RESEARCH ARTICLE

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Multigene Phylogeny and Morphology of *Ophiocordyceps alboperitheciata* sp. nov., A New Entomopathogenic Fungus Attacking Lepidopteran Larva from Yunnan, China

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ABSTRACT

A new fungus, *Ophiocordyceps alboperitheciata*, parasitic on the larva of Noctuidae (Lepidoptera) was identified from a survey of entomopathogenic fungi in Kunming Wild Duck Forest Park, Yunnan Province, China. It can be primarily distinguished from relatives by its longer fertile parts, sterile tips, superficial perithecia, narrower asci, and smaller septa of ascospores. As revealed from phylogenetic analyses inferred from nrSSU, nrLSU, tef-1 α , rpb1, and rpb2 sequence data, *O. alboperitheciata* belongs to the *Hirsutella citriformis* clade in the genus *Ophiocordyceps* of Ophiocordycipitaceae, and forms a separated clade from other related species. The uniqueness of the taxon is significantly evidenced by both molecular phylogeny and morphology. Furthermore, the interspecific relationships in the *H. citriformis* clade are discussed.

ARTICLE HISTORY

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KEYWORDS New species; *Hirsutella*;

Ophiocordyceps; phylogenetic analyses

1. Introduction

The entomopathogenic Ophiocordyceps Petch is the largest genus with the maximum number of species in the family Ophiocordycipitaceae (Hypocreales) [1–3]. The genus was originally established by Petch based on four species, i.e., the type O. blattae Petch occurring on a cockroach, O. unilateralis (Tul. & C. Tul.) Petch on ants, O. peltata (Wakef.) Petch on a coleopteran larva, as well as O. rhizoidea (Höhn.) Petch on a coleopteran larva [4]. Ophiocordyceps was separated from Cordyceps sensu lato by the existing phylogenetic classification [5], accommodating over 270 names of accepted species to date [3,6,7]. Main hosts of Ophiocordyceps pertain to Lepidoptera, Coleoptera, Hymenoptera, Hemiptera, Diptera, Orthoptera, and Odonata, most of which are larvae of Lepidoptera or Coleoptera inhabiting wood or soil [5,8]. Species of Ophiocordyceps are distributed worldwide, primarily located in temperate, subtropical to tropical areas [9]. It is noteworthy that the species diversity of Ophiocordyceps appears to be the maximal in East and Southeast Asia [5].

Numerous associated-asexual morphs of *Ophiocordyceps* were reported, (e.g., *Hirsutella* Pat., *Hymenostilbe* Petch, *Paraisaria* Samson & B.L. Brady, and *Syngliocladium* Petch) [2,3,5,10,11]. On

the whole, asexual types of Ophiocordyceps are discovered from Hymenostilbe and Hirsutella, and the latter is recognized as the most common isolation source. The genus Hirsutella was erected by Patouillard based on the type species H. entomophila Pat., as suggested to attack an adult beetle collected from Ecuador [12]. First, the genus Hirsutella was defined as a clavariaceous hymenomycete with simple sterigmate basidia. Subsequently, this genus was critically investigated and then identified as anamorphic insect pathogens [13]. The generic name Hirsutella was affected by the ending of dual nomenclature for various morphs of pleomorphic fungi in 2011 [14]. Next, Simmons et al. initially adopted the Ophiocordyceps name for a novel species, O. myrmicarum D.R. Simmons & Groden, described only from the asexual Hirsutella morph [15]. The suppression of the generic name could positively impact the study on those groups in phylogeny and facilitate taxonomic revisions of the family Ophiocordycipitaceae. Thus far, over 100 asexual morphs of the genus Ophiocordyceps were identified (Index Fungorum: http://www.indexfungorum.org), as associated with more than 30 sexual species [16]. The Hirsutella consists of six groups, i.e., H. citriformis Speare, H. thompsonii F.E. Fisher, H. nodulosa Petch, H. guyana Minter & B. L. Brady, H. sinensis

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Liu, Guo, Yu & Zang, and *Hirsutella* ant pathogen clades.

