petch (1931)
O. pseudoacicularis		Superficial, ovoid, brown-dark brown, 343.5–386 × 257–292	Cylindrical, 129–187 × 5–7.5	Filiform, 152.5–205 × 2, septate		Luangsa-ard et al. (2018)
O. pseudocommunis	Solitary, simple, cylindrical, 215 × 0.5, brown	Superficial, subglobose, 536.5–596.5 × 373.5–425	Filiform, 160–164.5 × 14–17	Filiform, 120.5–138 × 6.5–7		Tasan. et al. (2019)
O. pseudolloydi	Single, pale to yellow, 0.8–1.5 × 0.1–0.2	Semi-erumpent, flask-shaped 250–300 × 80–110, embedded	Cylindrical, 240–280 × 4.5 –6.0	Filifom	Ellipsoidal with truncate, ends, 3–3.5 × 1–1.5	Evans and Samson (1984)
O. pseudorhizoidea	Solitary, simple, filiform, up to 210 long, 1 wide, light brown	Superficial, ovoid, 287.5–315.5 × 177–209.5	Cylindrical, 120–150 × 5–7	Filiform, 69.5–78.5 × 2–2.8, septate		Tasan et al. (2019)
O. pulvinata	Emergent as it were completely encircling the host with a brownish or brown	400–600 × 150–250, dark brown	Clava, 220–300 × 9–19	Filiformes, 160–220 × 3–5	10–14 × 3–5	Kepler et al. (2013)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. rami	Single or several, variable in length, up to 35 in length, dark-brown, becoming light purple	Semi-immersed, fusoid-ellipsoid 325–500 × 275–300	Cylindrical, 200–340 × 7–10	Filiform, 200–215 × 2–3		Kobmoo N et al. (2015)
O. ramosissimum	70–150 × 2–4, cylindrical	340–350 × 225–255, superficial, ovoid	170–265 × 6.9–17.3, cylindrical	130–245× 2–3.5, fasciculate, filiorm, sepatitate		Wen et al. (2014)
O. rhizoidea			Elongated clavate, 160–210 × 13–16		Cylindrical, 80 × 5–7	Petch (1931)
O. ridleyi	Cylindrical, 3–4 mm, stipitate	Immersed, ovoid, 250 diam. With ostiolo	Cylindrical, 150 × 7	Filiform, multi-septated, 110 × 1.5		Massee (1899)
O. rubripunctata	Stipe up to 60 × 0.5–1.5, dark brown. Head cylindrical, 2.5–15 × 1–2.5, pinkish red	Embedded, ovoid to obclavate, 360–600 × 145–325	Asci cylindrical 2–3 thick	Hyaline, filiform	One celled, bone-like, 6–9 × 1.0–2.5	Evans and Hoekstra (1982)
O. ryogamiensis	Cylindrical to flat, usually curved, 16.4–29.1 × 0.3–1.7, dark brown at the basal part, light to dark brown at the fruiting middle part, white at the upper part	Superficial 430–600 × 260–390	450–610 × 3.8–5.0		Cylindrical, 2.5–5.0 × 1.5–2.0	Ban et al. (2009)
O. salebrosa	Clavate, 35–40 long, capitate, globose, 1.0 wide, pale cream	Immersed, narrowly conical, 840–1200 × 240–300	Cylindrical, 600–660 × 64	Filiform, 6–10 × 1–1.5		Mains (1947)
O. satoi	Produced from pronotum, dorsal and laterally on both sides, clavate, 5–7.5 × 0.35–0.45, unbranched	Immersed to partially erumpent, flask-shaped, 230–270 × 120–160, with short, exposed neck	Cylindrical to clavate, 120–160 × 8–10	Cylindrical, straight, 85–100 × 4, 5-septate, apex rounded, tapering at base		Araujo et al. (2018)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. septa	Single, up to 25 long, dark-brown at the base, pale purple at the tip, fertile region of lateral cushion	Immersed, fusoid-ellipsoid with rounded ostioles, 280–300 × 100–150	Cylindric, 125–165 × 12.5–15	Lanceolate with rounded ends, 45–50 × 6–8, 7–8 septates		Kobmoo et al. (2015)
O. sessilis	Stroma lacking or obscure	Separately or aggregated, dark brown, superficial, ovoid and obpyriform	Cylindrical, 245–288 × 4.8–6.0	Filiform, 200–240 × 1.2–2.0	1.0–1.7 × 1.0–1.2	Kaitsu et al. (2013)
O. siamensis	Flattened and discoid, white	Superficial, elongated ovoid, ochracea, 580–660 × 300–330	Filiform, 570 long		11.3–15.3 × 1.3–1.5, truncate	Hywel–Jones (1995)
O. sichuanensis	Single, stiptate, cylindrical, salmon pink	Immersed, pyriformia, 465–750 × 255–450	Cylindrical, 120–300 × 3–4.2	Multiseptate	Cylindrical, 1-celled, 2.4–3.6 × 1–1.5	Liang and Wang (2003)
O. sinensis	Black, with cylindrical stipe and slightly swollen head, usually with sterile apex	330–370 × 170–270 ovoid	200–210 × 7–8			Shrestha and Sung (2005)
O. sobolifera	Single, rarely fasciculated by twos or threes, clavate or cylindrical, 20–80 × 2–6	Rectangularly immersed, ampullaceous 500–600 × 220–260	Cylindrical 400–470 × 5.6–6.3		6–12 × 1–1.3, truncate	Kobayasi Shimizu (1963)
O. spatafor ae	Up two, 45 × 0.5, cylindrical, cream to pale brown	Superficial, ovoid, dark brown.				Luangsa-Ard et al. (2018)
O. sphecoce phala	Stipe is 30–55 × 1	Immersed 620–780 × 200–230, obliquely vertical, elongated flask-shaped or conoid in shape.	350 × 6–7	9–10.5 × 1–1.3, fusiform in shape with pointed ends		Shrestha and Sung (2005)
O. sporangi fera	3–50 × 2.0	Superficial, obovoid	Clavate, 100× 7.2	Cylindrical, septate 4.8–7.2 × 1.8–2.0		Liang et al. (2002)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. stylophora	Cylindrical	Immersed 270–417 × 150–210	154–220 × 6–10		Septate 4.8–7.2 × 1.8–2.0	Chachua et al. (2011)
O. subflavida	White slightly yellowish, stipitate, with 2–4 thick fertile part	500–600 × 150–200, ovoid attenuated above into narrow necks, brownish walls	225–300 × 3–4, cylindric	Filiform		Mains (1959)
O. superficialis	Single, small, cylindric, simple, 50 long, lower half 0.6 thick, upwards incrassate, dark grayish brown	470–520 × 400–420	200–250 × 7		10–20 × 1.5–2	Kobayasi and Shimizu (1980)
O. takaoensis	15 long	Pyriform 510–530 × 300				Kobayasi (1939)
O. termitico la	Solitary, simple, filiform, up to 140 × 1, yellow-brown	Pseudo-immersed, globose to subglobose, 225–261 × 178–229	Filiform, 76.5–100.5 × 4.5–5.5	Filiform, 85 × 2		Tasanatha i et al. (2019)
O. thanatho nensis	50–90 × 0.5–3, single, stipitate, pale yellow to yellow	546–692 × 193–254, immersed, oblique flask-shaped	369–496 × 5–7, cylindrical	365–490 × 1–2, filiform	5.1–6.4 × 1.6–2.0, fusiform to cylindrical, truncated, mostly curved	Xiao et al. (2017)
O. tiputini	Stromata single, simple or branched, capitate, slender, wiry, and stiff 150 long	Ovoid, 300 × 200–250, dark brown immersed	Broadly fusoid, 125–200 × 5	Elongate to fusiform, 120–180 × 1–1.5		Sanjuan et al. (2015)
O. truncata		Partly immersed, pale yellow, broadly flask–shaped or conoid, 100 × 250	Clavate, 85–95 × 14–15	Fusoid, sometimes attenuated below, 7-14 septate, 40–50 × 7–9		Petch (1935)
O. uchiyam ae	Cylindrical, irregularly curved, polished or compressed	Semisuperficial , ovoid, 400–450 × 210–230, dark purple, then becoming black.		2 thick, multiseptitate		Kobayasi and Shimizu (1980)

Table 3.2 (continued)

Species	Stromata (mm)	Perithecia (µm)	Asci (µm)	Ascospores (µm)	Secondary spores (µm)	Reference
O. wuyishanensis	3-fasciculate, ramified, 50–65 × 2–3, stipitate	Superficial, ovoid, 265–290 × 130–150	Cylindrical 150–250 × 3	Filiform, not breaking into secondary spores, interval cells 6–10 × 0.6–1.2		Liang et al. (2002)
O. xuefengensis	140–460 × 2–7, cylindrical, yellow-brown	416–625 × 161–318, superficial, long ovoid	191–392 × 4.5–8.9, cylindrical	130–380 × 1.4–5.2, fasciculate, thread-like, slender, septate		Wen et al. (2013)
O. yakusimensis	Stroma very long attaining 140, simple or dichotomously with short branch on the upper part, cylindrical	Immersered, ovoid or almost naviculate, 740–800 × 170–230	270–310 × 5		Cylindrical, terminally truncate, 10–15 × 1	Kobayasi and Shimizu (1963)
O. zhangjiajiensis	Single or 2, cylindrical, 100 × 2, not ramified, leathery, fertile part brown to snuff-colored	Pseudo-embedding, ovoid, 330–375 × 180–230	Fusiform, 200 × 10		Cylindrical, 15–23 × 3	Liang et al. (2002)

Table 3.3 Asexual morph species of *Ophiocordyceps*

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. acridiorum	Clavate, 2–5 × 0.5-0.8, white	Solitary or doubled, woolly or subulate, 12–20 × 2.5–3.5, often polyphialdic	Dimorphic conidia forming mucous sections: macro-aseptate, cylindrical or sub-cylindrical, 6.5–8 × 2.5–3.5; microconidia aseptate, hyaline, fusiform, 4.5–6.5 × 1–1.5	Evans and Shah (2002)
O. aphidis	Cylindrical, up to 2 long, 0.1 thick, brown	Flask-shaped or subcylindrical, 12–18 × 4–6, pale brown, abruptly narrowed at the apex into a short cylindric sterigma, 3–6 × 1	Narrowly ovoid or fusoid, 9–15×4–5, with a short truncate apex	Spatafora et al. (2015)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. asiatica	PDA, attaining a diam of 27 after 20 d at 25 °C	Monophialidic or rarely polyphialidic, 15–18.5 × 2–3, hyaline, smooth, tapering gradually towards the apex, which often forms a thin warty neck	Fusiform, 7.6–9 × 2–3, hyaline, aseptate, with a mucous sheath	Tasan. et al. (2019)
O. arachneicola	Clavate, cylindrical or more or less compression of 24. 1–1.5 long, obtuse at the apex		Narrowly ellipsoid or fusiform, base acute, 9–10 × 3.2–3.5, hyaline, spinal as in the trunk	Kobayasi (1941)
O. brunneirubra	PDA, attaining a diam. of 25 within 20 d at 25 °C		Fusiform, 13.5–15.5 × 2–3, hyaline, one-celled, with a distinct gold cap covering the tip of the conidia	Tasanathai et al. (2019)
O. camponoti-sexguttati	*Hirsutella* A-type associated with apical region of stroma, mycelium produced sparsely from joints, not covering the host body, dense when touching the substrate, dark brown	lageniform, 5–8 × 3–4, tapering to a long neck, 8–12	Limoniform, 5 × 2, hyaline	Araújo et al. (2018)
O. camponoti-renggeri	*Hirsutella* A-type not observed. *Hirsutella* C-type, produced from brown cushions (sporodochia) on leg and antennal joints, brown at maturity	Subulate at base, 40–60 × 3–5 long, tapering to a long, hyaline neck	Conidia not observed	Araújo et al. (2018)
O. camponoti-hartificis	*Hirsutella* A-type associated with apical region of stromata, initially white turning brown	Lageniform, 5–6 × 3, tapering to a robust neck, 4–8 in length	Fusiform to limoniform, 7 × 2.6	Araújo et al. (2018)
O. camponoti-idulantis	*Hirsutella* A-type associated with the apical part of stroma. *Hirsutella* C-type, produced from light brown cushions on leg and antennal joints	Subulate, robust,70–120 × 4–6	Limoniform, 8 × 3	Araújo et al. (2018)
O. camponoti-femorati	*Hirsutella* A-type only; produced laterally on upper stroma, initially white, becoming ginger brown	Cylindrical to lageniform, 7–10 × 3–4, tapering to a long neck, 10–15	Limoniform, 7–9 × 3	Araújo et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. camponoti-hippocrepidis	*Hirsutella* A-type only; produced on the clavate part of upper stroma, external mycelium produced from all the orifices and sutures, initially white, becoming ginger brown	Cylindrical to lageniform,8–9 × 4, tapering to a long neck 9–10 in length	Limoniform, 5 × 2	Araújo et al. (2018)
O. camponoti-floridani	*Hirsutella* A-type present on the stroma, *Hirsutella* C-type occurring exclusively at early stages of development, produced from leg joints and dorsal pronotum	With a terminal capilliconidium,10–13 × 2–3		Araújo et al. (2018)
O. camponoti-atricipis	*Hirsutella*-A type only, produced on the upper stromatal surface, external mycelium abundant, initially white, turning light-brown	Cylindrical to lageniform, 5–7 × 2–3 µm, tapering to a long neck, 5–11	No conidia observed	Araújo et al. (2015)
O. camponoti-bispinosi	*Hirsutella*-A type only, produced at the swollen upper part of stroma, mycelium dark-brown to black	Cylindrical to lageniform, 6 × 2.5–3, tapering to a long hair-like neck, 10–16 µm length	Narrow limoniform, 6–7 × 2, with a distinct	Araújo et al. (2015)
O. camponoti-indiani	*Hirsutella*-A type associated with the apical region of all stromata, ginger in color.	Cylindrical to lageniform, 7.5 × 3.5, tapering to a long hair-like neck, 6.5–11 in length	No conidia observed	Araújo et al. (2015)
	Hirsutella-C type produced from ginger cushions (sporodochia) on legs and antennal joints	And subulate at the base, robust, hyaline	No conidia observed	Araújo et al. (2015)
O. camponoti-saundersi	Anamorph *Hirsutella*	Up to 25 long, 2–3 wide	Fusoid, 2–3 × 1–2, hyaline	Araújo et al. (2015)
O. camponoti-leonardi		Up to 22.5 long, 2.0–3.5 wide	Fusoid, 2–4 × 1–2, hyaline	Araújo et al. (2015)
O. communis		Cylindrical, 10–14 × 2.7–3.3, hyaline, prominent, terminal denticle	Almond-shaped, 7–9 × 2–3, hyaline	Sung et al. (2007)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. camponoti-rufipedis	silky, becoming ginger to chocolate brown	cylindrical to lageniform, 10 x 2 um, tapering to a long neck, 15–25, up to 45	Fusiform to narrowly limoniform, 5 × 1.5, with a distinct tail	Evans et al. (2011)
O. camponoti-balzani	Chocolate brown, forming aggregations or cushions around joints, especially on legs and antennae	Subulate at base, robust, 20–25 × 3–4 um, subhyaline, tapering to a long, hyaline neck, 30–50 × 1.0–1.5	Cylindric to fusiform, 12–14 × 2–3, hyaline, rounded at apex, truncate at base	Evans et al. (2011)
O. camponoti-melanotici	*Hirsutella* A-type only, on upper part of stromata:both specimens bearing only remnant hymenium on ageing stromata mycelium chocolate to dark brown, relatively sparse			Evans et al. (2011)
O. camponoti-novogranadensis	*Hirsutella* A-type on stromata. *Hirsutella* B-type produced from lower joint foot on all legs, consisting of solitary, upright synnema; black, cylindrical, 8–10, 0.035–0.040 at base, tapering to 0.015–0.018 towards apex and broadening into globose head	Subulate, up to 45 long, 1.5–2.0, hyaline	Narrowly clavate to obclavate, 10–12 × 1.5–2.0, hyaline, truncate at base tapering to drawn-out beak-like tip, produced in pinkish, powdery masses	Evans et al. (2011)
O. camponoti	Cylindrical, 8 long, 0.3 thick below, furcate above into two short branches, grayish brown, composed of longitudinal, closely compacted hyphae	Subcylindric, 6–10 × 3–3.5, narrowing above to an acute apex terminatedby a sterigma up to 4 long, hyaline	Broadly fusoid, 4–6 × 2, hyaline, acute at the ends	Mains (1950)
O. cleoni		Elongated conoid or subulate phialides about 18 long, 3 below	Cylindrical or narrow-oval, 6–13 × 1.5–3, with rounded ends	Petch (1942)
O. brunneiperitheciata		12–16 long, 3–4 wide at the base and 0.5–1 wide at neck, hyaline	Fusiform, 4–6 × 2, hyaline, without a mucous sheath	Luangsa-ard et al. (2018)
O. brunneinigra		15–18, phialide base 8.5–11.5 × 4–5, phialide neck 5–7 × 1, hyaline	Obovoid to falcate, 5–7 × 2–3, hyaline, embedded in a mucous sheath	Luangsa-ard et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. cuboidea	Colonies effuse, growing 25–35,25°C 2 weeks on PSA, pale yellowish brown to cream, mycelium immersed and superfi cial, hyaline to cream, pale brown. Synnemata not formed	Acremonium-like, 18.9–22.2 × 0.8–1.1, sometimes *Hirsutella*-like with broader base, particularly formed in the sporodochium, 17.7–27.8 long, 1.1–2.4 wide at the base, 0.5–0.9 wide at the neck, hyaline	Globose to elliptical, 1.3–3.7 × 1.1−2.3, forming a spore drop with fewer than 10 spores at the apex of phialide, hyaline	Evans and Samson (1982)
O. cucumispora	Synnemata seperate anamorphosis	Lagen-formed 4.5–6 × 2–3 acicular to the neck 6–8 ×0.4–1.0, hyaline	Ovoid to pyriform, 2.8–3.5 × 1.5–1.8, hyaline, sometimes with mucous sheath	Evans and Samson (1982)
O. cucumispora var. dolichoderi		Ovoid or cylindrical with upper surfaces, 5–10 × 3-4, interspersed, hyaline, inflated at the base, 70–85 × 20–35 in narrow neck, 11–14 × 0.2–0.8	Ellipsoid to moderately apiculate at the base, 4.5–6.0 × 1.8–2.5	Evans and Samson (1982)
O. ditmarii	Synnemata convey 2–3 distinct branches, 15–25 long	Elongated, cylindrical, tapering to the apex, 20–37 × 1.5–2.5	Fusoid-ellipsoidal, 7–10 ×2, hyaline	Kobayasi (1978)
O. daceti	Cylindrical, velvety, 12 in length, ginger brown	*Hirsutella*-like phialides, cylindrical to lageniform, 16–18 × 4, tapering to a long neck 4–6 in length	Cylindrical, 7–10 × 3	Araújo (2018)
O. engleriana	Filiform, branched at the apex, 10–15 long, 0.2 thick		4–5 × 3–3.5, hyaline	Hennings (1897)
O. furcata	Synnemata slender, cylindrical, 10–14 long, 94–120 wide, white	Clavate or cylindrical, 5–18 × 3.5–6.5, apically with 2–7 furcellate denticles, 0.6–2.4	Fusiform, 8.5–15 × 3–4.5, hyaline	Ohnmar et al. (2006)
O. geometridicola	5–7 long, 0.5–1 wide, pale grey to dark grey	12–16, phialide base 6.5–9 × 4–5, phialide neck 5–7 × 0.5–1	Fusiform, 6–7 × 2–3, hyaline, without a mucous sheath	Luangsa-Ard et al. (2018)
O. granospora		Obclavate, oppiryform, denticles, stout, protuberant, 7–10 × 3–5, pigmented	Obovoid, fusiform-elliptical, cymbiform, cylindrical, 4–7 × 1–2, pigmented	Khonsanit et al. (2018)
O. halabalaensis		20–30 × 2–3, long neck of 10–25 × 1–1.5	Fusoid, 5–6 × 3, hyaline, one-celled	Luangsa-ard et al. (2011)
O. intricata	0.25 diam, loose, white, branched, intricate	Narrow ampullaceae or conoid, tapering above, 7-12 × 1.5	Oval or oblong-oval, rounded on both sides, 2–3.5 × 1, sometimes globose, 1.5 cm in diam.	Petch (1942)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. houaynhangensis		18–26 × 3–5, necks present, 9–16 × 0.5	Spherical, 3–5, hyaline	Crous et al. (2018)
O. khokpasiensis	Colonies on PDA, attaining a diam. of 25.5 within 20 d at 25 °C, cream to grey	Swollen towards the base, hyaline, tapering gradually towards the apex, which often forms a thin neck, monophialidic orpolyphialidic, 16.5–23 × 3–4.5	Globose to oval, 4.5–5.5 × 2.5–4, one-celled, embedded in a mucous sheath	Tasanathai et al. (2019)
O. kniphofioides	Cylindrical, 2.5–3.5 × 0.08–0.11, narrowed upwards of 20–25, brown	Phialides and conidia are of two forms: (A) lateral phialides, hyaline to yellow, echinulate or warty, continuous or septate, inflated at the base 10–13 × 3–4, tapering at the neck 6–8 × 0.6–1. (B) phialides terminal, subulate, much longer and scarcely discernible at the base, slightly echinulate, colorless, 75–150 × l.5-2.2	Ovoid to cylindrical, 9–10 × 4–5, colorless, covered in grayish mucus	Evans and Samson (1982)
O. kniphofioides var. dolichoderi	Dichotomously multiramose, with uncommon primary 0.3–0.4 × 0.05–0.06	Phialides of two types. A-phialides lateral, compacted in a layer below head. B-phialides terminal, compact, up to 150 long, 1.8–2.2 wide	Cylindrical to ovoid, 7–8.5 × 3.5–4.5, in mucous balls.	Evans and Samson (1982)
O. kniphofioides var. kniphofioides	Cylindrical, 2.5–3. 5 × 0.08–0.11, brown	Lateral phialides, hyaline to yellow, echinulate or warty, continuous or septate, inflated at the base, 10–13 × 3–4, neck pointed to 6–8 × 0.6–1	Narrowly clavate, apiculate at the base, 7–9 × l.5–2.2, hyaline, mostly 1-septate	Evans and Samson (1982)
O. kniphofioides var. monacidis	Cylindrical, 1.5–2.5 × 0.15–0.2, brown at the base, sulphurous above	11–15 × 4.5–5.5, tapering neck 11–14 × 0.6–1.0	Narrowly cylindrical, 7×1.0–1.4	Evans and Samson (1982)
O. kniphofioides var. ponerinarum	Separate synnemata with stroma and veluna	6 diam, with a broad and elongate neck, 10–14 × 1.8–2.5	Clavate, 7–9 × 1.8–2.5,1-septate	Evans and Samson (1982)
O. kobayasii	Up to 10 long and c. 0.5 wide, powdery due to sporulation, pale cream		narrow fusoid, 6–8 × 1–2, hyaline, one-celled	Thanakitpi pattana et al. (2020)
O. lacrimoidis	Cylindrical, 3 × 0.3, orange brown	Clavate, surface roughened, hyaline	Lacrimoid, 4–5 × 3–5, hyaline	Hyde et al. (2016)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. laojunshanensis		Acerate, 15–39 long, hyaline, with verrucose,	Elliptic, 6.0–13.5 × 3.0–4.0, hyaline, one or two encased in a mucus drop	Chen et al. (2011)
O. macroacicularis		Phialidic, sometimes polyphialidic with swollen base and slender neck (*Hirsutella*-like), hyaline, produced directly on prostrate hyphae or secondary branches	Oval to lemon-shaped, hyaline, one-celled, often covered with mucilage	Ban et al. (2014)
O. megacuculla		Clavate, obclavate, denticled, stout and protuberant, 8–11 × 3–6 with oilglobules asorange pigments	Obovoid, fusiform-elliptical 4–8 × 1–2.5, pigmented	Khonsanit et al. (2018)
O. mosingtoensis		Conidiogenous cells swollen towards the base, hyaline, tapering gradually towards the apex, which often forms a thin neck, monophialidic, 12.5–16 × 2.5–3	Oval, 3–4.5 × 2–2.5	Tasanathai et al. (2019)
O. multiperitheciata		Phialides 43–57, phialide base 25–34 × 4–5, phialide neck 16–27× 1–2, rough to warty, non-septate or sometimes septate below the phialide base	Oval to lemon shaped, 9–11 × 6–7, hyaline, 1-celled, embedded in a mucous sheath	Luangsa-ard et al. (2018)
O. myrmicarum	Secondary synnemata, cylindrical, up to 0.35 long, narrow (0.025) at base, hyaline aging to rufous brown, common on agar but not observed on host.	Subulate, 27.2–47.0 long, 2.4–3.3 wide at base, hyaline	Reniform to ovoid, 7.3–9.6 × 3.2–5.1, hyaline, aseptate, bound in mucilaginous spheres, composed of 1–4 conidia, at phialide apex	Simmons et al. (2015)
O. naomipierceae		Cylindrical to clavate, 15–35 × 3, producing up to 10 needle-like, verrucose conidiophores, averaging 10	Bearing a terminal conidium, 5–7 × 3	Araújo et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. odonatae	Synnemata from the thorax and abdominal joints or from the abdominal cleft, breaking out into simple, pale-ochraceous firmocarnose in dry leather.	Hymenium-clavate, 10–15 long, 2.5–2.8 thick, apiculate hyaline, with short sterig-mate ones bearing a single conidium	Fusiform to narrowly ellipsoid, 8.4–11.2 × 2–2.8, hyaline	Kobayasi (1941)
O. ootakii		Cylindrical to lageniform, 6–8 × 3–4, tapering to a long neck, 9–10 long	Bearing a terminal conidium, averaging 5 × 3	Araújo et al. (2018)
O. oecophyllae		Conidiogenous cells 30–50, 3–4 at base, tapering evenly to 1–1.5 at apex, terminal, subhyaline	Ovoid to cylindrical, 5.5–10 × 1.5–3, hyaline, rounded at apex, truncate at base, slightly darkened periclinally at base	Araújo et al. (2018)
O. nooreniae	Cylindrical, up to 10 long, pale brown.	Tapering in the upper half to a narrow neck, 1.5–2.5 wide, from a cylindrical base 6–8 wide, 35–50 long	Ovoid, slightly tapered at base, 5–6 × 2–3, conidia formed in groups of 2–4, fusiform with slightly curved apex and refractive base, 13–18 × 2.5–4.5	Crous et al. (2016)
O. neovolkiana		Clavate, 30–40 long, 5–8 thick, apic obtuse, truncate to the coarse-parietal lobes at the base		Kobayasi (1941)
O. owariensis f. viridescens		Phialides 3–8 in the verticil, ovoid or ellipsoidal, appressed, 6.5–12 × 3.5–5, hyaline, without distinct neck. Solitary phialides sometimes present as a simple, thick-walled, proliferating branch on the hypha, cylindrical, with a thin, funnel-shaped and flaring collarette	Catenulate,ellipsoidal or cylindrical, 9.5–11 × 4–5.5, hyaline to pale green to pastel green, one-celled, often with a distinct connective	Uchiyama and Udagawa (2002)
O. myrmicarum	Feather-like, white, 1–3 × 100–200, composed of hyaline conidiophores with both	Conidiogenous cells phialidic, flask-shaped, 13–18 × 3–4, often sympodially branching to produce1–4 short, pointed necks, 5.0–8.5 × 2.5–3.0	Hyaline to subhyaline, smooth, aseptate, of two distinct types: cylindrical to obclavate,7.0–10.5 × 2–3; fusiform, 3.5–5.5 × 1.5–2.0	Evans et al. (2010)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. paracuboidea		Conidiogenous cells monophial, hyaline, whorled, with 2−3 phialides, mostly *Hirsutella*-shaped, 10.9–21.5 long, 1.2–1.6 wide at the base, 0.4–0.8 wide at the neck	Subglobose or fusoid, 1.3–1.9 × 1.0–1.9, hyaline, aseptate	Ban et al. (2009)
O. ryogamiensis		Conidiogenous cells are phialidic and have a broad base and slender neck similar to *Hirsutella* Phialides cylindrical, 17.5–55.2 × 0.8–2.7	Ellipsoid, 2.5–3.9 × 1.0–1.4	Ban et al. (2009)
O. pauciovoperitheciata	Asexual morph, terminal, pale grey-dark grey, 4 long	Conidiogenous cell monophialidic, rarely polyphialidic, hyaline. Phialides 9–10 µm, 5–6 × 3.5–4 at base, phialide neck 3.55 × 0.51	Fusiform,5–7.5 × 2–3, hyaline, with a mucous sheath.	Luangsa-ard et al. (2018)
O. pseudoacicularis	Terminal, 4–5 long, pale grey-dark grey	Conidiogenous cells monophialidic or polyphialidic, hyaline. Phialides 12–15, 6.5–9 × 4–5 at base, phialide neck 4–7 × 0.5–1	Fusiform, 5–6 × 2, hyaline, surrounded by mucous sheath	Luangsa-ard et al. (2018)
O. spataforae	*Hirsutella* type having a broad base and slender neck with unclear border developed on the aged colony	Cylindrical, 17.5–55.2 × 0.8–2.7	Fusiform to ellipsoidal, herbarium material does not have a mucous sheath due to drying, 5–7 × 1.5–3, hyaline	Ban et al. (2009)
O. septa	*Hirsutella* -A type produced laterally on upper stromata, *Hirsutella* -C type produced from brown cushions (sporodochia) on the joint of legs and antennal joints	Cylindrical, tapering to long neck, up to 25 long, 2–3 wide, phialide slender cylindrical tapering to long, up to 50 long, up to 5.5 wide	Fusiform to narrowly lemoniform, 5–6 × 1–2, hyaline	Kobmoo et al. (2015)
O. rami	*Hirsutella* -A type produced laterally on upper stromata *Hirsutella* -C type produced from brown cushions (sporodochia) on the joint of legs and antennal joints	Phialide cylindrical, tapering to short neck, 9–10 um long, up to 3–4 wide Phialides cylindrical to lageniform, averaging 12 × 7, tapering to a long neck	Conidia hyaline, cylindrical to narrow fusiform, 3.5–6.5 × 1–2 wide; conidia hyaline, fusiform to narrowly lemoniform, averaging 9 × 5	Araujo et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. retorta	Cylindrical, tapering at the end, arising from the thorax of the insect, sometimes simple-branched, 60–100 × 0.3, brown, fawn yellow near the apex	Conidiogenous cells with two types: A-phialides, subulate with barely inflated base, 24–28.8 × 1 long, 3–3.5 broad, taperingto a slender, verruculose and twisted neck, 9.6–10 long, 1 wide ; B-phialides,slender gourd-shaped or awl-shaped and tapered,width of base 3.5 × 1.5–2, length 40.8–52.6, width of neck 1.8–2.0	Shaped like orange segments or oval, 8.5–9.6 × 4.8–6, enveloped in hyalinemucus, thickness, 1.8–2.7	Zou et al. (2018)
O. sporangifera	Primary synnema 90–180 high 1–2 diam., arising from the head region of the larva, branching into 2–5, cylindrical, brown to deep brown, with small white fertile head on the top. Secondary synnemata 1.092–1.937 × 0.021–0.034, laterally from the primary synnema, cylindrical, brown to white, not smooth	*Hirsutella*-like, 25–40 × 1.3–2.5, hyaline	Subglobose to reniform, 6.7–9.8 × 2.5–3.8, one cell, hyaline, bound in mucilaginous spheres	Xiao et al. (2019)
O. spiculata	Cylindrical, 0.5–3 × 0.05–0.13, covered with a hymenoid layer of conidiogenous cells	Conidiogenous cell polyblastic, cylindrical or clavate, 10.1–15.6 × 2.7–3.9, non-verrucose	Obovoid, 5.6–8.6 × 1.3–2.7, smooth or echinulate, hyaline	Bo et al. (1998)
O. rubripunctata		Conidiogenous cylindrical, 6–12 × 2.5–5, hyalineseveral hills at one terminal, the other transversal, 1.5–2.5 long, 0.5–0.7 long	Cylindrical to clavate, apiculate at the base, 2.5–4.0 × 1.5–2.0, hyaline	Evans and Hoekstra (1982)
O. ponerus	Cylindrical, 20–50 × 0.2, tapering at the end, black, fawn brown near the apex	Conidiogenous cells 13–25 × 2.5–5, cylindrical or oval inflated at the base, suddenly tapering to the short and thin neck, verrucose	Nearly oval or shaped like curved orange segments, 7.5–10 × 3.8–5, hyaline	Qu et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. pseudocommunis		Conidiogenous cells forming a compact hymenium-like layer and had 2–4 denticles at their apices, cylindrical to clavate, 18.5–21 × 2.5–7.5	Fusiform, 6.5–7.5 × 2–3, hyaline	Tasan. et al. (2019)
O. pseudorhizoidea	60 long, light brown to grey.	Conidiogenous cells monophialidic, hyaline, tapering gradually or abruptly into a long slender neck, 12–16.5 long, 2–3 wide at the base, 1–1.5 wide at tip with warty surface	Fusiform, one-celled, 6.5–8× 1.5–2.5, hyaline, with mucous sheath	Tasan. et al. (2019)
O. pseudogibellulae	Narrowly cylindric, 1–2 long, 0.05–0.15 thick, composed of longtudinal somewhat interwoven hyphae, very light brown to brown	Conidiophores 50–150 long, 2–4-septate, the lower cells 3–5 wide, the walls brownish, asperulate, the terminal cell obovoid, 7–8 × 4–8, hyaline, bearing a globose to cylindrical head of prophialides and phialides ovoid to cylindrical, 4–14 × 1.5–2.5	Cylindrical, rounded at the ends, 3–4.5 × 1–1.5, hyaline	Mains (1949)
O. spiculata	Cylindrical, 0.5–0.3 × 0.05–0.13 covered with conidiogenous cells	Conidiogenous cell polyblastic, cylindrical or clavate,10.1–15.6 × 2.7–3.9, non-verrucose	Obovoid, velechinulate, 5.6–8.6 × 1.3–2.7, hyaline	Huang (1998)
O. termiticola		Conidiogenous cells formed a compact hymenium-like layer and had from 2–4 denticles at their apices, cylindrical to clavate, 11.5–16 × 3–5	Fusiform 7 × 3, hyaline	Tasanathai et al. (2019)
O. unitubercula ta		Conidiogenous cells monophialidic, with an inflated awl-shaped base, tapering gradually or abruptly into a long slender neck, 31.9–128.3 long, 1.8–5.0 wide at the base, 0.5–1.2 wide at the tip, non-septate or sometimes septate below	Lanceolate to fusiform, 6.3–10.6 × 1.9–3.7, aseptate, embedded in a mucous sheath of 6.6–10.8 × 4.2–7.6, hyaline	Wang et al. (2018)

Table 3.3 (continued)

Species	Synnemata (mm)	Phialides (µm)	Conidia (µm)	Reference
O. verrucosa	Narrowly cylindric or slightly clavate, 1–4 long, 0.2–0.4 thick, pale brown, composed of longitudinal hyphae	Cylindric or clavate, 12–18 × 2–3, verrucose or tuberculate at the apices	Obovoid, 6–8 × 2–3.5, hyaline	Mains (1950)
O. wuyishanensis		6 × 1.2	3–3.6 × 1.8–2, sometimes adhering into loose head	Liang et al. (2002)

3.3.3.2 *Drechmeria*

Drechmeria W. Gams & H.-B. Jansson, Mycotaxon 22(1): 36 (1985)

Index Fungorum number: IF11076

Synonym: *Haptocillium* W. Gams & Zare, Nova Hedwigia 72(3-4): 334 (2001)

Parasitic and pathogenic on protozoans and insects, as well as soil-inhabiting. **Sexual morph**: Undetermined. **Asexual morph**: Hyphomycetous. *Mycelium* hyaline, growing very slowly, *Phialides* verticillate or solitary. *Conidiophores* erect or prostrate, swollen near the base. *Conidia* balanoid campanulate to cylindrical, subglobose to irregular in shape, crescent-shaped helical, may be cone-shaped, formed on conidiogenous cells in rosettes or verticils, or paecilomyces-like, with rounded base and almost pointed apex, one-celled, hyaline, smooth-walled (adapted from Gams & Jansson, 1985; Zare et al., 2001; Yu et al., 2018).

Type species: ***Drechmeria coniospora*** (Drechsler) W. Gams & H.-B. Jansson, Mycotaxon 22(1): 37 (1985).

Notes: Drechmeria was proposed to accommodate *Meria coniospora* Drechsler (Gams & Jansson, 1985). *Meria harposporioides* G.L. Barron & Szijarto was transferred to *Drechmeria* because of being a nematode parasitic and having falcate conidia (Gams & Jansson, 1985). *Haptocillium* was established by Zare and Gams (2001) with seven asexual parasitic species of nematode with morphology and phylogenetic evidence. Two asexual nematode parasitic species *Acrostalagmus* were transferred to *Haptocillium* (Glockling & Holbrook, 2005). Both *Drechmeria* and *Haptocillium* were recognized belonging to the family Clavicipitaceae (Gernandt &

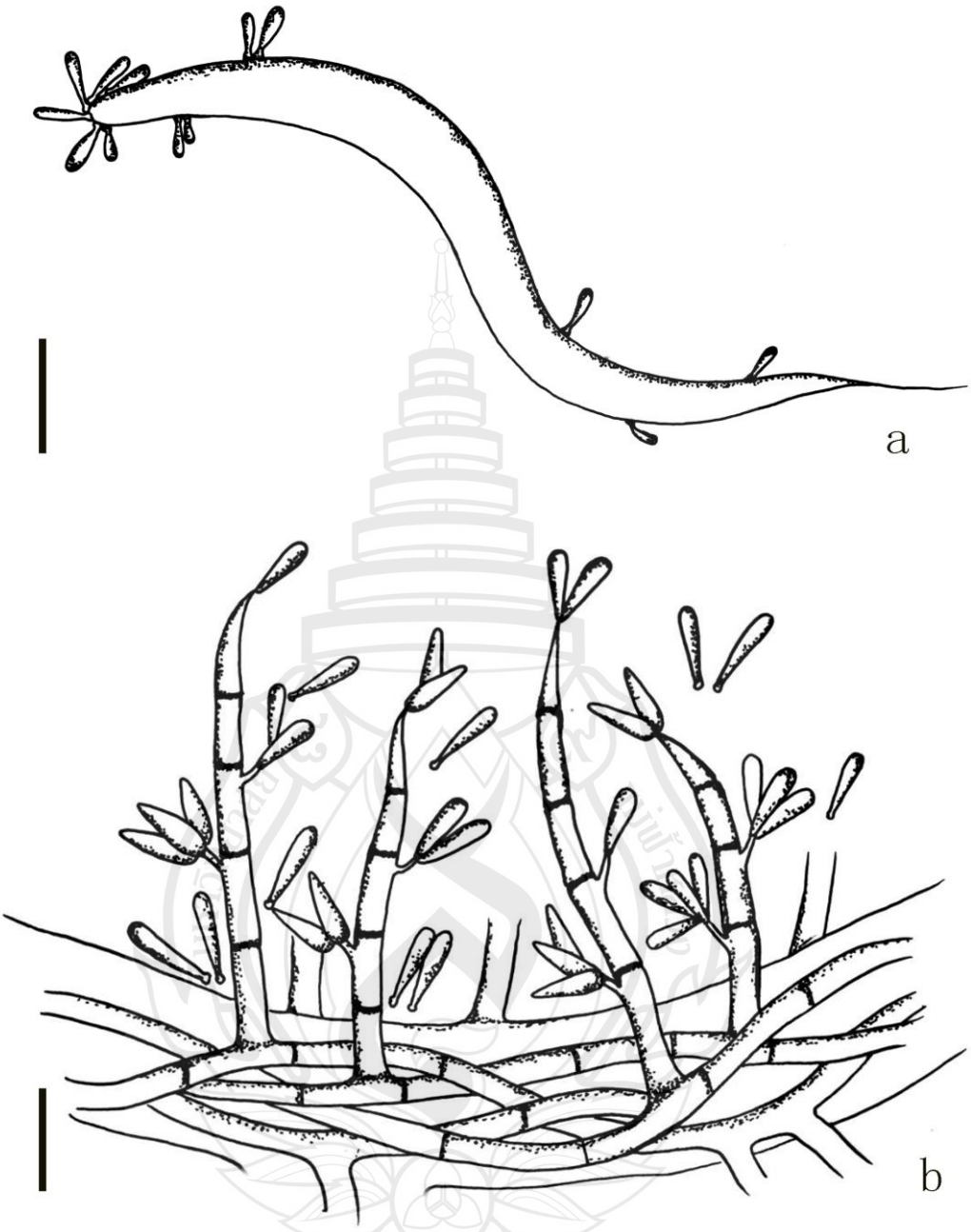
Stone, 1999; White et al., 2003). Sung et al. (2007) clearly placed *Haptocillium* to Ophiocordycipitaceae based on phylogenetic evidence. However, Quandt et al. (2014) proposed to protect *Drechmeria* over *Haptocillium* as the earlier genus name. *Cordyceps gunni* (Berk.) Berk. was transferred to *Drechmeria* as the unique sexual entomogenous species based on phylogenetic evidence (Quandt et al., 2014). Yu et al. (2018) introduced one new species *D. panacis*, which produces campanulate conidia. The synonym of *Drechmeria* is *Haptocillium* (Spatafora et al., 2015).

