Dissertation Title	Taxonomy, Phylogeny and Evolution of Hypogeous Fungi in the Southwest China
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ABSTRACT

Hypogeous fungi represents a unique ecological type of macrofungi, characterized by the production of sequestrate (truffle-like) fruiting bodies that develop underground. Most species form ectomycorrhizal associations with plants and rely on animals for spore dispersal. In addition to their important ecological roles, many hypogeous fungi are edible or medicinal. In this study, an extensive survey of hypogeous fungi was conducted in southwestern China, encompassing 59 sampling sites, of which 209 specimens were collected. Based on combined morphological and molecular phylogenetic analyses, 21 new species were described, *viz. Hydnotrya oblongispora*, *H. zayuensis*, *Tuber albicavum*, *T. laojunshanense*, *T. umbilicicavatum*, *Truncocolumella pseudocolumella*, *Gautieria zixishanensis*, *Hymenogaster zayuensis*, *Chamonixia laojunshanensis*, *Rhizopogon laojunshanensis*, *R. melanocuticularis*, *R. zayuensis*, *R. weixiensis*, *Hysterangium alpinum*, *Hysterangium shibaoshanense*, *Protubera yunnanensis*, *Russula densiobtusispora*, *R. laojunshanensis*, *Jimgerdemannia cangshanensis*, *J. zixishanensis*, and *J. laojunshanensis*. Additionally, four new distribution records were documented: *Melanogaster panzhihuaensis* in Chuxiong, Yunnan; *Rhizopogon songmaodan* in Huili, Sichuan; *Rhizopogon jiyaozi* and *Rhizopogon sinoalbidus* in Linzhi, Xizang.

A comprehensive statistical survey of hypogeous fungal specimens from southwest China (including Yunnan, Sichuan, and Xizang provinces) revealed a total of 166 species in three phyla: Ascomycota (two orders, five families, eight genera, 91 species), Basidiomycota (five orders, 14 families, 20 genera, 72 species), and Mucoromycota (one order, one family, one genus, three species). Among these, 38 species are known to be

edible or medicinal. Each species was annotated with detailed specimen information, habitat and distribution data, molecular sequences, and known economic value.

Furthermore, this study analyzed the geographical distribution patterns of hypogeous fungi in southwestern China. The results show that these fungi are primarily concentrated in the Yarlung Zangbo River basins, Nujiang River, Lancang River, and Jinsha River basins, with the Jinsha River basin being the most prominent. This basin harbors the richest hypogeous fungal diversity, with 110 recorded species, including 92 endemics. The distribution pattern between river basins indicates that hypogeous fungi in this region exhibit high habitat specificity and strong basin-restricted distributions. Notably, 84.5% of species were confined to a single river basin, and cross-basin distributions were rare. The highly folded terrain and alternating ridges and valleys of the Hengduan Mountains are likely key drivers of the geographical isolation of hypogeous fungal species. The elevational range of these fungi spans from 860 m to 4005 m, with 96.1% of species occurring in alpine and subalpine forests between 1500 and 4000 m. Species diversity peaks between 2000 and 2500 m, and 40 species are found in alpine fir (*Abies*) forests at elevations of 3000–4000 m. It is noteworthy that 95% of hypogeous fungi in this region form ectomycorrhizal associations with trees of the families Pinaceae and Fagaceae. In addition, analysis of collection dates reveals a multimodal pattern in sporocarp formation, influenced by the complex interplay of monsoonal patterns and vertical climatic zonation in mountainous areas of southwestern China. The primary fruiting peak occurs from August to October, during the mid-to-late rainy season. A secondary peak is observed from November to January—the early dry season, which corresponds to the intensive harvesting of *Tuber* species. A minor spring peak, occurring between Day of Year (DOY) 100–160, is likely associated with increased soil moisture due to pre-monsoon rainfall.

The evolutionary history of hypogeous fungi in southwestern China was also investigated. Using a five-gene phylogenetic dataset, divergence times were estimated for 28 hypogeous *Boletales* species with valid molecular data. The results suggest that the evolution of hypogeous fruiting bodies within *Boletales* likely began in the late Eocene (ca. 50 Mya) and continued through the early Miocene (ca. 22 Mya). Within the southwestern China taxa, the earliest divergence was traced to the Eocene (e.g.,

Truncocolumella pseudocolumella, 50.09 Mya), and most diversification events occurred from the Oligocene (ca. 34 Mya) to the early Pliocene (ca. 5–3 Mya).

These findings highlight the unique climatic and geographic conditions that have fostered the rich diversity and distinct distribution patterns of hypogeous fungi in southwestern China.

Keywords: 21 New Species, Distribution Pattern, Evolutionary History, Hypogeous Fungi, Southwestern China, Taxonomy