A series of surveys were conducted to reveal the species diversity of entomopathogenic fungi in Kunming, Yunnan Province, China [16-20]. To be specific, the richness of cordycipitoid fungi was found to be relatively higher in Kunming Wild Duck Lake Forest Park. On the whole, 41 species were found here (with 20 species proposed as new species), belonging to eight genera of three families Clavicipitaceae, Cordycipitaceae (i.e., and Ophiocordycipitaceae), which are Flavocillium, Cordyceps, Beauveria, Samsoniella, Simplicillium, Ophiocordyceps, Polycephalomyces, and Metarhizium. Among these species, a fungus attacking caterpillar was determined as a novel taxon of Ophiocordyceps by conducting the analyses of both morphology and molecular phylogeny. This study attempts to introduce the new species and investigate its biological and phylogenetic status.

2. Materials and methods

2.1. Specimen collection and strain isolation

In the present study, a specimen of the novel species was collected from the Kunming Wild Duck Lake Forest Park, Yunnan Province, China, in August 2018. The isolate was obtained with the methods presented by Wang et al. [18]. The specimen was deposited in Yunnan Herbal Herbarium (YHH), Yunnan University. The cultures were deposited at Yunnan Fungal Culture Collection (YFCC), Yunnan University. To describe the new species, the macroand micromorphological characteristics were observed by complying with Wang et al. [20].

2.2. Morphological observations

The sample was photographed with a digital camera and Olympus SZ61 (Tokyo, Japan) stereomicroscope. Subsequently, the macromorphological characteristics were recorded (e.g., texture, shape, color, length, diameter of the stroma and color, shape, length, diameter of the fertile head, and host type). Furthermore, Olympus CX40 (Tokyo, Japan) and BX53 (Tokyo, Japan) microscopes were employed to observe the micromorphological characteristics of perithecia, asci, asci-caps and ascospores Next, the morphology of cultures was characterized by using the method presented by Wang et al. [16].

2.3. DNA extraction, PCR, and sequencing

The total genomic DNAs were extracted by employing the CTAB method of Liu et al. [21]. Five nuclear gene regions were amplified and sequenced, i.e., the small subunit of ribosomal DNA (nrSSU), the large subunit of ribosomal DNA (nrLSU), translation extension factor 1-gene (tef-1 α), the largest subunit of RNA polymerase II (rpb1), as well as the second largest subunit of RNA polymerase II (rpb2) [5,22,23]. Polymerase chain reaction (PCR) was performed by adopting the method presented by Wang et al. [20]. Moreover, amplifications were conducted in 25 µL, and PCR conditions were referenced from Sung et al. [5]. Furthermore, PCR products were sequenced by the Beijing Genomics Institute (Shenzhen, China).

2.4. Phylogenetic analyses

Five-gene sequences (i.e., nrSSU, nrLSU, tef- 1α , rpb1, and rpb2) of taxa pertaining to Hirsutella, Ophiocordyceps, and Polycephalomyces were downloaded from GenBank, and combined with those generated in here. Table 1 lists the specimen accession information and GenBank numbers of the five loci. Sequences were aligned by employing the programs Clustal X2.0 and MEGA5 [24]. Phylogenetic analyses were conducted with Bayesian inference (BI) and maximum-likelihood (ML) methods with the use of the programs MrBayes v.3.1.2 and RaxML7.0.3 [25,26], respectively. In addition, the BI analysis was conducted on MrBayes v.3.1.2 for five million generations with the GTR + G + I model, as determined by jModelTest version 2.1.4 [27]. Specific to the ML analysis based on RaxML7.0.3, GTR + I acted as the optimal model, and 500 fast bootstrap replications were conducted on the fivelocus dataset. Trees were sampled every 100 generations. The first 25% trees were discarded as burn-in and the remaining trees were used to create a consensus tree using the sumt demand.