Many species produce two types of conidia and have different description in different papers (Gams & Jansson, 1985, Zare & Gams, 2001). We name the two types as α-conidia and β-conidia respectively.

Ecological and economic significance of Drechmeria: Species of *Drechmeria* have been demonstrated as having antibiotic activity (Jansson, 1982a, 1982b; Barron, 2013) and are possible biocontrol agents against plant-pathogenic nematodes (Dackman et al., 1992). *Drechmeria coniospora* produces a novel peptaibiotic family that shows antibacterial, antifungal and nematicidal activities (Zhang et al., 2016). *Drechmeria* sp. produces indole diterpenoids as natural antimicrobial agents, which have natural antagonists of human pregnane receptor (Zhao et al., 2018a, b; Liang et al., 2019).

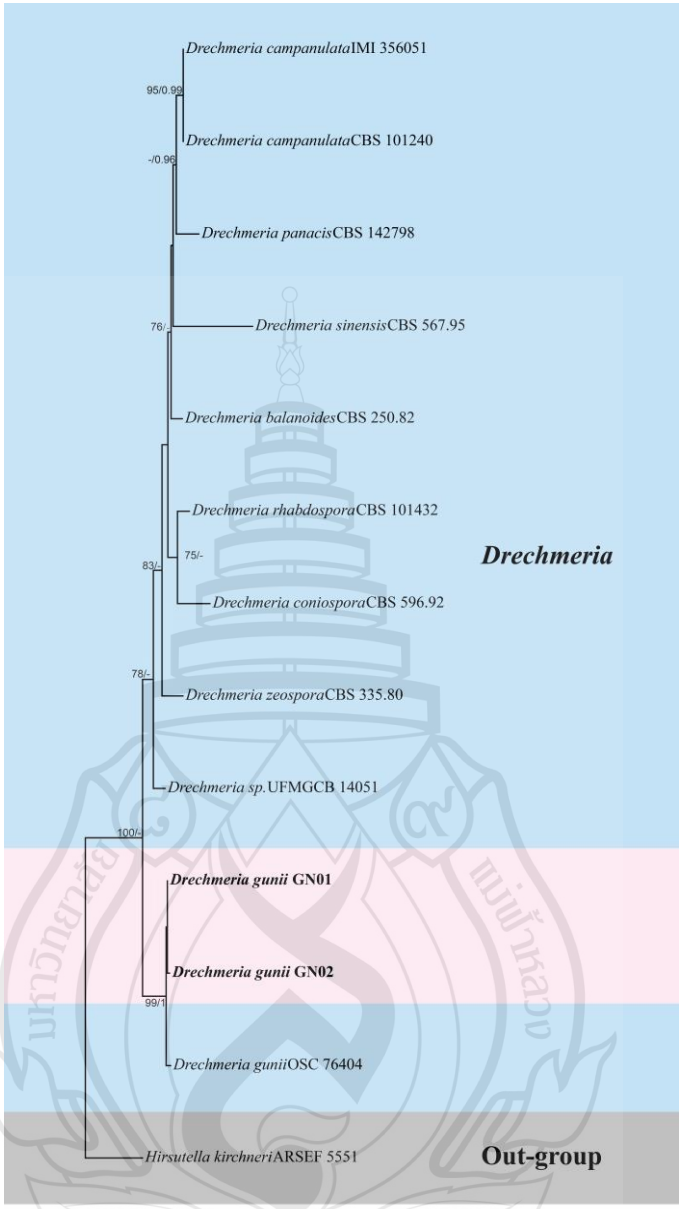
Distribution: America, Antarctic, Argentina, Austria, Australia, Canada, China, Denmark, Germany, Japan, Netherlands, Russia, Sweden, Switzerland, United Kingdom (Gams & Jansson, 1985; Persmark et al., 1995; Zare & Gams, 2001; Quandt et al., 2014; Yu et al., 2018).

Conclusion: Illustrating the type species, list all the species, list all the GenBank accession numbers for *Drechmeria*.



Note a Conidia arising from infected nematodes. b Conidiophores and developing conidia. Scale bars: a = 10 µm, b = 5 µm.

Figure 3.48 Morphology of *Drechmeria coniospora* (redrawn from Barron, 1977)



Note Phylogenetic tree of *Drechmeria* species generated from maximum likelihood analysis of ITS, SSU, LSU, RPB1, RPB2 and TEF1α sequence data. *Hirsutella kirchneri* (ARSEF 5551) was used as outgroup taxon. This phylogenetic tree of *Drechmeria* comprises 13 taxa (including the 2 newly collected taxa) analysed. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.95 are indicated above the nodes. The ex-types are indicated in bold.

Figure 3.49 Phylogenetic tree of *Drechmeria* species

Drechmeria gunnii (Berk.) Spatafora, Kepler & C.A. Quandt, in Spatafora, Quandt, Kepler, Sung, Shrestha, Hywel-Jones & Luangsa-ard, IMA Fungus 6(2): 358 (2015)

Index Fungorum number: IF814717

Synonym: *Sphaeria gunnii* Berk., London J. Bot. 7: 577 (1848)

Cordyceps gunnii (Berk.) Berk., in Hooker, Bot. Antarct. Voy., III, Fl. Tasman. 2: 278 (1859)

Cordyceps gunnii var. minor Z.Z. Li, C.R. Li, B. Huang, M.Z. Fan & M.W. Lee, Korean J. Mycol. 27(3): 232 (1999)

Parasitic and pathogenic on larva of Lepidotera. **Sexual morph**: *Stromata* 7–16 cm long, 1–1.5 cm wide, cylindrical or lanceolate, sometimes compressed, yellow below with the top of the stem, becoming grey dark above, stipitate, with a slightly different fertile head. *Stipe* 8–12 cm long, 1–1.2 cm wide, cylindrical, yellow to grey, gradually becoming dark grey from lower part to upper part. *Fertile head* 3–4 cm long, 1.3–1.5 cm wide, grey to dark grey, cylindrical to lanceolate. *Perithecia* 1080–1200 × 280–540 µm ($\bar{x}$ = 1140 × 400 µm, n = 30), vertical immersed to the axis within the fertile head, flask-shape, ostiole scarcely projecting beyond the surface. *Asci* 380–520 × 8.2–10.3 µm ($\bar{x}$ = 450 × 9.3 µm, n = 30), 8-spore, slender cylindrical, hyaline. *Secondary spores* 4.8–5.6 × 3.4–3.6 µm ($\bar{x}$ = 5.2 × 3.5 µm, n = 30), hyaline truncate, cylindrical. **Asexual morph**: undetermined.

Material examined: Australia. On larva of Lepidoptera, burin in the soil, 19 September 2017, Tingchi Wen, GN01.

Notes: This is the first time to describe *Drechmeria gunnii* with a photo plate and update molecular data.

Note a Overview of *Drechmeria gunnii*. b Stroma. c Perithecia. d, e Asci. f, g Secondary spores. Scale bars: c = 200 µm, d, e = 100 µm, f, g = 10 µm.

Figure 3.50 Morphology of *Drechmeria gunnii*

Table 3.4 Asexual morph species of the genus *Drechmeria*

Species	Substrate	Phialides (µm)	Conidia (µm)	Reference
D. bactrospora	Nematodes	Phialides whorls of elongate, tapered 12–15 × 2.5–4.0, conidia adhering in a bundle at the conidiogenous cell tip, at the swollen base, tapering gently to a long slender neck.	Two types conidia: α-conidia ovoid 4.0 × 2.5–3.0; β-conidia bacilliform 3.0 × 2.0, truncate or slightly rounded at the ends	Gams and Jansson (1985)
D. balanoides	Nematodes	Phialides usually slender, aculeate and diverging, 14–18 × 1.5–2.0 in the lower part, gradually tapering to about 1 µm; inflated phialides up to 3 µm wide in the lower part.	Two types conidia: α-conidia triangular with thin or slightly thickened apical wall, 2.0–3.0 × 1.5–1.8; β-conidia elongate rather frequent, 5.0–7.5 × 1.5–2.0, lacking an apical wall thickening. Dictyochlamydospores not observed, but chlamydospore-like thickened cells reported by Dowsett et al. (1982).	Gams and Jansson (1985)
D. campanulatum	Nematodes	Phialides flask-shaped, produced singly, in pairs or whorls, tapering towards the apex, 4.0–4.5 × 1.5–2.0 pm.	Two types conidia: α-conidia campanulate, cylindrical to obovate, 2.7–3.0 × 1.3–1.5, with adhesive wall thickening at the slightly broader end; β-conidia broadly obovate, nearly broadly ellipsoid to subglobose, measuring 4.2–4.5 × 3.0–3.5, produced in heads and chains	Zare and Gams (2001)
D. coniospora	Plant (Larix spp.) and soil	Conidiogenous cells are thus one terminal and number of intercalary phialides, 5–13 × 2.0–2.5, with conidiiferous pegs of 1–4 × 0.6–1.0 um, with a minute, slightly widening collarette	Conidia appearing to be formed singly on each conidiiferous peg and almost pointed tip, one-celled, hyaline, smooth-walled, 4.5–7 × 1.5–2.0 in the broadest part.	Zare and Gams (2001)
D. glocklingiae	Nematodes	Phialides rather long, 17–21 × 2.0–2.5, slightly swollen at the base and tapering gradually to the apex, frequently producing dichotomous ends and sometimes proliferating sympodially and producing another conidiogenous opening at the end (polyphialides).	Two types conidia: α-conidia balanoid measuring 3.2–3.5 × 2.5–3.0, with upper surface visibly thick-walled, often adhering in round, rosette-like aggregates; β-conidia Elongate conidia 5.7–6.5 × 2.0–2.2	Zare and Gams (2001)

Table 3.4 (continued)

Species	Substrate	Phialides (µm)	Conidia (µm)	Reference
D. harposporioides	Protozoa (Vorticella)	Small, barely angles, up to a diameter of 2 µm	Conida, producing through the mouth of the tubular, rising up out of the fertile hyphae; conidia hyaline, continuous or uniseptata	Zare and Gams (2001)
D. obovata	Nematodes	Conidiogenous cells saccate or flask-shaped, 7.0–9.0 × 2.0–3.5 at the swollen base, with a short narrow apex 0.5–1.0	Two types conidia: α-conidia obovoid, 3.0–3.5 × 2.0–2.5; β-conidia broad cylindrical, with rounded ends, 10.0–15.0 × 3.0–4.0. β-conidia occasionally forming α-conidia directly. β-conidia often borne apically on the conidiophore, but also produced from flask-shaped or saccate conidiogenous cells further down the conidiophore	Zare and Gams (2001)
D. panacis	Plant, root of *Panax notoginseng*	Conidiogenous cells, unbranched, mostly flask-shaped, 2.5–3.7 × 5.6–16.7, ampulliform conidiogenous cells 15.2–21.2 long, 1.4–1.7 at the top, 2.1–2.9 at the base, occasionally ampulliform, single not in pairs or in a verticillate arrangement, bearing one conidium,	Two types conidia: α-conidia oval, 3.3–4.7 × 4.7–7.1; β-conidia elonged 2.6–3.1 × 6.9–8.0	Yu et al. (2018)
D. sinensis	Nematodes	Conidiophores erect, hyaline, bearing phialides singly or in whorls of 2–6. Phialides swollen in the lower part, 5–12 × 1.5–2.7, tapering towards the apex to 0.5–0.7	Conidia formed in heads or short chains, acorn-shaped to irregularly angular, 1.3–2.0 × 1.0–1.7	Zhang et al. (1996)
D. sphaerospora	Nematodes	Conidiophores more or less erect, bearing phialides singly or 2–4 in whorls. Phialides on water agar with nematodes mostly solitary with a strongly swollen base, on richer agar media more regularly subulate and more densely verticillate, sometimes sympodially proliferating, 7–19 × 1.7–3.2	Two types conidia: α-conidia acorn-shaped (balanoid), at least partly truncate and thick-walled at the tip, 2.2–3.2 × 1.3–2.3. β-conidia elongate rarely present, 6.0–7.5 × 2.2–2.5	Zare and Gams (2001)

Table 3.4 (continued)

Species	Substrate	Phialides (µm)	Conidia (µm)	Reference
D. zeospora	Nematodes	Phialides solitary or rarely up to 2–3 at each node, 6.5–7.0 × 2.3–2.8, constricted at the base and swollen immediately above, becoming very narrow towards the apex	Conida acorn-shaped to triangular, 3.0–4.0 × 1.7–2.0 at the broadest part	Zare and Gams (2001)
D. rhabdospora	Nematodes	Phialides solitary or verticillate up to 3–4 at each node, rather wide, swollen at the base and tapering towards the apex, 1.0 × 2.0–2.7	Conidia produced in small heads, rod-like with truncate ends, usually one end slightly broader, 3.8–4.0 × 1.3–1.5	Zare and Gams (2001)

Table 3.5 Sexual morph species of the genus *Drechmeria*

Species	Stromata (mm)	Perithecia	Asci	Secondary spores
Drechmeria gunnii	Cylindrical or lanceolate, obtuse or subacute, sometimes compressed, yellow below with the top of the stem, becoming black above, with stipe	Elongated, ostiola scarcely projecting beyond the surface.	Asci fusiform, flexuous; inner membrane terminated by a bipartite globe,	Short, truncate, cylindrical, forming long threads at length detached

3.3.3.2 *Harposporium*

Harposporium Lohde, Tagbl. Versamml. Ges. Deutsch. Naturf. 47: 206 (1874)

Index Fungorum number: IF8454

Synonym: *Atricordyceps* Samuels, N.Z. Jl Bot. 21(2): 174 (1983)

Podocrella Seaver, Mycologia 20(2): 57 (1928)

Polyrhina Sorokīn, Annls Sci. Nat., Bot., sér. 6 4: 65 (1876)

Wakefieldiomyces Kobayasi, Bull. natn. Sci. Mus., Tokyo, B 7(1): 2 (1981)

Parasites and pathogens of nematodes and rotifers, as well as soil-inhabiting. **Sexual morph**: *Stromata* mostly black, rarely dark brown, stipitate, expanding into a horizontally flattened fruiting cap, upper surface of cap slightly to strongly tuberculate due to protruding perithecia; on substrata only cap visible because

stipe typically buried in the wood. *Peridium textura angularis* outter layer; *textura intricata* inner layer. *Perithecia* ovoid to obpyriform. *Asci* cylindrical, somewhat capitate, with shallow apical caps. *Ascospores* hyaline, smooth, multiseptate, filiform to fusiform, disarticulating at the middle septum forming two secondary ascospores. *Secondary ascospores* lanceolate, multiseptate (adapted from Chaverri et al., 2005). **Asexual morph**: Hyphomycetous. *Conidiophores* simple or sparsely branched, bearing flask-sharped phialides, in aggregates or clusters. *Phialides* mostly consisting of an almost globose venter and one to several narrow coniferous necks. *Conidia* adhering in heads, mostly gracefully bent, rarely cylindrical or more irregularly shaped (adapted from Lohde, 1874; Zopf, 1888; Chaverri et al., 2005; Quandt et al., 2014; Spatafora et al., 2015).

Type species: ***Harposporium harposporiferum*** (Samuels) Spatafora & Kepler, in Spatafora, Quandt, Kepler, Sung, Shrestha, Hywel-Jones & Luangsa-ard, Mycosphere 6(2): 358 (2015).

Index Fungorum number: IF 236760

Synonym: *Atricordyceps harposporifera* Samuels, N.Z. Jl Bot. 21(2): 174 (1983)

Podocrella harposporifera (Samuels) P. Chaverri & Samuels, Mycologia 97(2): 439 (2005)

Harposporium anguillulae Lohde, Tagebl. Versamm. dt. naturf. Ärzte (Breslau) 47: 203-206 (1874)

Notes: Lohde (1874) described *Harposporium* in Hyphomycetes based on nematode (*Angullula sp*.) parasitic species, which produced basidia-like conidiophores and crescentic or sickle-shaped conidia. Sorokin (1876) renamed *Harposporium* as *Polyrhina* and included it in Chytridiales. Zopf (1888) proposed to protect the name *Harposporium* over *Polyrhina* and gave a clear description for *Harposporium anguillulae*. The developmental stages of the conidiophores and conidia were detailed by Karling (1938). Two monotypic genera *Atricordyceps* and *Wakefieldiomyces* were placed under *Harposporium* under the family Clavicipitaceae (Chaverri et al., 2005) based on morphology and phylogenetic evidence. Chaverri et al. (2005) linked *Podocrella* as a sexual morph genus to *Harposporium* and clearly described four entomopathogen species of *Podocrella*. *Podocrella* was placed in the family

Clavicipitaceae as incertae sedis, while *Harposporium* was placed under the family Ophiocordycipitaceae as an asexual morph genus by Sung et al. (2007). Quandt e al. (2014) preserved the older name *Harposporium* rather than *Podocrella* and Spatafora et al. (2015) combined four species from *Podocrella* to *Harposporium*. The synonyms of *Harposporium* are *Atricordyceps*, *Podocrella*, *Polyrhina* and *Wakefieldiomyces* (Zopf, 1888, Chaverri et al., 2005; Quandt e al., 2014; Spatafora et al., 2015).

Most asexual morph species in this genus were reported as pathogens of nematodes while sexual morph species were reported as pathogens of insects (Chaverri et al., 2005; Quandt et al., 2014; Spatafora et al., 2015). The asexual morph species are characterised by sphaerical or hirsutella-like conidiogenous cells, and crescent-shaped or helicoid conidia (Zopf, 1888; Chaverri et al., 2005). The sexual morph species are characterised by ascospores breaking into two lanceolate multi-septate part spores, (Chaverri et al., 2005).

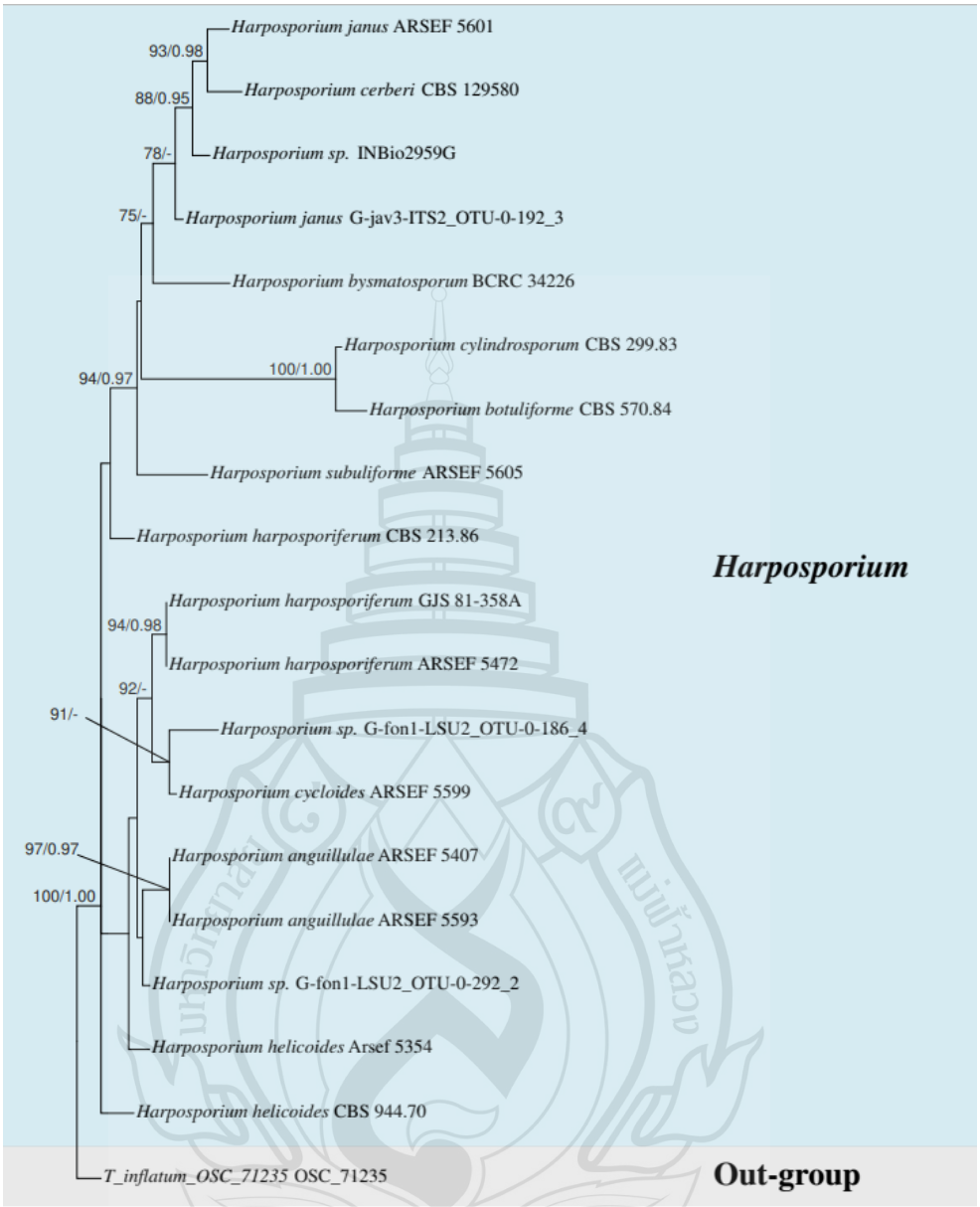
Ecological and economic significance of Harposporium: Species of *Harposporium* have been discovered as a potential biocontrol against of livestock-parasitic nematodes (Aschner & Kohn, 1958; Charles et al., 1996; Cai et al., 2016).

Distribution: Canada, China, Denmark, France, Netherlands, New Zealand, Saint Vincent, Trinidad-Tobago, USA, UK (Drechsler, 1946, 1950, 1959, 1963, 1965, 1968; Barron, 1972, 1977, 1979, 1980, 1983, 1986; Monoson & Pikul, 1974; Shepherd, 1955; Chaverri et al., 2005; Barron & Szijarto, 1991; Hodge et al., 1997; Evans & Whitehead, 2005; Li et al., 2005; Wang et al., 2007).

Conclusion: Illustrating the type species and typification one spcies of the genus, list all the species and all the accession GenBank number.

Note Conidia arising from infected nematodes.

Figure 3.51 Morphology of *Harposporium anguillulae* (redrawn from Zopf, 1888)



Note Phylogenetic tree of *Harposporium* species generated from maximum likelihood analysis of ITS, SSU and LSU sequence data. Tolypocladium inflatum (OSC 71235) were used as outgroup taxa This phylogenetic tree of *Harposporium* comprises 19 taxa analysed herein and their accession numbers . Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.95 are indicated above the nodes .The ex-types are indicated in bold

Figure 3.52 Phylogenetic tree of *Harposporium* species

Harposporium microsporum Glockling, in Glockling & Dick, Mycol. Res. 98(8): 854 (1994).

Index Fungorum number: IF 362507

Holotype: IMI 375096

Host: Nematodes

Parastic on nematodes. **Sexual morph**: Undetermined. **Asexual morph**: Hyphomycetous. Assimilative hyphae in the nematode body, septate, sparsely branched, sometimes cellular. *Conidiophores* short, usually comprising only one cell; disarticulating at the base near the nematode cuticle, occasionally with long conidiophores. *Conidiogenous cells* lop-sided, flask-shaped, with a single tapering apical neck region, sometimes conidiogenous cells subglobose, with several cylindrical necks. *Conidia* produced only in non-axenic watery culture; dome-shaped, near the base; apical on short necks on conidiogenous cells. *Macroconidia* produced aerially in subculture and pure culture; cresent-shaped, with a slight helicoidal twist, the base with a small basal swelling; curved at the apex before maturity; sharply pointed at the apex when mature. *Aerial conidiophores* with subglobose to flask-shaped conidiogenous cells, with a narrow tapering neck region, producing macroconidia singly.

Material examined: UK, rabbit dung, IMI 375096, isolated from infected nematode from a sample of rabbit dung (holotype IMI 375096).

Notes: Description with the photo plate were provided in this study to help the further study of *Harposporium microsporum*.

Note a. Herbarium material. b. Dry culture. c, d. Conidiogenous cells e. Conidia. Scale bars: b = 500 µm, c–e = 10 µm.

Figure 3.53 Morphology of *Harposporium microsporum* (holotype IMI 375096)

Table 3.6 Morphological characters of asexual morph species of the genus *Harposporium*

Name	Conidiogenous cells (µm)	Conidia	Reference
H. anguillulae	Phialides globose to ellipsoid, often with narrow tapering necks 4.3–9.3 × 3.1–6.2 with one or more short (1.9–3.8) necks	Conidia sickle-shaped, cohered in bundles at the apices of the necks, left-handed helix, with a small drop of mucus covering the base, 6.0–15.2 × 0.9–2	Hodge et al. (1997)
H. angulare	Phialides globose to ellipsoid, often with narrow tapering necks (ampulliform) 7–12 × 4–5, arise singly, less often in clusters, just below the septa of the conidiophores.	Conidia 23–28 × 2.2 at their greatest width, have a right-angled bend about two-thirds the way along their length, composed of a narrow basal portion, 14–17 long, flaring out at the bend to a swollen distal portion, 9–11 long, which tapers gradually to a narrow acutely pointed, slightly reflexed tip, with a small blob of mucus at the end of conidium	Barron (1980a)

Table 3.6 (continued)

Name	Conidiogenous cells (µm)	Conidia	Reference
H. cylindrosporum	Phialides globose to subglobose 3–5 × 2–3.5	Conidia aseptate, cylindrical with rounded ends, 22–27 × 1.7–2.5	Barron (1980a)
H. sinense	Phialides globose, 2–4, or flask–shaped, 9–19 × 1.8–3, with 1–3 short necks, or a branched neck, 1–3 × 0.5–1	Conidia aseptate, arcuate, 1–2 in the greatest width, and 9–29 in length along the curved axia, sharply pointed at the apex when matured, rounded at the base and surrounded with a droplet of mucus, 1–5 conidia produced successively and cohering in a head on a short neck	Wang et al. (2007)
H. multiformis (culture)		Arthroconidia septate, clavate, produced in branching chains, produced apically on the conidiophores, 25–102 × 2.5–5, germinating to produce typical globose conidiogenous cells and helicoid conidia,	Li et al. (2005)
H. multiformis	Phialides globose, 3–4.5, or long ellipsoid, 5–13 × 1.8–3.5, with a short neck, 1.8–3.5 × 0.6–1, borne in single or in irregular cluster on the conidiophores	Conidia aseptate, crescent–shaped or helicoid, 8.4–18.6 × 0.6–1.3, 1–5 conidia produced successively and cohering in a head on a short neck	Wang et al. (2007)
H. bredonense	Phialides densely formed on the loose network of conidiophores, solitary or in whorls, globose to subglobose, 4.0–5.5 × 4.0–4.5, with a short apical neck, 2.5–3.5 × 0.5–0.8	Conidia formed in basipetal succession, hyaline, lunate or crescent–shaped, 10.5–13.5 × 1.2–1.5, narrow at the apex.	Evans et al. (2005)
H. bredonense (Culture)	Phialides globose, 13.0–28.0, with a subulate basal part, 5.0–12.5 × 3.0–4.0, Hirsutella Phialides: narrowing to a long neck region, 8.0–15.0 × 0.5–1.0	Conidia consistently bigger and less curved or arcuate, 15.0–18.5 × 1.5–2.0, Hirsutella conidia ellipsoidal, truncate at base, dry, 3.5–5.5 × 1.2–2.0	Evans et al. (2005)
H. bredonense	Phialides slender, 42–55 in length, subulate and inflated at the base, 8–15 × 2.5–3.5, tapering to a long, acerose or needle–like neck, 0.5–0.8	Conidia enveloped in a mucoid droplet and appearing limoniform, devoid of mucus, the conidia are narrowly fusiform to falcate, 8.0–10.5 × 1.5–2.5, aseptate and guttulate	Evans et al. (2005)

Table 3.6 (continued)

Name	Conidiogenous cells (µm)	Conidia	Reference
H. angustisporum	Phialides borne along the hyphae, the lower 3-celled, ovoid to flask shaped, 3 × 3, provided distally with 1–4 break–like extensions through which are proliferated 2–4	Conidia cylindrical, straight or slightly twisted, 6–9 × 0.3–0.5	Monoson et al. (1974)
H. arcuatum	Phialides spherical, 3.5–4.5 with narrow cylindrical apex up to 4 long, singly or in irregular clusters but are often in nodal groups	The conidia narrow, 18–50 × 0.8–1.0, taper to an acute, very sharp point at their distal end and more gradually to a narrow basal end which has a mucoid secretion	Barron (1980b)
H. baculiforme	Phialides globose, 3–4.5, or long ellipsoid, 5–8 × 1.5–2, with a short neck, 1.5–6 × 0.2–0.5, occasionally with 2–3 necks, borne singly or in irregular clusters on the conidiophores	Conidia cylindrical or tapering very slightly toward the apex, always with rounded ends, 2.5–5 × 0.7–1.5	Drechsler (1959)
H. sicyodes	Phialides globose, 2.8–3.7, branch, with 1 or 2 sterigmata 1.2–3.7, or flask–shaped, 4–8 long	Conidia cylindrical though tapering slightly toward both broadly rounded ends, straight or slightly curved, hence resembling cucumber fruits in shape, mostly 3–5 × 0.9–1.2	Drechsler (1959)
H. arthrosporum	Phialides each phialide consisting of a swollen lower portion and short, cylindrical upper portion, 7–12	Conidia crescent shaped, 7–16 × 0.7–2.5, in water mounts appear coiled to form part of a helix, with 21 mucoid secretions, very variable in size, one or two larger conidia and a series of increasingly smaller conidia inn nested arrangement are produced.	Barron (1979)
H. botuliforme	Phialides spherical base 3–4.5 across with a short, narrow, tubular mouth up to 2 long, 0.5 wide	Conidia cylindrical, 9–11 × 1.7–2.5, straight or slightly curved with rounded ends, aseptate, and produced in short, irregular chains	Barron (1983)
H. bysmatosporum	Phialides spherical base 3–4, with a single sterigma, simple and usually measuring 2–4 × 0.8	Conidia clusters of 4–6, the human upper–arm–bone in shape, at the base recurved obliquely into a minute pedicel, at the distal end rounded and often noticeably widened, 4.5–6.5 × 0.8–2.1	Drechsler (1946)
H. cerberi	Phialides single or in whorls, subglobose, 3.7–5 × 2.8–5, with a short neck, 1.2–5 × 0.6–1.2 that may become sympodial with age.	Conidia basipetal succession, describing 1–1.5 turns of a left-handed helix, beaked at their apices with a small mucous drop at the base, 12.4–20.5 × 1.2–2	Hodge et al. (1997)

Table 3.6 (continued)

Name	Conidiogenous cells (µm)	Conidia	Reference
H. cerberi (culture)	Phialides 12.4–21.7 × 2.5–3.7, basally subulate, becoming extensively polyphialidic through the sympodial proliferation of new conidiogenous loci, conidiogenous necks with refractive periclinal thickening.	Arthrconidia fragile chains of broad, thick-walled heterothallic arthroconidia, 11.1–23.7 × 3.2–4.7. Ameroconidia ellipsoid, with truncate basal apiculus, dry, 5.6–8.7 × 1.8–3.1	Hodge et al. (1997)
H. cocleatum	Phialides globose or elongate–ellipsoidal, mostly 4–6 × 4–5.5, distally with a protuberance which is mostly 1–2.5 × 1.5–2 and borne 1–3 sterigmata commonly 1—3 × 0.5	Conidia filamentous, convolved often in a helical turn of righthanded rotation, 25–33 × 0.5–2 near base and tip, 1.3–1.7 in greatest width about 3/2 above the middle.	Drechsler (1965)
H. crassum	Phialides subspherical, 2.5–4.5	Conidia, arcuate, 18–22 × 2–3, with a small protuberances from the tiny fertile branches	Shepherd (1955)
H. cycloides	Phialides globose basal, 3.5–4.5, with a cylindrical sterigma 2–3 × 0.8–1	Conidia convolved in a helicoid spiral of approximately one turn, left–handed rotation, 20–30 × 1.3–1.9, furnished at the tip with a rather thick–walled beak mostly 1.5–2 long. Chlamydospores produced intercalarily in assimilateive hyphae, yellowish, elongate–ellipsoidal or globose or barrel–shaped, 8–19 × 6–9	Drechsler (1968)
H. diceraeum		Conidial apex pointed in axial direction, slender, apex rounded or with a simple point, with a laterally displaced basal apiculus and various shapes of the distal part 3.5–4 × 1–1.5	Drechsler (1941)
H. dicorymbum	Phialides globose basal, 4.5–13 × 4–6.5, with 1–3 sterigmata, 2–7 × 0.9–1.2	Conidia consisting of a globose proximal part, 4–7, and of a columnar outgrowth arising from it in an equatorial or somewhat more proximal position, furnished with a pedicle 0.5–1 × 1, at its tip drawn out at nearly right angles to its axis into a short posterior and a longer anterior beak.	Drechsler (1963)
H. drechsleri	Phialides globose to subglobose with narrow cylindrical mouth, measuring 3.5–5 × 4–6	Conidia aseptate, helicoid, 5–11 × 0.7–1.5, accessory phialospore state with two–celled spores produced in culture, 12–15 × 3–4	Barron (1972)
H. harposporiferum	Phialides globose to ampulliform, 4, with an apical elongation or neck 3–4 × 1	Conidia arcuate, 8–12 × 1–2	Chaverri et al. (2005)

Table 3.6 (continued)

Name	Conidiogenous cells (µm)	Conidia	Reference
H. peltatum	Phialides subglobose to ampulliform, 3.5–4.5 × 3.0–4.0, with a narrow cylindrical neck 1.2–2.5 × 0.5–1.0	Conidia produced enteroblastically, arcute and slightly helically twisted, distal end with a slight asymmetrical beak, proximal end narrowly truncate, 5.5–7.5 × 0.9–1.3	Chaverri et al. (2005)
H. peltatum (hirsutella–like synanamorph)	Hirsutella-like 16–22 × 2.0–3.1, awl-shaped or with somewhat inflated base tapering gradually into a narrow neck (4.0–5.5)	Conidia acerose, straight or slightly curved, with truncate narrow base and rounded apex, 8.0–11.8 × 1.2–2.5	Chaverri et al. (2005)
H. peltatum		Arthroconidia cylindrical, 12.0–160.0 × 3.5–4.4 with refractive contents and slightly thickened walls	Chaverri et al. (2005)
H. reniforme		Conidia reniform, umbilicate, 3.2–4 long	Wang et al. (2007)
H. rhynchosporum	Phialides spherical or ovoid with an elongate, tubular apex up to 6 long	Conidia (phialospores), heart–shaped at first, when matures a thick spine develops from the convex surface on the side away from the attachment to the phialide, 4–5 × 4–5	Barron et al. (1977)
H. spirosporum	Phialides globose to ellipsoid or bottle shaped and 3–3.5 × 2.2–2.5, with narrow necks.	Conidia bird–shaped, tapered narrowly at both ends, and have a helicoid twist along their length, 6–8 × 1.5–2.0	Barron (1986)
H. subuliforme	Phialides flask–shaped, 5–12 × 2.8–4.8, with 1–3 sterigmata on which collectively are often borne 4–6 conidia, commonly 1–2.5 × 0.6–0.8	Conidia awl–sharped, straight or curved, 12–26 × 1–1.8, distally often 0.4–0.6 wide, soon putting forth obliquely from the tip an adhesive spur 2–5 × 0.6	Drechsler (1950)
H. thaumasium	germinating to produce typical globose conidiogenous cells and infection conidia.	Arthroconidia septate, yellow–brown, cylindrical or clavate, produced in branching chains, formed from the apices of conidiophores, 52–145 × 4–8.5	Li at al. (2005)
H. thaumasium	Phialides globose, 3–4.5, or long ellipsoid, 5–8 × 1.5–2, with a short neck, 1.5–6 × 0.2–0.5	Conidia hyaline with yellow brown tint, aseptate, crescentic–shaped, 4–8 × 0.7–1.2, bluntly beaked at the apex and narrow and truncate at the base. Accessory conidia hyaline, narrowly elliptical to D–shaped, 2–6 × 1–3, typical of Hirsutella, conidiogenous cells hyaline, basally subglobose to elliptical, 4–22 × 2–5, with single neck or 2–6 necks.	Li and Zhang (2005)

Table 3.6 (continued)

Name	Conidiogenous cells (µm)	Conidia	Reference
H. trigonosporum	Phialides are globose to subglobose, proliferates at its mouth, 3.0–4.5 × 3.0–3.5	Conidia triangular, equidistant between the three apices, 7.2–9.0 × 6.3–7.2, when produced in culture, conidia are slightly larger and sometimes irregular in shape	Barron and Szijarto (1991)

Table 3.7 Morphological characters of sexual morph species of the genus *Harposporium*

Name	Stromata	Perithecia	Secondary ascospore	Reference
H. fuscum	Stromata solitary, dark brown, stipitate-capitate, 3.0–4.5 mm	Perithecia obpyriform, 520–563 × 190–209	Secondary ascospore lanceolate, multiseptate, 56.7–62.2 × 2.7–3.0	Chaverri et al. (2005)
H. harposporiferum	Stromata solitary, black, stipitate-capitate, 7 mm	Perithecia ovoid, 470–590 × 250–330	Secondary ascospore lanceolate, multiseptate, 48.5–57.5 × 2.0–2.5	Chaverri et al. (2005)
H. peltatum	Stromata solitary, dark brown, stipitate-capitate, 3–4.5 mm	Perithecia obpyriform, 489–519 × 186–200	Secondary ascospore lanceolate, multiseptate, 41.5–47.2 × 3.5–4.2	Chaverri et al. (2005)
H. poronioides	Stromata solitary, dark green almost black, stipi-tate-capitate, 3–4 mm	Perithecia obpyriform, 550–850 × 250–300	Secondary ascospore lanceolate, multiseptate, 41.5–45.7 × 2.7–3.2	Chaverri et al. (2005)

3.3.3.3 *Hirsutella*

Hirsutella Pat., Revue mycol., Toulouse 14(no. 54): 67 (1892)

Index Fungorum number: IF8538

Synonym: *Atricordyceps* Samuels, N.Z. Jl Bot. 21(2): 174 (1983)

Didymobotryopsis Henn., Hedwigia 41: 149 (1902)

Didymobotrys Clem. & Shear, Gen. fung., Edn 2 (Minneapolis): 228 (1931)

Mahevia Lagarde, Archs Zool. exp. gén. 56: 292 (1917)

Synnematium Speare, Mycologia 12(2): 74 (1920)

Trichosterigma Petch, Trans. Br. mycol. Soc. 8(4): 215 (1923)

Troglobiomyces Pacioni, Trans. Br. mycol. Soc. 74(2): 244 (1980)

Parasitic and pathogenic on insects, mites, plants and nematodes, as well as soil-inhabiting. **Sexual morph:** The sexual morph is linked to the genus *Ophiocordyceps* and *Cordyceps*. **Asexual morph:** *Synnemata* observed or absent, single or several, simple or branched, usually white, sometimes pigmented. *Conidiophores* observed or reduced to sessile conidiogenous cells, erect, lateral or verticillate. *Phialides* (conidiogenous cells) scattered to crowded, single or clustered, mono- or polyphialidic, swollen or inflated base with one or several short or long tapering neck, sometimes forming two types of phialides. *Conidia* globose or ellipsoid or fusiform or cylindrical, sometimes forming two types of conidia, hyaline or pigmented, with or without mucus. (Speare, 1920; Hodge, 2003; Quandt et al., 2014).

Type species: ***Hirsutella entomophila*** Pat., Revue mycol., Toulouse 14(no. 54): 69 (1892)

Notes: The genus was introduced by Doassans and Patouillard (1892) with one entomopathogenic species. *Hirsutella* has become a large and variable asexually reproducing group with over 70 species (Species Fungorum 2021). Species of *Hirsutella* have been reported as asexual morph pathogens of insects, mites and nematodes as well as being soil-inhabiting, and are characterised by swollen or inflated phialides with tapering neck and mucilaginous packets of one or several conidia (Speare, 1920; Hodge, 2003; Minter & Brady, 1980; Simmons et al., 2015). The sexual morph of this genus was link to *Ophiocordyceps* (Simmons et al., 2015). *Hirsutella* is similar to *Hymenostilbe* forming comparable phialides but lacks the denticies (Hodge, 2003).

