

Dissertation Title Entomopathogenic Fungi *Cordyceps* Sensu Lato:
Species Diversity and Host Association

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ABSTRACT

Cordyceps sensu lato (cordyceps), the most important group of entomopathogenic fungi, have always been highly researched for their species diversity, edible and medicinal values and use for biological control. This group currently has more than 1,000 species, which are distributed in three families (Cordycipitaceae, Ophiocordycipitaceae and partial Clavicipitaceae) in the order Hypocreales. In nature, cordyceps develop mainly on insects, spiders, other cordyceps species and hypogeous fungi *Elaphomyces*. These ascomycetes can reproduce via ascospores, conidia and mycelia that generally inhabit soil, plants, nematodes, other invertebrates, mushrooms and other organisms. Among them, insects account for a major proportion, and 19 Insecta orders have been reported as hosts of cordyceps.

Due to lack of molecular evidence or inconclusive morphology and ecology, more than 100 undetermined cordyceps species need to be confirmed. And due to confusion of sexual and asexual morphs, many cordyceps species still have two or more names. Furthermore, ecology and relationships with host insects have always been poorly studied, which seriously affects the identification, application and exploitation of cordyceps. Based on these problems, related cordyceps researches have been carried out and the findings are included in this dissertation.

This study reviews the medicinal history and distribution of the medicinal mushroom Chanhua and reinvestigates its phylogenetic relationships with allied species. Based on results obtained the study clarifies its taxonomy and reviews its host and biological and ecological aspects. The molecular phylogeny proved Chanhua to be an independent species of the genus *Cordyceps*. Although Chanhua, *I. cicadae* and *I. sinclairii* have generally been accepted as the same species, the latter two lack DNA sequence data from their type localities. *C. cicadae* S.Z. Shing (syn. *C. zhejiangensis*), which has been treated as the sexual morph of Chanhua for over 40 years, has been proved to be *Tolypocladium paradoxum*, and the sexual morph of Chanhua is considered to be *C. kobayasi* (syn. *C. cicadae-sm*). This study proposes to use the scientific name *C. cicadae* (Miq.) Massee to describe or record Chanhua fungi.

Cordyceps qingchengensis sp. nov., found in southwestern China and growing on a cocooned pupa of a silk moth (Lepidoptera: Bombycidae), is described, illustrated and compared with allied taxa. It is morphologically and molecularly related to *C. bifusispora*, Chanhua (*C. cicadae* (Miq.) Massee) and *C. tenuipes*. The taxonomy of *C. tenuipes* and *C. pruinosa* is reviewed and *C. ninchukispora* (≡ *Phytocordyceps ninchukispora*) is considered to be a synonym of *C. pruinosa*. The ecology and life cycles of *C. qingchengensis*, *C. tenuipes*, *C. pruinosa* and *C. ningxiaensis* are recorded and inferred. This study clarifies some taxonomical and biological aspects of related *Cordyceps* species.

Furthermore, the current study discusses the species diversity of Xuefeng Cordyceps and identifies the host insects and the plants on which the insects reside. Xuefeng Cordyceps refers to those fungi that grow on larvae of *Endoclita davidi* living in basal trunks or roots of the medicinal plant *Clerodendrum cyrtophyllum* in the Xuefeng Mountain region, Hunan, China. The fungi deal with *Beauveria bassiana* (sexual and asexual), *Metarhizium guizhouense* (asequential), *Ophiocordyceps macroaciculalis*, *O. ramosissimum* and *O. xuefengensis*. The host insects, that were

previously mistaken for larvae of *E. nodus*, are corrected as larvae of *E. davidi*. Molecular phylogenetic data confirmed the name of the host plants, and morphological variations of the plant are discussed. The biology and ecology of Xuefeng Cordyceps and the host insects are also outlined. The study provides necessary information for studying the precious traditional Chinese medicine, Xuefeng Cordyceps.

Cicadicolous cordyceps refers to the cordyceps fungi growing on cicadas (Hemiptera: Cicadidae). Currently, there are 35 cicadicolous species distributed worldwide, with many known from southern Asia. In this study, the relationships between cicadicolous species and their relatives are studied based on multigene phylogeny. The taxonomy of 16 known species, 1 new species and 2 new records of cicadicolous species from China are discussed. *O. bannaensis* sp. nov., *Metarhizium owariense* and *Polycephalomyces nipponicus* are newly reported from China. These taxa are detailed with descriptions, photographs, DNA sequence data and taxonomic notes.

A total of 25 cordyceps species have been reported on Orthoptera insects, and this study reviews their hosts and distributions and gives taxonomical notes. Using a combined ITS and TEF1- α sequence dataset, the molecular phylogeny of cordyceps species on Orthoptera insects was constructed, and current species are assigned to three clades: the *Beauveria*, the *Metarhizium* and the *Ophiocordyceps* clade, respectively. The ecology and habits of well-known groups of Orthoptera are explored and cordyceps on them show distinct host specificity. The study also displays the occurrence mechanism and conidiogenous mode of cordyceps. The rhizomorphs of cordyceps, a special root-like structure situated somewhere between fruiting bodies and synnemata, were observed on *Beauveria* spp. and *Metacordyceps taii* (syn. *Metarhizium guizhouense*). Taxonomical revisions of *Beauveria grylli* (Teng) L.S. Zha comb. nov. \equiv *Cordyceps grylli* Teng = *Beauveria loeiensis* Luangsa-ard, Ridkaew

& Tasan., *Beauveria kirkii* (G. Cunn.) L.S. Zha comb. nov. \equiv *Cordyceps kirkii* G. Cunn., are provided. Host corrections were made as follows: *Beauveria grylli* on katydid nymphs (Gryllacrididae) and *O. tettigonia* on cricket adults (Gryllidae).

Elateroidea and Tenebrionoidea are two large groups of Coleoptera, and their larvae are generally called wireworms. Most wireworms live in humid soil, humus layers or decayed wood and are thus easily parasitized by cordyceps fungi. Fifty-five cordyceps species have been reported on wireworms, and this study updates their hosts, summarizes their distributions and provides taxonomic notes. Among them, 52 species are accepted as parasites of wireworms and three are rejected. *O. borealis* sp. nov. and *O. spicatus* sp. nov. are described, photographed and compared with their allies. *Polycephalomyces formosus* is newly reported on wireworms (Elateroidea) and is described from this host. *Metarhizium jiangxiensis* comb. nov. (\equiv *Cordyceps jiangxiensis*) is proposed for its typical *Metarhizium*-type conidiogenous structure. The multi-gene phylogeny supports the two new species and the identification of *P. formosus*.

Keywords: Biology, Ecology, Distribution, Morphology, Phylogeny, Taxonomy