3. Results

3.1. Phylogenetic analyses

In ML and BI phylogenetic analyses, five-gene eighty taxa of from Hirsutella, sequences Ophiocordyceps, and the outgroup taxa Cordyceps tenuipes (Peck) Kepler, B. Shrestha & Spatafora and C. militaris (L.) Fr. were retrieved from GenBank, which were combined with those generated in the present study. The combined dataset consisted of 4082 bp (i.e., 794 bp for tef-1 α , 859 bp for nrLSU, 999 bp for nrSSU, 543 bp for rpb1, as well as 887 bp for rpb2). Phylogenetic trees analyzed by ML and BI exhibited the nearly identical overall topologies (Figure 1). The mentioned results shared similar phylogenetic structures with existing analyses [14,15,18,19]. The phylogenetic trees recognized four statistically well-supported clades in

Table 1. Specimen information and GenBank accession number for sequences used in this study.

Species specimes Host		Icolato no /			Ger	Bank accession	no.	
Deficie/orgo: altopenthycitati VHI 10755 Lepidoptera VYS87216 VYS87217 VYS87214	Species	specimen no.	Host	nrSSU	nrLSU	tef1-α	rpb1	rpb2
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Hirsuella ARSEF 2227 Lepidoptera KM652065 KM652103 KM652051 KM652014 KM652015 KM652014 KM652016 KM652103 KM652016 KM650116 KM65016 KM650116 KM65016 KM65016	Hirsutella strigosa	ARSEF 2197	Hemiptera	KM652085	KM652129	KM652012	KM652050	
Hissuella thompsoni ARSEF 2800 Isodalda KM652103 KM652103 KM65203 KM652043 KM652043 KM652044 KM652044 KM652054 KM652054<	Hirsutella subulata	ARSEF 2227	Lepidoptera	KM652086	KM652130	KM652013	KM652051	
Hissuella thompsonii ABSEF 3323 Ixodidia KM652046 KM652046 KM652046 Hissuella thompsonii ABSEF 1037 Hemiptera KM652102 KM652102 KM652026 Hissuella shomongjatensis GZUIFF-Snj21022 KV945357 KV945357 KV945357 Ophicoardyceps aciculari OSC 128580 Coleoptera DQ522543 DQ518754 DQ522320 DQ5223266 DQ522342 Ophicoardyceps aphodili ABSEF 5692 Arthropoda DQ522541 DQ518754 DQ522326 DQ522364 DQ522342 DQ522326 DQ522364 DQ52364 CM68784 EF468914 KM652065 KM652065 </td <td>Hirsutella thompsonii</td> <td>ARSEF 2800</td> <td>Ixodida</td> <td>KM652095</td> <td>KM652142</td> <td>KM652023</td> <td>KM652058</td> <td></td>	Hirsutella thompsonii	ARSEF 2800	Ixodida	KM652095	KM652142	KM652023	KM652058	
Hissuella versioolar ARSEF 1947 Ixoolida NM652105 NM65205 Hissuella versioolar ARSEF 1037 Hemiptera KM652105 KM652020 KM652020 KM652020 Hissuella senonogiaensis GZUIFR-5nj121022 Coleoptera DQ522541 DQ522352 DQ5223237 DQ5223237 DQ5223237 DQ522342 Ophicocrityceps agriotidis ARSEF 5498 Coleoptera DQ522541 DQ522342 DQ522342 DQ522342 DQ522342 DQ522342 DQ522342 DQ522442 DQ522445 DQ522445 DQ522445 DQ522445 DQ522445 DQ522445 DQ522445 DQ52445 DQ522445 DQ522445 DQ522445 DQ522445	Hirsutella thompsonii	ARSEF 3323	Ixodida	KM652096	KM652143	KM652024	KM652059	