The lack of molecular data is the main problem to identify species of *Hirsutella* even though the morphological analyses are well-discussed. Only one quarter of *Hirsutella* species have molecular data. The genus name *Hirsutella* was suppressed because of a lack of type material (Quandt et al., 2014). This suggestion has been followed by Simmons et al. (2015b) and Xiao et al. (2019) in propose a new

species form asexually reproducing only. Simmons et al. (2015) provided 46 isolates of 23 *Hirsutella* species sequence data to imply investigation in the future.

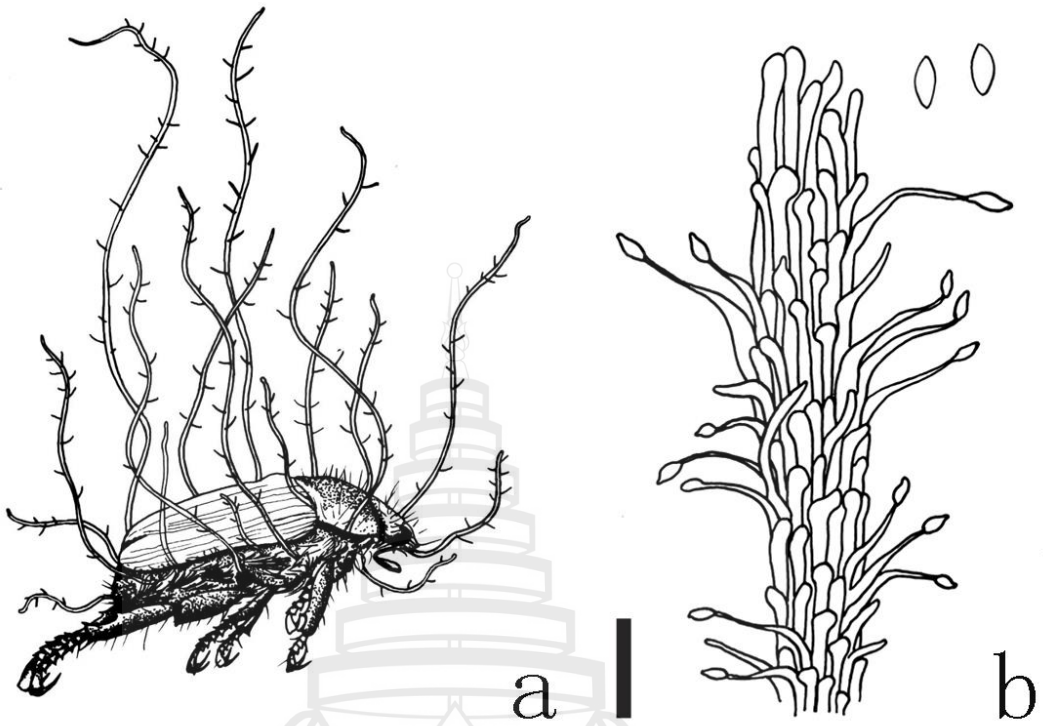
Didymobotryopsis has been considered as synonymy of *Hirsutella* since Samson & Evans (1991) removed the type species of *Didymobotryopsis* as *Hirsutella* based on morphology exam.

We redraw the type species in this genus for the future investigation but without describe any new species by following the suggestion of Quandt et al. (2014). And we do not provide a phylogenetic tree for this genus but incorporate taxa in the *Ophiocordyceps* phylogenetic tree.

Ecological and economic significance of Hirsutella: *Hirsutella kobayasii* was reported the *Hirsutellide A* as a new antimycobacterial metabolite (Vongvanich et al., 2002). Hirsutellones A–E, antimycobacterial alkaloids, was extracted from *Hirsutella nivea* (Isaka et al., 2005). *Hirsutella beakdumountainsis* was reported as a potential substitute for *Ophiocordyceps sinensis* based on testing the chemical compounds (Li et al., 2011). In addition, two active compounds were reported from different strains of *Hirsutella sp.*, which were hirsutide (Lang et al., 2005), and antimalarial tetrapeptides (Thongtan et al., 2006).

Distribution: Australia, Austria, Brazil, China, Ecuador, England, Europe, France, Germany, Ghana, Great Britain, Guyana, India, Indonesia, Japan, Liberia, New Zealand, Nigeria, Poland, Russia, Sri Lanka, Thailand, Togo, Ukraine, USA (Petch, 1923; Bourdot & Galzin, 1928; Charles, 1937; Petch, 1939; Kobayasi, 1941; Mains, 1949; Aoki, 1957; Evans & Samson, 1982; Evans & Samson, 1984; Balazy & Wiśniewski, 1986; Fernández-García et al., 1990; Fang & Tan, 1992; Hywel-Jones et al., 1998; Chen et al., 2000; Bałazy et al., 2008; Kurihara et al., 2009; Zou et al., 2010; Ciancio et al., 2013; Zou et al., 2016).

Conclusion: Illustrating the type species.



Note a Overview of *Hirsutella entomophila*. b Synnemata with phialides and conidia. Scale Bars: b = 20 µm.

Figure 3.54 Morphology of *Hirsutella entomophila* (redrawn from Speare, 1920)

Table 3.8 Morphological characters of *Hirsutella* species

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. abietina	Awl-shaped, 3 × 300, scattered or in rows	Cluster of four spores, lemon-shaped or oval, 5–6 × 3	Up to 26 high, with an oval base, 8–10 × 5	Oval or subcymbiform, ends usually obtuse, 4–6 × 2–2.5
H. acerosa	Narrow cylindrical, up to 23 mm in length, dark brown becoming pale brown to white towards apex	Hyaline, with a cylindrical to ellipsoidal base, up to 6 um diam, 12–35 × 0.7–1.2		Aseptate, hyaline, smooth, needle-like or fusiform, apiculate, 18–24 × 2–2.5 um

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. acridiorum	No synnemata, mycelium covered	Sessile, 16–28µm, 2–3µm in diameter, base conical or gently flask	Reduced to sessile conidiogenous cells arising from vegetative hyphae.	Hyaline, aseptate, smooth, ellipsoidal
H. aphidis		Conidiophores laterally borne on the hyphae, up to 55 µm high		cymbiform or oval, 10 × 5–6 µm
H. asiae		16–25 µm long, with cylindrical ellipsoid base and acuminate sterigma		2.6–5.2 × 2.0–3.0
H. barberi	White or ashy, becoming brown, mostly detached	Phialide base ovate, conoid or cylindrical, 5–7 × 3–4 um, attenuated into a slender sterigma, 7–9 um long.	Cylindrical-conical, 4–5 um high, with one, sometimes two, slender sterigmata, 3–4 um high, terminated by an ovoid spore, 1–5 um long	Narrow-oval or fusoid, 4.5–7 × 2 um, one end acute.
H. besseyi	Synnemata infrequently produced	phialides acuminate, 2.5–4.9 × 21.6–66.4, typically attenuated into a sterigma 8.3–19.9	conidiophores lateral or erect, rigid, tapering, hyaline above, pale fuliginous below, 29.9–74.7	Hyaline, narrowly elongate but appearing lemon-shaped due to a gelatinous capsule, 2.5–5.8 × 4.1–8.3
H. brownorum		monophialidic, hyaline, smooth, 15–25 long	Reduced to sessile conidiogenous cells, arising singly more or less at right angles from vegetative hyphae.	Hyaline, aseptate, more or less limoniform, 5–6 um long, 4–5 um wide, enveloped in a mucous sheath.
H. changbeisanensis		Phialid base 6.5–20.0 µm with 10–20µm sterigmata, conidia oval to citriform, in mucus.		4.0–7.0 × 2.5–3.5
H. citriformis	Flexible, brown, simple or branched		Simple, sessile or subsessile, with rather short, delicate sterigmata (20–30 um)	Fusoid, hyaline, 5.5–8.5 × 1.5–1.8 um, imbedded in gelatinous matrices.

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. clavispora	Simple, up to 8 mm high, 0.35 mm diameter below	Simple, filiform, 5–9 um high		Hyaline, continuous, clavate, 4–8 × 1–1.5 um
H. coccidiicola	Cylindrical to clavata, 5–8 mm long	Subulate, hyaline, 13–18 um long		Ellipsoidea or thickened-fusiform, hyaline, 2.5–3.4 × 1.5–2 um
H. crinita	slender cylindrical or filiform, unbranched, flexible to ligneous, dark brown, caespitose	Phialides somewhat scattered, forming a loose hymenium, hemispheric to globose or cylindrical, inflated at basal portion, 4.5–6(–10) × 3.5–4.5 um		Conidia infrequent, narrowly anisomerous obclavate, 6–9 × 1–1.5, absence of distinct mucus layer
H. cryptosclerotium		Mono- to polyphialidic hyaline, cylindrical, with an inflated base, 10–24 × 3.5–5 um		Hyaline, aseptate, globose, 5–6 um diam, initially smooth, later appearing verrucose due to differential thickning of gelatinous sheath
H. danubiensis		2.5–3.7 wide at the base, 35–62.5 long, sometimes forked, slender		4.5–6.6 × 1.9–2.7 of the shape of orange segment, more strongly narrowed at the distal end and bilaterally symmetrical
H. darwinii	White to pale yellow, narrowly cylindrical, acuminate, 4–8 mm long, 100–150 um wide, sterile over most of the length.	Phialides scattered, mainly in the upper part, slender, often awlshaped, 12–45 um long, 1.5–2.5 um wide at base, tapering to a 0.5–0.8 um wide neck		Hyaline, one-celled, narrowly fusiform, sometimes slightly curved, 4.5–11.5 × 1.5–2.0 um

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. dendritica	Single, tree-like, 2.0 × 0.5 cm	Mostly cylindrical or slightly tapering, 12–25 × 2.5–4 um, abruptly narrowing to a thin, 0.5–1.5 um undulate neck, up to 50 um long, straight or bent away from the axis; occasionally polyphialidic.		Conidia hyaline, one-celled, fusiform, 6–8 × 2–3 um, measured without mucus.
H. dipterigena	Up to 8 mm long 1.2 mm diameter, simple, terete, tapering to an acute apex, rigid, ashy, slightly pruinose, fuscous internally.	Up to 27 um high, with a conoid base, 4–6 × 3–4 um		Greenish hyaline, cymbiform, ends acute, 6–10 × 1.5–2 um
H. entomophila	5–15 mm. long, much branched, rigid, often spirally twisted, brownish		Simple, sessile, the basal portion inflated but short, tapering gradually into relatively short (25–35 um) sterigmata	Filiform, 7.5 × 1.5 um, hyaline, imbedded in gelatinous matrices.
H. exoleta	Up to 5 cm long, 0.25 mm diameter, tapering upwards, linear, simple or branched, terete when fresh	20–40 um high, and consist of an inflated base, usually flask-shaped but often irregular, 12–18 × 5 um, attenuated above into a stout sterigma, 20 um long		Hyaline, cymbiform, ends rounded, 9 × 2.5
H. floccosa	Short, verruciform, white, arising from a cottony subiculum.	Simple, sessile, extremely robust, the swollen basal portion tapering very gradually into the short, rather stumpy sterigmata (10–15 um)		Fusoid, hyaline, 9–10 × 3.2–3.8 um
H. fusiformis	Unbranched, uniform in height, measuring 4–5 mm., nearly black in color, singly.	Simple, sessile, the inflated basal portion tapering gradually to rather short (25–35 um) sterigmata.		Fusoid-cylindrical, measuring 9–10 × 2 um in size, hyaline, imbedded in gelatinous matrices.

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. gigantea	Simple or branched from near the base, terete, slightly attenuated upward, 2–10 cm. long, 0.5–1.0 mm. thick, olivaceous below, brown above	Scattered to crowded, the lower portions oblong to ellipsoid, 10–18 × 5–8 um, abruptly narrowing into slender sterigmata 10–20 um long		Oblong, slightly narrowing at each end, 5–8 × 2–2.5 um, 1–2 or rarely more in droplets of mucus 6–16 um in diameter.
H. gregis		Phialidic, hyaline, thin-walled, flask-shaped, 12–20 um long	Mononematous, merely sessile conidiogenous cells arising singly, more or less at right angles from the vegetative hyphae, or stromatic, producing conidiogenous cells more or less at right angles directly from the sides of the stromata.	Hyaline, aseptate, more or less lemon-shaped or the shape of an orange segment, often with a small apical point, with no visible scar after secession 4–6 × 2–3 um, generally clad in a mucous sheath which may be faintly pigmented.
H. guignardii	Synnemata emerging singly or in groups of up to 6 from the thorax and abdomen or from the stromata, pendulous from the host which is usually adhering to the wall of the cave, filiform, acicular, or terete, curved or sinuous, yellow-brown, pallid brown to grey	Phialides arising singly and laterally from the hyphae of the stroma, or terminally at the ape of the synnema, originating as lateral bumps on the hyphae which elongate, develop a basal septum, then develop a neck, lageniform to subulate, subhyaline, 20–35 long in entirety	Phialides awl, lateral and compacted in a layer below the head, >40	Ellipsoidal-fusiform, hyaline, 7.5–10 × 2.5–3 um
H. guyana Minter & B.L. Brady 1980		Conidiogenous cells monophialidic, occasionally polyphialidic, hyaline, 30–75 long	Reduced to sessile conidiogenous cells arising singly, usually at an acute angle next to a septum, or terminal on vegetative hyphae	Hyaline, aseptate, smooth, ellipsoidal (or the shape of an orange segment), 8–12 long, 3–7 pm wide, embedded in a pigmented mucous sheath,

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. haptospora Bałazy		The phialides were narrow-conoid, relatively short, 14.0–25.0 and 3.1–3.7 thick at the base, in the middle gradually tapering and elongated into the neck which is about 0.5 um thick. No forked necks or polyblastic phialides were observed. Culture:		The phialospores were short fusiform, acute or subacute on the tip, in lateral outline one-sided, asymmetrically convex, usually covered with a gelatinous coating or stuck in twos in mucus, forming subglobose aggregations of 7.0–8.6 um diam. The dimensions of the phialospores were very uniform, 7.0–7.5 × 3.2–3.6
H. heteroderae		18–33 um long		Hyaline, ovate or ellopsoid
H. heteropoda		Phialidic, 6.5–22.5 × 2.5–4.5 µm, simple		Ellipsoid or oblong, 4.5–5.5 × 2.2–2.8 µm
H. huangshanensis		Cylindrical, 4.0–14.5 × 2.0–2.5 µm	Cylindrical, 4.0–14.5 × 2.0–2.5 µm.	Hyaline, aseptate, cylindrical, 4.0–9.1 × 1.5–2.0 µm.
H. hunanensis	Filiform, erect, unbranched, 5–55 mm long	Solitary or crowded along synnemata		Long ellpsoidal to the shape of an orange segment, 6 × 1.5–2 um, embedded in a mucous sheath, ellpsoidal, 6 × 4.5 um

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. illustris		Monophialidic, hyaline solong, smooth and subcylindrical in the basal region, reaching 7 um wide, gradually tapering to a straight neck, sometimes minutely warty, 2–3 um wide at the tip.	Reduced to sessile conidiogenous cells, or more often composed of a conidiogenous cell and one or two other cells, arising singly at an acute angle from the vegetative hyphae, or terminal.	Hyaline, aseptate, smooth, arising in groups at the ape of the neck, more or less ellipsoid
H. jonesii	5–10 mm. high, 100–200 um in diam. much branched, often tree-like.	Sporophores in part arising as lateral branches of the elements of the synnemata, in part forming the terminal growth of the fruiting stalk, in the first instance occurring singly, in the second being fasciculate	Sporophores 40 um long, gradually attenuate upward from base, which is 3–4 um in diameter	Fusiform, hyaline, one-celled, 8–10 × 4–5 um, borne successively and cohering after they are cut off in mucus glomerules
H. kirchneri		Hyaline, thin-walled, smooth, flask-shaped, 15–24 um long	Mononematous, merely sessile conidiogenous cells arising singly, more or less at right angles from the vegetative hyphae.	Hyaline, aseptate, thin-walled, smooth, more or less lemon-shaped, minutely truncate at the base, with no visible scar after secession, 4.5–6 × 2.5–3.5 um, not or rarely clad in a mucous sheath.
H. leizhouensis		Phialides two types. A-type, aseptate, 13.5–19 um long, base 3.0–4.0 um diam, neck 0.5–1.0 um diam. B-type, 1–2 septate, the upper part spirally twisted, 17.5–26 um long, base 3.0–4.0 diam, neck 0.5–0.6 um diam, rough, sometimes forming 1–3 branches from the upper part.		One-celled, smooth, oval or the shape of an orange segment, 3.5–4.5 × 2.0–3.0 um, embedded in a mucous sheath, oval, ellipsoidal, or lemon-shaped, 4.5–6.0 × 3.0–4.5 um

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. liberiana	Few, scattered, whitish, slender, cylindric, slightly narrowing upward, up to 3 mm. long, 100 um thick, simple or occasionally branched above	Scattered to crowded, usually several arising from short, one-celled lateral hyphal branches from the outer hyphae of the synnemata, the lower part fusoid-ellipsoid to fusoid-oblong, 8–12 × 3		Cylindric, rounded at both ends, 3–4 × 0.7–1.0 um
H. liboensis		Monophialidic or polyphialidic, hyaline, smooth, 28–30 µm long, significantly swollen in basal portion, 3–4.5 µm width, tapering to 1–2 µm wide and 10–13 µm overall length, twisting in 2–3 helices at the apex.		Hyaline, aseptate or with a septum, smooth, fusiform or like orange segments, arising singly (or both-cell) from the ape of the neck, 6–8 µm long, 3–5 µm wide, enveloped in a hyaline mucous sheath.
H. minnesotensis	Synnemata not observed.	hyphae hyaline, septate, smooth, 2–3.5 um wide.	Conidiogenous cells 9–15 um long, single, smooth, hyaline, monophialidic or occasionally polyphialidic; basal part strongly swollen, globose or subglobose, rarely ellipsoid, 6–8 × 5–6	4–6 um diam, formed singly, globose or subglobose, aseptate, verrucose, frequently with gelatinous covering. True chlamydospores absent. ellipsoidal, single or in chains, 7–9 × 5–8
H. necatrix		Hyaline, thin-walled, smooth, flask-shaped, of two types: one type (a) borne singly direct from the stromata or from undifferentiated vegetative hyphae, or in more or less well-defined verticils on otherwise undifferentiated hyphae, 5.5–9 long, composed of an almost spherical to ovoid the other type	Variable, sometimes no more than sessile conidiogenous cells arising directly from the stromata or from undifferentiated or slightly swollen vegetative hyphae	Hyaline, aseptate, thin-walled, of two kinds: one type, produced by phialides (a) smooth, short ovoid to ellipsoid, 3–4 × 2.5–3

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. neovolkiana	Simple or branched, up to 5 mm long	Excel terminal (phialidic) or subfusifromibus shaped lower half in height, 10–40 um long 1.5–3 um thick colorless.		Ellipsoid or narrow-ovoid 2.4–4.2 um (reaching up to 5.5 um) long and 1–1.5–2 um wide.
H. nivea	Single needle-like, 8–13 mm long, 200–300 µm at the base, tapering to the tip	Monophialidic, subulate, 12–20 µm long, base 1–2 µm across, hyaline.		Acerose, hyaline, aseptate, smooth-walled, 5–14 × 0–5, lacking a mucilaginous coat.
H. nodulosa		Spore clusters broadly oval, apiculate, 9 × 6 um;		Oval, ape subacute, base truncate apiculate, 6–7 × 3 um.
H. nutans	Synnemata solitary from the host's joints, bursting, filamentous 4 cm long	10–15 × 1–1.3 um, hyaline		Ovoid, hyaline, 2–2.2 × 1.2–1.3 um.
H. ovalispora		Hyaline, smooth, flask-shaped at base, 4.5–6 × 2–3 um, tapering to a needle-like neck, 6–8 × 0.4–1.0 um		Hyaline, aseptate, with makedly apiculate base, ovoid to pyriform, 2.8–3.5(–4) × 1.5–1.8(–2) um, mucous sheath occasionally present
H. parasitica	Synnemata arising from insect host, consisting of thin parallel hyphae, without distinct stipe and capitulum, 200–300 × 50–90 um.	More or less in a hymenium-like layer, mostly cylindrical or slightly tapering, 15–25 × 2.5–3.0 um, abruptly narrowing to a thin, 0.5–1.5 um, undulate neck up to 30 um long, straight or bent away from the main axis.		Hyaline, initially one-celled, later two-celled, cylindrical, sometimes with slightly pointed ends, 14–25 × 2.5–4.0 um, measured without mucus.
H. patouillardii		Oblong-conical, 20 µm long, conidia globose to ovoid		4.5–5.0 (diam.) 3.0 × 5.0

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. petchabunensis	Single, from abdomen of host, 22 mm long by 300–400 µm wide at base, tapering to rounded tip, yellow brown at base becoming cream brown at fertile apex.	Monophialidic, hyaline, smooth-walled, subulate, 22.5–30 µm long.	Simple, fuscous or hyaline, 2–4 cells, 40–60 µm long, 8–16.5 × 3–6 µm across.	Hyaline, smooth-walled, clavate, 5.5–9 × 2–3 µm
H. pichilinguensis	Multiple, unbranched, clavate to vertricase 40–70 mm × up to 1.5 mm diam, ginger brown to dark brown at base, 0.7–0.9 mm thick, becoming paler and wider towards the middle, 0.8–1.5 mm and then tapering to an acute apex, 0.3–0.8 mm	Phialids sessile, arising at right angles, scattered, hyaline, cylindrical, 25–40(–45)um, smooth and inflated at base (3–4 um wide) tapering to a long, narrow, verruculose neck region (1.0–1.4 um wide).		Hyaline, smooth, thin-walled, 0 to 1-septate, obovoid or obpyriform, 12–13 × 3–4.5 um, apiculate; rarely enveloped in mucus but often adhering in groups
H. piligena	Mycelium smooth, nail 0.5–1 mm. long, 0.3–0.5 mm diam, oboval or ellipsoid, obtuse, blanche, pruineuse, fugace; stipe nicely gray, long about 1–4 mm	Up to 6 µm at septa; subhymenial hyphea with dichotomous divisions; subcylindrical claviform basidia, gemineous at the ends of the twigs, 15 × 4– 4.5 um, has 2–4 volume subfusiform sterigmas, 15 × 2.5–3 um (Polyphialidic (2–4) per base, dichotomic hyphae))		Ellipsoid, 4.5–6 (–9) × 2.5–3 (–5) um
H. polycolluta	Simple, minutely cylindrical, yellow, 20 × 1 mm.	Proliferous, with 1–4 necks	Simple or branched	Clavoid-fusoid, with mucus 5.0–8.5 × 1.5–2.0

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. proturicola		Monophialidic, non-septate or sometimes septate below, slightly roughened at the neck		One-celled, produced solitary, 9–18 × 2.5–4 µm, hyaline, smooth, fusiform, curved, truncate at the base, with a papillate projection.
H. radiata		The phialides have a conical base, 5–8 × 3–4 um, merging into a stout sterigma, 9–14 um long, or a cylindrical base, 6–18 × 1 um, with a sterigma 6 um long. In many of the latter, the base and sterigma together form a uniformly conical whole and can be differentiated only by staining.		Cymbiform, 6–9 × 2–2.5 um, or oval, 7–8 × 3–4 um.
H. rhossiliensis		Monophialidic, hyaline, smooth or slightly warted towards the apex, 23–35 um long, swollen to 5 pm wide near the base, tapering to a straight neck up to 17 um long, 1–2 um wide at the base, 1 um wide at the apex.	Reduced to sessile conidiogenous cells arising singly, more or less at right angles from the vegetative hyphae.	Hyaline, aseptate, smooth, more or less ellipsoid (often the shape of an orange segment), arising from the ape of the neck singly or in a group, 6–11 um long, 4–5 um wide, enveloped in a pigmented mucous sheath, the groups being limoniform, 10–12 um in their largest dimension.
H. rostrata		Phialides conical, rather slender, narrowing gradually into single necks in the middle or somewhat higher, perpendicular to the hyphae		Narrow fusiform with the apical part elongated into a bent, somewhat subacute beak, 9.4–10.4 × 2.4–2.5, of arithmetic mean 9.9 × 2.7

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. rubripunctata		More or less cylindrical, hyaline, 6–12 × 2.5–5 um, with lateral and terminal tapering necks up to 1.5–2.5 um long.		Singly, cylindrical to clavate, hyaline, without a conspicuous slime layer, 2.5–4 × 1.5–2 um.
H. satumaensis	Sleeves flexible, brown, simple or say 20–50 mm long, 0.4–0.6 mm thick, gradually tapering; sporophores sinhyalinnis; basidia sessile or sessile, conical cylindrical, 5–17 um long, 5 um thick	Sporophores sinhyalinnis; basidia sessile or subsessile, conical or cylindrical, 5–17 nm long, 5 wide; short, clamped thin, about 7 nm long.		Accordingly; spores subacute fusoideis, gently curved, smooth, hyaline, 5–7.5 × 3–5, the mucus in the subacute fusoideis, gently curved, smooth, hyaline, 5–7.5 × 3–5, with mucus
H. shennongjiaensis	Synnemata arising on the edge of colonies after 60d, cylindrical, brown, up to 1.0–2.0mm width and 60.0mm length.	Phialides of two types, A-phialides cylindrical, 14.4–26.1×0.4–1.4μm; B-phialides significantly swollen in basal portion, 4.5–7.2×1.4–2.5μm, and tapering to 0.4–0.9μm wide and 6.3–14.4μm overall length.		Hyaline, aseptate, smooth, sausage-shaped, single or double from the apex of the neck, 6.3–10.8×3.6–6.3μm, enveloped in a hyaline mucous sheath
H. sinensis		Monophialidic, hyaline, smooth or wart, acicular or subuliform, erect or strongly curved, 17.3–47.6 um long, apex sharp, 1–2 um wide, the base 3.2–5.4 um wide.	Hyaline, 56–103 × 4.8–8.7 um.	Hyaline, aseptate, smooth, reniform or ellipsoid, 5.4–14 × 3.2–4.3(–5.4) um,
H. sphaerospora		Phialidic, borne at regular intervals along the hyphae, with a cylindrical to ellipsoidal base, 12–22 × 3–6 um, tapering to a thin neck, 3–7 × 1– 1.5		Singly, globose, hyaline, smooth-walled, occasionally covered by mucus, 4.5–5.0 pm in diameter

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. sporodochialis		Terminal or integrated, pale brown, smooth-walled, flask-shaped, tapering to a long, hyaline neck, 50–80 × 5–7 um.		Aseptate, hyaline to pale yellow, smooth, fusiform, truncate at base or at both ends, 10–27 × 3.5–4 um, solitary or in groups of 2–4 in mucus which darkens with age.
H. stilbelliformis	Simple to branched, flexuous, dark brown, cylindrical, (2–)2.5–3.5(–5) mm × 80–110 um at base, narrowing to 20–25 um, then broadening into a bulbous, funnel–like, white.	A-phialides occurring laterally, scattered, hyaline to yellow, echinulate to verrucose, aseptate to septate, with a swollen base, 10–13(–16) × 3–4 um and acuminate neck, 6–8 × 0.6–1 um. B-phialides terminal, finely echinulate, hyaline, subulate, up to 75–150 um long, 1.5–2.2 um wide.		A-conidia narowly clavate, often curved, hyaline, predominantly 1–septate, apiculate, 7–9 × 1.5–2.2(–2. 5) um, adhering in groups. B-conidia ovoid to cylindrical, often curved, aseptate, guttulate, hyaline, enveloped in mucus, (8–)9–10(–12) × 4–5 um.
H. stilbelliformis var. dolichoderi		Base inflated, ellipsoid and awl		Cylindrical to ovoid 6.5–9.5 × 3.5–4.5
H. strigosa		Scattered, lateral or terminal on the hyphae, up to 36 um high, 2 um diameter at the base, elongated conoid, attenuated into a rather stout sterigma, or up to 50 um high, with a subcylindrical base		The spore cluster is oval, 12 × 5 um, or lemon-shaped, 16 × 8 um, or globose, 12um diameter, and the conidia are cymbiform or narrowly oval, sometimes attenuated at one end, 8–12 × 3–5 um
H. stylophora	Subulate, 1.5–4.5 cm. long, 0.2–1.0 mm. thick, dark brown and pubescent below, grayish brown and slightly pul–verulent above;	Scattered, 6–10 × 3–4		Fusoid to obovoid, 8 × 2.5–4, covered with a slight mucus

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. subramanianii		Hyaline, smooth, subcylindrical, 15–25 um long		Hyaline, curved, obclavate (or banana-shaped), aseptate, 10–13.5 × 1–8–2.5 um, encased in a thin mucous sheath
H. subulata	Slender, terete, slightly attenuated upward 5–50 × 0.1–0.3 mm, light brown to gray, simple or furcate, longitudinal hyphae 2.5–3.0 um wide	Scattered, arising as lateral cells or buds of the cells of the outer hyphae of the synnemata or from the hyphae of the mycelium, the lower portions narrowly ellipsoid, broadly obovoid or conoid, 4–8 × 3–5		Narrowly ellipsoid, often slightly asymmetric, more conve on one side than the opposite, 4–8 × 1.5–2.5 um, 1 or 2 in spherical droplets of mucus 6–7 um in diameter
H. surinamensis				Conidia bonded together, often in rows, usually with a few granules, synnema 2 or a little more
H. thompsonii	Synnemata not produced	Conoid to strobiloid, 3.3–4.9 × 5.4–9.9, typically attenuated into two sterigmata, 1.7–6.7, but frequently only one sterigma or occasionally 3 sterigmata develop at ape	Lateral or erect, rigid, hyaline, 10.8—16.7 in length,	Hyaline, oval to round, may appear lemon-shaped due to a gelatinous capsule, 2.1–3.3 × 2.1–3.3
H. tunicata		Phialidic, mean 27.6 long, with an inflated awl-shaped lower portion 15.5 × 3.5, gradually tapering to a slender neck 12.1 × 1.0–2.0		Solitary, cymbiformecitriform (the shape of an orange segment) sometimes with a more pointed apex, due to a slightly asymmetric curvature and less conve on one side

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. tydeicola		Phialides are borne at regular distances on the hyphae and have an inflated base, 9–12 × 3–4		Singly or in pairs in a slimy substance, one-celled, hyaline, more or less fusiform and curved, measuring 4.5–6 × 1.5–2.2
H. uncinata		Phialidic, 21–36 long, in whorls of 3–6	Macronematous, scattered and single, or in pairs or caespitose groups, erect or nodding, stiff, hyaline, 200–400 um tall, the stipe 8–10 um wide at the base	Conidial mass bright white under the dissecting microscope, hyaline with the compound microscope, 7–11 um diam, containing 1–3 conidia. Conidia 5.5–7.0 × 3–4
H. vandergeestii		Narrowly conical, thickest at the base, protruding perpendicularly, sometimes somewhat obliquely in the terminal parts of hyphae, 30–36 × 4–4.5 um at the base		4.2–5.5 × 2.1–2.5, shaped like an orange segment, more strongly narrowed at the distal end and ventrally sinuous beneath subapiculate tip
H. vermicola		Singly, or occasional in pairs oppositely, monophialidic or polyphialidic, hyaline, smooth, 14–20		Hyaline, aseptate, smooth, more or less ellipsoid, arising from the ape of the neck singly or in a groups of 2–3, 6–6.5–8 µm long, 3–4–5 µm wide
H. versicolor		Monophialidic, sometimes polyphialidic, hyaline, smooth 15–25 um long, swollen up to 41 um wide near the base	Reduced to sessile conidiogenous cells or occasionally a conidiogenous cell with a single intercalary cell, arising singly	Aseptate, hyaline, smooth, more or less fusiform, 4–7 um long, about 1 um wide
H. verticillioides		Phialides 3–6 verticillate, flask-shaped, 4–7 × 20–28 um, attenuated into a sterigma 8–15 um in length.	Reduced to sessile conidiogenous cells arising singly, more or less at right angles from the vegetative hyphae, or terminal	Hyaline, oval but apparently pip-shaped due to a gelatinous substance which surrounds them, 4–5 × 6–8 um

Table 3.8 (continued)

Species	Synnemata	Phialides (um)	Conidiophores (um)	Conidia (um)
H. zhangjiajiensis	Stroma single or 2, cylindrical, 100 × 2 mm, not ramified, leathery. Stipe and fertile part brown to snuff-colored	Conidiogenous structure deriving from the microcycle conidiation of ascospores from Cordyceps zhangjiajiensis	Phialides slender awl-shaped, 30–52 × 2–4.5 um or inflated ellpsoidal at basal portion, 4.5 × 3 um	Lanceolate or the shape of an orange segment, 4.5–7.5 × 1.5–2.5 um, embedded in a mucous sheath, limoniform, 10 × 4 um

3.3.3.4 *Hymenostilbe*

Hymenostilbe Petch, Naturalist (Hull), ser. 3: 101 (1931)

Index Fungorum number: IF8598

Type species: ***Hymenostilbe muscaria*** Petch, Naturalist (Hull), ser. 3: 101 (1931).

Parasitic on insects. **Sexual morph:** The sexual morph is linked to *Ophiocordyceps*. **Asexual morph:** Hyphomycetous. Host sometimes covered with dark brown mycelium. *Synnemata* arising from the abdomen and between the segments of the body, subcylindrical, somewhat tapering upwards, composed of longitudinal somewhat interwoven, closely compacted hyphae the outer sometimes brownish and the inner part hyline. *Phialides* forming a dense palisade layer covering the synnema, developed as terminal cells of short lateral branches from the longitudinal hyphae, cylindric to clavate, bearing scattered short cylindric to slightly capitate projections especially towards the apices, with sterigmata inconspicuous. *Conidia* obovoid, hyaline, one celled. (Adapted from Mains, 1950, Samson & Evans, 1975).

Notes: This genus was introduced by Petch (1931) to accommodate two entomopathogenic taxa. The type species is parasitized a fly, which was collected from UK, the other one is parasitized a spider transfered from *Isaria*, later removed to *Gibellula* (Petch, 1931, Shrestha et al., 2019). All species of the genus are asexual morph taxa that are pathogens of arthropods (Samson & Evans, 1975), typically producing polyblastic, cylindrical to clavate conidiogenous cells, bearing multiple apical or subapical denticles (Mains, 1950, Samson & Evans, 1975). The sexual

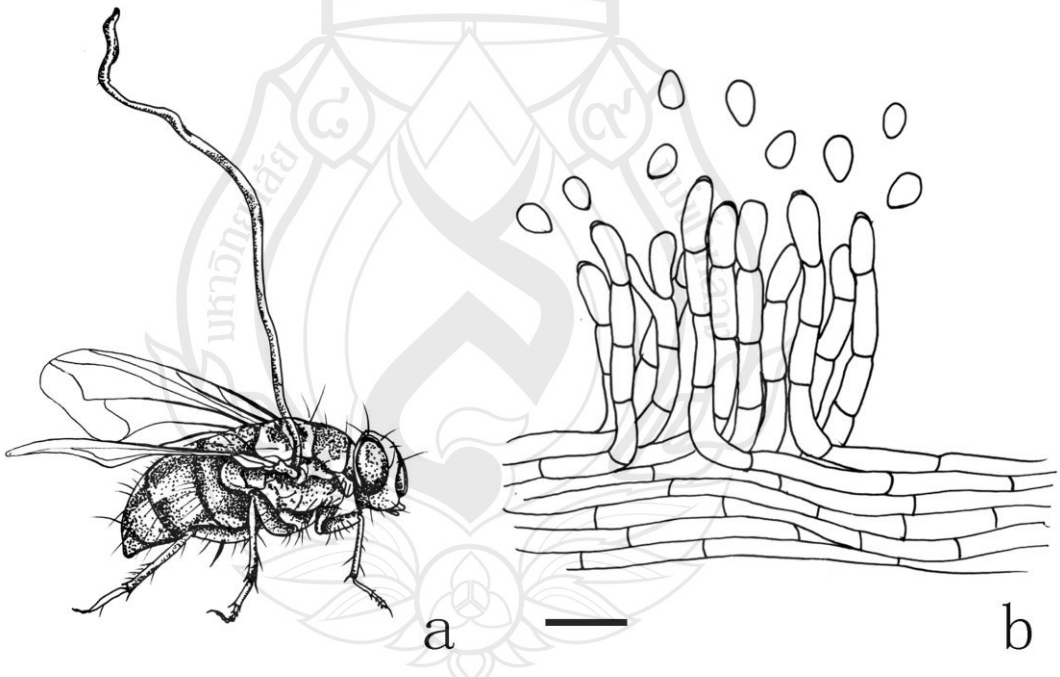
morph was linked to *Ophiocordyceps* (White et al., 2003). *Hymenostilbe* was considered as a suppressed genus in the family (Quandt et al., 2014).

Hymenostilbe aurantiaca (OSC 128578) was revised in Qu et al. (2018) revised it as *Ophiocordyceps aurantiaca*, while Araujo et al. (2018) changed it to *O. irangiensis*.

Ecological and economic significance of Hymenostilbe: Few studies investigated the chemical compounds of this group. Thus, more information is requested for the species of Hymenostilbe.

Distribution: Brazil, Japan, Great Britain, China, USA (Petch 1931, Petch 1933, Mains 1950, Hywel-Jones 1995)

Conclusion: The type species is illustrated.



Note a Overview of *Hymenostilbe muscaria*. b Synnemata with phialides and conidia. Scale Bars: b = 10 µm.

Figure 3.55 Morphology of *Hymenostilbe muscaria* (redrawn from Van Vooren & Audibert, 2006)

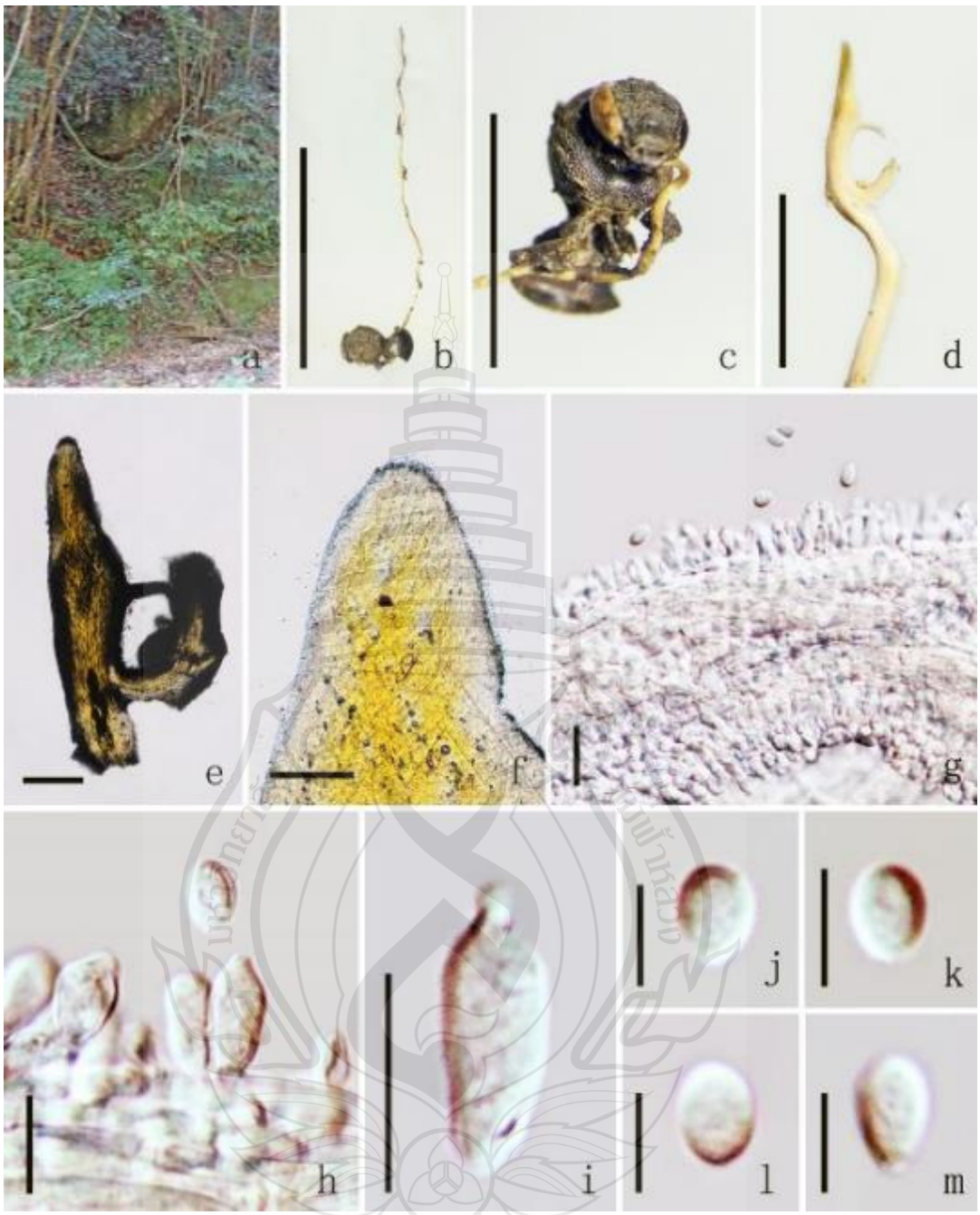
Hymenostilbe muscaria Petch, Naturalist (Hull), ser. 3: 101 (1931).

Index Fungorum Number: IF 537952

Parasitic in fly (Diptera), collected from leaf litter. **Sexual morph:** undetermined. **Asexual morph:** Hyphomycetes. *Synnemata* arising from the abdomen and between the joint of the body, cylindrical, branched or unbranched, tapering upwards, composed of longitudinal somewhat interwoven, closely compacted hyphae the outer yellowish and the inner hyaline. *Conidiophores* 27–33 μm ($\bar{x}$ = 30, n = 60) long, erect, arising from vegetative hyphae, bearing phialides aggregates. *Phialides* 12.9–18.9 × 7–9.1 μm ($\bar{x}$ = 15.9 × 8.1 μm, n = 90), cylindrical to clavate, forming a dense palisade layer covering the synnemata, developed as terminal cells of short lateral branches from the longitudinal hyphae, earing scattered short cylindrical to slightly capitate projections specially towards the apices. *Conidia* 7–9.5 × 4.8–6.2 μm ($\bar{x}$ = 8.3 × 5.5 μm, n = 90) globose to subglobose or obovoid, hyaline, smooth, 1-celled.

Material examined: China, Guizhou Province. Parasitic on fly 11 June 2018, YuanPin Xiao.

Notes: *Hymenostilbe muscaria* was sister with *Ophiocordyceps sphecocephala* and CM10 in the phylogenetic tree. However, *Ophiocordyceps sphecocephala* and CM10 were parasite on wasp, while *Hymenostilbe muscaria* paracite on fly (Diptera). Morphologically, the new collection simmlar to *Hymenostilbe muscaria* by paracitizing on fly and producing yellowish synnemata, globose to subglobose conidia (Van Vooren & Audibert, 2006). Thus, the new collection was identified as *Hymenostilbe muscaria*. Although, *Hymenostilbe muscaria* was proposed to be suppressed (Quandt et al., 2014). We would like to update the morphology and molecular data of *Hymenostilbe muscaria* for further study.



Note a Habitat of *Hymenostilbe muscaria*. b Overview of host. c–f Synnema. g, h Conidiophores. i phialides. j–m Conida. Scale Bars: b = 1 cm, c = 5 mm, d = 2 mm, e, f = 200 µm, g = 20 µm, h, i = 10 µm, j–m = 5 µm.

Figure 3.56 Morphology of *Hymenostilbe muscaria*

Table 3.9 Morphological comparison of asexual morph species of *Hymenostilbe*

Species name	Synnemata	Phialides (um)	Conidia (um)
H. ampullifera	Synnemata small, white, irregularly cylindric or conical clavae from the joints of the legs, the body, and the tip of the abdomen,	Phialides flask-shaped, 11–15 × 4–5, and barren, cylindric or clavate cells, rounded above, not verrucose, 10 × 3	Conidia narrow oval, 7–11 × 2–2.5, compressed and appearing cylindric
H. aurantiaca	Synnema emerging from between thorax and head of host; single, rarely multiple, slender, cylindrical, up to 150 × 150–200	Conidiogenous cells pigmented, orange, clavate, 9.3–25.0 × 3–6, indeterminate polyblastic with sympodial succession	Conidia solitary, cymbiform to obclavate to strongly obclavate, orange, 5.3–17.0 × 1.3–3.0
H. lecaniicola	Synnemata several, cylindric to slightly clavate, 3 × 0.1–0.5, gray to brownish, pruinose, consisting of closely compacted, longitudinal, parallel hyphae	Phialides scattered to moderately crowded, very variable, subcylindric, frequently with one or more constrictions, 10–30 × 4–5	Conidia ellipsoid to broadly fusoid, 4–8 × 2–2.5 um, hyaline single
H. melanopus	Species statum conidicum cordicipitis australis Speg. Facillime sistum; stipites glabri rectiusculi laeves 4–5 × 450–200	More or less developed in the trunk decurrentibus (0.5–4 × 250–500 um) laugh; sterigmata cylindrical (40–45 × 3 um) thin blunt tip intact;	Conidia elliptical-obovato walled 5–10 × 3–4
H. ventricosa	Synnemata several, 6–13 mm long × 200–350 um wide, cylindrical, very pale pink	Conidiogenow cells polyblastic, cylindrical to clavate, 11.3–20.0 × 4.5–6.0	Conidia solitary, ventricose, 10.0–14.0 × 3.7–5.3

3.3.3.5 *Paraisaria*

Paraisaria Samson & B.L. Brady, Trans. Br. mycol. Soc. 81: 285 (1983)

Index Fungorum: IF 25834

Type species: ***Paraisaria gracilis*** (Grev.) Luangsa-ard, Mongkolsamrit & Samson, comb. nov.

Parasitic and pathogentic on insects. **Sexual morph:** *Stroma* robust, solitary. *Fertile head* 2–10 × 1.5–7 mm, globose or ovoid. *Stipe* fleshy and cream. *Perithecia* ovoid-ellipsoid or obclavate, completely immersed and ordinal in orientation. *Peridium* three layers. *Asci* hyaline, cylindrical, eight-spored. *Ascospores* hyaline, filiform, multiseptated. *Secondary spores* regular cylindrical. **Asexual**

morphs: *Synnemata* white, loose. *Conidiophores* verticillately branched, polyphialidic. *Phialides* flask-shaped, bases swollen with a thin tapering neck. *Conidia* narrowly cylindrical to fusiform, produced in slimy heads (Adapted to Mongkolsamrit et al., 2019).

Notes: This genus was introduced to accommodate a single species *Paraisaria dubia* (Synonyms: *Isaria dubia*), which sexual morph linked to *Cordyceps gracilis* (Basionym: *Xylaria gracilis*) (Greville, 1824, Samson & Brady, 1983, Mains, 1951). *Ophiocordyceps* was proposed to be protected over *Paraisaria*, which is younger and contained fewer taxa (Quandt et al., 2014). A new combination, *Ophiocordyceps gracilis*, was proposed to represent *Paraisaria dubia* (Quandt et al., 2014). Mongkolsamrit et al. (2019) resurrected the genus *Paraisaria* with three new species and eight new combinations based on morphology and phylogenetic evidence. In addition, Wei et al. (2021) introduced three new species under the genus from China and Thailand.

The sexual morphs of *Paraisaria* are distinct from other species of *Ophiocordyceps* in producing solitary stipitate stromata with globose or ellipsoid fertile heads, immersed perithecia, cylindrical asci, multiseptate ascospores and regular cylindrical secondary spores; the sexual morphs of *Paraisaria* have verticillate branched conidiophores, flask-shaped usually sympodially proliferating phialides, which terminate in 1–4 necks, and aseptate, hyaline, smooth-walled conidia, which usually aggregate in slimy heads (Samson & Brady, 1983, Mongkolsamrit et al., 2019; Wei et al., 2021). The species of *Paraisaria* are pathogens associated with cicada nymphs (Hemiptera), larvae of Coleoptera, Diptera, Lepidoptera, adult and nymphs of Orthoptera, adult Dictyoptera (Blattaria) and ants (Hymenoptera) (Mongkolsamrit et al., 2019; Wei et al., 2021).

In this study, the morphology characters of peridium from six species are recorded, including *Pa. alba*, *Pa. arcta*, and *Pa. rosea*, *Pa. amazonica*, *Pa. tettigonia* and *Pa. obovate*. These six species of peridium have three layers, *textura porrecta* outer layer formed a dense palisade layer covering the fertile head, *textura intricata* middle layer, *textura porrecta* inner layer. This character has potential to be one of the significant features for genus rank identification.

Ecological and economic significance of Paraisaria: Few taxa in

Paraisaria was reported as benefiting ecology and economy except *Paraisaria gracilis,* which used in traditional Kazakh medicine (Huang et al., 2019). The strains of *Paraisaria gracilis* have antioxidation and antibacterial activity (Ma et al., 2012; Suo et al., 2014).

Distribution: Algeria, Argentina, Australia, Belgium, Brazil, China, Czech, Denmark, France, Germany, Korea, Luxembourg, Mexico, Nepal, Norway, Poland, Slovakia, Russia, Serbia, Switzerland, Britain, USA (Hennings, 1904; Kobayasi, 1939, 1941; Samson & Brady, 1983; Evans et al., 2010; Sanjuan et al., 2015; Simmons et al., 2015; Wen et al., 2016; Mongkolsamrit et al., 2019).

Conclusion: The type species is illustrated; One new host and one new species are described; three species have updated the description of the peridium with the illustration respectively; one new combination is introduced.

Type species: ***Paraisaria gracilis*** (Grev.) Luangsa-ard, Mongkols. & Samson, in Mongkolsamrit, Noisripoom, Arnamnart, Lamlertthon, Himaman, Jangsantear, Samson & Luangsa-ard, Mycol. Progr. 18(9): 1219 (2019)

Basionym: *Xylaria gracilis* Grev., Scott. crypt. fl. (Edinburgh) 2: 86 (1824).

Synonyms: *Cordyceps gracilis* (Grev.) Durieu & Mont., in Durieu, Expl. Sci. Alg., Fl. Algér. 1(livr. 12): 449 (1848).

Cordyceps entomorrhiza var. gracilis (Grev.) Cooke, Grevillea 12(no. 64): 102 (1884).

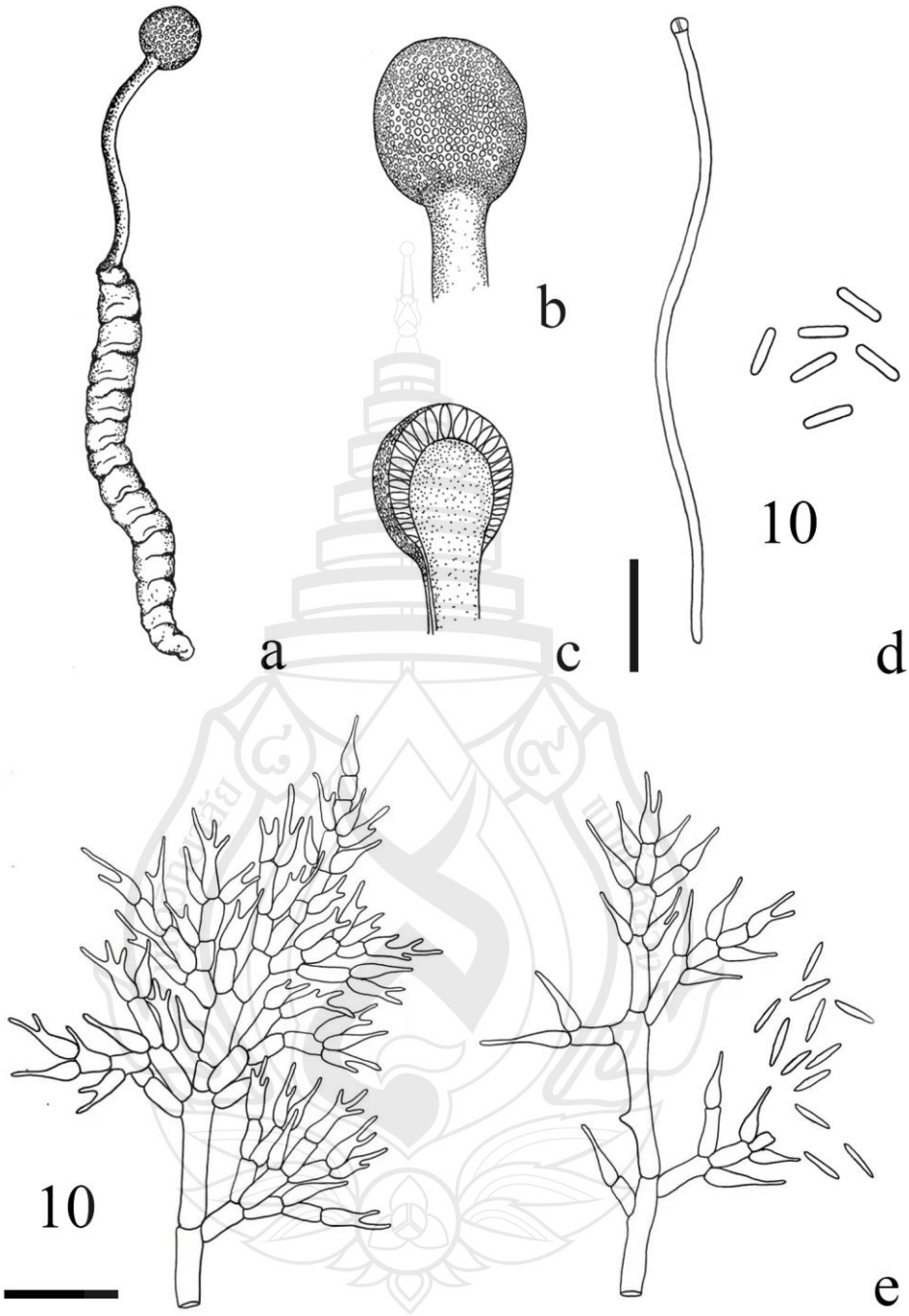
Cordyceps mawleyi J.O. Westwood, Gard. Chron., Ser. 3: 553 (1891)

Isaria dubia Delacr., in Patouillard & Lagerheim, Bull. Soc. mycol. Fr. 9(3): 163 (1893)

Spicaria dubia (Delacr.) Petch, Trans. Br. mycol. Soc. 21(3-4): 297 (1938)

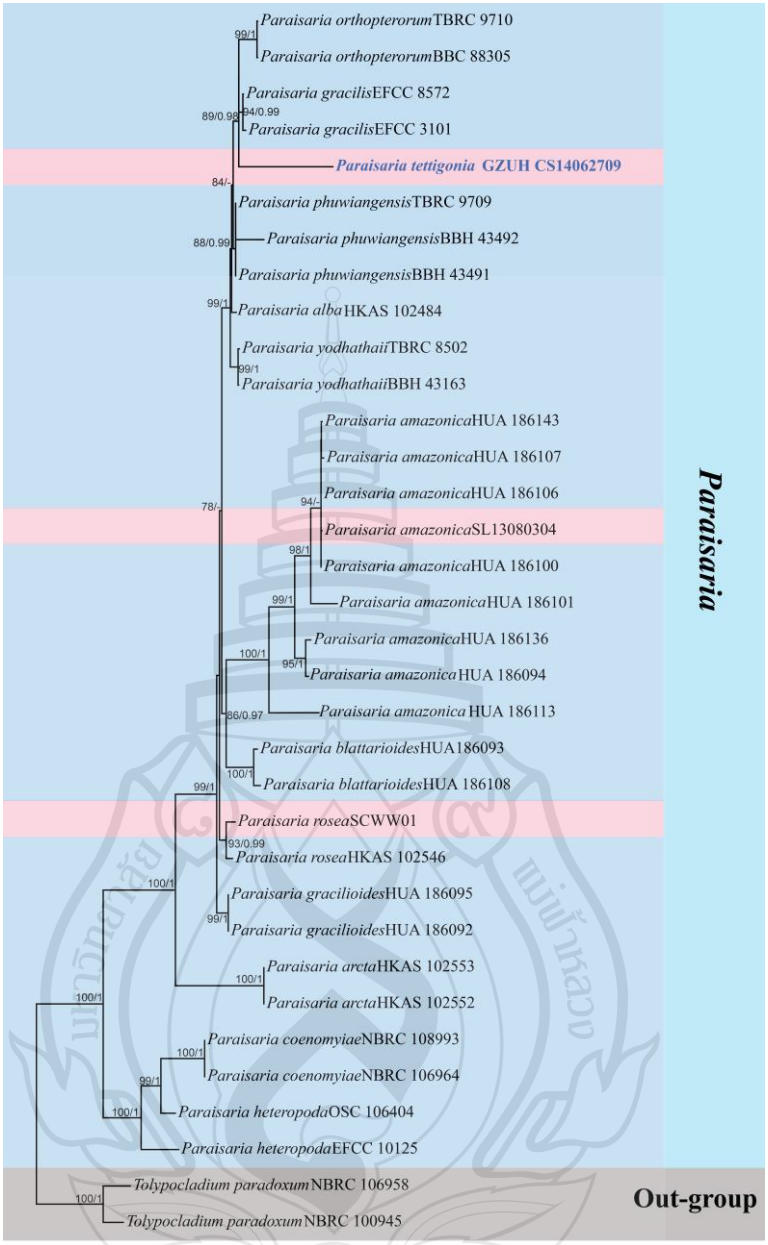
Paraisaria dubia (Delacr.) Samson & B.L. Brady, Trans. Br. mycol. Soc. 81(2): 285 (1983)

Neotype: IMI 41601



Note a-e. *Paraisaria gracilis* (a, e, redrawn from Samson & Brady, 1983, c-d, redrawn from Greville 1824). a Overview of *Paraisaria gracilis*. b Fertile head. c Vertical section of fertile head. d Ascus and secondary ascospores. e Conidiophores, phialides and conidia. Scale Bars: d, e = 10 µm.

Figure 3.57 Morphology of *Paraisaria gracilis*



Note Phylogenetic tree of *Paraisaria* species generated from maximum likelihood analysis of ITS, SSU and LSU sequence data .*Tolypocladium paradoxum* (NBRC 106958) and *Tolypocladium paradoxum* (NBRC 100945) were used as outgroup taxa This phylogenetic tree of *Paraisaria* comprises 34 taxa (including the 3 newly collected taxa) analysed. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.95 are indicated above the nodes .The ex-types are indicated in bold.

Figure 3.58 Phylogenetic tree of *Paraisaria* species

Paraisaria amazonica (Henn.) Luangsa-ard, Mongkols. & Samson, in Mongkolsamrit, Noisripoom, Arnamnart, Lamlertthon, Himaman, Jangsantear, Samson & Luangsa-ard, Mycol. Progr. 18(9): 1225 (2019).

Basionym: Cordyceps amazonica Henn. 1904

Index Fungorum number: IF 831112

Parasitic on grasshopper (Orthoptera), collected from the underside of leaves litter. **Sexual morph:** *Host* 23–25 mm long, 5–10 mm wide, glasshopper without hyphae on the surface. *Stromata* 30–32 mm long, 2–5 mm wide., mostly single, stipitate, arising from between the abdomen of adult glasshopper, yellow to brown. *Stipe* 28–30 mm long, 2 mm wide, clavate, with a fertile apex. *Fertile head* 4–5 mm diam, global, brown, upper surface roughened, ridged and furrowed. *Perithecia* 952–1176 × 192–265 µm ($\bar{x}$ = 1064 × 228 µm, n = 30), immersed, long ovoid, thin-walled. *Peridium* 32–65 mm ($\bar{x}$ = 48 µm, n = 60) wide, three layer, *textura porrecta* outer layer formed a dense palisade layer covering the fertile head, *textura intricata* middle layer, *textura porrecta* inner layer. *Asci* 660–740 × 5–7 µm ($\bar{x}$ = 700 × 6 µm, n = 60), 8-spored, hyaline, narrow cylindrical, with a thickened apex. *Apical cap* 3.8–5.2 × 6.7–7.9 µm ($\bar{x}$ = 4.5 × 7.3 µm, n = 60), with a small channel in the center. *Ascospores* as long as asci, easily breaking into part-spores, filiform. *Secondary ascospores* 9.4–11.9 × 1.6–2.1 µm ($\bar{x}$ = 10.7 × 1.8 µm, n = 90) cylindrical, mostly straight, hyaline, smooth. **Asexual morph:** undertermined.

Material examined: Ecuador, Amazonia, Orellana, NP Yasuni, rainforest, on dead grasshopper (Orthoptera) burin in leaf litter, 18 March 2013, Kautmanova, V. Kautman, SL13031804 (new host).

Notes: The new collection is identified as *P. amazonica* because it shares the same clade with *P. amazonica* in the phylogenetic tree and morphology also support the conclusion. *Paraisaria amazonica* was a common pathogen of the imagos and adult's species of Acrididae and Romelidae and widely distributed in Amazon region, including Brazil, Colombia and Ecuador (Henning, 1904; Mains, 1959; Sanjuan et al., 2015). Sanjuan et al. (2015) redescribed this species and designed its lectotype and epitype. In this study, a new host, grasshopper (Orthoptera), is reported as pathogen of *P. amazonica.* Moreover, the peridium characters for the species are updated.

Note a. Habitat. b. Ascostroma emerging from infected host. c. Host. d. Fertile head. e. Vertical section of the stroma. f. Perithecia. g. Peridium. h–j. Asci. k. Parts of asci. l. Apical cap of asci ascospores. m–o. Secondary ascospores. Scale Bars: e = 1000 µm, f, h–j = 500 µm, g, k = 50 µm, l–o = 10 µm.

Figure 3.59 Morphology of *Paraisaria amazonica*

Paraisaria tettigonia (T.C. Wen, Y.P. Xiao & K.D. Hyde) Luangsa-ard, Mongkols. & Samson [as 'tettigonia'], in Mongkolsamrit, Noisripoom, Arnamnart, Lamlertthon, Himaman, Jangsantear, Samson & Luangsa-ard, Mycol. Progr. 18(9): 1225 (2019).

Index Fungorum number: IF 839725

Parasitic on grasshopper (Orthoptera), **Sexual morph:** *Parasitic* on adult of *Tettigonia*. Host covered with white, dense mycelium, substratum buried in the soil, red to red-brown. Sexual morph: *Stromata* 35–40 mm long, 2–2.5 mm wide, growing from the head, with two branches. *Stipe* 32–37 mm long, 2 mm wide, flexuous, white. *Fertile head* 2–2.5 mm wide, globose, differentiated from stipe. *Ascomata* 520–677 × 207–276 μm ($\bar{x}$ = 599.1 × 242.0, n = 30), completely immersed, elongated or ampuliform, with the ostioles opening on the surface of the head. *Peridium* comprised of three layers, 30–78 μm ($\bar{x}$ = 54 μm, n = 90) wide, the outer layer of the ascostroma, *textura prismatica* with a palisade covered the fertile head, 22–35 μm ($\bar{x}$ = 28, n = 30) wide for the next two layers, *textura porrecta* middle layer formed a dense palisade layer covering the fertile head, *textura intricata* inner layer filled up the interval, hyaline. *Asci* 533.7–612.8 × 6.5–9.3 μm ($\bar{x}$ = 573.3 × 7.9, n = 30), 8-spored, hyaline, cylindrical, possessing a prominent apical cap. *Apical cap* 3.88–4.81 μm wide ($\bar{x}$ = 4.35, n = 30). *Ascospores* 350.4–463.6 × 1.5–2.2 μm ($\bar{x}$ = 407.0 × 1.8, n = 60), fasciculate, thread-like, slender and long, breaking into secondary ascospores when mature. *Secondary ascospores* 6.7–9.4 × 1.5–2.3 μm ($\bar{x}$ = 8.1 × 1.9, n = 60), hyaline, cylindrical. **Asexual morph**: Undetermined.

Material examined: China, Guizhou Province: Chishui City, Shizhangdong scenic spot, Chishui Danxia natural world heritage site, on adult of Tettigonia in the soil, 9 June 2014, Ting-Chi Wen CS14062709 (**Holotype**: GZUHCS14062709).

Notes: This species was described by Wen et al. (2016) and removed to *Paraisaria* based on morphology and phylogenetic analyses (Luangsa-ard et al., 2019). Here we add the description for the peridium, which covered the fertile head.

Note a. Overview of stromata and the host. b. Pale, superficial ascomata on stroma. c. Cross section showing the complete stroma and perithecia. d–f. Sections of ascomata. g, h. Part of perithecia. i–k. Asci. l. Ascus with apical cap. m. Ascus with apical cap dyed by iodine solution. n. Asci dyed by iodine solution. o. Secondly ascospores. p. Secondly ascospore dyed by iodine solution. Scale bars: d = 10000 µm, e, f = 2000 µm, g = 20 µm, h = 50 µm, i–k = 1000 µm, l, m, o, p = 10 µm, n = 500 µm.

Figure 3.60 Morphology of *Paraisaria tettigonia*

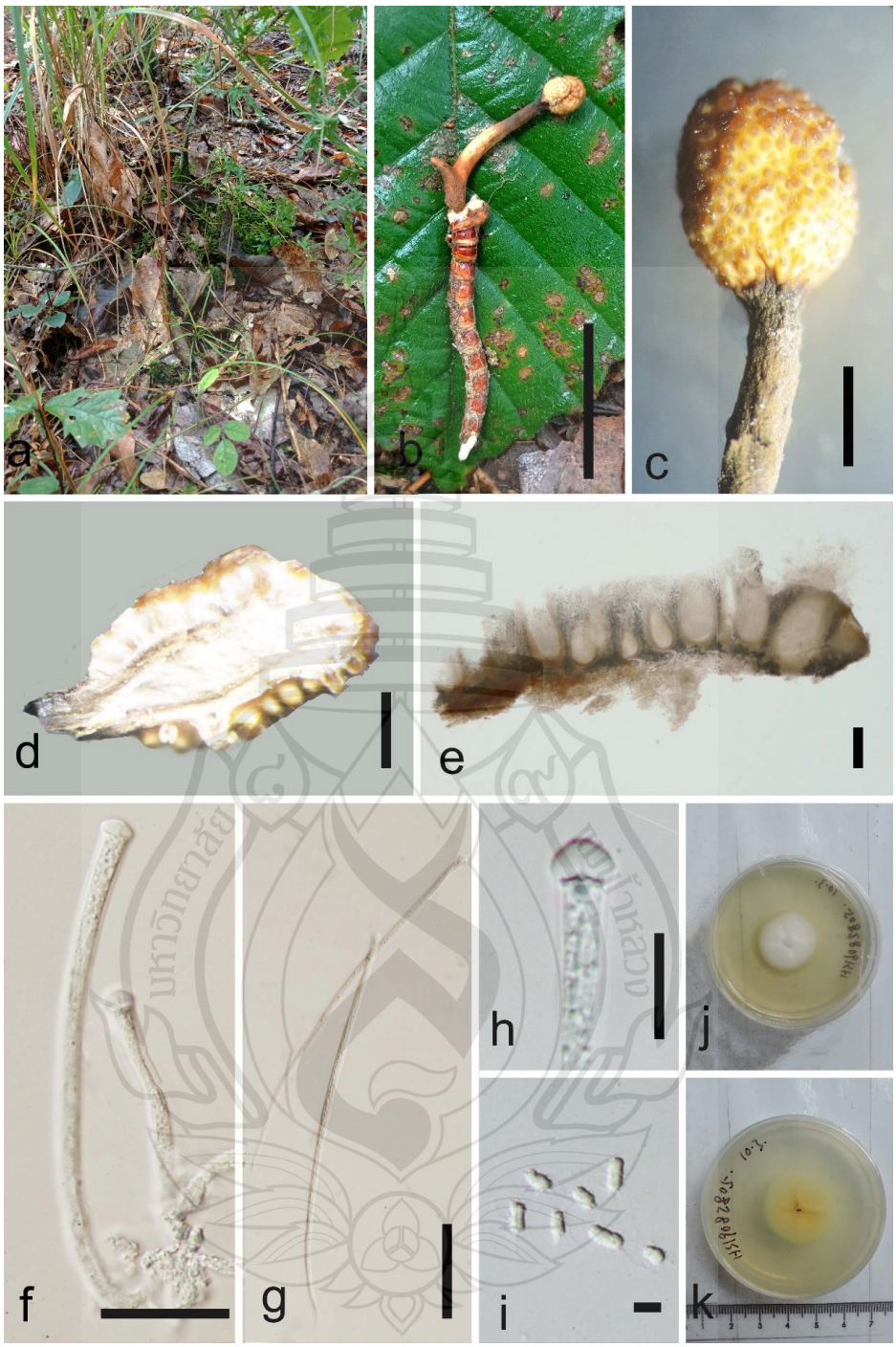
Paraisaria rosea D.P. Wei & K.D. Hyde, in Wei, Wanasinghe, Xu, To-anun, Mortimer, Hyde, Elgorban, Madawala, Suwannarach, Karunarathna, Tibpromma & Lumyong, Frontiers in Microbiology 11(no. 608991): 11 (2021)

Index Fungorum number: IF 808698

Parasitic in *Parasitic* on Coleoptera larva, buried in the soil. **Sexual morph:** *Stromata* 2–3 cm long, 1–3 mm wide, capitate, bi-colored, brown to dark brown at the stipe, brown at the fertile head when fresh, dark when dry, hard, mostly solitary, branched, stipitate, inside hollow when mature. *Stipe* 1.5–2.5 cm long, 2–5 mm wide, cylindrical with a branch, brown to dark brown when fresh, dark brown when dry, hollow when mature, with fertile head on the top. *Fertile head* 3–5 mm wide, globose, with minutely mammilate on the surface, brown when fresh, dark brown when dry, distinctly separated from stipe, hard, solitary, with a cortex of closely interwoven hyaline hyphae pseudoparenchymatous in section. *Perithecia* 735–867 × 217–241 μm ($\bar{x}$ = 801 × 229 μm, n = 30), immersed, globose to ovoid. *Peridium* 30–45 μm ($\bar{x}$ = 38 μm, n = 60) wide, three layers, out layer: textura angularis with palisade issue on the surface, up to 25 μm thick, brown; light brown, dense textura angularis middle layer; hyaline, textura porrecta inner layer. *Asci* 486–539 × 4.4–6.2 um ($\bar{x}$ = 512.5 × 5.3 μm, n = 60), 8-spored, unitunicate, narrow cylindrical, hyaline, with thick apex. *Apical cap* 4.1–5.2 × 4–6.2μm ($\bar{x}$ = 4.7 × 5.1 μm, n = 60) μm, hyaline. *Ascospores* as long as asci, filiform, hyaline break into secondary spores. *Secondary spores* 4.2–8.5 × 1.4–1.9 μm ($\bar{x}$ = 6.4 × 1.7 μm, n = 60), cylindrical, smooth, hyaline, aseptate. **Asexual morph:** Undetermined.

Material examined: China, Guizhou Province, Zunyi City, Wuchuan County. 28 August 2019, Yu Yang (HS19082805, reference specimen).

Notes: The new collection grouped with *Paraisaria rosea* with a high value in the phylogenetic tree. We indicate a reference specimen of *Paraisaria rosea* in this study.



Note a Habitate. b Overview of the *Paraisaria rosea*. c Fertile head of stroma. d, e Vertical section of the stroma. f, g Asci. h Apical cap of asci. i Secondary ascospores. j, k Culture. Scale Bars: d = 1000 µm, e = 500 µm, f = 100 µm, g = 50 µm, h = 20 µm, i = 5 µm

Figure 3.61 Morphology of *Paraisaria rosea*

Table 3.10 Morphological comparison of asexual morphic species of the genus *Paraisaria*

Species	Phialides (um)	Conidia (um)	Reference
P. gracilioides	5.5–27 × 2.0–3.9	Narrowly cylindrical to fusiform, one-celled, 3.0–14.5 × 1.0–2.0	Kobayasi (1941)
P. gracilis	4–6.4 × 2.4–3.2, frequently sympodially proliferating, with a swollen venter giving rise to 1-6 sharply narrowed necks, 1.6–2.4 × 0.8–1.5	Narrowly cylindrical to fusiform, one-celled, hyaline, smooth-walled, 3.2–4.8 × 0.8	Samson and Brady (1983), Mongkolsamrit et al. (2019)
P. heteropoda	Phialides in whorls of 2–3, 2–16 × 2–3, swollen at the base or slightly flask-shaped tapering into a long neck, 4–7 × 1–1.5	Conidia ellipsoidal, 3.5–5 × 1.5–2 mostly aggregated in slimy heads at the apex of the 2–3 phialides	Kobayasi (1939), Mongkolsamrit et al. (2019)
P. orthopteroru m	Phialides solitary or in whorls of 2–3, cylindrical at the base or slightly flask-shaped, 7–15 × 2–3; phialide necks distinct, 3–5 × 1, polyphialidic.	Conidia two types; type1: fusiform, 3–7.5 × 1.5–2, mostly aggregated in slimy heads at the apex of three phialides; type2: cylindrical, 5.5–7 × 1–1.5, fusiform, 3.5–5 × 1,	Mongkolsamrit et al. (2019)
P. paramyrmicar um	Primary phialides subulate, hyaline or pigmented at base, 39.9–86.2 × 3.6–5.4. Secondary phialides subulate and hyaline, 27.2–47.0, 2.4–3.3 um wide at base	Conidia 7.3–9.6 × 3.2–5.1, reniform to ovoid, biguttate, bound in mucilaginous spheres, composed of 1–4 conidia, at phialide apex	Evans et al. (2010), Simmons et al. (2015)
P. phuwiangensi s	MEA: Phialides solitary or in whorls of 2–3, swollen at the base or slightly flask-shaped, 7–11 × 3–4, with short phialide necks, 2.5–3 × 1. PDA: Phialides solitary or in whorls of 2–3, swollen at the base or slightly flask-shaped, 6–9 × 2–3, tapering into short phialide necks, 1.5–3 × 1	Conidia 6–8 × 2, PDA: Conidia distinctly of two types: mostly cylindrical, 7–9.5 × 1.5–2; fusiform, 3–4 × 1–1.5	Mongkolsamrit et al. (2019)

Table 3.10 (continued)

Species	Phialides (um)	Conidia (um)	Reference
P. yodhathaii	Conidiogenous cells monophialidic or polyphialidic, hyaline. Phialides mostly solitary, seldom in whorls of 2–3, cylindrical at the base or slightly flask-shaped, 7–15 × 2–3, with a distinct phialide necks,2–6 × 1–1.5, with numerous branching on the neck (polyphialidic).	MEA: Conidia hyaline, smooth, aseptate, fusiform, 5–7 × 1.5–2. PDA or PSA: distinctly of two types: mostly cylindrical, 5.5–7.5 × 1–1.5; fusiform, 3–5 × 1, mostly aggregated in slimy heads at the apex of three phialides	Mongkolsamrit et al. (2019)

Table 3.11 Morphological comparison of sexual morphic species of the genus *Paraisaria*

Species	Stromata (mm)	Perithecia (um)	Secondary spores (um)	Reference
P. amazonica	Stromata solitary to single or gregarious, capitate 20-45	Perithecia ellipsoid, 800-1100 × 250-400	Rgular cylindrical 9-15 × 1.5-2	Sanjuan et al. (2015)
P. amazonica	Stromata capitate, solitary to several, growing from the body of adult Orthoptera.	Perithecia completely immersed, evenly distributed, ordinal, narrowly ovoid.	10 × 0.5-0.7	Hennings (1904)
P. blattarioides	Stromata solitary to gregarious, capitate, 10-20 mm long.	Perithecia ellipsoid, 760-800 × 220-300 um, wall 15-25 um	Regular cylindrical 6-12 × 1.5	Sanjuan et al. (2015)
P. coenomyiae	Stroma: solitary, arising from the head of host larva living in soil.	Perithecia: lanceolate, alutaceous, 700–750×200–220 μm, vertically immersed	Cylindrical, 8–15 × 1.8–2.5, 11.4–2.0 on average	Mongkolsamrit et al. (2019)
P. phuwiangensis	Stroma arising from head region of Coleoptera larva.	Perithecia obpyriform, crowded, 800–1200 × 300–380, completely immersed.	Cylindrical, 6–9 × 1–2	Mongkolsamrit et al. (2019)

Table 3.11 (continued)

Species	Stromata (mm)	Perithecia (um)	Secondary spores (um)	Reference
P. yodhathaii Mongkolsamrit	Stromata arising from prothorax and abdomen of Elateridae larva (Coleoptera).		Cylindrical part-spores, 5–8.5 × 1–2	Mongkolsamrit et al. (2019)
P. tettigonia	Stromata 35–40 mm long, 2–2.5 mm wide, growing from the head, with two branches.	Ascomata 520–680 × 205–275, completely immersed, elongated or ampuliform, with the ostioles opening on the surface of the head.	6.7–9.4 × 1.5–2.3, hyaline, cylindrical	Wen et al. (2016)
P. orthopterorum	Stromata arising from head of orthopteran nymphs.	Perithecia obclavate, completely immersed, 553–627× 155–222	Cylindrical, 6–9 × 1–1.5	Mongkolsamrit et al. (2019)
P. gracilis	It forms striking solitary stromata, 15--0 mm long, with a deep chrome yellow	perithecia are completely embedded, 560-840 × 200-360	6–8 × 1–1.5	Samson and Brady (1983), Mongkolsamrit et al. (2019)
P. gracilioides	Stromata single, fruit body usually arising from the head of host (Larvae of Coleoptera).	Perithecia immersed, elongate- ampullaceous, 830–900 × 200–280	Cylindrical, 6.3–8.5 × 1.2–1.5	Mongkolsamrit et al. (2019)

3.3.3.5 *Purpureocillium*

Purpureocillium (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson, FEMS Microbiol. Lett. 321(2): 144 (2011)

Index Fungorum number: IF519529

Pathogenic of insects, nematodes, human and other vertebrates, or air-inhabiting or soil-inhabiting **Sexual morph:** Undetermined. **Asexual morph:** Hyphomycetous. *Phialides* ovate to cylindrical, with distinct necks or erect and densely grouped phialides. *Conidia* straight to slightly curved or ellipsoidal to fusiform, slightly roughened, purple in mass, in dry divergent chains (adapted from Luangsa-ard et al., 2011).

Type species: ***Purpureocillium lilacinum*** (Thom) Luangsa-ard, Houbraken,

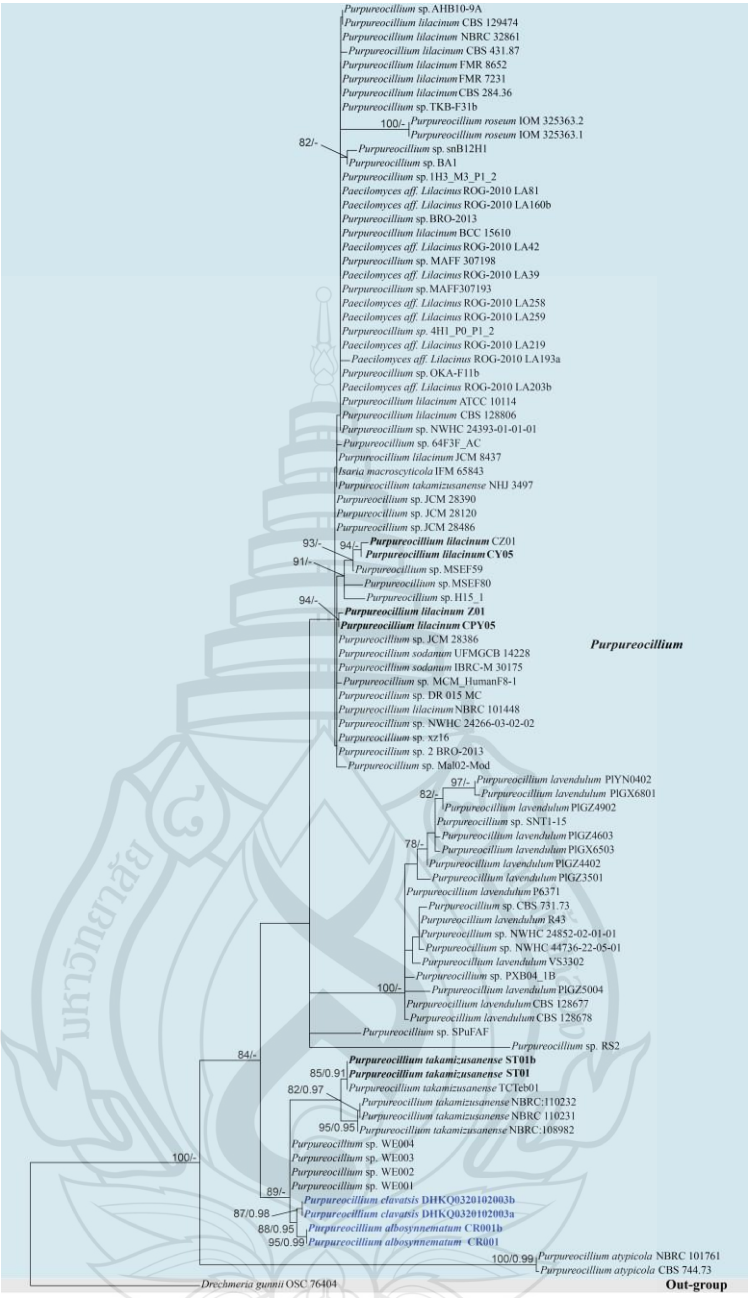
Hywel-Jones & Samson

Notes: The genus was described by Luangsa-ard et al. (2011) for one emended medical species, *Paecilomyces lilacinum*, based on morphology and phylogenetic evidence (Luangsa-ard et al., 2011). Two new species were added to the genus by Perdomo et al. (2013) and Hyde et al. (2016) respectively; two new combinations were introduced by Ban et al. (2015) and Spatafora et al. (2015). No sexual morph has been reported for this genus. The genus is characterised by ovate to cylindric phialides with distinct necks or erect and densely grouped phialides, which are purple in mass conidia (Matočec et al., 2014, Xiao et al., 2018).