Instantial versicului Anster Tusty Inelinpleta NM02/U2 NM02/U2 NM02/U2 NM02/U2 NM02/U2 Ophicocrdyceps aciculari OSC 128580 Coleoptera DQ522541 DQ518754 DQ522320 DQ522326 DQ522362 DQ522326 DQ522364 DQ522341 DQ518754 DQ522320 DQ522364 DQ522341 DQ518754 DQ522320 DQ522364 DQ522341 DQ518754 DQ522326 DQ522364 DQ522341 DQ522342 DQ518754 DQ522342 DQ523242 DQ518754 DQ522346 DQ522340 DQ522342 DQ523264 DQ522364 DQ522454 DQ523564 DQ522364 DQ522454 DQ522454 DQ523564 DQ522364 DQ522364 DQ522364 DQ522364 DQ522364 DQ522364 DQ52056 KR78986 KR79002 KR78940 KR78946 KR79002 KR78946 KR79002 K	Hirsutella thompsonii Hirsutella varsisolor	ARSEF 1947	Ixodida	KM650100	KM652146	KM652026	KMGEDOGD	
Initiation and an optimization OSC 128580 Coleoptera DQ522543 DQ522326 DQ522321 DQ522337 DQ522349 DQ522341 DQ522341 DQ522354 DQ523545 DQ523545 DQ523545 DQ523545 DQ523545 DQ53555 DQ51371 DQ523545 DQ51374 DQ523545 DQ51374 DQ523754 DQ523754 DQ523754 <th< td=""><td>Hirsutella shennonaijaensis</td><td>G7UIER-Spi121022</td><td>пеппріега</td><td>KINI052102</td><td>KIVIO32130 KV045357</td><td>KIVI052029</td><td>KV945364</td><td></td></th<>	Hirsutella shennonaijaensis	G7UIER-Spi121022	пеппріега	KINI052102	KIVIO32130 KV045357	KIVI052029	KV945364	
Ophiocordyceps agnotidis ARSEF 5692 Arthropoda DOS22540 DOS18754 DOS22322 DOS22328 DOS22341 DOS22328 DOS22341 DOS22349 DOS22349 DOS22349 DOS22349 DOS22349 DOS22349 DOS22349 DOS22349 DOS22419 DOS22419 DOS22499 DOS22419 DOS22499 DOS22349 DOS22418 Ef468576 Ef468576 Ef468574 Ef468576 Ef468574 Ef468576 Ef468576 Ef468571 Ef468573 Ef468571 Ef468573 Ef468573 Ef468573 Ef468573 E	Ophiocordycens aciculari	OSC 128580	Coleoptera	D0522543	DO518757	D0522326	D0522371	D0522423
Ophicocardyceps aphodii ARSEF 5498 Coleoptera DQS22141 DQS1755 DQS22331 DQS22430 Ophicocardyceps brunnelpunctata OSC 128576 Coleoptera DQS22420 DQS18756 DQS22342 DQS21805 DQS22420 Ophicocardyceps brunnelpunctata OSC 11989 Lepidoptera EF468806 EF468748 EF468875 EF468975 EF468875 EF468975	Ophiocordyceps agriotidis	ARSEF 5692	Arthropoda	DQ522540	DQ518754	DQ522322	DQ522368	DQ522418
Ophicocrdyceps appendiculata NBRC 106959 JN941729 JN941729 JN941729 JN94172 AB968378 JN92463 AB968364 Ophicocrdyceps brunneipuncta OSC 110989 Lepidoptera DO522324 DQ518756 DQ52234 DQ52878 DQ52243 AB968385 AB968378 CF468874 EF468876 EF468874 EF468876 EF468876 EF468876 EF468876 EF468876 EF468871 KB78900 KB789906 KB789906 KB789907 KB789907 KB789907 KB789896 KB78997 KB789896 KB789896 FF468811 MF863827 MK863829 Ophicocrdyceps functiment MF116A MK874747 MK875336 MK863829 DQ522445 DQ518760 DQ522354 DQ522445 DQ518760 DQ522354 DQ522445 <t< td=""><td>Ophiocordyceps aphodii</td><td>ARSEF 5498</td><td>Coleoptera</td><td>DQ522541</td><td>DQ518755</td><td>DQ522323</td><td></td><td>DQ522419</td></t<>	Ophiocordyceps aphodii	ARSEF 5498	Coleoptera	DQ522541	DQ518755	DQ522323		DQ522419