Ecological and economic significance of Purpureocillium: Shared characters for this clade include purple-hued conidia and pathogenesis of arthropods, although *P. lilacinum* and P. lavendulum have been cultured from various substrates (Perdomo et al., 2013), and *P. lilacinum* can cause keratitis and other mycoses in humans and other vertebrates (Pastor & Guarro, 2006, Rodríguez et al., 2010).

Distribution: Antarctica, Austria, Brazil, China, Colombian, Costa Rica, France, Germany, Ghana, India, Iran, Iraq, Japan, Mexico, Peru, Portugal, South Africa, Spain, Sri Lanka, Thailand, Venezuela (Rakeman et al., 2005; Gazis et al., 2011; Oliveira et al., 2013; Perdomo et al., 2013; Eberhard et al., 2014; Kepler et al., 2014; Schoch et al., 2014; Fazli et al., 2015; Penkhrue et al., 2015; Rédou et al., 2015; Yamamoto-Tamura et al., 2015; Hyde et al., 2016; Lorch et al., 2016; Salamone et al., 2016; Carrino-Kyker et al., 2017; Sugiyama et al., 2017; Wang et al., 2017; Araújo et al., 2018; Glynou et al., 2018; Manganyi et al., 2018; Meyer et al., 2018; Schmidt et al., 2018; Xiang et al., 2018; Campos-Rivero et al., 2019; Milanesi et al., 2019; Niu et al., 2019; Skaltsas et al., 2019; Trovão et al., 2019; Vu et al., 2019)

Conclusion: The type species is illustrated; two new species is described, two new records; all the species are listed; all the GenBank accession numbers for *Purpureocillium* are listed.



Note Phylogenetic tree of *Purpureocillium* species generated from maximum likelihood analysis of ITS, SSU, LSU, RPB1, RPB2 and TEF1α sequence data. *Drechmaria gunnii* (OSC 76404) was used as outgroup taxa. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.95 are indicated above the nodes .The new species are in red. The ex-types are indicated in bold.

Figure 3.62 Phylogenetic tree of *Purpureocillium* species

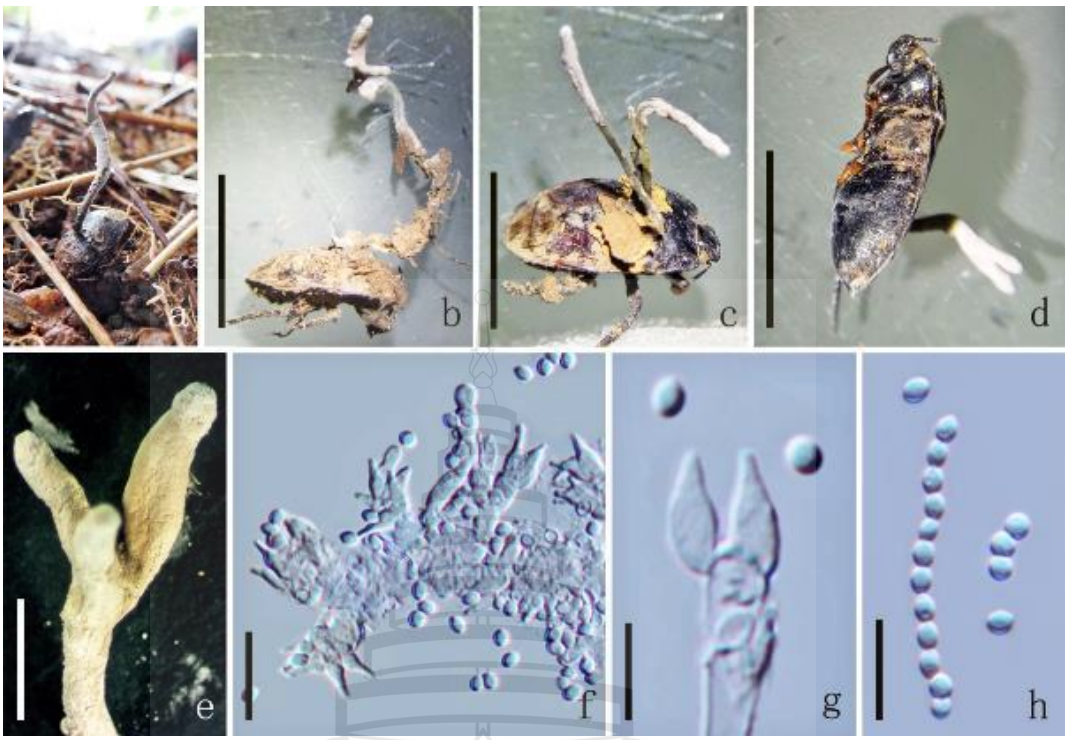
Purpureocillium lilacinum (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson, in Luangsa-ard, Houbraken, Doorn, Hong, Borman, Hywel-Jones & Samson, FEMS Microbiol. Lett. 321(2): 144 (2011).

Index Fungorum Number: IF519530

Parasitic on insects (Hymenoptera, Cydnidae), collected from the underside of leaves litter. **Sexual morph**: undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* on insect, usually solitary, sometimes double or more, cylindrical, unbranched or branched, up to 4 cm long, 2 mm wide, with stipe. *Stipe* cylindrical, black, unbranched, hard, up to 2 cm long, 1 mm wide. *Fertile head* cylindrical, unbranched or branched, purple, up to 2cm long, 2mm wide, with masses of conidia on surface. *Conidiophores* arising from the fertile head, 13.4–16.3 × 2.9–4.1 µm ($\overline{x}$ = 14.9 × 3.5 µm, n = 150), divaricate or terverticillate. *Metula* 5.9–8.7 × 2.6–3.9 µm ($\overline{x}$ = 7.3 × 3.3 µm, n = 150), hyaline, cylindrical, swollen. *Phialides* 7.3–9.1 × 2.2–3.5 µm ($\overline{x}$ = 8.2 × 2.9 µm, n = 150), with a short neck. Conidia 2.6–3.3 × 1.9–2.5 µm ($\overline{x}$ = 2.9 × 2.2 µm, n = 150) in dry divergent chains, ellipsoidal or fusiform, 1-celled, smooth-walled, hyaline, purple in mass.

Material examined: Thailand, Chiang Rai, on dead insect (Hymenoptera, Cydnidae), 19 July 2018, YuanPin Xiao.

Notes: The new collections were clusted with *Purpureocillium lilacinum* in the phylogentic tree with high support. The morphology similar to *Purpureocillium lilacinum*. Thus, we identified the new collections as *Purpureocillium lilacinum*.



Note a Habitat of *Purpureocillium lilacinum*. b-d Fungus on insect. e Synnemata. f, g Conidiophores. h Conidia. Scale Bars: b-d = 1 cm, e = 2000 µm, f, h = 10 µm, g = 5 µm.

Figure 3.63 Morphology of *Purpureocillium lilacinum*

Purpureocillium takamizusanense (Kobayasi) S. Ban, Azuma & Hiroki Sato, in Ban, Azuma, Sato, Suzuki & Nakagiri, Int. J. Syst. Evol. Microbiol. 65: 2463 (2015).

Index Fungorum Number: 811842

Synonyms: *Isaria takamizusanensis* Kobayasi, Sci. Rep. Tokyo Bunrika Daig., Sect. B 5: 229 (1941)

Cordyceps ryogamimontana Kobayasi, Bull. natn. Sci. Mus., Tokyo 6: 303 (1963)

Parasitic on adult *Tessaratoma* sp. (Pentatomidae), collected from the underside of leaf litter. **Sexual morph**: Undetermined. **Asexual morph:** Hyphomycetous. *Synnemata* on adult *Tessaratoma* sp., congregated or scattered, with greyish brown stipe with swollen white tips, unbranched or branched, up to 4 mm long

and 0.4 mm wide. *Fertile head* 0.2–0.4 × 0.2–0.3 mm, globose to subglobose, with mass conidia on surface. *Conidiophores* densely grouped, arising from the fertile head, 66.4–96.5 × 2.2–3.2 µm ($\overline{x}$ = 81.4 × 2.6 µm, n = 150), biverticillate or terverticillate, forming dense clusters of branched, each bearing two or three compacted phialides around the stalk. *Branches* 6.5–10 × 2.2–3.2 µm ($\overline{x}$ = 8.4 × 2.7 µm, n = 150), hyaline, swollen. *Metula* 6.2–8 × 1.9–2.8 µm ($\overline{x}$ = 7.1 × 2.3 µm, n = 150), hyaline, divergent, terminal, vertical. *Phialides* 6.6–8.8 × 1.6–2.3 µm ($\overline{x}$ = 7.7 × 1.9 µm, n = 150), cylindrical, greyish brown, with a short neck. Conidia 2.5–3.2 × 1.6–2 µm ($\overline{x}$ = 2.8 × 1.8 µm, n = 150) in dry divergent chains, mostly fusiform or lemon-shaped, 1-celled, smooth-walled, hyaline.

Material examined: Thailand, Chiang Rai, on adult *Tessaratoma sp*. (Pentatomidae), 27 August 2018, YuanPin Xiao, ST01.

Notes: The new collection cluster with *Purpureocillium takamizusanense* in the phylogenetic tree. The morphology characters similar to *Purpureocillium takamizusanense*. Meanwhile, it is a new record of *Purpureocillium takamizusanense* from Thailand.

Note a Habitat of *Purpureocillium takamizusanense*. b, c Fungus on *Tessaratoma sp*. d-h Synnemata. i Hyphae. j, k Conidiophores. l-o Conidia. Scale Bars: b, c = 1 cm, d, e, g = 1000 µm, f = 200 µm, g = 100 µm, h = 50 µm, i-k = 20 µm, l = 5 µm, m-o = 2 µm.

Figure 3.64 Morphology of *Purpureocillium takamizusanense*

Purpureocillium albosynnematum Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the host species.

Not clear parasitic on adult cicada (Hemiptera) or *Metarhizium sp*., collected from the underside of leaf litter. **Sexual morph**: Undetermined. **Asexual morph:** *Synnemata* 1.2–2 mm long, 0.1–0.3 mm wide, scattered on the ascostromata of *Metarhizium sp*. and the body of cicada, white to yellowish, pulvinate tomentose, unbranched. *Fertile head* 0.2–0.23 mm wide, globose to subglobose, with masses of conidia on surface. *Conidiophores* 24–50 µm long ($\bar{x}$ = 37 µm, n = 60), densely grouped, arising from the fertile head or stipe, biverticillate, forming dense branched clusters, each bearing two to four compacted phialides around the stalk. *Metula* 10–14 × 1.8–2.4 µm ($\bar{x}$ = 12 × 2.1 µm, n = 90), hyaline, swollen. *Phialides* 13.2–16.5 × 1.8–2.5 µm ($\bar{x}$ = 14.8 × 2.1 µm, n = 60), cylindrical, with a short neck. *Conidia* 3–3.7 × 1.6–2 µm ($\bar{x}$ = 3.3 × 1.8 µm, n = 150, mostly fusiform, 1-celled, smooth, hyaline, white to light purple in mass.

Not clear host: *Metarhizium sp*., **Sexual morph**: *Stromata* arising from abdomen of the host, clavate, 1.5–2 cm long, 1.5–3.5 mm wide. *Stipe* 5–8 mm long, 0.5-1 mm wide, cylindrical, dark brown, with a terminal fertile head. *Fertile head* 1–1.2 cm long, 1–2.5 mm wide, cylindrical, terminal at the top, dark brown. *Perithecial* 204–350 × 46–154 µm ($\bar{x}$ = 277 × 100 µm, n = 30), oblique flask-shaped, immersed. No asci or ascospore observed. **Asexual morph**: undetermined.

Material examined: Thailand, Chiang Mai, Mushroom Research Center, on dead adult cicada, 19 December 2013, YuanPin Xiao, CR001.

Notes: The new species *Purpureocillium albosynnematum* was sister to *Purpureocillium takamizusanense* with a strong support. *Purpureocillium albosynnematum* differ from *Purpureocillium takamizusanense* by producing subglobose to fusiform conidia. According to the morphology and phylogenetic analyses, a new species is introduced under *Purpureocillium*.

Note a. Ascostromata emerging from infected cicada host. b–d. Fertile head of ascostroma. e–i. m Cross sections showing the completely embedded obliquely aligned perithecia. j–l, p, q. Part of perithecia. n–o. Peridium. r–s. Asexual morph. t. Phialides. u–x. Conidia. Scale Bars: b, e, g, h, I, r, s = 1000 µm, c, f, k, m = 500 µm, d = 200 µm, j, p = 100 µm, l = 200 µm, n–o = 20 µm, q, t=50µm, u–x = 5 µm, y–z = 30 mm.

Figure 3.65 Morphology of *Purpureocillium albosynnematum*

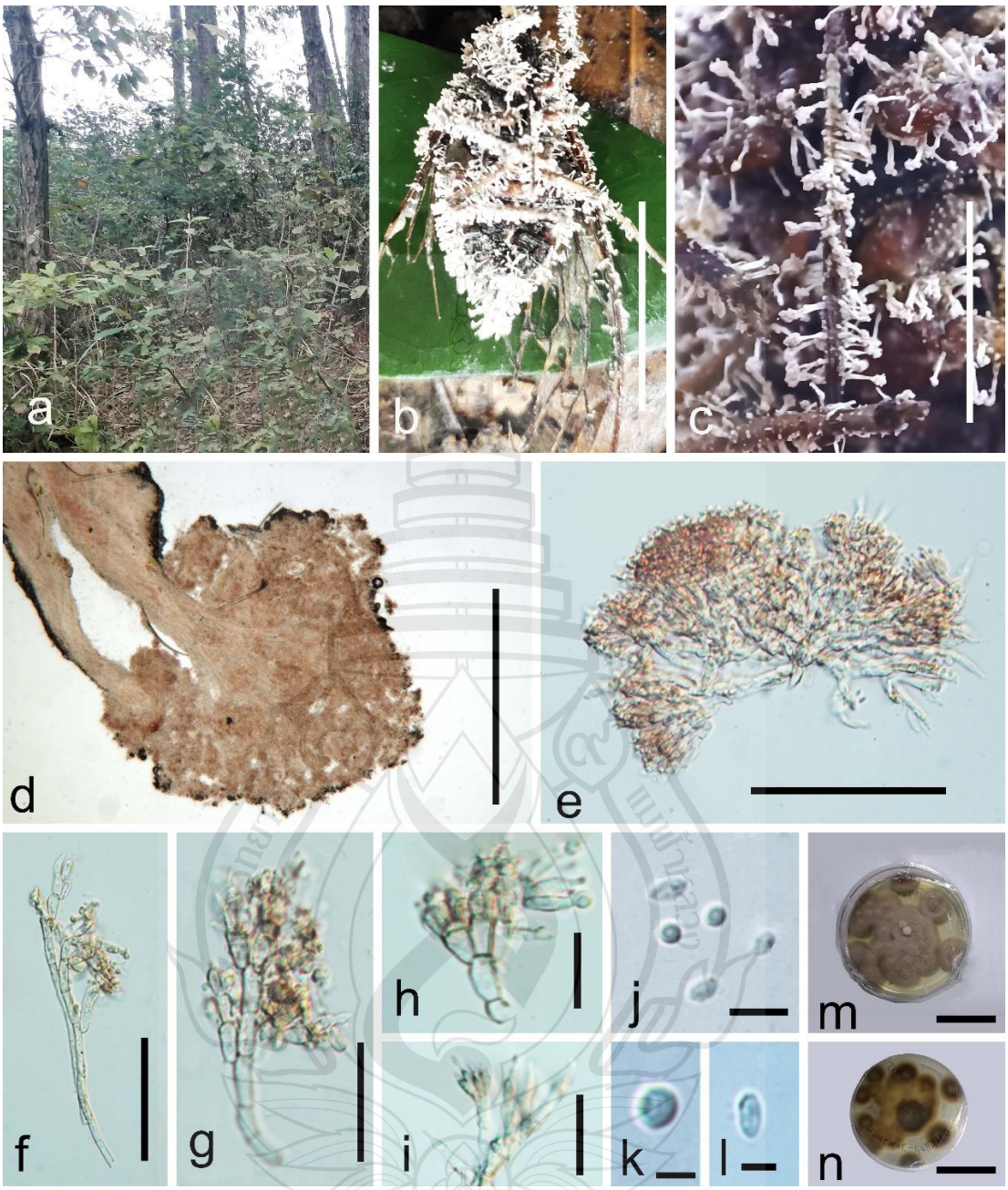
Purpureocillium clavatsis Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the clavate synnemata.

Parasitic on adult cicada (Hemiptera), collected from the underside of leaf litter. **Sexual morph**: Undetermined. **Asexual morph:** *Synnemata* 1.5–3 mm long,0.1–0.2 mm wide, scattered on the whole body of adult cicada, pale to light purple, clavate, stipe with swollen white tips, unbranched. *Fertile head* 0.2–0.23 mm wide, globose to subglobose, with masses of conidia on surface. *Conidiophores* densely grouped, arising from the fertile head or stipe, 22.4–28.2 µm long ($\bar{x}$ = 26.3 µm, n = 60), biverticillate, forming dense branched clusters, each bearing four to six compacted phialides around the stalk. *Metula* 4.2–6.8 × 2–2.6 µm ($\bar{x}$ = 5.5 × 2.3 µm, n = 150), hyaline, swollen. *Phialides* 10.2–12.4 × 2.1–2.4 µm ($\bar{x}$ = 11.3 × 2.3 µm, n = 60), cylindrical, with a short neck. *Conidia* 4.5–5.5 × 2–2.2 µm ($\bar{x}$ = 5 × 2.1 µm, n = 150, mostly fusiform, 1-celled, smooth, hyaline, purple in mass.

Material examined: China, Guizhou Province, Zunyi City, Xishui Conty. On adult cicada (Hemiptera), 20 October 2020, Yu Yang, DHKQ0320102003.

Notes: The new species, *Purpureocillium clavatsis*, grouped with *Purpureocillium albosynnematum* and *Purpureocillium takamizusanense* in the phylogenetic tree. It has unbranched synnemata, biverticillate conidiophores and long fusiform conidia.



Note a Habitat. b Overview of *Purpureocillium clavatsis*. c Synnemata emerging from infected cicada host. d. Synnema. e Conidiophores. f, i Phialides. j–l Conidia. l, m Culture. Scale Bars: b, m, n = 2 cm, c = 0.5 cm, d = 1000 µm, e, f= 50 µm, g = 50 µm, h, i = 20 µm, j = 10 µm, k, l = 3 µm.

Figure 3.66 Morphology of *Purpureocillium clavatsis*

Table 3.12 Morphological comparison of asexual morph species of the genus *Purpureocillium*

Species name	Phialides (um)	Conidiophores (um)	Conidia (um)	Reference
P. atypicola	3.5–5 × 2–2.5, usually cylindrical, neck absent or very short,	Densely grouped, arising from the submerged hyphae, 150 × 3.5-5, forming dense clusters of branched, each bearing two or three compacted phialides around the stalk. Branches swollen, 6-7 × 3-5	Conidia in dry divergent chains, cylindrical, slightly curved, smooth-walled, hyaline to slightly purple, 4-6 × 1.2-1.5	Samson (1974)
P. albosynnematum	13.2–16.5 × 1.8–2.5, cylindrical, with a short neck.	24–50 long, densely grouped, arising from the fertile head or stipe, biverticillate, forming dense branched clusters, each bearing two to four compacted phialides around the stalk	Conidia 3–3.7 × 1.6–2, mostly fusiform, 1-celled, smooth, hyaline, white to light purple in mass.	This study
P. clavatsis	10.2–12.4 × 2.1–2.4, cylindrical, with a short neck	Conidiophores densely grouped, arising from the fertile head or stipe, 22.4–28.2, biverticillate, forming dense branched clusters, each bearing four to six compacted phialides around the stalk.	4.5–5.5 × 2–2.2, mostly fusiform, 1-celled, smooth, hyaline, purple in mass	This study
P. lavendulum	Phialides were 7–12 × 2–3 µm, with a short cylindrical, ellipsoidal or swollen basal portion tapering into a distinct neck up to 5 µm long	Conidiophores growing from the uperficial mycelium were up to 400 long, bearing verticillate branches with terminal whorls of 3–6 phialides; stipe erect, septate, brownish yellow to pale purple-brown, rough-walled, profusely verrucose and up to 5 µm wide near the base.	Conidia in long dry chains, unicellular, subglobose with apiculate base or limoniform, 2–3 × 2–2.5, smooth-walled, mostly subhyaline, pinkish purple in mass; intercalar globose conidia, 3.5–4.5 × 3–4.	Perdomo et al. (2013)

Table 3.12 (continued)

Species name	Phialides (um)	Conidiophores (um)	Conidia (um)	Reference
P. lilacinum	Phialides 6–9 × 2.5–3, having a wollen basal portion tapering into a short distinct neck about 1 Um wide. Structures formed near the agar atypical: phialides solitary or in verticils	Conidiophores arising from sub-merged hyphae 4–6 um in length, occasionally forming loose synnemata up to 2 um high; stalks with roughened thick walls 3–4 um wide consisting of verticillate branches with whorls of two to four phialides.	Conidia in divergent chains, ellipsoidal to fusiform, smooth-walled to slightly roughened, hyaline, purple en masse, 2–3 × 2–4 um.	Luangsa-Ard et al. (2011)
P. sodanum	Phialides 5–13 × 2–3 mm, with a cylindrical basal portion tapering into a distinct neck up to 3 lm long.	Conidiophores growing from the superficial mycelium, with a stipe, bearing 6–8 long monoverticillate branches with terminal whorls of 2–3 phialides; stipe erect, septate, hyaline to pale purple-brown, rough-walled, profusely verrucose and up to 5 wide	Conidia were in long dry chains, unicellular, subglobose with apiculate base or limoniform, 3.5–5.5 × 3–4.5, smooth-walled, mostly subhyaline, pinkish-purple in mass.	Hyde et al. (2016)
P. takamizusanense	Phialides solitary, lageniform or cylindrical, variable in length, 4–15 × 2–2.5 mm, sometimes reduced to pegs of intercalary cells.	Conidiophores on media, 490–880 × 2.8–4.7, the mean value is 680 × 3.9	Conidia are in slimy heads, hyaline, one-celled, smooth-walled, subglobose to oblong, 3–7 × 2–3, the mean value is 5.0 × 2.7	Ban et al. (2015)

3.3.3.6 *Tolypocladium*

Tolypocladium W. Gams, Persoonia 6(2): 185 (1971)

= *Chaunopycnis* W. Gams, Persoonia 11(1): 75 (1979)

= *Elaphocordyceps* G.H. Sung & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 36 (2007)

= *Mitrasphaera* Dumort., Comment. bot. (Tournay): 92 (1822)

Index Fungorum: IF 324640

Parasitic and pathogenic of other fungi, insects and rotifers, as well as soil-inhabiting. **Sexual morph:** *Stromata* robust stipitate, clavate to capitate to highly reduced, comprising rhizomorphs and aggregated perithecia. *Stipe* cylindrical to clavate, usually light in colour. *Fertile part* cylindrical to capitate, usually dark coloured. *Perithecia* immersed, along axis of the stroma or superficial and produced on a highly reduced stromatic pad. *Asci* unitunicate, cylindrical with apical cap. *Apical cap* thick. *Ascospores* filiform, approximately as long as asci, septate and typically disarticulating into secondary spores. Secondary spores cylindrical to fusiform, hyaline (adapted from Hodge et al., 1996; Sung et al., 2007; Quandt et al., 2014). **Asexual morph:** Colonies moderate to fast-growing, typically white to cream. Sporulation mononematous, conidiophores branching, producing conidiogenous cells terminally and laterally, singly or whorled, at right angles to the conidiophores. *Phialides*, with a flask-shaped base that tapers into a narrow neck. The neck is often bent away from the axis of the conidiogenous cell. *Conidia* one-celled, hyaline, smooth, typically globose to cylindrical, produced in slimy heads (adapted from Gams 1971, 1979; White et al., 2003).

Type species: ***Tolypocladium inflatum*** W. Gams, Persoonia 6(2): 185 (1971).

Notes: Gams (1971) established this genus with three soil inhabiting species, which are similar to *Beauveria* Vuill. However, Von Arx (1986) merged the genus with *Beauveria*, which was not accepted by later researchers (Todorova et al., 1998; Gams et al., 1998). *Tolypocladium* was the only known asexual morph until Hodge et al. (1996) linked *Cordyceps subsessilis* Petch (Current name: *Tolypocladium inflatum*) to the sexual morph of *Tolypocladium inflatum*. Sung et al. (2007) transferred *Tolypocladium* to Ophiocordycipitaceae and also proposed a new genus *Elaphocordyceps* based on phylogenetic analyses. The oldest valid name, *Mitrasphaera* was transferred to *Cordyceps* (Donk, 1968; Shrestha et al., 2014). The type species of *Mitrasphaera* (Current name: *Tolypocladium capitatum* (Holmsk.) C.A.

Quandt, Kepler & Spatafora) was transferred to *Elaphocordyceps* (Dumortier, 1822; Sung et al., 2007; Shrestha et al., 2014). Quandt et al. (2014) preserved *Tolypocladium* over *Elaphocordyceps* and *Chaunopycnis*. The synonyms of *Tolypocladium* are *Chaunopycnis*, *Elaphocordyceps* and *Mitrasphaera* (Donk, 1968; Sung et al., 2007; Quandt et al., 2014).

Four species of *Tolypocladium* are both sexual morph and asexual morphs; 16 species are asexual morphs, and 21 species are sexual morphs. Most species have been found in temperate regions. The hosts of the genus have been expanded to rotifers (Barron, 1980, 1981; Bissett, 1983), insects (Samson & Soares, 1984; Weiser 1991; Hodge et al., 1996) and other fungi (Sung et al., 2007; Quandt et al., 2014). The asexual morph of *Tolypocladium* was recognized as beauveria-like (Gams, 1971; Von Arx, 1986), harposporium-like, hirsutella-like and verticillium-like (Sung et al., 2007; Quandt et al., 2014; Hyde et al., 2020). However, *Tolypocladium* differs from *Beauveria* on the basis of its discrete phialides, rather than the characteristic zigzag, conidiogenous cells typical of *Beauveria* (Seifert & Gams, 2001). Some species of *Tolypocladium* are similar to *Harposporium* and *Hirsutella* by producing two kinds of conidia with associated kinds of conidiogenous (Hodge et al., 1997; Glockling, 1998). Some species of *Tolypocladium* are similar to *Harposporium* and *Verticillium* by infecting nematodes and producing phialidic conidiogenous cells with adhesive conidia (Bissett, 1983; Sigler et al., 1987; Gams & Zare, 2001). Even though *Tolypocladium*, *Harposporium*, *Verticillium* and *Hirsutella* share many common asexual morph characters, molecular analyses have shown that they are distinct generic clades in the phylogenetic trees (Zare et al., 2000; Sung et al., 2001; Quandt et al., 2014). All GenBank accession numbers for *Tolypocladium* are listed in the, excluding SSU: KF747159 for the strain NHB59 (*Tolypocladium endophyticum*) and SSU: KF747308 for the strain IQ45 (*Tolypocladium tropicale*). This is because both of the DNA sequences do not cluster in the family after blasting in NCBI.

Most species of *Elaphocordyceps* have been placed under *Tolypocladium* one exception being *Elaphocordyceps* ×*jezoensoides* (Kobayasi) Hiroki Sato, S. Ban, Masuya & Hosoya (Sato et al., 2010; Quandt et al., 2014). In this study, we transfer this species to *Tolypocladium*. *Elaphocordyceps* ×*jezoensoides* infects other fungi

(*Elaphomyces granulatus* Fr.) and has a cylindrical or clavate fertile part with cylindrical stipe and cylindrical, rounded at both ends secondary ascospores.

Barron (1980, 1983) described *Tolypocladium parasiticum*, *Tolypocladium lignicola* and *Tolypocladium trigonosporum*, which are similar to *Rotiferophthora* G.L. Barron species in infecting rotifers and producing irregular conidia. *Tolypocladium parasiticum* was transferred as *Metapochonia parasitica* (G.L. Barron) Labuda, Bernreiter & Kubátová based on phylogenetic analyses (Labuda et al., 2018). Vu et al. (2019) updated the molecular data for *Tolypocladium lignicola* (CBS 489.83 ITS: MH861631, LSU: MH873346) from a new collection, while *T. lignicola* only has slide herbarium (OAC 10828). The strain (CBS 489.83) is clearly distinct from the *Tolypocladium* group and merges with the Cordycipitaceae group. We therefore transfer these species to *Rotiferophthora* as *R. lignicola* and *R. trigonosporum*.

Vu et al. (2019) updated the molecular data for *Tolypocladium extinguens* (ITS: NR_160156, LSU: MH872842) from the holotype (CBS 345.77). *Tolypocladium extinguens* was described by Samson and Soares (1983), characterised by parasitizing glowworms (*Arachnocampa luminous* Skuse) and producing a verticillium-like asexual morph. This species does not cluster in the same clade with other *Tolypocladium* sp. and groups with the *Cordyceps* sp. clade. Therefore, we transfer this species to *Cordyceps extinguens* based on the phylogenetic analyses.

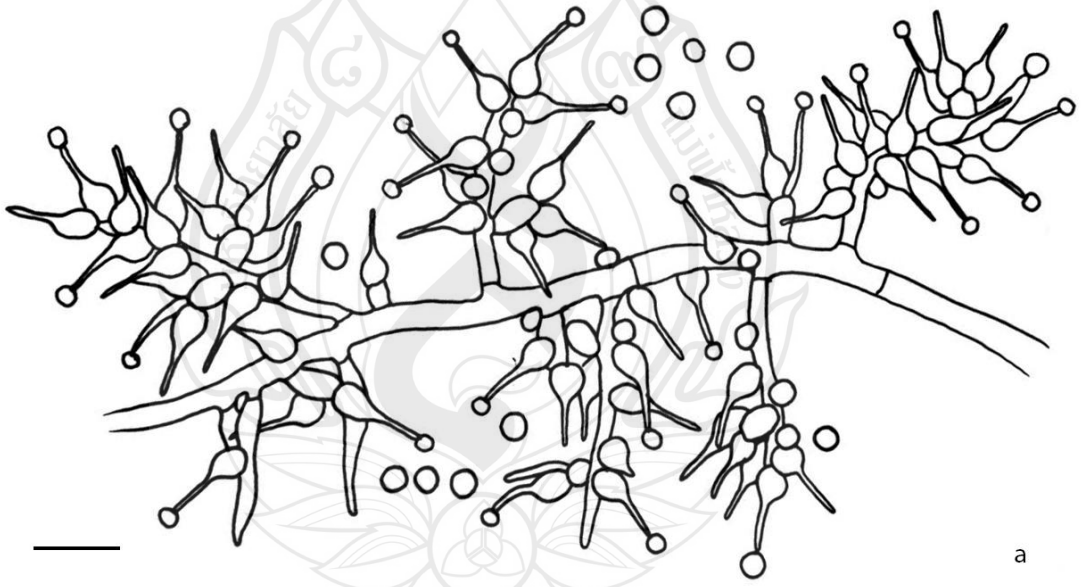
Most species of *Tolypocladium* produce secondary ascospores with the exception of *Tolypocladium ramosum*. When Petch (1937) described this species, he commented that this species may be an *Ophiocordyceps* species. We transfer *Tolypocladium ramosum* to *Ophiocordyceps* as *Ophiocordyceps ramosum*.

Ecological and economic significance of Tolypocladium: This group has been recognized as significant, since Borel et al. (1976) found Cyclosporin A from *Tolypocladium inflatum*. Cyclosporin A is an important human medicine with immunomodulatory activities (Ruegger et al., 1976; Traber et al., 1977, 1982, 1982; Wenger, 1984; Jegorov et al., 1995). Steroids, ergokonins and efrapeptins have been found from *Tolypocladium inflatum* and *Tolypocladium koningii* (Grafe et al., 1991; Krasnoff & Gupta, 1992), while the bioactivities of these compounds are antifungal, antitumor and insecticidal (Yang et al., 2004; Leung et al., 2006; Survase et al., 2011).

Tolypocladium ophioglossoides is also reported as a Chinese Traditional Medicine (Quandt et al., 2015; Huang et al., 2017).

Distribution: Australia, Austria, Brazil, Canada, China, Denmark, Finland, France, Germany, Japan, South Korea, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Russia, United Kingdom, USA (Lloyd, 1920; Imai, 1929, 1934; Petch, 1937; Kobayasi, 1939; Kobayasi & Shimizu, 1960, 1963, 1982; Mains, 1957; Gams, 1971, 1980; Candoussau, 1976; Barron, 1981; Fries & Hoffmann, 1982; Bissett, 1983; Samson & Soares, 1984; Ginns, 1988; Weiser et al., 1991; Moller & Gams, 1993; Hodge, 1996; Zang, 2001; Sato et al., 2010; Gazis et al., 2014; Crous et al., 2017; Li et al., 2018)

Conclusion: Illustrating the type species, 4 reference specimens are illustrated; 6 new species are described; 2 new records; 3 revised species.



Note a Overview of the *Tolypocladium inflatum*. b Ascostroma. c Perithecia. d Asci. e Part of the ascospore. f Secondary ascospore. g Conidiogenous cells and conidia. Scale Bars: a = 10 μm.

Figure 3.67 Morphology of *Tolypocladium inflatum* (redrawn from Gams, 1971)

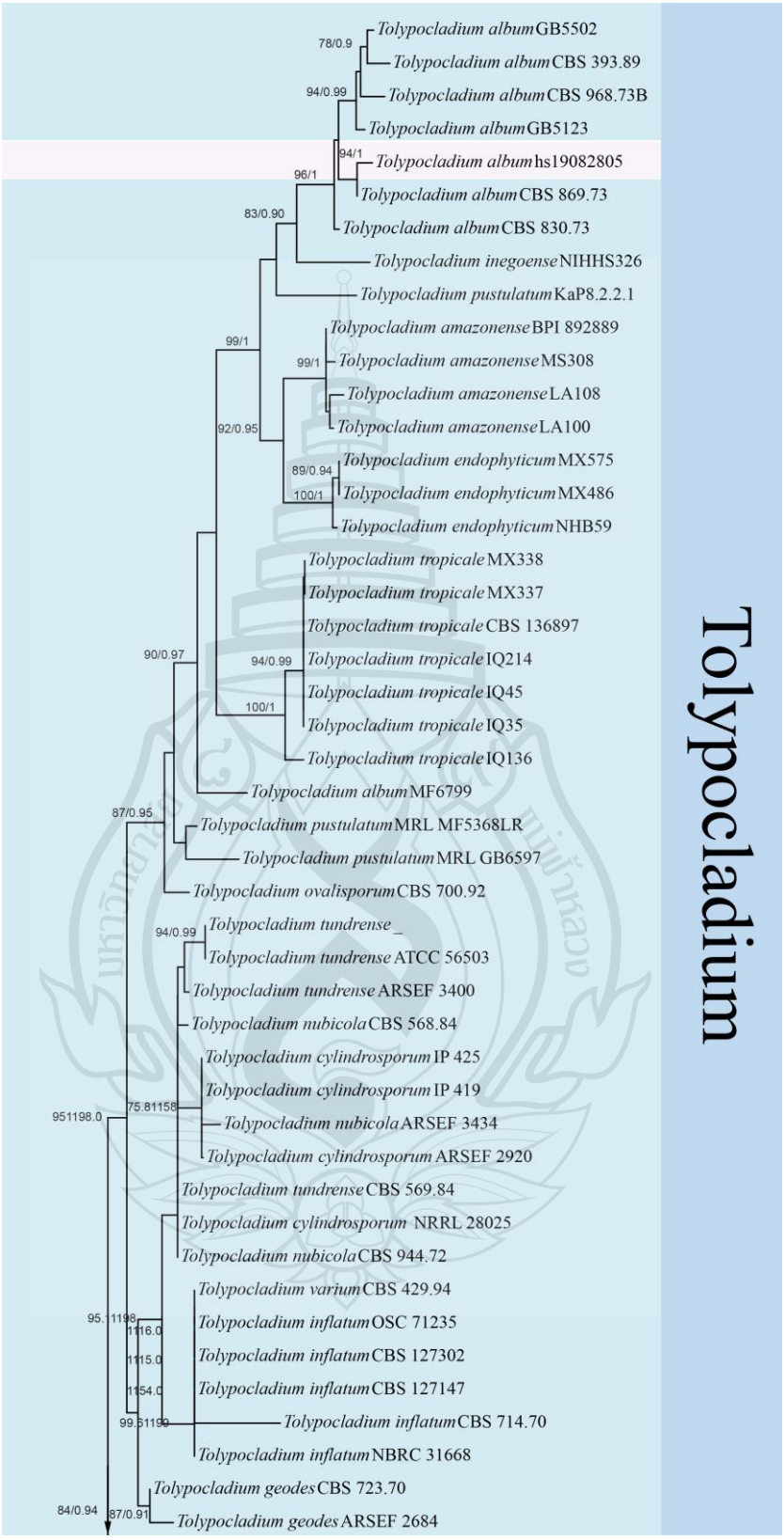
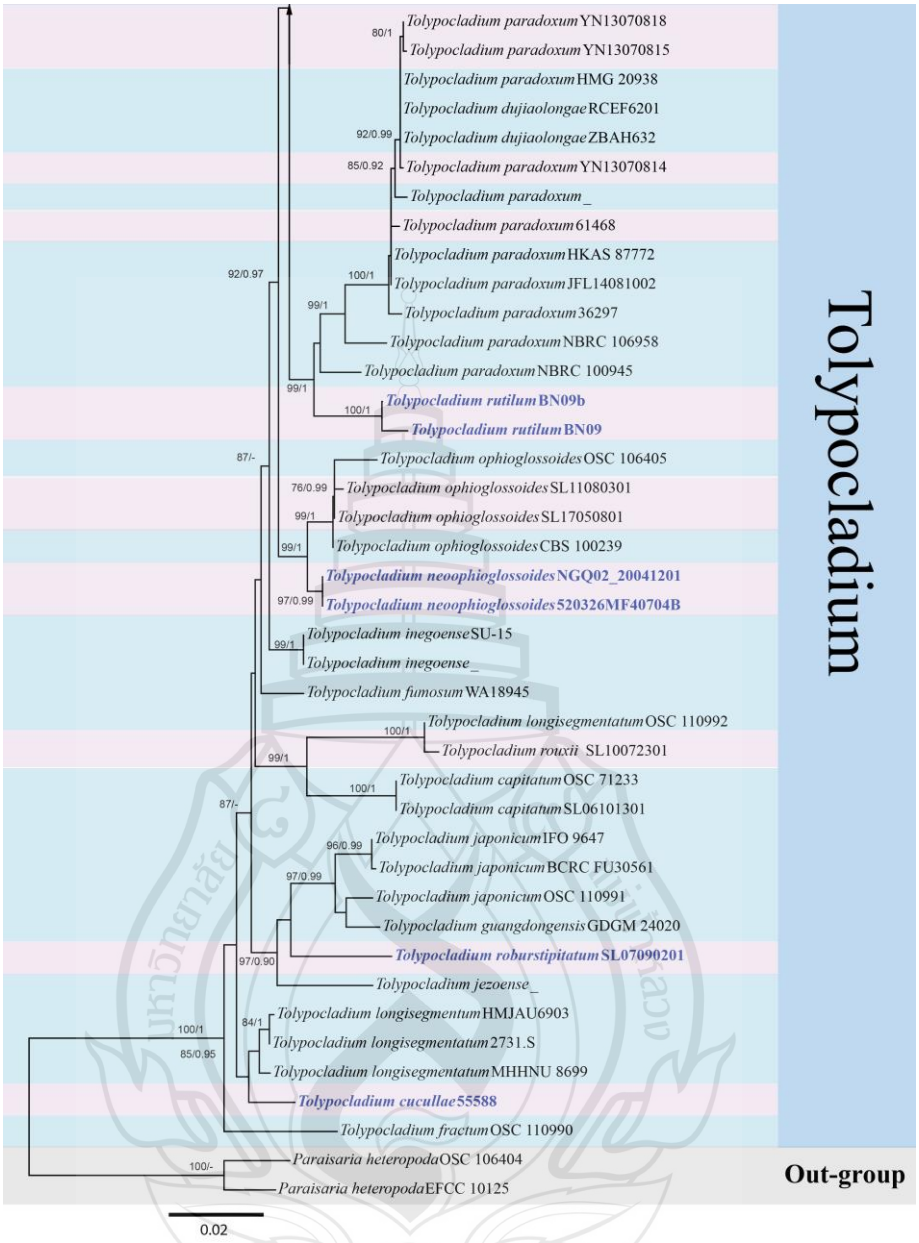


Figure 3.68 Phylogenetic tree of *Tolypocladium species*



Note Phylogenetic tree of *Tolypocladium species* generated from maximum likelihood analysis of ITS, SSU, LSU, RPB1, RPB2 and TEF1α sequence data. *Paraisaria heteropode* was used as outgroup taxa. This phylogenetic tree of *Tolypocladium* comprises 87 taxa (including the 18 newly collected taxa) analysed. Maximum likelihood bootstrap values greater than 75% and Bayesian posterior probabilities over 0.95 are indicated above the nodes. The new species were indicated in blue. The ex-types are indicated in bold.

Figure 3.68 (continued)

Tolypocladium cucullae Y.P. Xiao & K.D. Hyde, ***sp. nov.***

Etymology: The specific epithet refers to the feature of the white stromata.

Holotype: HKAS 55588

Parasitic in an unidentified host buried in the upper 1 cm of soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 8–13 cm long, 5–10 mm wide, brown to olive when fresh, dark when dry, hard, capitate, mostly solitary, stipitate, inside hollow when mature. *Stipe* 8–12 × 0.5–0.7 cm, cylindrical, yellow to brown when fresh, dark brown when dry, with green scales on the surface when fresh, with dark furfuraceous when dry, fibrous, hollow, with stromata on the top. *Fertile head* 8-10 mm in diam, hemispherical, minutely mammilate, bracken green to dark olive when fresh, dark when dry, distinctly separated from stipe, hard, solitary, with a cortex of closely interwoven hyaline hyphae pseudoparenchymatous in section. *Perithecia* 500–600 × 340–420 µm ($\bar{x}$ = 560 × 380 µm, n = 30), subglobose to ovoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 20–25 µm ($\bar{x}$ = 22 µm, n = 60) wide, of brown pigmented cells of *textura porrecta* to paler *textura prismatica*. *Asci* 320–400 × 10–15 um ($\bar{x}$ = 360 × 13 µm, n = 60), 8-spored, unitunicate, narrow cylindrical, hyaline, with thick apex. *Apical cap* 5.5–7.5 × 5–7.5µm ($\bar{x}$ = 6.5 × 6 µm, n = 60) µm diam, hyaline. *Ascospores* as long as asci, filiform, hyaline break into secondary spores. *Secondary spores* 25–35 × 3–4.5 µm ($\bar{x}$ = 30 × 3.8 µm, n = 60), cylindrical to fusoid with truncated ends, smooth, hyaline, with or without septa. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Lijiang City, Laojun Mountain. 15 July 2008, Yun Ting Huang (HKAS 55588, **holotype**).

Notes: According to phylogenetic analysis, the new species *T. cucullae* is closely related to *T. capitatum, T. delicatistipitatum, T. fumosum* and *T. longisegmentatum*. *Tolypocladium cucullae* is distinct from *T. capitatum* in producing a hollow, furfuraceous stipe, smaller perithecia and smaller asci, while *T. capitatum* produces hard stipe, larger perithecia and longer asci (Mains, 1957). *Tolypocladium cucullae* is distinct from *T. fumosum* in having larger and brown to olive stromata when fresh, dark when dry; larger, hemispherical and bracken green to dark olive when fresh dark when dry fertile head; smaller perithecia; longer and cylindrical to fusoid secondary spores. *Tolypocladium fumosum* has smaller, pale chalcedony yellow

stromata at the base to dark gull grey at the apex; ellipsoidal when young and capitate when mature fertile head; larger perithecia; shorter and cylindrical to cubic secondary spores. The phylogenetic tree also shows that the *T. cucullae* is distinct from *T. capitatum* and *T. fumosum*.

The characters of *T. cucullae* are similar to *T. delicatistipitatum*, which has no molecular data. Both form stipitate stromata, subglobose to ovoid perithecia, cylindrical asci and cylindrical secondary spores with truncate ends. *Tolypocladium cucullae* is different from *Tolypocladium delicatistipitatum* in producing stromata with a hemispherical, dark (when dry) fertile part, with a thinner (5.5–6 μm in diam) apical cap and longer (25–35 μm long) secondary spores, while *T. delicatistipitatum* produces stromata with a spherical or ovoid fertile part, a thicker (8 μm in diam) apical cap and shorter (18–28 μm long) secondary ascospores.

The type strain DAOM 137162 that *T. longisegmentatum* (Ginns) C.A. Quandt, Kepler & Spatafora was described as *Cordyceps longisegmentis* (Ginns, 1988), which was moved to the genus *Elaphocordyceps* (Sung et al., 2007) and revised as *T. longisegmentatum* (Quandt et al., 2014), is lacking molecular data. Molecular data have been supplemented by four strains including OSC 110992 (Sung et al., 2007), HMJAU6903 (Yan & Bau, 2014), MHHNU 8699 (Chen & Zhang, 2019) and 2731.S (Stensrud et al., 2005; Engh, 1999). Furthermore, HMJAU6903 (Yan & Bau, 2014) and MHHNU 8699 (Chen & Zhang, 2019) were reported molecular data with descriptions and illustrations among these four strains. Comparing with three description of *T. longisegmentatum*, *T. cucullae* is distinct from *T. longisegmentatum* ((DAOM 137162) Ginns, 1988; (HMJAU6903) Yan & Bau, 2014; (MHHNU 8699), Chen & Zhang, 2019) in having a hemispherical fertile head, brown perithecia and shorter secondary spores. Molecular data indicated that the new species has 31 bp in ITS that are different from HMJAU 6903, 36 bp in ITS that are different from MHHNU 8699, 38 bp in ITS that are different from 2731.S, 26 bp in LSU that are different from OSC 110992. In conclusion, we propose *T. cucullae* as a new species.

Table 3.13 Morphological comparison of closely related species of *Tolypocladium cucullae*

Strain	Location	Stipe (cm)	Fertile head (mm)	Perithecia (µm)	Asci (µm)	Secondary spores (µm)	Reference
DAOM 137162	America	13 × 0.7, greyish yellow above and the lower one-third a deep yellow, cylindrical, olive, some with the basal part dark olive or black, glabrous, hollow	Broadly rounded, above the stipe apex, brown, dark brown to olive brown, glabrous, 13 diam	Imbedded, ellipsoid 500 × 300	Cylindrical to narrowly ellipsoid 440 × 10–15	40–65 × 3–5	Ginns (1988)
HMJAU6903	China	2.5–6.5 × 0.2 wide, yellow-brown, with black scales on the surface,	Broadly rounded, dark brown, 4–9 diam	Imbedded, ellipsoid or flask-shaped, 632–681 × 273–292	Cylindrical, 341–428 × 12	29.3–48.8 × 3.7–4.9	Yan and Bau (2014)
HKAS 55588	China	8–12 × 0.5–0.7, cylindrical, yellow to brown when fresh, dark when dry, with green scales on the surface, hollow	Hemispherical, bracken green to dark green when fresh, dark when dry, 8-10 in diam	Immersed, subglobose to ovoid, 500–600 × 340–420	Cylindrical to fusoid 320–400 × 10–15	25–35 × 3–4.5	This study

Note a, b Material of *Tolypocladium cucullae*. c Ascostromata. d Fertile head of ascostroma. e Vertical section of stroma. f Peridium. g-j Asci. k Apical cap of asci. l-o Secondary ascospores. Scale Bars: d = 5000 µm, e = 100 µm, f = 50 µm, g-j = 200 µm, k = 20 µm, l-o = 20 µm.

Figure 3.69 Morphology of *Tolypocladium cucullae* (holotype HKAS 55588)

Tolypocladium rouxii (Cand.) C.A. Quandt, Kepler & Spatafora, in Quandt, Kepler, Gams, Araújo, Ban, Evans, Hughes, Humber, Hywel-Jones, Li,

Luangsa-ard, Rehner, Sanjuan, Sato, Shrestha, Sung, Yao, Zare & Spatafora, IMA Fungus 5(1): 127 (2014)

Index Fungorum number: IF 808866

Synonymy: *Cordyceps rouxii* Cand., Mycotaxon 4(2): 544 (1976)

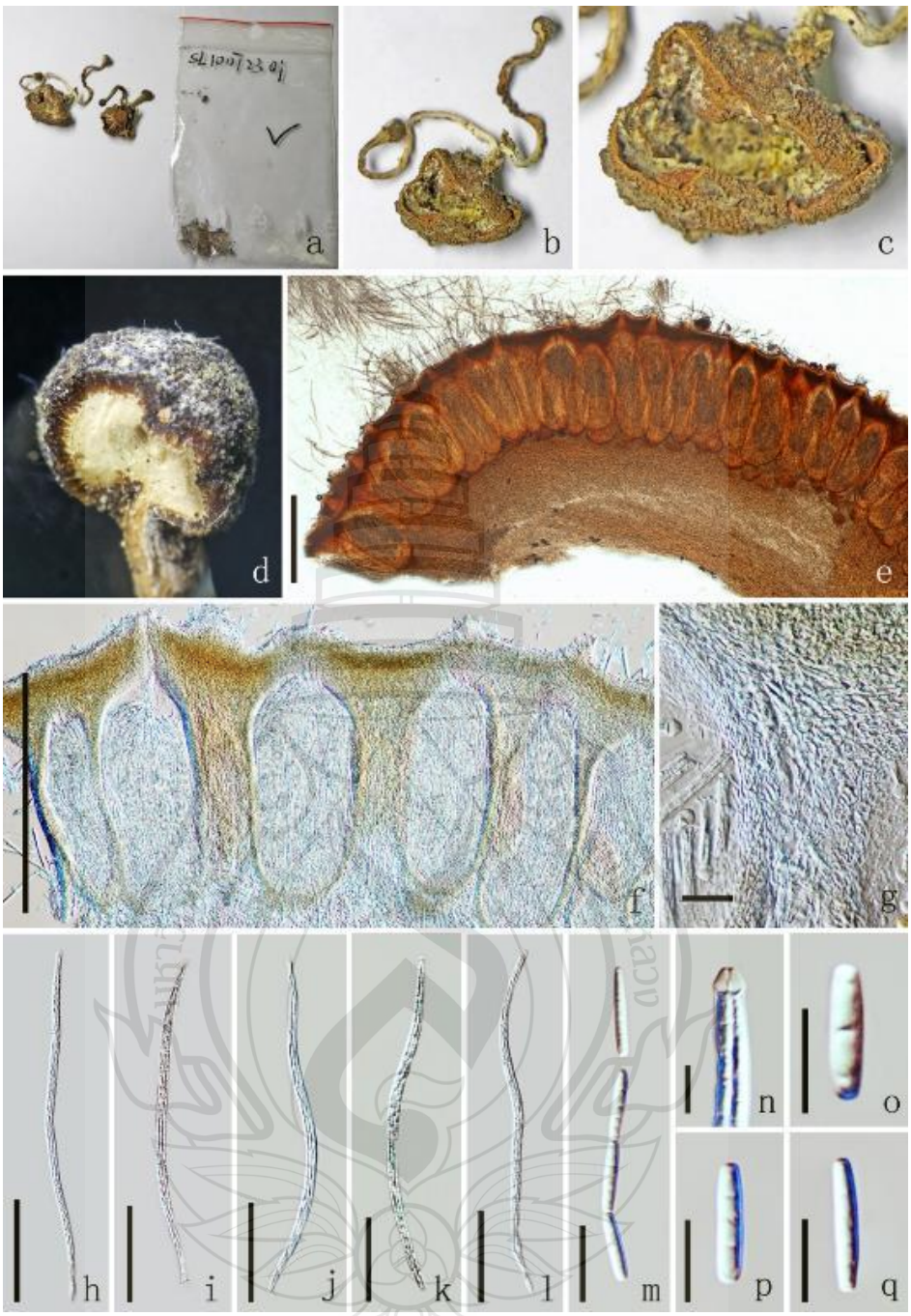
Elaphocordyceps rouxii (Cand.) G.H. Sung, J.M. Sung & Spatafora, in Sung, Hywel-Jones, Sung, Luangsa-ard, Shrestha & Spatafora, Stud. Mycol. 57: 37 (2007)

Parasitic in *Elaphomyces sp.* (Elaphomycetaceae) buried in the soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 4–12 cm long, 2–10 mm wide pale to yellow when fresh, yellow to dark brown when dry, capitate, hard, mostly branched, stipitate. *Stipe* 3–11 cm long 2–3 mm wide, cylindrical, contorted, pale to pale yellow. *Fertile head* 0.5–1 cm diam, capitate, minutely mammilate, yellow to brown when fresh, dark brown when dry, distinctly separated from stipe hard. *Perithecia* 470–555 × 170–260 µm ($\overline{x}$ = 510 × 310 µm, n = 30), ellipsoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 12–17 µm ($\overline{x}$ = 14 µm, n = 60) wide, yellow pigmented *textura prismatica* to hyaline *textura porrecta*. *Asci* 352–420 × 10–13 um ($\overline{x}$ = 390 × 8 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 4.6–6.3 × 5.8–7.3µm ($\overline{x}$ = 5.4 × 6.5 µm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 15.9–20.4 × 2.8–3.6 µm ($\overline{x}$ = 18.1 × 3.2 µm, n = 60), distosepta, cylindrical with tapered ends, smooth, hyaline, one-celled, 0–4 septate.

Material examined: Slovakia, Zazriva-Kozinska Village, V. Kautman leg. V. Kautman det. 23 July 2010, SL10072301.

Notes: Parasitizing *Elaphomyces variegatus*, *Tolypocladium rouxii* was reported from France as "*Cordyceps rouxii*" (Candoussau, 1976), removed to the genus *Elaphocordyceps* (Sung et al., 2007) and revised as *Tolypocladium* (Quandt et al., 2014). This species was frequently discovered from Austria, Belgium, Czech Republic, France, Germany, Norway, Poland, and Slovakia (Mornard, 1994; Hertzog, 2001, 2005; Ghyselinck, 2002; Kautmanova & Kautman, 2006; Chachuła et al., 2018). An epitype (BRA CR8028) was designated by Kautmanova & Kautman (2006) after checking the holotype specimen (CUP 54973), which was almost immature.

According to the observation of Kautmanova & Kautman (2006), many specimens of *T. rouxii*, *T. capitatum* and *T. longisegmentatum* have been mis-identified because the microcharacters of these three species are very similar. In this study, we provide the molecular data of *T. rouxii* with illustrating at the first time. And the strain was group with *T. longisegmentatum* (OSC 110992), which has no description or illustrating reported. Unfortunately, we could not check the specimen of OSC 110992. So we would like to keep OSC 110992 as *T. longisegmentatum* and introduced as *T. rouxii* based on morphological comparison.



Note a Material of *Tolypocladium rouxii*. b Overview of the *Tolypocladium rouxii*. c Host. d Fertile head of ascostroma. e, f Vertical section of the stromata. g Peridium. h-l Asci. m Part of ascospores. n Apical cap of asci. n-q Secondary ascospores. Scale Bars: e, f = 500 µm, g = 20 µm, h-l = 100 µm, m = 20 µm, n-q = 10 µm.

Figure 3.70 Morphology of *Tolypocladium rouxii*

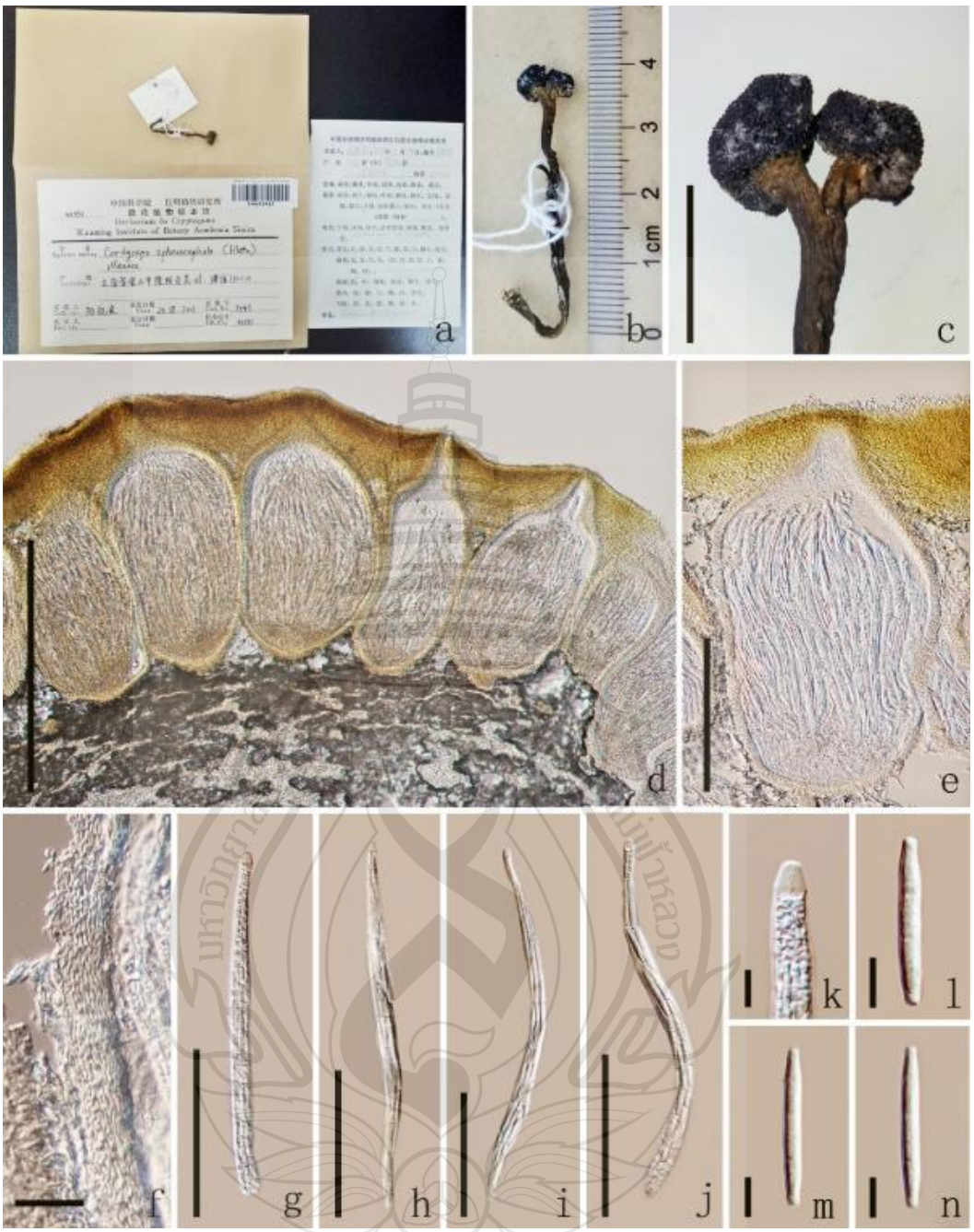
Tolypocladium cautis Y.P. Xiao & K.D. Hyde, ***sp. nov.***

Holotype: HKAS 42995

Parasitic in an unidentified host buried in the soil, forming dark stromata. **Sexual morph:** *Stromata* 5 cm long, 3–10 mm wide, brown to dark brown, hard, capitate, mostly solitary, stipitate. *Stipe* 4.5 cm long 2 mm wide, cylindrical, brown when fresh, dark brown to dark when dry, with stromata on the top. *Fertile head* 5 mm in diam, hemispherical, minutely mammilate, brown to dark brown when fresh, dark when dry, distinctly separated from stipe, hard, solitary. *Perithecia* 440–520 × 240–310μm ($\bar{x}$ = 480 × 270 μm, n = 30), ovoid to obpyriform, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 14–20 μm ($\bar{x}$ = 17 μm, n = 60) wide, comprising yellow cells of *textura porrecta*. *Asci* 310–380 × 11–15 um ($\bar{x}$ = 345 × 13 μm, n = 60), 8-spored, narrow cylindrical, with thick apex. *Apical cap* 5–6.8 × 5–6.5 μm ($\bar{x}$ = 5.9 × 5.7 μm, n = 60) μm diam, hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 29–38.6 × 2.9–4.4μm ($\bar{x}$ = 33.8 × 3.7 μm, n = 60), cylindrical with truncated ends, smooth, hyaline, 1-celled. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Baoshan City, Baihua Mountain. 24 Octorber 2003, Zhuliang Yang (HKAS 42995, **holotype**).

Notes: We did not obtain DNA sequence data from the specimen. The new species is similar to *T. longisegmentatum* and *T. cucullae* when considering the morphology. *Tolypocladium cautis* differs from *T. cucullae* in having brown to dark brown (when fresh) fertile heads, a hard stipe, ovoid to obpyriform perithecia and shorter secondary spores. *Tolypocladium cautis* differs from *T. longisegmentatum* in having ovoid to obpyriform perithecia, shorter asci and shorter secondary ascospores.



Note a Material of *Tolypocladium cautis* b Ascostroma. c Fertile head of ascostroma. d Vertical section of the stroma. e Perithecia. f Peridium. g-j Asci. k Apical cap of ascus. l-n Secondary ascospores. Scale Bars: e = 5000 µm, d = 500 µm, e = 200 µm, g-j = 100 µm, f = 20 µm, k-n = 10 µm.

Figure 3.71 Morphology of *Tolypocladium cautis* (holotype HKAS 42995)

Tolypocladium ophioglossoides (J.F. Gmel.) C.A. Quandt, Kepler & Spatafora, in Quandt, Kepler, Gams, Araújo, Ban, Evans, Hughes, Humber, Hywel-Jones, Li, Luangsa-ard, Rehner, Sanjuan, Sato, Shrestha, Sung, Yao, Zare & Spatafora, IMA Fungus 5(1): 127 (2014)

Index Fungorum number: IF808859

Parasitic in *Elaphomyces* sp. (Elaphomycetaceae) buried in the soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 2–5 cm long, 2–5 mm wide, dark brown, hard, mostly solitary, stipitate. *Stipe* 1–4 cm long 2–3 mm wide, clavate, brown when fresh, dark brown when dry, with stromata on the top. *Fertile head* 0.5–1 cm long, 3–5 mm wide, cylindrical, minutely mammilate, brown to dark brown when fresh, dark when dry, distinctly separated from stipe, hard, solitary. *Perithecia* 535–600 × 290–335μm ($\bar{x}$ = 570 × 310 μm, n = 30), ovoid to obpyriform, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 17–21 μm ($\bar{x}$ = 19 μm, n = 60) wide, comprising yellow cells of *textura intricata* to hyaline *textura porrecta*. *Asci* 440–495 × 7–9 um ($\bar{x}$ = 470 × 8 μm, n = 60), 8-spored, narrow cylindrical, with thick apex. *Apical cap* 2.8–4.4 × 5.1–6 μm ($\bar{x}$ = 3.6 × 5.5 μm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 2.4–3.4 × 1.7–2.2 μm ($\bar{x}$ = 2.9 × 1.9 μm, n = 60), cylindrical, smooth, hyaline, 1-celled. **Asexual morph:** Undetermined.

Material examined: USA, New Hampshire, Chocorua, August 1915 (HKAS 35132, reference specimen).

Notes: We illustrate the oldest specimen of *T. ophioglossoides* which came from the USA and is housed in the HKAS herbarium. *Tolypocladium ophioglossoides* which has been commonly named the “Golden Thread Cordyceps”, parasitizes *Elaphomyces* sp. As a Chinese Traditional Medicine, this fungus is used for alleviating female metrorrhagia and menstrual disorders (Zang et al., 1975; Ding, 1982; Chen et al., 2020). This species has been recognized as a highly potential medicinal species as it has antioxidant, antitumor, antibiosis and antifungal activities (Xu et al., 2012; Sun et al., 2013; Sun et al., 2014; Quandt et al., 2015). This study provides a reference specimen to help researchers to identify *Tolypocladium ophioglossoides*.

Note a Material of *Tolypocladium ophioglossoides*. b Ascostroma emerging from infected fungus. c Fertile head of ascostroma. d Host. e Vertical section of the stroma. f Perithecia. g-i Asci. j Apical cap of asci. k Secondary ascospores. Scale Bars: c, d = 5000 µm, e, f = 500 µm, g-i = 100 µm, j, k = 10 µm.

Figure 3.72 Morphology of *Tolypocladium ophioglossoides*

Tolypocladium ophioglossoides J.F. Gmel.) C.A. Quandt, Kepler & Spatafora, in Quandt, Kepler, Gams, Araújo, Ban, Evans, Hughes, Humber, Hywel-Jones, Li, Luangsa-ard, Rehner, Sanjuan, Sato, Shrestha, Sung, Yao, Zare & Spatafora, IMA Fungus 5(1): 127 (2014).

Index Fungorum number: IF 808859

Parasitic in *Elaphomyces granulatus* (Elaphomycetaceae) buried in soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 4–5 cm long, 5–10 mm wide, clavate, dark brown to dark, hard, mostly solitary, stipitate. *Stipe* 3-4 cm long 2–3 mm wide, clavate, dark brown when fresh, dark when dry, with stromata on the top. *Fertile head* 1–2 cm long, 5–10 mm wide, clavate, minutely mammilate, dark brown when fresh, dark when dry, distinctly separated from stipe, hard, solitary. *Perithecia* 670–770 × 310–430 µm ($\bar{x}$ = 720 × 370 µm, n = 30), ovoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 19–25 µm ($\bar{x}$ = 22 µm, n = 60) wide, comprising yellow cells of *textura prismatica* to hyaline *textura porrecta*. *Asci* 370–450 × 6–9 um ($\bar{x}$ = 410 × 8 µm, n = 60), 8-spored, narrow cylindrical, with thick apex. *Apical cap* 3–3.7 × 4.4–5.7 µm ($\bar{x}$ = 3.4 × 5 µm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, irregular, breaking into secondary spores. *Secondary spores* 2.4–4.2 × 1.6–2.1 µm ($\bar{x}$ = 3.3 × 1.9 µm, n = 60), cylindrical, some of the secondary spores quite long (up to 20 µm long), smooth, hyaline, 1-celled. **Asexual morph:** Undetermined.

Material examined: Slovakia, Javorníky Mountains, Desna-Rotov Village, V. Kautman leg. et det. (SL11101901).

Notes: The new collection is closely related to *T. ophioglossoides* based on phylogenetic analyses and the morphology also indicates this specimen is similar to *T. ophioglossoides*. However, some of the secondary spores are up to 20 µm long. Furthermore, this study reports a new record of *T. ophioglossoides* from Slovakia.

Note a Material of *Tolypocladium ophioglossoides*. b Overview of the Tolypocladium *ophioglossoides*. c Host. d Fertile head of ascostroma. e, f Vertical section of the stromata. g Perithecia. h Peridium. i-k Asci. l Apical cap of asci. m Part of ascospores. n Secondary ascospores. Scale Bars: f = 1000 μm, g = 500 μm, i-k = 100 μm, h = 20 μm, l-n = 5 μm.

Figure 3.73 Morphology of *Tolypocladium ophioglossoides* (new records SL11101901)

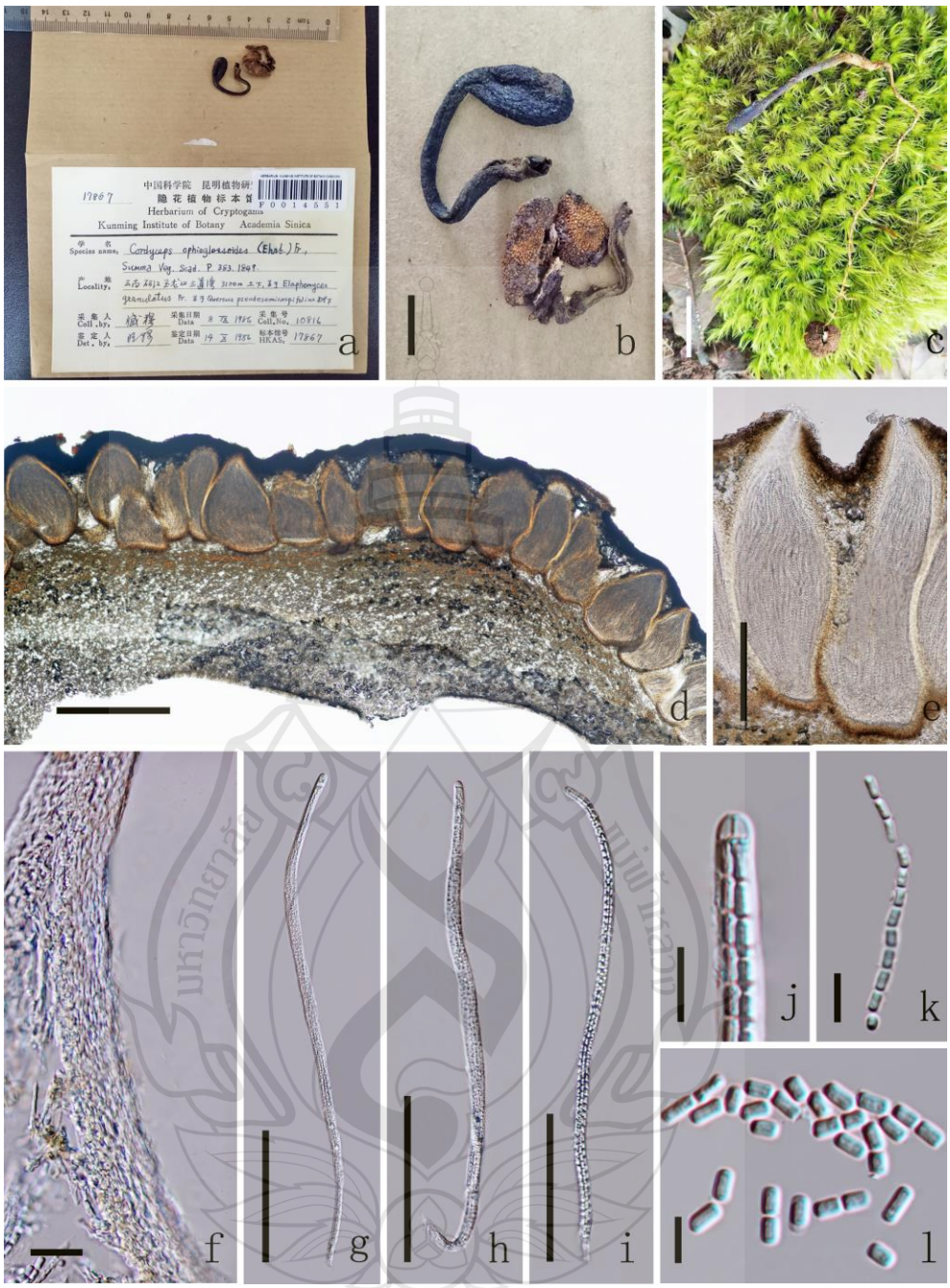
Tolypocladium neoophioglossoides Y.P. Xiao, T.C. Wen & K.D. Hyde***, sp. nov.***

Etymology: The specific epithet refers to the similar species *Tolypocladium ophioglossoides*.

Parasitic in *Elaphomyces* sp. (Elaphomycetaceae) buried in the soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 5 cm long, 3–10 mm wide, dark brown to dark, hard, capitate, mostly solitary, stipitate observed. *Stipe* 4 cm long 3 mm wide, cylindrical, brown when fresh, dark brown to dark when dry, with stromata on the top. *Fertile head* 2 cm long, 1 cm wide, obovoid, minutely mammilate, brown to dark brown when fresh, dark when dry, distinctly separated from stipe hard, solitary. *Perithecia* 420–500 × 190–260µm ($\bar{x}$ = 460 × 220 µm, n = 30), oval, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 15–25 µm ($\bar{x}$ = 20 µm, n = 60) wide, yellow pigmented *textura porrecta* to hyaline *textura prismatica*. *Asci* 360–430 × 5–8 um ($\bar{x}$ = 400 × 7 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 3.1–4 × 4.3–5.1µm ($\bar{x}$ = 3.5 × 4.7 µm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 3.5–5.0 × 1.5–2.5µm ($\bar{x}$ = 4.4 × 2.2 µm, n = 60), cylindrical, smooth, hyaline, one-celled. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Lijiang City, Yulong Mountain. 8 Sept 1986, Mu Zang, (HKAS 17867, **holotype**), China, Guizhou Province, Xishui City, Yu Yang. 20 May 2019 (NGQ02_20041201, **paratype**), China, Guizhou Province, Zunyi City, Yu Yang. 25 June 2019 (520326MF40704B),

Notes: Tolypocladium ophioglossoides-like species ditincted in two main branches in the phylogenetic tree. The strains from Slovakia (SL11101901) and Denmark (CBS 100239) were cluster together. However, the new collections from China (NGQ02_20041201, 520326MF40704B) were distinct with SL11101901 and CBS 100239. Morphologically, the new collections and herbarium specimens differ with *Tolypocladium ophioglossoides* in smaller perithecia, longer secondary spores and no irregular secondary spores observed. Thus, a new species, *Tolypocladium neoophioglossoides*, is introduced in this study.



Note a Material of *Tolypocladium neoophioglossoides*. b Ascostroma emerging from infected fungi. c Fertile head of ascostroma. d Vertical section of the stromata. e Perithecia. f Peridium. g-i Asci. j Apical cap of asci. k, l Secondary ascospore. Scale Bars: b = 1 cm, c = 5000 µm, d = 500 µm, e = 200 µm, g-i = 100 µm, f = 20 µm, j, k = 10 µm, l = 5 µm.

Figure 3.74 Morphology of *Tolypocladium neoophioglossoides* (HKAS 17867)

Tolypocladium paradoxum (Kobayasi) C.A. Quandt, Kepler & Spatafora, in Quandt, Kepler, Gams, Araújo, Ban, Evans, Hughes, Humber, Hywel-Jones, Li, Luangsa-ard, Rehner, Sanjuan, Sato, Shrestha, Sung, Yao, Zare & Spatafora, IMA Fungus 5(1): 127 (2014)**.**

Index Fungorum number: IF 808863

Parasitic in Cicada (Hemiptera, Cicadidae) buried in the soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 4-9 cm long, 2–5 mm wide, cylindrical, dark brown to dark, hard, mostly solitary, stipitate observed. *Stipe* 1–6 cm long 2–3 mm wide, cylindrical, brown when fresh, dark brown to dark when dry, with stromata on the top. *Fertile head* 2–4 cm long, 3–5 mm wide, cylindrical, minutely mammilate, brown to dark brown when fresh, dark when dry, distinctly separated from stipe hard, solitary. *Perithecia* 360–440 × 155–200 µm ($\bar{x}$ = 400 × 180 µm, n = 30), ovoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 11–16 µm ($\bar{x}$ = 14 µm, n = 60) wide, yellow pigmented *textura porrecta* to hyaline *textura prismatica*. *Asci* 240–295 × 7–10 um ($\bar{x}$ = 268 × 9 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 4.2–5.4 × 4.9–5.9µm ($\bar{x}$ = 4.8 × 5.4 µm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 3–4.1 × 2.1–2.8 µm ($\bar{x}$ = 3.6 × 2.4 µm, n = 60), cylindrical, smooth, hyaline, one-celled. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, June 2000, Taixiang Li, (HKAS 36297, reference specimen designated here).

Notes: The new collection is closely related to *T. paradoxum* in the phylogenetic tree. The morphology comparing supports the reference specimen is *T. paradoxum*. This study provides a reference specimen to help researchers to identify *T. paradoxum*.

Note a Material of *Tolypocladium paradoxum* b Ascostroma emerging from infected cicada host. c. Host. d Fertile head of ascostroma. e, f Vertical section of the stromata. g Perithecia. h Peridium. i–k Asci. l Part of the asci. m Apical cap of asci. n–p Secondary ascospores. Scale Bars: c, d = 1 cm, e, f = 500 µm, g = 200 µm, i–k = 100 µm, h, l = 20 µm, m–p = 5 µm.

Figure 3.75 Morphology of *Tolypocladium paradoxum* (reference specimen HKAS 36297)

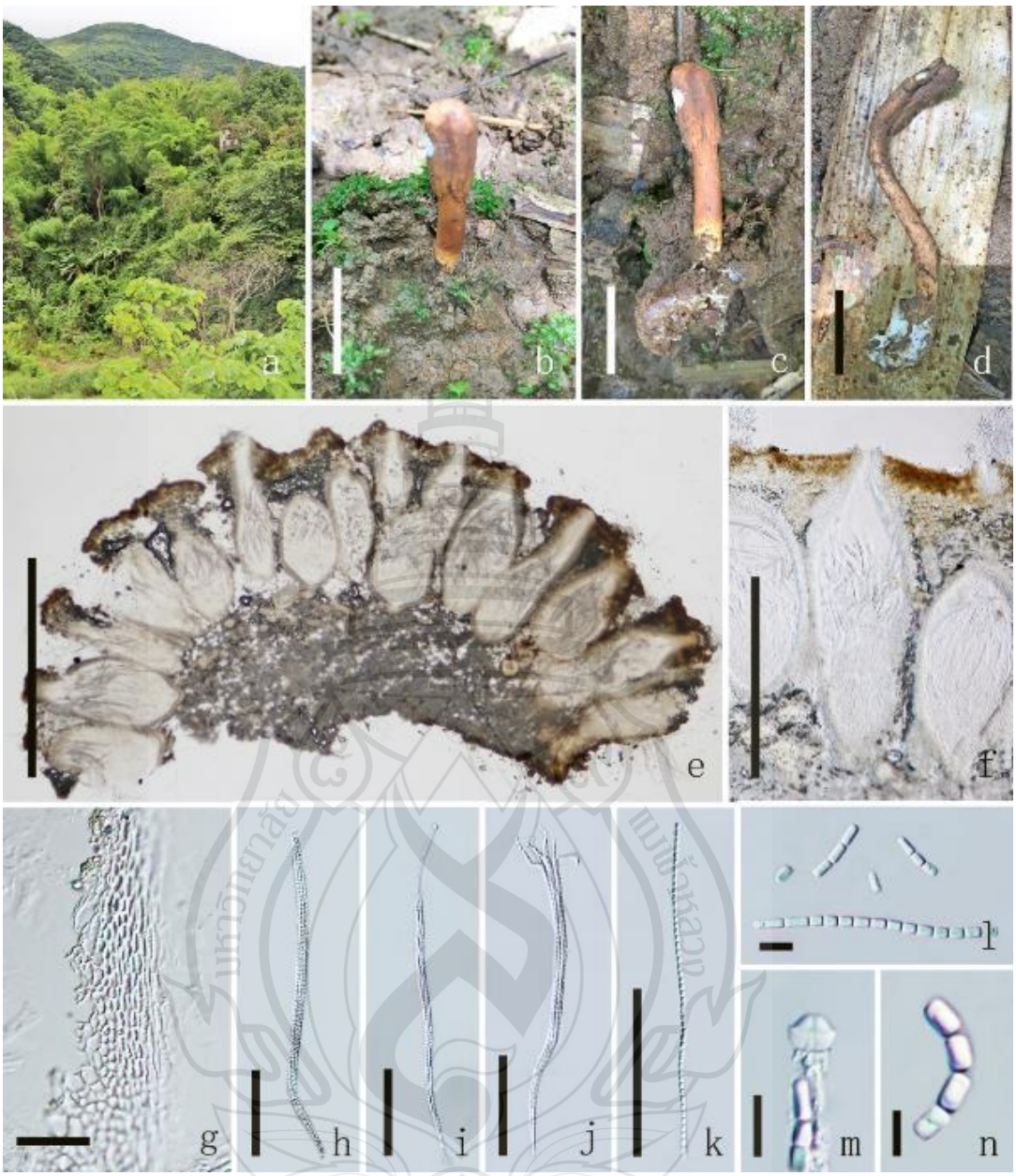
Tolypocladium rutilum Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Parasitic in cicada (Cicadoidea, Hemiptera), collected from soil. **Sexual morph:** *Host* 1.8–2 cm long, 0.8–1 cm wide, brown cicada with white hyphae on the surface. *Stromata* 2.5–10 long × 0.4–0.6 cm diam, unbranched, arising from the head of cicada, reddish ochre when fresh, blackish brown when dry, hard, clavate. *Stipe*

4.5–5 cm long, 0.2–0.25 cm diam., reddish ochre when fresh, brown when dry, with a fertile apex. *Fertile head* 2.5–4 cm long, 1.5–1.8 cm diam., orange to brown, single, unbranched, oblong with a channel in middle, hard, with ostiole. *Perithecia* 577–690 × 183–299 µm ($\bar{x}$ = 633 × 241 µm, n = 60), immersed, crowded, ovoid to obpyriform, ostiolate. *Ostiole* lined with periphyses, brown, thick-walled. *Peridium* 16–30 µm ($\bar{x}$ = 23 µm, n = 90) wide, hyaline to brown, two layers, *textura angularis* to *textura prismatica*. *Asci* 354–431 × 7.3–10.4 µm ($\bar{x}$ = 393 × 8.9 µm, n = 90), 8-spored, hyaline, filiform, with a thick apex. *Apical cap* 5.0–6.3 × 5.5–7.2 µm ($\bar{x}$ = 5.7 × 6.3 µm, n = 60), thick, hyaline, with a small channel in the center. *Ascospores* 344–431 × 2.6–3.5 µm ($\bar{x}$ = 388 × 3.1 µm, n = 90), filiform, hyaline, breaking into secondary spores. *Secondary spores* 4.3–5.9 × 2.6–3.6 µm ($\bar{x}$ = 5.1 × 3.1 µm, n = 90) oblong to cylindrical, one celled, straight, hyaline, smooth. **Asexual morph:** undetermined.