Ophicocrdyces brunneipunctata OSC 128576 Coleoptera D6322542 D05322542 D05322542 D05322420 D05322420 Ophicocrdyces coenonyin NBRC 106964 AB966835 AB968371 AB968371 AB968373 Ophicocrdycess coenonyin NSR 106964 AB9668373 AB968374 EF4688748 EF4688748 EF4688749 EF468871 EF468912 Ophicocrdyceps formicarum TNS F18565 KJ878908 KJ878908 KJ878908 KJ878908 KJ878995 KJ878934 KJ878934 KJ878908 KJ878935 KJ878936 KJ878937 KJ878937 KJ868327	Ophiocordyceps appendiculata	NBRC 106959		JN941729	JN941412	AB968578	JN992463	AB968540
Ophicocrdyceps conomia NBRC 106964 Lepidoptera EF468305 AB968313 AB968571 AB968531 Ophicocrdyceps elongata OSC 110989 Lepidoptera EF468809 EF468748 EF468856 EF468874 EF468856 Ophicocrdyceps formicarum TNS F18565 KJ878908 KJ878988 KJ878956 KJ878986 KJ878943 KJ	Ophiocordyceps brunneipunctata	OSC 128576	Coleoptera	DQ522542	DQ518756	DQ522324	DQ522369	DQ522420
Ophicocrdyceps enomorniza OSC 110399 Lepidoptera EF468954 EF468806 EF468743 EF468816 Ophicocrdyceps enomorniza KW 33484 Coleoptera EF468954 EF468857 EF468811 Ophicocrdyceps formicarum TNS F18565 KI878908 KI878908 KI878908 KI878908 KI878900 KI878947 Ophicocrdyceps formicarum OSC 151908 KI878908 KI878989 KI878903 KI878947 Ophicocrdyceps gracilis CFC 10125 Lepidoptera EF468957 EF468751 EF468751 Ophicocrdyceps humbertii MF116A MK874747 MK875537 KI878808 KI87892 Ophicocrdyceps irangiensis OSC 128577 DQ522345 DQ522345 </td <td>Ophiocordyceps coenomyia</td> <td>NBRC 106964</td> <td>Level de méreire</td> <td>AB968385</td> <td>AB968413</td> <td>AB968571</td> <td>FF 460056</td> <td>AB968533</td>	Ophiocordyceps coenomyia	NBRC 106964	Level de méreire	AB968385	AB968413	AB968571	FF 460056	AB968533
Ophicocolyceps Er408039 Er40811 Er408039 Er40811 Er40811 Er40811 Er40813 Er40814 Er40814 Er40813 Er40813 <td>Ophiocordyceps elongata</td> <td>USC 110989</td> <td>Lepidoptera</td> <td>EFACODEA</td> <td>EF468808</td> <td>EF468/48</td> <td>EF468856</td> <td>EE469011</td>	Ophiocordyceps elongata	USC 110989	Lepidoptera	EFACODEA	EF468808	EF468/48	EF468856	EE469011
Chronologies Consol Consol <thconsol< th=""> <thconsol< th=""> <thcons< td=""><td>Ophiocordyceps entomorniza</td><td>TNS F18565</td><td>Coleoptera</td><td>K 1878921</td><td>K 1878888</td><td>K 1878968</td><td>K 1879002</td><td>K 1878946</td></thcons<></thconsol<></thconsol<>	Ophiocordyceps entomorniza	TNS F18565	Coleoptera	K 1878921	K 1878888	K 1878968	K 1879002	K 1878946