Material examined: China, Yunnan province, Xishuangbanna city. 16 June 2018, Yuanpin Xiao.

Notes: The new species *T. rutilum* is related to *T. paradoxum* and *T. jezoense* according to phylogenetic and morphologic comparison. *Tolypocladium rutilum* differ from *Tolypocladium paradoxum* in producing reddish ochre (when fresh) fertile heads and stipes, and longer secondary ascospores. *Tolypocladium rutilum* is distinct from *Tolypocladium jezoense* in having reddish ochre (when fresh) fertile head and stipe, shorter secondary ascospores. Molecular data indicate that the new species has 20 bp in ITS, 16 bp in LSU, 38 bp in TEF that are different from *T. paradoxum* (NBRC 100945). We described *Tolypocladium rutilum* as a new species.



Note a, b Habitat of *Tolypocladium rutilum*. c, d Stromata emerging from infected cicada. e Cross-section through part of stroma with perithecia. f Perithecia. g Peridium. h-j Asci. k, l Part of ascospores. m Apical cap of asci. n Secondary ascospores. Scale Bars: b-d = 2 cm, e = 1000 µm, f = 500 µm, h-k = 100 µm, g = 20 µm, l = 10 µm, m, n = 5 µm.

Figure 3.76 Morphology of *Tolypocladium rutilum*

Tolypocladium graciliscucullae Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Parasitic in a truffle *Elaphomyces sp.* (Eurotiales, Elaphomycetaceae) buried in the soil, forming yellow to dark violet stromata. **Sexual morph:** *Stromata* 8–13 cm long, 5–10 mm wide, yellow to dark violet when fresh, brown to dark when dry, hard, capitate, mostly solitary, stipitate observed, fertile head portion abruptly enlarged into ovoid. *Stipe* 7 cm long, 3–5 mm wide, yellow to brown when fresh, brown to dark brown when dry, with fertile head on the top. *Fertile head* 2–10 mm in diam, ovoid, minutely mammilate, dark violet to dark when fresh, dark when dry, distinctly separated from stipe, hard, solitary. *Perithecia* 510–600 × 340–460µm ($\bar{x}$ = 560 × 400 µm, n = 30), subglobose to ovoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 21–33 µm ($\bar{x}$ = 28 µm, n = 60) wide, brown pigmented *textura porrecta* to paler *textura prismatica*. *Asci* 365–440 × 8–12 um ($\bar{x}$ = 402 × 10 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 3.9–4.9 × 4.8–6.1µm ($\bar{x}$ = 4.4 × 5.4 µm, n = 60) µm diam, hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 14.6–19.1 × 2.5–3.5µm ($\bar{x}$ = 16.8 × 2.9 µm, n = 60), cylindrical with truncated ends, smooth, hyaline, aseptate. **Asexual morph:** Undetermined.

Material examined: China, Yunnan Province, Zhongdian city, Yuhuang mountain. 19 Sept 1993, Mu Zang.

Notes: We did not obtain sequence data from the specimen. The new species is similar to *T. japonicum* and *T. roburstipitatum* according to morphology comparison. *Tolypocladium graciliscucullae* is distinct with *T. japonicum* in producing dark violet to dark (when fresh) fertile heads, longer asci, and shorter apical caps. *Tolypocladium graciliscucullae* differs from *T. roburstipitatum* in having ovoid, yellow to dark violet stromata (when fresh), abruptly enlarged into an ovoid fertile head, subglobose to ovoid perithecia, longer asci, thin apical cap, shorter secondary spores.

Note a Material of *Tolypocladium graciliscucullae* b Ascostroma emerging from infected fungi. c Fertile head of ascostroma. d Host. e Vertical section of the stroma. f Peridium. g-i Asci. j Apical cap of asci. k-m Secondary ascospores. Scale Bars: c, d = 5000 µm, e = 500 µm, f = 100 µm, g-i = 200 µm, j-m = 10 µm.

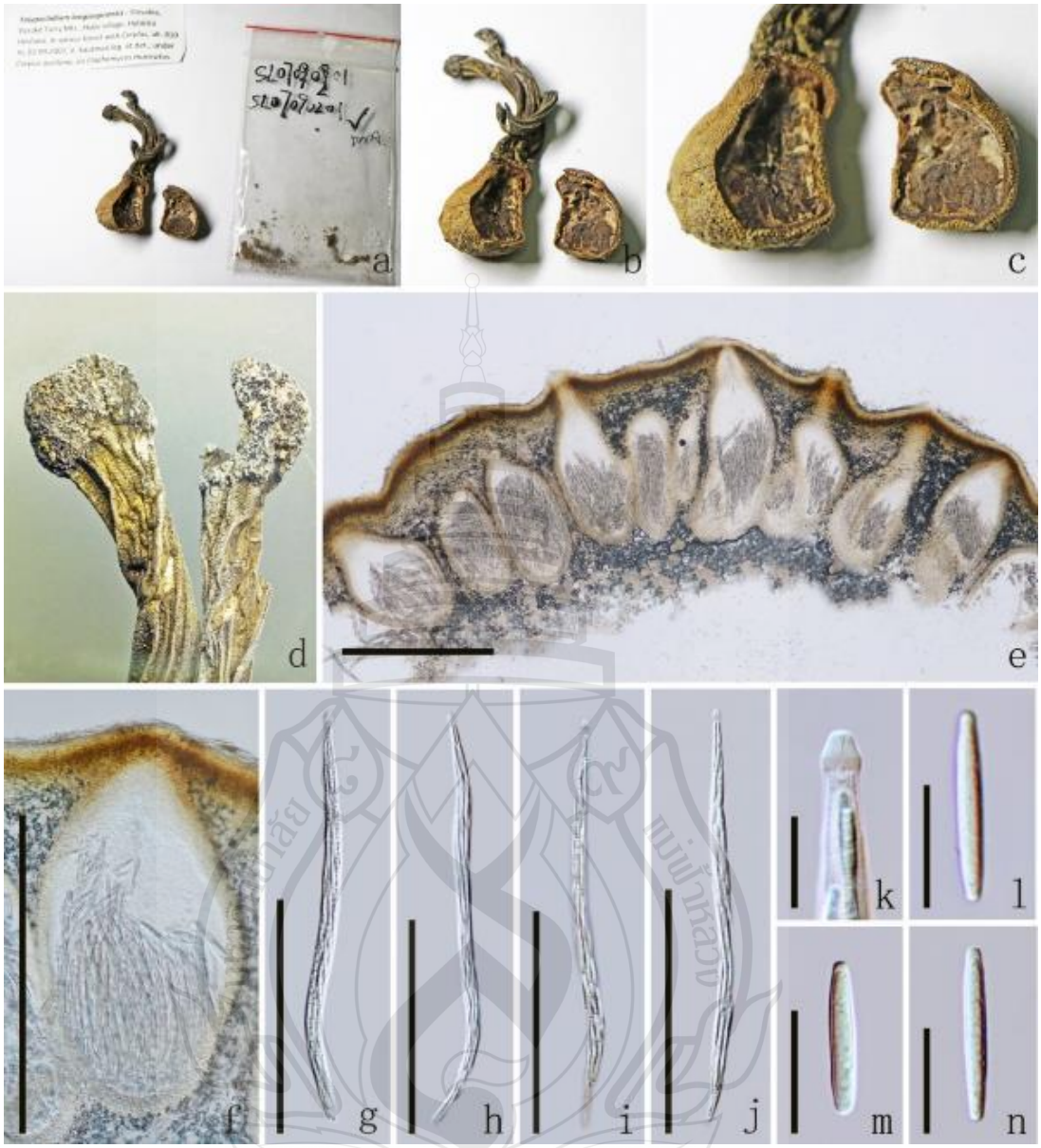
Figure 3.77 Morphology of *Tolypocladium graciliscucullae*

Tolypocladium roburstipitatum Y.P. Xiao, T.C. Wen & K.D. Hyde, ***sp. nov.***

Parasitic in *Elaphomyces muricatus* (Elaphomycetaceae) buried in the soil, forming brown to dark stromata. **Sexual morph:** *Stromata* 3–5 cm long, 3–5 mm wide brown to dark brown, clavate, hard, mostly branched, stipitate observed, not abruptly enlarged from the stipe. *Stipe* 3–4 cm long 3–4 mm wide, cylindrical, brown when fresh, dark brown when dry, with fertile head on the top. *Fertile head* 0.5–1 cm long, 4–5 mm wide, spathulate, minutely mammilate, brown to dark brown when fresh, dark when dry, distinctly separated from stipe, hard. *Perithecia* 470–560 × 200–240 µm ($\overline{x}$ = 520 × 220 µm, n = 30), ovoid to flask-shaped, immersed in stroma with slightly protruding ostiolar papilla. Ostiole lined with periphyses. *Peridium* 19–26 µm ($\overline{x}$ = 22 µm, n = 60) wide, yellow pigmented *textura prismatica* to hyaline *textura porrecta*. *Asci* 300–340 × 10–14 um ($\overline{x}$ = 320 × 12 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 6.4–7.6 × 6.3–7.2 µm ($\overline{x}$ = 7.0 × 6.8 µm, n = 60), hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 27.8–33.1 × 3.7–4.9 µm ($\overline{x}$ = 30.4 × 4.3 µm, n = 60), cylindrical to ellipsoid, with truncated ends, smooth, hyaline, one-celled.

Material examined: Slovakia, Vysoké Tatry, Hybe village, Hybická tiesňava monument, collected by václav kautman leg. et det, in spruce forest with *Corylus*, 02 September 2007.

Notes: According to phylogenetic analysis, the new collection is closely related to *Tolypocladium japonicum*, *T. fractum* and *T. cucullae*. *Tolypocladium roburstipitatum* differs from *Tolypocladium japonicum* in producing spathulate, minutely mammilate fertile heads, and longer secondary ascospores. *Tolypocladium roburstipitatum* is distinct from *Tolypocladium fractum* in having reddish ochre (when fresh) fertile head, ovoid to obpyriform perithecia, longer secondary ascospores. Molecular data indicates that the new species has 30 bp in ITS, 25 bp in LSU, 33 bp in TEF that are different from *T. fractum* (SL06101301).



Note a Material of *Tolypocladium roburstipitatum* b Overview of the *Tolypocladium roburstipitatum.* c Host. d Fertile head of ascostroma. e Vertical section of the stromata. f Perithecia. g-j Asci. k Apical cap of asci. l-n Secondary ascospore. Scale Bars: e, f = 500 µm, g-j = 200 µm, k-n = 20 µm.

Figure 3.78 Morphology of *Tolypocladium roburstipitatum*

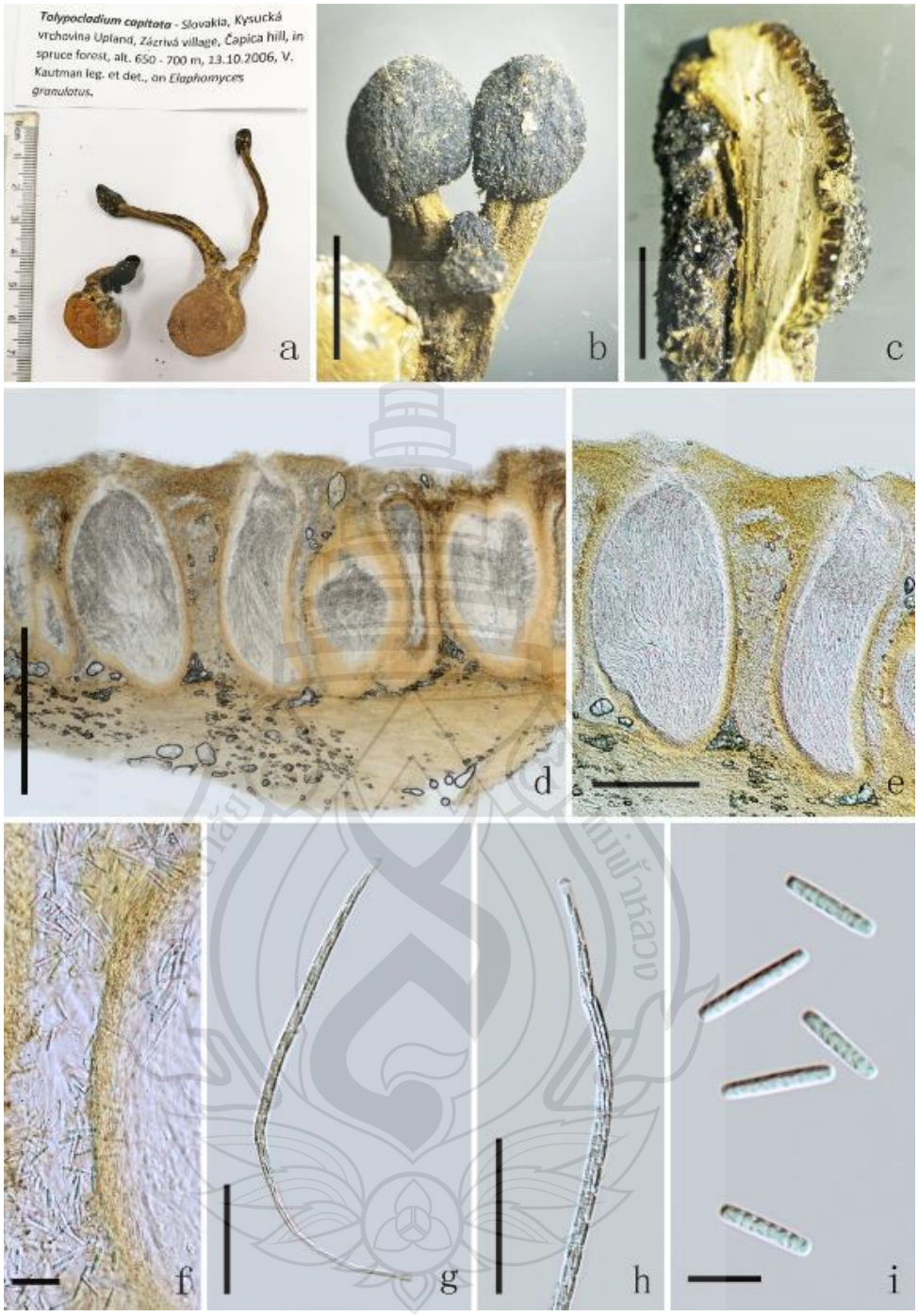
Tolypocladium capitatum (Holmsk.) C.A. Quandt, Kepler & Spatafora, in Quandt, Kepler, Gams, Araújo, Ban, Evans, Hughes, Humber, Hywel-Jones, Li, Luangsa-ard, Rehner, Sanjuan, Sato, Shrestha, Sung, Yao, Zare & Spatafora, IMA Fungus 5(1): 126 (2014)**.**

Index Fungorum number: IF 808699

Parasitic in a truffle *Elaphomyces granulatus* (Eurotiales, Elaphomycetaceae) buried in the soil, forming dark stromata. **Sexual morph:** *Stromata* 2–6 cm long, 0.5–1.2 cm wide, yellow to brown when fresh, brown to dark when dry, hard, capitate, mostly solitary, stipitate observed. *Stipe* 1–5 cm long, 4–7 mm wide, cylindrical, yellow when fresh, brown when dry, with fertile head on the top. *Fertile head* 0.8–15 mm in diam, hemispherical to globe-shape, brown when fresh, dark when dry, distinctly separated from stipe, hard, solitary. *Perithecia* 400–700 × 200–250µm ($\bar{x}$ = 536 × 267 µm, n = 30), subglobose to ovoid, immersed in stroma with slightly protruding ostiolar papilla. *Ostiole* lined with periphyses. *Peridium* 21–33 µm ($\bar{x}$ = 28 µm, n = 60) wide, brown pigmented *textura porrecta* to paler *textura prismatica*. *Asci* 360–540 × 6–10 um ($\bar{x}$ = 478 × 8 µm, n = 60), narrow cylindrical, hyaline, with thick apex, 8-spored. *Apical cap* 3.5–5.4 × 5–5.8µm ($\bar{x}$ = 4.9 × 5.4 µm, n = 60) µm diam, hyaline. *Ascospores* as long as asci, filiform, hyaline, breaking into secondary spores. *Secondary spores* 13–21 × 2–4 µm ($\bar{x}$ = 16.7 × 3 µm, n = 60), cylindrical with truncated ends, smooth, hyaline, aseptate. **Asexual morph:** Undetermined.

Material examined: Slovakia, Zazriva Village, Capica Hill, V. Kautman leg. et det. 13 October 2006 (SL06101301)

Notes: The new collection (*T. capitatum* SL06101301) clusters with *Tolypocladium capitatum* in the phylogenetic tree. According to morphology, the new collection is identified as *T. capitatum*. This fungus is used as tradition Mexican medicinal as “Hombrecitos” (Guzman, 2008). This study introduces a new record from Slovakia.



Note a Material of *Tolypocladium capitatum* b Fertile heads. c Vertical section of the stromata. d, e Perithecium. f Peridium. g Asci. h Apical cap of asci. i Secondary spores. Scale Bars: b = 5000 µm, c = 2000 µm, d = 500 µm, e = 200 µm, g = 100 µm, h = 50 µm, f = 20, i = 10 µm.

Figure 3.79 Morphology of *Tolypocladium capitatum*

Table 3.14 Morphological comparison of asexual morph species of the genus *Tolypocladium*

Species	Conidiomata (µm)	Phialides (µm)	Conidiophores (µm)	Conidia (µm)
T. album	Irregular globose, discrete or confluent, aerial mycelia, its diameter 80–250	Cylindrical, tapering slightly at the end, 3.5–10 × 1.0–1.5, neck 0.6–0.9 wide		spherical or ovoid, thin, smooth, 1.5–2.0 wide
T. amazonense		Phialidic, discrete, lageniform, hyaline, smooth-walled, 4.6 × 1.2 long 1.5 × 0.3 wide	Trichodermoid branching pattern	Globose, hyaline, aseptate, smooth, 1.4 × 0.2 diam.
T. capitatum	Constantly produced in a stag, often caespitose	1-4 long, 2-4 thick, smooth, hairless, citrus, and finally fibrous-strigose, yellowish-black		
T. cylindrosporum		Out of the side of the basal flata, 3-5 2.0-2.8, filiform, 1.5-2.0, 0.3-0.5, things consist		Cylindrical, thin, smooth, 4.0-5.8 × 1.2-1.6.
T. dujiaolongae		Solitary, occasionally verticillate, 11–35 × 1.0–2.7, cylindrical or conical, slightly swollen basally, neck 1.0 wide		One-celled, hyaline, smooth-walled, globose to ovoid when separate, 3–4 × 2.4–3.7
T. endophyticum		Phialidic, discrete, lageniform, hyaline, smooth-walled, 4.1 × 0.9 long 1.6 × 0.2 broad	Trichodermoid branching pattern.	Globose, hyaline, aseptate, smooth, 1.3 × 0.2 diam.
T. fumosum			1-celled, discrete, hyaline, monophialidic, narrow neck, smooth-walled, 8–10 × 1.5–2	Obovate to cylindrical, smooth, hyaline, aseptate, without oil drops, 2–3.5 × 1.5–2
T. geodes		Branch or in an isolation, 3-6 × 1.2-2.5, base is slightly inflated, 5-6 × 1.2-2.0		Heads are connected, spherical or globose, 1.6-2.0

Table 3.14 (continued)

Species	Conidiomata (µm)	Phialides (µm)	Conidiophores (µm)	Conidia (µm)
T. inflatum type	3.5 × 2–3	2.5–3.5 × 2.0–2–5		Heads are connected, subglobose, hyaline, smooth, 2.0–2.5 × 1.4–2.0
T. lignicola		Single or adsociatae, 3–4.5 wide × 4–8 long, apical part 2–5 × 0.8 wide	Short, simple or branched small quantities, up to 100 high 100 × 2–3.5	Hyaline, septate, septate, thick, solitary, attenuate, diameter 2.5–3.2, and 1.5–2.0 wide
T. microsporum		6.5–15.0 × 1.4–2.3 um, solitary or in verticils of two to five, nearly cylindrical or slightly swollen basally	Hyaline, smooth walled, cylindrical, up to 120 um long, 1.8–2.9 um wide at the base	One celled, hyaline, smooth walled, 1.8–2.5 × 1.3– 1.7
T. nubicola		Solitary or in verticils of two or three, mostly 4.4–7.8 × 1.5–2.7, subglobose to broadly ellipsoidal, neck about 0.3 wide and 2.0–4.5 long	Hyaline, smooth walled, cylindrical, up to 70 long, 1.1–2.4 wide, irregularly branched; branches cylindrical, 3–12 × 1.2–2.4	One celled, hyaline, smooth walled, cylindrical, straight or slightly curved, both ends broadly rounded, 2.6–4.1 × 0.8–1.3
T. ovalisporum	Globose or of irregular shape, 100–750 diam	10–30 long, 1.0–2.0 wide at the base, < 0.5–1 wide at the tip		Vaeiable in shape, tapering and truncate at the base, hyaline, smooth-walled, 4.5–9 × 2.5–3.5
T. pustulatum		Cylindrical to lageniform, 4–10 long, when mature inflated at the base, 2–4 wide		Hyaline, thin-walled, broadly ellipsoidal or obovate, with a slightly flattened base, 2–3 × 1.5–2.5
T. terricola		Single or in verticils on the end of conidiophores, 2.8–3.5 × 2–3 and a thin neck 3–4 × 0.5–1	Hyaline, small, cylindrical, 20–30 × 3–6	Solitary, uniform in size and shape, 2.5–3 × 2–2.5, broad oval, smooth-walled
T. trigonosporum		4–7 × 2.5–3.5 wide, elongate cylindrical upper portion 7–10 long by 0.5– 1.0 wide		Equilateral triangle with rounded comers and slightly concave edge, 2.5–3.2
T. tropicale		Phialidic, discrete, lageniform, hyaline, smooth–walled, 4.6–6.8 long 1.5–1.8 wide	Trichodermoid branching pattern.	Globose, hyaline, aseptate, smooth, 1.5–1.6 diam
T. tundrense		Solitary or in verticils of two or three, 6–13 × 1.8–3.0, swollen and ellipsoidal in the lower part	Hyaline, smooth walled, cylindrical, less than 40, sparingly branched; branches cylindrical, 6– 11 × 1.2–2.5	One celled, hyaline, smooth walled, ellipsoidal or reniform, mostly 2.3–4.2 × 1.3–2.3; rarely cylindrical, and up to 10 × 2.4

Table 3.14 (continued)

Species	Conidiomata (µm)	Phialides (µm)	Conidiophores (µm)	Conidia (µm)
T. extinguens	without	Small, consisting of a swollen base and a thin neck, 3.5–9 × 1.5–2	Up to 100 long, with stipe 3–5 wide	One celled, ellipsoidal, hyaline, small walled, 2–2.5 × 1.5–2, sometimes larger, subglobose to ellipsoidal conidia are also formed, 3.5–4 × 3–3.5

Table 3.15 Morphological comparison of sexual morph species of the genus *Tolypocladium*

Species	Stromata (mm)	Fertile part (mm)	Perithecia (um)	Secondary spores (um)
T. delicatistipitatum	Solitary, simple, thin, fleshy, up to 100 long	Spherical or ovoid, brownish-yellow to olive-brown, 2–2.5 in diameter, 2–3.5 long	Ordinally immersed, ovoid, 480–540 × 225–255	Large, 18–28 × 3–5, cylindrical, truncate or rounded at ends
T. fractum	Capitate, 15–25 long	Purplish black, 2.5 in diameter, distinct from stipe	Ovoid, 500–600 × 250–350, completely immersed	2–5 × 1.5–2, 1–celled, cylindric
T. japonicum	Simple or branched, solitary or caespitose, 70–110 in height	Cylindrical to clavate, 15–35 × 4–8, deep olive–gray, internally yellowish	Ovoid, 500–700 × 200–350, immersed with ostioles slightly protruding	Cylindrical, ellipsoid, 10–18 × 2.5–4
T. ophioglossoides	Simple or rarely branched above, 20–80 long, 3–8 thick, reddish brown to olivaceous brown		Ovoid, 600–800 × 250–500, entirely embeddedin the stroma	1–celled segments 2–4 × 1.5–2, truncated
T. tenuisporum	Up to 70 long, clavate; dark chestnut–brown when dried	Obovoid, 10–15 × 8–10, dark brown, not distinctly separated from the stipe	Narrowly ovoid, 750–100 × 250–300, slender neck, completely immersed.	1–celled cylindric segmen 6–8 × 1–1.5
T. capitatum	Capitate, 20–110 long, natal–brown, olive–brown to olive–black	Clavate to capitate, rarely undifferentiated, 5–20 × 5–15	Ovoid, 650–950 × 250–420, entirely embedded;	1–celled, cylindric or somewhat fusoid segments 8–25 × 2.5–3
T. valliforme	Capitate, 50–70 long, dark brown		Ovoid, 500–700 × 200–350, entirely embeddecl	1–celled cylindric segments 3–8 × 2

Table 3.15 (continued)

Species	Stromata (mm)	Fertile part (mm)	Perithecia (um)	Secondary spores (um)
T. dujiaolongae	Blackish brown to blackish–purple, fleshy, 26–70 long, clavate or obclavate, corniform or oblate	Clavate, 40–55 × 4–12, clearly defined from the stipe, brown to black, without sterile tip	Wholly immersed, 520–740 × 300–330	Cylindrical, 3–5 × 2–3
T. fumosum	Yellowish, single, unbranched, rounded apex, pale chalcedony yellow at the base to dark gull grey at the apex	1/5–1/4 of the total length, ellipsoidal when young and capitate when mature, enlarged up to 3.8 diam	Ovoid to pear–shaped, 740–760 × 444–558, perithecial wall of brown pigmented textura angularis and of paler textura epidermoidea	Short cylindrical to cubic, with flattened ends and wall equally thick, 2–4.5 × 1–1.5
T. guangdongense	Cylindrical to clavate, 30–70 long, tender fleshy, 10–30 × 5–8, olive, dark olive, oilive brown to golden gray or brownish gray	20–40 × 4–6,yellowish gray, olive, grayish olive, olive–gray to gray, with white mycelium	Deeply embedded in stroma, ellipsoid to ovoid, 245–495 × 160–320	10–17 long, with truncated ends
T. intermedium	Simple, usually solitary, 70–90 long	Capitate, 6–12 in diameter, brown to black in color, blackening when drying	Crowded subellipsoideis gently protruding out of the rough	3–7.5 × 2–3, yellow to hyaline
T. intermedium f. intermedium	Obscurely in diameter differs, 35–40	3 in diameter, dark olivaceous	470–530 × 250–300, ovoid	2.5–3 × 1.5
T. inegoense	Cylindrical, single, fleshy, 140 long	Cylindric, equal 50 long 6 thick, apex obtuse, without sterile tip, dark olivaceous, apical part somewhat bluish	Superficial, half-immersed, pyriform, 520–550 × 260–280	short cylindric, truncate at both ends, 2.5–3 × 2
T. jezoense	Solitary or rarely cesptose, simple or rarely branched, 60–130 high.	Clavate or oblong, dark olive-gray or olivaceous black, becoming nearly black in drying, subcarnose, yellow within, 10–27 × 3–8	Ovate, slightly protruded or immersed	Segments fusoid–elongated or subbacillary, 16–50 × 3.5–4.5

Table 3.15 (continued)

Species	Stromata (mm)	Fertile part (mm)	Perithecia (um)	Secondary spores (um)
T. longisegmentatum	When fresh broadly rounded, 13 diam, brown, dark brown to olive brown; when dried nearly obcordiform, to 14 diam and 13 tall, glabrous, minutely punctate, black or dark brown		Imbedded, ellipsoid, hyaline, about 500 × 300 um	40–65 × 4–5, truncated, thickwalled, slightly refractive apices
T. minazukiense	Solitary, simple, and 50–120	Capitate to depressed–globose, 5–12 in diameter, dark gray	Immersed, ampullaceous, tall and narrow, 900–930 × 220–250	fusoid, 16–18 × 3
T. miomoteanum	Capitate, 65 long, 3–4 wide, white		Ovoid, regularly immersed, 770–800 × 350–43, ostioles conical and protruding,	8–11 × 1.5–2, truncated on both sides.
T. paradoxum	Solitary, simple, firm and fleshy, 40–90 in length	Oblong to clavate, distinct from stipe	Densely, ordinally immersed, ovoid, hyaline, 550–700 × 280–350	Short, cylindric, truncate at both ends, 3–5 × 1.5–2
T. ramosum	Clavae, 70 high, 1 diameter below, attenuated upwards, longitudinally sulcate, terete, ashy brown, glabrous		Dark brown, subtranslucent, collapsing laterally, while those on the main stem are rufous brown and rigid	Neither free ascospores nor part–spores have been seen
T. rouxii	Solitary or caespitosa, 20–40	3–8, with a dark brown, viscous, sturdy shape	Immersa, minuta, ovoidea collis plusve minusve elongatis 400–500 × 200–280	Cylindrical articles 16 × 2.5–3 sides fusiform
T. toriharamontanum	Solitary, simple, 100 in height	Clavate, pear shaped, elongate, subcompressed, 10–80 in length, 10 thick, rounded at the tip, dark olive green in color	Oblong with elongated neck, 680–740 × 290–340	Cuboid, 1.5–2.5 × 1.5–1.7
T. szemaoense	Clavate, in clusters, occasionally 2,3 or more from host, 50–70 long, 1.5–3 diam,	Punctate with ostioles of the perithecia, with a cortex	Globoid or ovoid, 250–400 × 300–500, orange–brown and brown when mature.	Segment, 3 –3.5 ×2–2.5 articulate, moniliform

Table 3.15 (continued)

Species	Stromata (mm)	Fertile part (mm)	Perithecia (um)	Secondary spores (um)
T. valvatistipitatum	Solitary or cespitose, 45–70 in height, capitate	Ovoid, oblong, or barrel shaped, 7–18 × 5–9, pale blue to grayish–blue	Medium sized, with rather short neck, 630–700 × 240–270	Cylindrical with truncated ends, 7.5–16 × 2.5–3
T. virens	Capitate	Globose, 1.8–2 in diameter, minutely mammilate, black	Ovoid, immersed, 400 × 250	6 × 1.5, truncated
T. inflatum	Solitary, 15 tall and are constructed of loosely woven hyaline hyphae	Yellow color, capitate, (bearing pads of perithecia)	Narrowly ovoid to conoid, pseudoimmersed, large, 800–1100 × 320–450, yellow to brown	4.0 × 1.0
Elaphocordyceps xjezoensoides	70–150 or more long, solitary simple	Cylindrical or long clavate, 25–27 long, 3.5–4.5 wide, dark olivaceous brown or nearly black	Small, 480–500 long, 220–230 wide	Cylindrical 11–15 commonly 12 long, 2.5–3 wide, rounded at both ends
T. cucullae	Capitate, stipitate	Hemispherical, 8–10 in diameter, minutely mammilate, deep green to dark green when fresh, dark when dry	500–650 × 380–430, subglobose to ovioid, immersed	22–32 × 3–4.5, cylindrical with truncated ends
T. cautis	50 long, 3–10 wide, brown to dark brown, hard, capitate, mostly solitary	5 in diam, hemispherical, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	480–560 × 170–240, ovioid to obpyriform, immersed	33–40 × 3.5–4.8, cylindrical with truncated ends, smooth, hyaline, one-celled, without septate
T. neoophioglossoides	50 long, 3–10 wide, dark brown to dark, hard, capitate, mostly solitary	20 long, 10 wide, obovoid, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	420–500 × 190–260, oval to ovoid, immersed	3.4–4.8 × 1.6–2.3, cylindrical, smooth, hyaline, one–celled
T. ophioglossoides	80–130 long, 5–10 wide, yellow to dark violet when fresh, brown to dark when dry, hard, capitate, mostly solitary	2–10 in diam, ovoid, minutely mammilate, dark violet to dark when fresh, dark when dry, solitary	513–601 × 341–458 subglobose to ovoid, immersed	14.6–19.1 × 2.5–3.4, cylindrical with truncated ends, smooth, hyaline, aseptate
T. ophioglossoides	20–50 long, 2–5 wide, dark brown to dark, hard, mostly solitary	5–10 long, 3–5 wide, cylindrical, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	535–600 × 290–335, ovoid to obpyriform, immersed	2.4–3.4 × 1.7–2.2, cylindrical, smooth, hyaline, one–celled

Table 3.15 (continued)

Species	Stromata (mm)	Fertile part (mm)	Perithecia (um)	Secondary spores (um)
T. paradoxum	40–90 long, 2–5 wide, cylindrical, dark brown to dark, hard, mostly solitary	20–40 long, 3–5 wide, cylindrical, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	360–440 × 155–200, ovoid, immersed	3.0–4.1 × 2.1–2.8, cylindrical, smooth, hyaline, one–celled
T. paradoxum	20–30 long, 3–8 wide, cylindrical, dark brown to dark, hard, mostly solitary	5–10 long, 3–5 wide, capitate to clavate, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	290–400 × 170–230, ovoid, immersed	3.0–4.4 × 2.2–2.8, cylindrical, smooth, hyaline, one–celled
T. rutilum	25–100 long × 4–6 diam, unbranched, yellow to brown, hard, cylindrical	25–40 long, 15–18 diam, orange to brown, single, unbranched, oblong with a channel in middle	577–690 × 183–299, immersed	4.3–5.9 × 2.6–3.6 oblong to cylindrical, one celled, straight, hyaline, smooth
T. rouxii	30–50 long, 3–5 wide brown to dark brown, hard, mostly branched	5–10 long, 4–5 wide, spathulate, minutely mammilate, brown to dark brown when fresh, dark when dry, solitary	470–560 × 200–240, ovoid to obpyriform, immersed	27.8–33.1 × 3.7–4.9, cylindrical with truncated ends, smooth, hyaline, one–celled
T. ophioglossoides (SL11101901)	40–50 long, 5–10 wide, clavate, dark brown to dark, mostly solitary	10–20 long, 5–10 wide, clavate, minutely mammilate, dark brown when fresh, dark when dry, solitary	670–770 × 310–430, ovoid, immersed	2.4–4.2 × 1.6–2.1, cylindrical, some of the secondary spores quite long, smooth, hyaline, one–celled
T. rouxii (SL10072301)	40–120 long, 2–10 wide pale yellow to dark brown, capitate, mostly branched	5–10 diam, capitate, minutely mammilate, dark brown	470–555 × 170–260, ellipsoid, immersed	15.9–20.4 × 2.8–3.6, cylindrical with truncated ends, smooth, hyaline, one–celled
T. ophioglossoides (SL17050801)	20–30 long, 2–5 wide yellow to titian, clavate, solitary	10–20 long, 3–6 wide, cylindrical, minutely mammilate, brow	380–440 × 170–230, oval to ovoid, immersed	3.5–5.5 × 1.0–1.4, cylindrical, smooth, hyaline, one–celled

3.4 Discussion

Ophiocordycipitaceae has attracted a lot of research attention since it was established by Sung et al. (2007). Thus, this decagde, new species and combinations have been introduced or revised under this family (Evans et al., 2011; Wen et al., 2014; Quandt et al., 2014; Sanjuan et al., 2015; Ban et al., 2015; Araújo et al., 2019; Mongkolsamrit et al., 2019; Xiao et al., 2019; Tasanathai et al., 2020; Khao-ngam et al., 2021). Ophiocordycipitaceae species are noted for high commercial value in medicine, chemistry, agriculture, and ecology (Yang et al., 2004; Leung et al., 2006; Survase et al., 2011). Some Ophiocordycipitaceae species have been investigated for potentially high economic and ecological values: *Ophiocordyceps sinensis*, *Ophiocordyceps xuefengensis*, *Ophiocordyceps communis*, *Tolypocladium inflatum*, *Tolypocladium koningii*, *Tolypocladium ophioglossoides*, *Drechmeria coniospora*, *Hirsutella kobayasii*, *Hirsutella nivea*, *Hirsutella beakdumountainsis* (Grafe et al., 1991; Krasnoff & Gupta, 1992; Vongvanich et al., 2002; Yang et al., 2004; Leung et al., 2006; Haritakun et al., 2010; Survase et al., 2011; Qin et al., 2018; Elshamy et al., 2020). More than 20 bioactive compounds from these species were reported to have anti-cancer, anti-microbial, anti-plasmodium, antioxidant, immune modulation, insecticidal and antimalarial properties (Grafe et al., 1991; Krasnoff & Gupta, 1992; Vongvanich et al., 2002; Yang et al., 2004; Leung et al., 2006; Zhang et al., 2012; Yu et al., 2012; Xiang et al., 2014; Reis et al., 2017). Species of *Harposporium* and *Drechmeria* have been investigated for antibiotic biocontrol of livestock-parasitic nematodes, as well as antibacterial and antifungal activities (Jansson, 1982a, 1982b; Aschner & Kohn, 1958; Charles et al., 1996; Barron, 2013; Cai et al., 2016; Zhao et al., 2018a, b; Liang et al., 2019). Moreover, some active strains that were named *Ophiocordyceps* sp. or *Hirsutella* sp. have been reported as produce bioactivity compounds (Lang et al., 2005; Thongtan et al., 2006; Khaokhajorn et al., 2015; Kil et al., 2020; Bernatchez et al., 2021). Thus, in these large fungi group, clear identification is necessary. In this study, lists almost all the species of Ophiocordycipitaceae in this group.

This family consists of: *Drechmeria*, *Harposporium*, *Hirsutella*, *Hymenostilbe*, *Ophiocordyceps*, *Paraisaria*, *Purpureocillium*, and *Tolypocladium* (Sung et al., 2007; Kirk et al., 2013; Quandt et al., 2014; Spatafora et al., 2015; Xiao et al., 2021 in press). This is a large family that contains more than 400 species and high diversity in *Ophiocordyceps*, which contains more than 250 species (Species Fungorum, 2021). Current methods of species identification usually analyze comparisons of morphology and molecular phylogeny. However, many species of Ophiocordycipitaceae were proposed without molecular data. For instance, many old species were described before the development of molecular techniques. Moreover, it is hard to extract the DNA of very tiny species such as species associated with ants. In addition, the morphologies of these groups are complex due to the number of species, which have quickly increased year by year (Araújo et al., 2019; Mongkolsamrit et al., 2019; Xiao et al., 2019; Tasanathai et al., 2020; Khao-ngam et al., 2021), and more species are expected to be introduced under the family Ophiocordycipitaceae.

Ophiocordycipitaceae species are widely distributed throughout the world, with high diversity in tropical and subtropical regions. Many species in Ophiocordycipitaceae are entomopathogens, which are parasites on 11 orders of arthropods including, Araneae, Blatteria, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Megaloptera, Orthoptera, and Trombidiformes. Some species of Ophiocordycipitaceae are parasites on protozoans, rotifers, nematodes, humans, and other fungi (Sung et al., 2007; Quandt et al., 2014; Spatafora et al., 2015).

Although Arthropoda-associated species occurred in all eight genera, different genera have different diversity in hosts groups. All most all the species of *Ophiocordyceps* and *Hymenostilbe* were parasitic on species of Arthropoda. The hosts of asexual morph species in *Drechmeria* and *Harposporium* were mainly protozoans, rotifers and nematodes. Excepting *Harposporium peltatum* (Host: Coleoptera) (Chaverri et al., 2005), *Drechmeria coniospora* (Soil habitat or plant) (Zare & Gams, 2001) and *Drechmeria panacis* (Host: Plant, *Panax notoginseng*) (Yu et al., 2018). The hosts of sexual morph species *Drechmeria* and *Harposporium* are species of Arthropoda (Berkeley, 1848; Chaverri et al., 2005; Spatafora et al., 2015). Sexual morphic species of *Tolypocladium* were parasites on *Elaphomyces sp.*, except *Tolypocladium fumosum* (Host: Psychidae) (Crous et al., 2017), *Tolypocladium*

dujiaolongae (Host: Cicada) (Li et al., 2018), *Tolypocladium inegoense* (Host: (Cicada) *Oncotympana maculaticollis*) (Kobayasi & Shimizu, 1963) and *Tolypocladium paradoxum* (Host: (Cicada) *Platypleura kaempferi*) (Kobayasi, 1939). The host of asexual species of *Tolypocladium* are diverse on insects, rotifers and habitat in soil (Gams, 1980; Bissett, 1983; Moller & Gams, 1993; Gazis et al., 2014; Fries & Hoffmann, 1821; Gams, 1971; Li et al., 2018; Crous et al., 2017; Wijayawardene et al., 2021). The host of most *Hirsutella* species were Arthropoda. However, several species of *Hirsutella* were parasite on nematodes (Sturhan & Schneider 1980; Chen et al., 2000; Xiang et al., 2006).