Ophiocordyceps forquignonii OSC 151908 KJ878922 KJ878829 KJ87903 KJ87903 KJ879047 Ophiocordyceps gracilis OSC 151908 EF468912 EF468913 EF468912 EF468913 EF468912 EF468915 EF468912 EF468912 EF468915 EF468915 EF468915 Dicocrdyceps humbertii MF116A MK874748 MK875537 MK863829 Dy522345 Dy522346	Ophiocordyceps formosana	TNM F13893		KJ878908	100/0000	KJ878956	KJ878988	KJ878943
Ophicocrdyceps EFCC 8572 Lepidoptera EF468915 EF468811 EF468751 EF468859 EF468912 Ophicocrdyceps fractionard GPA K1878923 K1878890 K1878969 K1878969 EF468812 EF468957 EF468812 EF468957 EF4688152 EF468852 EF468812 GPA	Ophiocordyceps forquignonii	OSC 151908		KJ878922	KJ878889		KJ879003	KJ878947
Ophicocrdyceps OSC 151906 Lepidoptera KJ878890 KJ878890 KJ878890 Ophicocrdyceps herniptera EF468957 EF468812 EF468872 EF468860 EF468814 Ophicocrdyceps humbertii MF116A MK874747 MK875536 MK863828 Ophicocrdyceps humbertii MF116B MK874748 MK875536 MK863829 Ophicocrdyceps irangiensis OSC 128577 DQ522546 DQ518760 DQ522345 DQ522345 DQ522457 Ophicocrdyceps irangiensis OSC 128578 DQ522457 DQ522374 DQ522457 Ophicocrdyceps konnoana EFCC 7295 Coleoptera EF468958 EF468816 EF468915 Ophicocrdyceps konnoana EFCC 7315 Coleoptera EF468917 KJ878891 KJ879004 KJ879494 Ophicocrdyceps langingensis YHOS 0705 Lepidoptera KC417458 KC417460 KC417462 KC417464 KC456333 Ophicocrdyceps nymicarum CG1357 Hymenoptera MG922551 MG922554 MG922556 Ophicocrd	Ophiocordyceps gracilis	EFCC 8572	Lepidoptera	EF468956	EF468811	EF468751	EF468859	EF468912
Ophiocordyceps humbertii EFCC 10125 Hemiptera EF468957 EF468812 EF468872 EF468860 EF468914 Ophiocordyceps humbertii MF116A MK874747 MK875336 MK863828 MK863828 Ophiocordyceps humbertii MF116B MK874748 MK87536 DQ522374 DQ5222475 Ophiocordyceps irangiensis OSC 128578 DQ522256 DQ522370 DQ5222345 DQ522374 DQ522445 Ophiocordyceps konnoana EFCC 7295 Coleoptera EF468958 EF468862 EF468916 Ophiocordyceps konnoana EFCC 7315 Coleoptera EF468959 EF468753 EF468861 EF468916 Ophiocordyceps longisima EFCC 6814 Hemiptera KC417450 KC417460 KK217892 KJ878970	Ophiocordyceps gracilis	OSC 151906	Lepidoptera	KJ878923	KJ878890	KJ878969		
Opnicocordyceps humbertii MF116A MK8/34/47 MK8/3537 MK8/328 Ophicocrdyceps humbertii MF116B MK8/34/47 MK8/3536 MK8/3828 Ophicocrdyceps humbertii MF116B MK8/34/47 MK8/3536 MK8/3828 Ophicocrdyceps irangiensis OSC 128577 DQ522356 DQ518770 DQ522345 MK8/3788 F468861 E7468916 E7468916 E7468916 E7468757 E7468866 E7468916 Dpicocrdyceps ingringinsis FF405 SC417462 KC417464 KC455333 Dpicocrdyceps ingringinginsis KS7004 KS1879004 KJ879004 KJ879004 KJ879004 KJ879004	Ophiocordyceps heteropoda	EFCC 10125	Hemiptera	EF468957	EF468812	EF468752	EF468860	EF468914
Ophilocordyceps irangiensis OSC 128577 DQ52254 DQ522374 DQ522373 DQ522374 DQ522374 DQ522374 D	Ophiocordyceps humbertii	MF116A		MK8/4/4/	MK8/553/		MK863828	