There are three Ants-associated species groups of *Ophiocordyceps* were considered as host-specific groups, including *Ophiocordyceps australis* complex *Ophiocordyceps mymecophila/ irangiensis* complex and *Ophiocordyceps unilateralis* complex (Kobmoo et al., 2012; De Bekker et al., 2017; Kobmoo et al., 2019; Khonsanit et al., 2019). The morphology characters of ants-associated species are quite similar, but the phylogenetic analysis showed their independent state (Kobmoo et al., 2012; Kobmoo et al., 2019). Thus, ant-associated species of *Ophiocordyceps* were recognized as a host specific group based on phylogenetic evidence. Khonsanit et al. (2019) introduced three ant-associated species, which were collected from the same type of habitat, that shared similar characters and are slightly different in the size of asci and apical caps, and the shape of secondary spores. This may reveal a cryptic diversification in the *Ophiocordyceps myrmecophila* complex, which is not related to the hosts or ecology. Moreover, the wasp-associated species group (*Ophiocordyceps sphecocephala* complex) also shows that they should be a host-specific group in this study. The fly-associated species group are expected to be a host-specific group but need more evidence.

Drechmeria, Harposporium, Paraisaria, Purpureocillium and *Tolypocladium* were clustered different independent clades in the phylogenetic tree. However, *Hirsutella*, *Hymenostilbe* and *Ophiocordyceps* were clustered within one clade. *Hirsutella* and *Hymenostilbe* are suppressed based on morphology and phylogenetic evidence (Quandt et al., 2014). Although, *Hirsutella* was refreshed with many updated molecular data. We would like to follow the system but keep the name and wait for

more evidence providing in the future. Thus, two new asexual morphic species were introduced under Ophiocordyceps instead of *Hirsutella* or *Hymenostilbe*.

CHAPTER 4

CONCLUSIONS

4.1 Overall Conclusion

4.1.1 Taxonomic Placement of Polycephalomycetaceae

The taxonomic placement of three genera, *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*, in Ophiocordycipitaceae have been problematic and challenging due to inadequate molecular data and unstable phylogenetic relationship. This study investigated reference specimens and fresh collections to improve the current taxonomic placement of the said genera. Six new species, four new hosts, and a new combination were described among these genera. Twenty fresh samples were obtained from China and Thailand, thus expanding the genera's taxa. Multi-loci ITS, LSU, SSU, TEF, RPB1, and RPB2 analyses clarified the phylogenetic placement. Consequently, a novel family, Polycephalomycetaceae, was segregated from Ophiocordycipitaceae based on morphologic and phylogenetic analyses.

The new family, Polycephalomycetaceae, comprises three genera, including *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps*. The taxonomy and phylogeny placements of these three genera are reassessed. All species of Polycephalomycetaceae are listed with main morphological characteristics.

Polycephalomyces is the type genus of the novel family Polycephalomycetaceae, forming an independent clade in the phylogenetic tree. A new host of the type species is recorded with modern concepts. In addition, one new species is proposed under the genus based on morphologic and phylogenetic analysis. The updated strains of the incertae sedis species (*Cordyceps pleuricapitata*) are clustered with *Polycephalomyces* in the phylogenetic tree. Thus, *Cordyceps pleuricapitata* is redrawn for future studies.

Perennicordyceps is a monophyletic genus within the novel family Polycephalomycetaceae. Its species parasitize on insects or *Elaphomyces sp.* They are characterized as producing superficial perithecia and typically having two types of conidia. The type species is redrawn in this study, and a new combination with one new host is indicated with molecular data. Moreover, all *Perennicordyceps* species with information regarding their primary morphologic characteristics are presented.

Pleurocordyceps is a monophyletic genus within the novel family Polycephalomycetaceae. Its species alternately parasitize on insects or fungi. *Ophiocordyceps* sp. has been frequently reported as the host of *Pleurocordyceps* species. This study defines five new species and two new hosts based on morphologic and phylogenetic analysis. Furthermore, all *Pleurocordyceps* species with information regarding their primary morphologic characteristics are presented.

4.1.2 Studies on Ophiocordycipitaceae

The identification and classification of Ophiocordycipitaceae species had been difficult due to the numerous species involved. This study clarified the morphology and taxonomy of each Ophiocordycipitaceae genus using fresh collections and herbarium specimens from Thailand, China, UK, America, and Slovakia. This study proposed the detail of the peridium as a primary morphologic characteristic, which would help resolve the natural classification of Ophiocordycipitaceae. Additionally, almost all species of Ophiocordycipitaceae were listed in the tables with their main characteristics. The phylogenetic placement and relationship of each Ophiocordycipitaceae genus was determined based on morphological comparisons and molecular data discussed in Chapter 3, which also included a monography of Ophiocordycipitaceae. The affiliation and connectivity between the sexual and asexual morphs of Ophiocordycipitaceae were analysed. Two asexual morphic genera, *Hirsutella* and *Hymenostilbe*, were suppressed. Nevertheless, their names were reserved, waiting for further study.

Ophiocordyceps is the type genus of Ophiocordycipitaceae. The *Ophiocordyceps* species are typically associated with eight orders of arthropods, including Blatteria, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Megaloptera, or Orthoptera. Their taxonomy has been problematic due to numerous

species that share similar morphologic characteristics. Moreover, many of them still lack molecular data. In addition, some of them had been introduced for many years, but the updated molecular data did not provide the morphologic details. Therefore, this study lists almost all necessary species and proposes 30 new species, ten new combinations, and ten new records. Multi-gene (ITS, nrSSU, nrLSU, tef-1α, rpb1, and rpb2) sequence data are used to build a phylogenetic tree. Furthermore, the intergeneric relationships among these species are discussed.

Hirsutella and *Hymenostilbe* are two asexual morphic genera; their species mainly parasitize on arthropods under the Ophiocordycipitaceae family. They have been recognized as the asexual morphs of Ophiocordyceps and are clustered with *Ophiocordyceps* in the phylogenetic tree without an independent clade. However, *Hirsutella* is a large genus with numerous species. Moreover, several *Hirsutella* and *Hymenostilbe* species lack molecular data; therefore, their taxonomy and phylogeny are chaotic. In this study, the names of both genera are reserved with illustrations of the type species for future studies. Almost all of their species are listed in the table with main morphologic characteristics. Moreover, no new species are introduced under them.

Drechmeria species mainly parasitize on nematodes. *Harposporium* species primarily parasitize on nematodes, rotifers, and species of Coleoptera. Both *Drechmeria* and *Harposporium* are a monophyletic genus in the family. However, several *Harposporium* species lack molecular data. In this study, the main morphologic characteristics of all *Drechmeria* and *Harposporium* species are listed, while the type species are redrawn for future studies.

Although *Purpureocillium* has only six species, they are widely distributed worldwide. This study proposes two new species, *Purpureocillium takamizusanense* and *Purpureocillium cicadaisis*, based on morphologic and phylogenetic analysis. A new record of the type species is described and illustrated using modern concepts. All species with information regarding their main morphologic characteristics are presented.

Tolypocladium is a monophyletic genus in the Ophiocordycipitaceae family. Some sexual morphic species of *Tolypocladium* parasitize on fungi (*Elaphomyces sp.*). In comparison, some asexual morphic species of *Tolypocladium* parasitize on insects

and rotifers. In this study, six new species are described, two new records are reported, and three species are revised with modern concepts. All species with information regarding their main morphologic characteristics are presented.

Paraisaria is reserved by morphologic and phylogenetic analyses in the Ophiocordycipitaceae family. Indicatively, it has a distinct lineage with Ophiocordycipitaceae. In this study, a new species, *Paraisaria obovata*, is proposed; a new combination is indicated, and a new host of *Paraisaria amazonic* is recorded. All species with information regarding their morphologic characteristics are presented.

4.2 Research Advantages

The identification and classification of Ophiocordycipitaceae species had been difficult due to the numerous species involved and inadequate molecular data. The taxonomic placements of *Polycephalomyces*, *Perennicordyceps*, and *Pleurocordyceps* were resolved. This study established a novel family, Polycephalomycetaceae, to accommodate the said three genera. A new method, RAxML, IQ-tree and consel combined to determine the p-value system, was proposed for placement detection of unstable phylogeny. All Polycephalomycetaceae species were listed in the tables with their main characteristics. Overall, this study, which involves all species of Polycephalomycetaceae, is undertaken to obtain further knowledge on its taxonomy and phylogeny.

Moreover, the Ophiocordycipitaceae species are highly diverse in Thailand and China. This study has introduced 30 novel species and 27 reference specimens. It has listed almost all species of Ophiocordycipitaceae with their main characteristics, which will help other researchers classify new samples easily for future work. Morphologic characteristics have been reassessed by new species, herbarium specimens, and new collections. Therefore, this study can provide further knowledge on the Ophiocordycipitaceae species. Furthermore, it has determined the relationships among the genera of Ophiocordycipitaceae.

This study has described the main character, peridium, to clarify the species of Ophiocordycipitaceae with fresh collections and herbarium specimens. It has

demonstrated the significance of morphologic characteristics in fungi classification and identification. It proposes a new host-specific group, the *Ophiocordyceps sphecocephala* complex, enabling a better knowledge of wasp and *Ophiocordyceps* sp.

4.3 Future Work

This study focuses on the morphologic characteristics and phylogeny placement of each species of Ophiocordycipitaceae and Polycephalomycetaceae. Several of those species are necessary to indicate the holotype or epitype, particularly the old ones. Thus, herbarium specimens should be carefully determined in the future.

Several species of Ophiocordycipitaceae and Polycephalomycetaceae have updated molecular data by new collection strains, but without morphologic details. Meanwhile, many species have the same name but are undivided into different clades in the phylogenetic tree. Thus, more morphologic details are necessary for updating the strains.

Additionally, the host species of both Ophiocordycipitaceae and Polycephalomycetaceae play a significant function in the identification of the species for these two families. Moreover, the *Ophiocordyceps myrmecophila* complex, the *Ophiocordyceps unilateralis* complex, and the *Ophiocordyceps sphecocephala* complex are considered host-specific groups. Thus, classification for the host species is essential to defining the species for these two families. Co-evolution in fungi associated with insects is expected to be better understood in future studies.

4.4 Publications

List of publications

First author

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APPENDIX

APPENDIX A

CHEMICAL REAGENTS AND MEDIA

1. Lactophenol-Cotton Blue is used to highlight fungal structures for viewing with the compound light microscope. Cotton blue is the most popular stain for observing pseudoparaphyses, septate or ascus walled. This gives excellent clarity and is also suitable for most fungal groups

Phenol (crystals) 20 g

Lactic acid 16 ml

Glycerol 31 ml

Dissolve phenol in distilled water, add lactic acid, glycerol and 0.05 g of Poirrier's (cotton) blue or acid fuchsin.

2. Melzer's Reagent is a good general mounting medium that clears the material somewhat and allows particularly brilliant resolution with a microscope, and is used for identification of ascomycete fungi. The amyloid reaction of asci changed to blue or heavily purple colours.

Chloral hydrate 100 g

Potassium iodide 5 g

Iodine 1.5 g

Distilled water 100 ml

3. Malt Extract Agar (MEA) used for fungal cultivation

Agar 15 g

Peptone 0.78 g

Glycerol 2.35 g

Dextrin 2.75 g

Maltose, Technical 12.75 g

Suspend 33.6 g of malt extract agar in distilled water and mix thoroughly. Heat with frequent agitation and boil for 1 minute to completely dissolve the power and bring volume to 1000 ml. Autoclave at 121ºC for 15 minutes

4. Potato dextrose agar (PDA) used for fungal cultivation

Potato starch (from the infusion) 4 g

Dextrose 20 g

Agar 15 g

Suspend 39 g of Potato dextrose agar in distilled water and mix thoroughly. Heat with frequent agitation and boil for 1 minute to completely dissolve the powder and bring volume to 1000 ml. Autoclave at 121ºC for 15 minutes.

APPENDIX B

ABSTRACT OF PUBLICATIONS

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Introducing *Ophiocordyceps thanathonensis*, a new species of entomogenous fungi on ants, and a reference specimen for *O. pseudolloydii*

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Abstract

Ophiocordyceps pathogens of ants (Hymenoptera) are considered to have a worldwide distribution. Species of *Ophiocordyceps* have been relatively poorly studied and there is little molecular data available in GenBank. Thus, fresh collections and sequence data are needed to improve the understanding of species in the genus. In this study, infected ant species were collected in northern Thailand and carefully studied. As a result, *O. thanathonensis* is introduced as a new species. The morphology of *O. thanathonensis* differs from related species in the genus in having smaller ascomata, shorter asci, shorter ascospores and curved secondary ascospores. A reference specimen for *O. pseudolloydii* is also designated with sequence data. Phylogenetic analyses using maximum likelihood and Bayesian combined LSU, SSU, ITS, TEF1α and RPB1 sequence data show the placement of *O. thanathonensis* (new species) and *O. pseudolloydii* (reference specimen) within the *Ophiocordyceps* clade.

Key words: *Ophiocordyceps*, fungi on ants, phylogeny, taxonomy

Introduction

Entomogenous fungi are parasites of insects and can kill or seriously disable insects (Roberts and Humber 1891, Fernandes *et al.* 2012b). Species of zombie-ant fungi are mostly characterized by producing stromata, synnemata or conidia from the dead insect body (Petch 1939, Mains 1948, Ferron 1978, Butt and Goettel 2000, Fernandes *et al.* 2012). Most fungal pathogens of ants are believed to be host-specific (Amnuaykanjanasin *et al.* 2009, Evan *et al.* 2011, Kobmoo *et al.* 2012, Simmons *et al.* 2015). There are over 12,500 ant species in the world, but only 48 fungal species have been found on ants (Fernández 2003). Fungal pathogens of ants are expected to have a high potential for biological control and behavioral manipulation (Kobmoo *et al.* 2015). For example, *Ophiocordyceps myrmicarum* D.R. Simmons & Groden can be used to control the population of *Myrmica rubra* L., which is recognized as an exotic ant species in the Black Sea area and Siberia (Simmons *et al.* 2015). *Ophiocordyceps unilateralis sensu lato* and its host ant *Camponotus leonardi* was used as a model for studying behavioral mechanisms and morphological symptoms (Hughes *et al.* 2011, Hughes *et al.* 2016).

Ophiocordyceps is placed in the order Hypocreales (Sordariomycetes) based on morphological and phylogenetic evidence (Sung *et al.* 2007, Quandt *et al.* 2014, Maharachchikumbura *et al.* 2015, 2016). Most of the sexual morph species of *Ophiocordyceps* (*Ophiocordycipitaceae*) were transferred from the genus *Cordyceps* (*Cordycipitaceae*) to *Ophiocordyceps* (*Ophiocordycipitaceae*) by Sung *et al.* (2007) based on their morphological and phylogenetic analyses. However, molecular data for many species of *Cordyceps* is lacking, thus, the identification and classification of fungal pathogens of ants is problematic.

In this study, we introduce a new species of *Ophiocordyceps*, which is closely related to *Hymenostilbe aurantiaca* Hywel-Jones (the asexual morph of *O. irangiensis* (Moureau) G.H. Sung *et al.*), *O. myrmecophila* (Ces.) G.H. Sung *et al.* and *O. irangiensis* phylogenetic analyses. A reference specimen for *O. pseudolloydii* (H.C. Evans & Samson) G.H. Sung *et al.*, with sequence data, is also designated.

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Multigene phylogenetics of *Polycephalomyces* (Ophiocordycipitaceae, Hypocreales), with two new species from Thailand

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Polycephalomyces **(Ophiocordycipitaceae) species are found in subtropical regions and are parasitic or hyperparasitic on insects. Two new species, *P. aurantiacus* and *P. marginaliradians*, parasitic on *Ophiocordyceps barnesii* and larva of Cossidae respectively, are introduced in this paper. Morphological comparison with extant species and DNA based phylogenies from analyses of a multigene dataset support the establishment of the new taxa. *Polycephalomyces aurantiacus*, exhibiting a hyperparasitic lifestyle on *Ophiocordyceps barnesii*, differs from other species in producing orange conidia in mass and have longer β-phialides in culture. *Polycephalomyces marginaliradians* differs from other *Ophiocordyceps* species by producing single stromata with a stipe, smaller perithecia and branched α-phialides and catenate α-conidia and is parasitic on Cossidae. A combined nrSSU, nrLSU, ITS, tef-1a, rpb1 and rpb2 sequence data was analysed phylogenetically including *Ophiocordyceps* and *Polycephalomyces* taxa. The new species described herein are clearly distinct from other species in *Polycephalomyces*. We provide a key to the species of *Polycephalomyces* and discuss relevant interspecies relationships.**

The genus *Polycephalomyces* was introduced by Kobayasi[1] to accommodate *P. formosus* Kobayasi (1941), based on its asexual characteristics[2] and it is presently accommodated in Ophiocordycipitaceae[3]. Phylogenetic placement of *Polycephalomyces* has always been a debate within the clavicipitoid fungi as the taxonomic hypotheses based on host substrate and sexual morph affinities were controversial[1,4,5]. Kepler *et al.*[5] amended the taxonomic circumscription of *Polycephalomyces* and accepted twelve species (*i.e. P. cuboideus*, *P. cylindrosporus*, *P. ditmarii*, *P. formosus*, *P. kanzashiznus*, *P. nipponicus*, *P. paracubiodeus*, *P. prolificus*, *P. ramosopulvinatus*, *P. ramosus*, *P. ryogamiensis* and *P. tomentosus*) in Ophiocordycipitaceae based on phylogenetic analyses. Later, *P. sinensis*[6], *P. lianzhouensis*[7], *P. yunnanensis*[8], *P. agaricus*[9] and *P. onorei*[10] were introduced as new species within *Polycephalomyces* based on morphology and DNA sequence data. Then, Liang *et al.*[11] introduced a new species *P. ponerae* in the genus *Polycephalomyces*. Based on recent morphological studies and DNA based phylogenetic analyses, *Polycephalomyces* taxa have been segregated in two sister clades within Ophiocordycipitaceae[5,12]. Matočec *et al.*[12] considered those two clades as two different genera, viz. *Perennicordyceps* Matočec & I. Kušan and *Polycephalomyces*. *Perennicordyceps* comprises four species (i.e. *Pe. cuboidea*, *Pe. paracuboidea*, *Pe. prolifica*, and *Pe. ryogamiensis*), which are characterized by superficial perithecia, and hirsutella-like or acremonium-like

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Two new entomopathogenic species of *Ophiocordyceps* in Thailand

Yuan-Pin Xiao[1,2,3], Sinang Hongsanan[2,4], Kevin D. Hyde[2,3], Siraprapa Brooks[3], Ning Xie[4], Feng-Yao Long[1], Ting-Chi Wen[1]

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Abstract

Ophiocordyceps is entomopathogenic and the largest studied genus in the family *Ophiocordycipitaceae*. Many species in this genus have been reported from Thailand. The first new species introduced in this paper, *Ophiocordyceps globiceps*, differs from other species based on its smaller perithecia, shorter asci and secondary ascospores and additionally, in parasitising fly species. Phylogenetic analyses of combined LSU, SSU, ITS, TEF1α and RPB1 sequence data indicate that *O. globiceps* forms a distinct lineage within the genus *Ophiocordyceps* as a new species. The second new species, *Ophiocordyceps sporangifera*, is distinguished from closely related species by infecting larvae of insects (Coleoptera, Elateridae) and by producing white to brown sporangia, longer secondary synnemata and shorter primary and secondary phialides. We introduce *O. sporangifera* based on its significant morphological differences from other similar species, even though phylogenetic distinction is not well-supported.

Keywords

2 new taxa, Hypocreales, morphology, phylogenetic, taxonomy

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Fungal diversity notes 491–602: taxonomic and phylogenetic contributions to fungal taxa

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Towards a natural classification and backbone tree for *Sordariomycetes*

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Abstract
Sordariomycetes is one of the largest classes of *Ascomycota* and is characterised by perithecial ascomata and inoperculate unitunicate asci. The class includes many important plant pathogens, as well as endophytes, saprobes, epiphytes, and fungicolous, lichenized or lichenicolous taxa. The class includes freshwater, marine and terrestrial taxa and has a worldwide distribution. This paper provides an updated outline of the *Sordariomycetes* and a backbone tree incorporating asexual and sexual genera in the class. Based on phylogeny and morphology we introduced three subclasses; *Diaporthomycetidae, Lulworthiomycetidae* and *Meliolomycetidae* and five orders; *Amplistromatales*, *Annulatascales*, *Falcocladiales*, *Jobellisiales* and

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Families of Sordariomycetes

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Abstract Sordariomycetes is one of the largest classes of Ascomycota that comprises a highly diverse range of fungi characterized mainly by perithecial ascomata and inoperculate unitunicate asci. The class includes many important plant pathogens, as well as endophytes, saprobes, epiphytes, coprophilous and fungicolous, lichenized or lichenicolous taxa. They occur in terrestrial, freshwater and marine habitats worldwide. This paper reviews the 107 families of the class

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Multigene phylogeny and morphology reveal a new species, *Ophiocordyceps vespulae*, from Jilin Province, China

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Abstract

Ophiocordyceps is entomopathogenic and is the best studied genus in Ophiocordycipitaceae. Members of *Ophiocordyceps* and ants form sophisticated interactions. However, taxonomy and evolutionary relationships of this group of pathogens remain unclear. During a survey in Changbai Mountains, Jiling Province, China, a new entomogenous species, *Ophiocordyceps vespulae sp. nov.* was found as a parasite on wasps (Hymenoptera). The new species is introduced with evidence from morphology and molecular analysis. This species is distinguished from closely related species by white to faint yellow stromata, shorter ascomata and asci, and smaller ascospores. We provide a phylogeny for *Ophiocordyceps* based on combined LSU, ITS, TEF1α and RPB2 DNA sequence data and the taxonomic status of the species is briefly discussed.

Keywords: 1 new species, Changbai Mountains, molecular phylogeny, *Ophiocordyceps*, taxonomy

Introduction

Ophiocordyceps species associated with insects comprise one of the most remarkable and interesting relationships between microbes and animals (Araújo *et al*. 2018). They are commonly found in tropical forests worldwide, with relatively few records from temperate ecosystems (Araújo *et al*. 2018). The genus *Ophiocordyceps* was described by Petch (1931) to accommodate a species of *Cordyceps* having clavate thick-walled asci and ascospores that do not disarticulate into part-spores. *Ophiocordyceps* is the type genus of Ophiocordycipitaceae (Hypocreales), which was separated from Cordycepitaceae based on the morphology and phylogenetic analyses (Sung *et al*. 2007a). Most species of this genus are parasitic on insects (Sung *et al*. 2007a, Maharachchikumbura *et al*. 2015, Wijayawardene *et al*. 2017). *Ophiocordyceps* is estimated to have arisen about 100 million years ago (Sung *et al*. 2008) and since then has colonized ten orders of insects (Sanjuan *et al*. 2015, Araújo & Hughes 2016). *Ophiocordyceps* is the most speciose genus in Ophiocordycipitaceae with over 200 accepted species (Index Fungorum, accessed 14 November 2019), with more than 30 species described recently (Wen *et al*. 2013, 2014, 2016, Ban *et al*. 2015, Sanjuan *et al*. 2015, Khonsanit *et al*. 2019, Araújo *et al*. 2018, Xiao *et al*. 2018, 2019).

Most *Ophiocordyceps* species have darkly pigmented or brightly coloured stromata that are pliant to wiry or fibrous, with immersed, ordinal or obliquely arranged perithecia (Sung *et al*. 2007a). The asexual morphs were reported as *Hirsutella* Pat. 1892, *Hymenostilbe* Petch 1931 and *Paraisaria* Samson & B.L. Brady 1983 (Quandt *et al*. 2014,

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Fungal diversity notes 603–708: taxonomic and phylogenetic notes on genera and species

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Abstract
This is the sixth in a series of papers where we bring collaborating mycologists together to produce a set of notes of several taxa of fungi. In this study we introduce a new family *Fuscostagonosporaceae* in Dothideomycetes. We also introduce the new ascomycete genera *Acericola*, *Castellaniomyces*, *Dictyosporina* and *Longitudinalis* and new species *Acericola italica*, *Alternariaster trigonosporus*, *Amarenomyces dactylidis*, *Angustimassarina coryli*, *Astrocystis bambusicola*, *Castellaniomyces rosae*, *Chaetothyrina artocarpi*, *Chlamydotubeufia krabiensis*, *Colletotrichum lauri*, *Collodiscula chiangraiensis*, *Curvularia palmicola*, *Cytospora mali-sylvestris*, *Dictyocheirospora cheirospora*, *Dictyosporina ferruginea*, *Dothiora coronillae*, *Dothiora spartii*, *Dyfrolomyces phetchaburiensis*, *Epicoccum cedri*, *Epicoccum pruni*, *Fasciatispora calami*, *Fuscostagonospora cytisi*, *Grandibotrys hyalinus*, *Hermatomyces nabanheensis*, *Hongkongmyces thailandica*, *Hysterium rhizophorae*, *Jahnula guttulaspora*, *Kirschsteiniothelia rostrata*, *Koorchalomella salmonispora*, *Longitudinalis nabanheensis*, *Lophium zalerioides*, *Magnibotryascoma mali*, *Meliola clerodendri-infortunati*, *Microthyrium chinense*, *Neodidymelliopsis moricola*, *Neophaeocryptopus spartii*, *Nigrograna thymi*, *Ophiocordyceps cossidarum*, *Ophiocordyceps issidarum*, *Ophiosimulans plantaginis*, *Otidea pruinosa*, *Otidea stipitata*, *Paucispora kunmingense*, *Phaeoisaria microspora*, *Pleurothecium floriforme*, *Poaceascoma halophila*, *Periconia aquatica*, *Periconia submersa*, *Phaeosphaeria acaciae*, *Phaeopoacea muriformis*, *Pseudopithomyces kunmingnensis*, *Ramgea ozimecii*, *Sardiniella celtidis*, *Seimatosporium italicum*, *Setoseptoria scirpi*, *Torula gaodangensis* and *Vamsapriya breviconidiophora*. We also provide an amended account of *Rhytidhysteron* to include apothecial ascomata and a J+ hymenium. The type species of *Ascotrichella*

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Englerulaceae (Dothideomycetes)

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Abstract

The family *Englerulaceae* presently includes seven genera that produce brown to dark-brown colonies on living leaves. Ascomata are superficial and scattered on the colonies and lack ostioles. Asci are 2–8-spored, bitunicate, ovate to globose and ascospores are multi-seriate, oblong to ellipsoid, brown, and smooth-walled with a single septum. This paper brings all genera of the family together in one place with descriptions and illustrations and discusses their current taxonomic placement. The type species of *Englerula*, *Parenglerula*, *Rhizotexis*, *Rhytidenglerula*, *Schiffnerula* and a new species of *Thrauste* are redescribed and illustrated with light photomicrographs, in this paper. It is suggested that *Butleria* should be accommodated in *Myriangiaceae*. *Rhizotexis* is excluded from the family and moved to Dothideomycetes genera *incertae sedis*, as morphological characters are not similar to type genus and other genera in the family. The type specimen of *Goosia* is missing and is redrawn from the protologue. By illustrating and redescribing the genera we expect renewed interest for recollection and molecular study so that these dothideomycetous genera can be placed in a natural taxonomic framework.

Key words: Dothideomycetes, Pleosporales, taxonomy

Introduction

We are in the process of studying genera of Dothideomycetes in order to provide a natural classification of this large class (Boonmee *et al.* 2011, Liu *et al.* 2011, 2012, Wu *et al.* 2011a,b, Zhang *et al.* 2008, 2009a,b, 2011a,b, 2012, Hyde *et al.* 2013). These studies involved examination of type specimens of the genera, provision of modern descriptions and illustrations or photomicrographs and, wherever possible, linking to their asexual states. In this study, we re-examined the type species of genera placed in *Englerulaceae*.

The family *Englerulaceae* was introduced by Hennings (1904) to accommodate *Englerula* and presently includes *Englerula*, *Goosia*, *Parenglerula*, *Rhizotexis*, *Rhytidenglerula*, *Schiffnerula* and *Thrauste* (Lumbsch & Huhndorf 2010). There is, however, no molecular data available for any of these genera. We redescribe the type species, provide descriptions and illustrations and discussed their possible taxonomic placements in this paper. It is hoped that with redescriptions of all genera in the family, fresh collections will be made so that molecular data can be used to resolve systematic relationships of the genera.

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Multigene phylogeny and morphology reveal that the Chinese medicinal mushroom '*Cordyceps gunnii*' is *Metacordyceps neogunnii sp. nov.*

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Abstract

Morphological and molecular phylogenetic analyses of an entomogenous fungus associated with larvae of Lepidoptera in Guizhou and Anhui, China showed it to be a new species, *Metacordyceps neogunnii*. It differs from similar species in having longer asci and wider ascospores. Multigene analysis of ITS, 18S, *TEF*1 and *RPB*1 sequence data also confirmed the distinctiveness of this species. This species has been wrongly regarded in China as '*Cordyceps gunnii*' for more than 30 years. *Cordyceps gunnii* from Tasmania is considered to be in the family Ophiocordycipitaceae based on its multigene phylogeny and morphological analysis.

Key words: Chinese medicinal mushroom, controversial taxa, molecular phylogeny, new species, revision

Introduction

Metacordyceps G.H. Sung, *et al.* introduced by Sung *et al.* (2007a), and previously treated as a member of *Cordyceps* Fr. (Hypocreales), is characterized by solitary or grouped stromata that are simple or branched, with fleshy or tough whitish stipe, a greenish yellow to greenish cylindrical to enlarged fertile part, and perithecia partially or completely immersed in stromata (Sung *et al.* 2007a). This genus comprises five species after transfer of 11 species to *Metarhizium* Sorokīn (Sung *et al.* 2007a, Kepler *et al.* 2012b, 2013, Quandt *et al.* 2014, Wen *et al.* 2015, Index Fungorum, 2017). In China, *Cordyceps sensu lato* has been extensively studied, and more than 140 species have been reported (Song *et al.* 2006, Liang 2007, Li *et al.* 2008a, 2008b, 2010, Lin *et al.* 2008, Yang *et al.* 2009, Gao *et al.* 2010, Zhang *et al.* 2010, Chen *et al.* 2011, 2013, Wen *et al.* 2013, 2014, 2015, Yan & Bau 2015, Yang *et al.* 2015). Of these species, the Chinese '*Cordyceps gunnii*' used as a medicinal mushroom by local people, currently sells for about US$2000/kg, its annual yield from nature is about ten tonnes and the species is only distributed in southern provinces. It has been long recognized as a prized medicinal mushroom and a desirable alternative for natural *Ophiocordyceps sinensis*. This mushroom contains many bioactive chemicals with a high biological activity (Xiao *et al.* 2004, Zhu *et al.* 2011, 2012a, b, 2013). Experiments towards its fermentation have been made in recent years (Fu *et al.* 2004, Sun *et al.* 2012, Wei *et al.* 2012). This species has been wrongly regarded in China as *Cordyceps gunnii* for more than 30 years. Its asexual morph was described in China as *Paecilomyces gunnii* Z.Q. Liang (Liang 1985).

Cordyceps gunnii (Berk.) Berk. is known only from Australia (Berkeley 1848, Hooker 1860). A similar species, *Cordyceps hawkesii* Gray has been reported from Australia (Saccardo 1891) and Japan (Kobayasi & Shimizu 1983). More recently, Chen *et al.* (1984) reported *C. hawkesii* and its anamorph (*Paecilomyces hawkesii*) from China based on morphological observations. Tian *et al.* (2010) added two sequences for *C. hawkesii* to GenBank that had been collected in China, but their study lacked morphological description. Liu *et al.* (2002) and Liang (2007) reported that *C. hawkesii* is a synonym of *C. gunnii* (all specimens used for study were collected in south China). Saccardo (1891) mentioned that it is easy to distinguish between *C. gunnii* and *C. hawkesii* even though they both occur in Tasmania, Australia. Chan *et al.* (2011) revealed that collections of *C. gunnii* from China and Tasmania are not conspecific. Thus, there is a need to re-investigate the classification of these two taxa to avoid unnecessary misidentification.

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Multigene phylogeny and morphology reveal a new species, *Ophiocordyceps tettigonia*, from Guizhou Province, China

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Abstract

A species of *Cordyceps sensu lato* associated with an adult of *Tettigonia* was collected in Chishui Danxia natural world heritage site, Guizhou Province, China. Following morpho-phylogenetic studies it was found to be a new species and is described as *Ophiocordyceps tettigonia sp. nov.* It differs from similar *Ophiocordyceps* species in having a unique host insect, and wide secondary ascospores. Combined sequence data from the ITS, SSU, TEF, and RPB1 gene loci also confirmed the distinctiveness of this new species.

Key words: *Cordyceps sensu lato*, new species, phylogenetic analyses, *Tettigonia*

Introduction

Cordyceps sensu lato is one of the most important genera of invertebrate pathogens (Hywel-Jones 2001) with more than 540 epithets (Index Fungorum, 2016). The genus *Cordyceps* Fr. (*Clavicipitaceae*, *Hypocreales*, *Ascomycota*) has been recently divided and placed into three families and more than six genera—*Polycephalomyces* Kobayasi (*Ophiocordycipitaceae* G.H. Sung *et al.*) (Kepler *et al.* 2013), *Tyrannicordyceps* Kepler & Spatafora (*Clavicipitaceae* Earle) (Kepler *et al.* 2012b), *Metacordyceps* G.H. Sung *et al.* (*Clavicipitaceae*), *Tolypocladium* W. Gams (formerly *Elaphocordyceps* G.H. Sung & Spatafora, *Ophiocordycipitaceae*) (Quandt *et al.* 2014), *Ophiocordyceps* Petch (*Ophiocordycipitaceae*) and *Cordyceps* (*Cordycipitaceae* Kreisel ex G.H. Sung *et al.*) (Sung *et al.* 2007a). Most species in *Cordyceps sensu lato* are pathogenic on insects and spiders, although a few grow on species of *Elaphomyces* Nees (soil fungi). More than 240 *Cordyceps* species have been placed into these six genera, but about half of *Cordyceps sensu lato* species need to be restudied and re-arranged (Sung *et al.* 2007a). Sung *et al.* (2007a) suggested that there are 153 *Ophiocordyceps* species. There are 166 epithets assigned to *Ophiocordyceps* in Index Fungorum (2016). Many *Cordyceps* species such as *C. militaris* (L.) Fr., *C. bassiana* Z.Z. Li *et al.*, *Isaria cicada* Miq. and *O. sinensis* (Berk.) G.H. Sung *et al.* are used in traditional medicines in China, Japan, Korea and other east Asian countries (Mortimer *et al.* 2012).

Chishui Danxia is a natural world heritage site in Guizhou Province, south China. This is a special karst landform preserving rare plants since the Jurassic. *Cordyceps chishuiensis* Z.Q. Liang & A.Y. Liu, *C. stipillata* Z.Q. Liang & A.Y. Liu and *C. suoluoensis* Z.Q. Liang & A.Y. Liu have been described from this area (Liang 2007).

In this study, a new species, *Ophiocordyceps tettigonia*, was found parasitizing an adult of a *Tettigonia* species collected from soil in Chishui Danxia natural world heritage site. This species is morphologically distinct from all other *Cordyceps sensu lato* species and a combined multi-gene analysis also showed it to differ from species of *Ophiocordyceps*.

Material and methods

Specimens and host

The collections were made in the Chishui Danxia natural world heritage site in June 2014. Specimens were stored in plastic containers at low temperature and transported to the laboratory for identification.

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Systematic analyses of *Ophiocordyceps ramosissimum* sp. nov., a new species from a larvae of Hepialidae in China

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Abstract

A new species, *Ophiocordyceps ramosissimum*sp. nov., is described and illustrated. It was associated with larvae of *Phassus nodus* (Hepialidae) collected from Xuefeng Mountains, Hunan Province, China. It differs from similar species in having branched stromata without a sterile apex, superficial ascomata, and very wide asci and ascospores and in its occurrence on *Phassus nodus* in living roots or trunks of *Clerodendrum cyrtophyllum*. Multi-gene phylogenetic analysis of 5.8S-ITS rDNA, nrSSU, EF-1α, and RPB1 gene loci also confirmed the distinctiveness of this new species.

Keywords: new species, multi-genephylogeny, *Clerodendrum cyrtophyllum*

Introduction

The genus *Cordyceps* Fr. (*Clavicipitaceae*, *Hypocreales*, *Ascomycota*) has been separated and placed into three families and five genera—*Tyrannicordyceps* (*Clavicipitaceae*) (Kepler *et al.* 2012), *Metacordyceps* (*Clavicipitaceae*), *Elaphocordyceps* (*Ophiocordycipitaceae*), *Ophiocordyceps* (*Ophiocordycipitaceae*) and *Cordyceps* (*Cordycipitaceae*) (Sung *et al.* 2007a). Most of its members are pathogens of insects and spiders, and some grow on the hypogeous fungus, *Elaphomyces* spp. (Wen *et al.* 2013). Many *Cordyceps* species such as *Ophiocordyceps sinensis*, *Cordyceps militaris* and *C. takaomontana* are important as they have been used in traditional Chinese medicines in China, Japan, Korea and other eastern Asian countries.

Cordyceps sensu lato is one of the most important fungal groups of invertebrate pathogens (Hywel-Jones 2001) with more than 500 species (Index Fungorum 2013). Although many *Cordyceps* species have been transferred to *Ophiocordyceps* or other genera, many species have yet to be restudied in this large group.

Ophiocordyceps is the largest genus of *Cordyceps sensu lato* and Sung *et al.* (2007a) reported that there are more than 150 *Ophiocordyceps* species, while 140 species were listed by Kirk *et al.* (2008). There are more than 180 epithets assigned to *Ophiocordyceps* in Index Fungorum (2013), however, some of them have been synonymised with other genera. Most species of *Cordyceps sensu lato* have been collected from hosts on leaves or in soil, but there are about 50 species that parasitize insects in dead wood, and a few species are known from insects in living tree trunks (Kobayasi & Shimizu 1983, Samson & Evans 1985, Li *et al.* 2008).

We recently introduced a new species, *Ophiocordyceps xuefengensis*, which parasitizes *Phassus nodus* Chu & Wang collected from the living roots or trunks of the medicinal plant *Clerodendrum cyrtophyllum* Turcz (Wen *et al.* 2013). In this study, a second *Ophiocordyceps* species was found parasitizing the same insect in the living trunk or root of *C. cyrtophyllum* in south China. This species is different from all other *Cordyceps sensu lato* species in morphology and combined multi-gene phylogeny analysis.

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Metacordyceps shibinensis sp. nov. from larvae of Lepidoptera in Guizhou Province, southwest China

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Abstract

A new entomogenous taxon, *Metacordyceps shibinensis* sp. nov., associated with a larva of Lepidoptera was found in Yuntai Mountains, Guizhou Province, China. It differs from similar species in its white to faint yellow stromata, short ascomata, and very short asci and ascospores. Combined sequence analyses of 5.8S-ITS rDNA, nrSSU, EF-1α and RPB1 gene-loci also confirmed the distinctiveness of this new species.

Key words: *Metacordyceps*, morphology, new species, phylogenetic analyses

Introduction

Cordyceps sensu lato is regarded as one of the most important genera of invertebrate pathogens (Hywel-Jones 2001) with more than 540 species (Index Fungorum, 2015). About 140 species have been reported from China (Song *et al.* 2006, Liang 2007, Li *et al.* 2008, Gao *et al.* 2010, Zhang *et al.* 2010, Yang *et al.* 2009, Li *et al.* 2008, Lin *et al.* 2008, Li *et al.* 2010, Chen *et al.* 2011, Chen *et al.* 2013, Wen *et al.* 2013, 2014, Yan & Bau 2015, Yang *et al.* 2015). *Cordyceps* has been recently divided and placed in three families and six genera—*Polycephalomyces* (*Ophiocordycipitaceae*) (Kepler *et al.* 2013), *Tyrannicordyceps* (*Clavicipitaceae*) (Kepler *et al.* 2012b), *Metacordyceps* (*Clavicipitaceae*), *Elaphocordyceps* (*Ophiocordycipitaceae*), *Ophiocordyceps* (*Ophiocordycipitaceae*) and *Cordyceps* (*Cordycipitaceae*) (Sung *et al.* 2007a). More than 240 *Cordyceps* species have been placed into these six genera, but about half of *Cordyceps sensu lato* species need to be restudied and re-arranged (Sung *et al.* 2007a). Sung *et al.* (2007a) and (Kepler *et al.* 2012a) suggested that there are 15 *Metacordyceps* species, while 14 epithets are assigned to *Metacordyceps* in Index Fungorum (2015).

In this study, a new *Metacordyceps* species was found parasitizing larvae of Lepidoptera collected from the Yuntai Mountains of Guizhou Province in southwest China. This species is morphologically and phylogenetically distinct from all other *Cordyceps sensu lato* species. The purpose of this paper is to introduce the new species with micrographs and a description, and to compare it with related taxa.

Material and methods

Specimens and host

Collection was made in the Yuntai Mountains, Shibin County of Guizhou Province in May 2013. Specimens were stored in plastic containers at low temperature and transported to the laboratory for identification.

Morphological studies

Fungal fruiting bodies were examined using an Olympus stereo dissecting microscope (Olympus Optec Instrument Co.,

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