Ophiocordyceps irangiensis OSC 128578 DQ522356 DQ518770 DQ522345 DQ522345 Ophiocordyceps kniphofioides MF90 Hymenoptera MK874746 MK875538 MK863827 Ophiocordyceps kniphofioides MF90 Hymenoptera EF468956 EF468852 EF468851 Ophiocordyceps kniphofioides MF90 Lepidoptera EF468959 EF468753 EF468862 EF468916 Ophiocordyceps lanpingensis YHOS 0705 Lepidoptera KC417458 KC417460 KC417462 KC417464 KC456333 Ophiocordyceps longissima EFCC 7315 Coleoptera EF468817 EF468857 EF468865 EF468865 Ophiocordyceps nymicarum CG1357 Hymenoptera MG922559 MG922554 MG922554 MG922556 Q518763 DQ522333 DQ522345 KM652083 KH68757 EF468873 EF468930 F468825 EF468875 EF46893	Ophiocordyceps numberui			DO522546	DO518760	DO522320	DO522374	DO522427
Ophiocordyceps kniphofioides MF90 Hymenoptera MK874746 MK875538 MK863827 Ophiocordyceps konnoana EFCC 7295 Coleoptera EF468958 EF468753 EF468862 EF468915 Ophiocordyceps konnoana EFCC 7315 Coleoptera EF468959 EF468753 EF468861 EF468915 Ophiocordyceps konnoana EFCC 7315 Coleoptera EF468959 EF468753 EF468861 EF468915 Ophiocordyceps konnoana EFCC 6814 Hemiptera K0417458 KC417462 KC417464 KC465333 Ophiocordyceps nyrmicarum CG1357 Hymenoptera MG922559 MG922551 MG922554 MG922554 MG922538 EF4688758 EF468865 EF468920 Ophiocordyceps nutans OSC 151914 DQ522549 DQ518763 DQ522378 DQ522378 Ophiocordyceps ravenelli OSC 151914 KJ878932 KJ87907 KJ878950 KJ878950 KJ878950 KJ878950 KJ878950 KJ878950 KJ878950 KJ878950 KJ878951 KJ878950 KJ878957 <td>Ophiocordyceps irangiensis</td> <td>OSC 128578</td> <td></td> <td>D0522556</td> <td>DQ518770</td> <td>D0522345</td> <td>D0522391</td> <td>D0522445</td>	Ophiocordyceps irangiensis	OSC 128578		D0522556	DQ518770	D0522345	D0522391	D0522445
Ophiocordyceps konnoana EFCC 7295 Coleoptera EF468958 EF468958 EF468853 EF468853 EF468853 EF468853 EF468861 EF468915 Ophiocordyceps konnoana EFCC 7315 Coleoptera EF468959 EF468753 EF468861 EF468916 Ophiocordyceps lanpingensis YHOS 0705 Lepidoptera KC417458 KC417460 KC417464 KC456333 Ophiocordyceps longissima EFCC 6814 Hemiptera EF468863 EF468817 EF468757 EF468865 Ophiocordyceps nigrella EFCC 9247 MG922559 MG922551 MG922534 MG9225378 MG9225378 GP468873 EF468873 EF468874 EF468930 Ophiocordyceps navenelii OSC 151914 KJ878932 KJ878978 KJ879012 KJ878950 Ophiocordyceps sinensis EF468971 EF468970 EF468874 EF468973 EF468764 <t< td=""><td>Ophiocordyceps kniphofioides</td><td>MF90</td><td>Hymenoptera</td><td>MK874746</td><td>MK875538</td><td></td><td>MK863827</td><td></td></t<>	Ophiocordyceps kniphofioides	MF90	Hymenoptera	MK874746	MK875538		MK863827	
Ophiocordyceps konnoana EFCC 7315 Coleoptera EF468959 EF468753 EF468861 EF468916 Ophiocordyceps lanpingensis YHOS 0705 Lepidoptera KC417458 KC417460 KC417464 KC456333 Ophiocordyceps lanpingensis OSC 151913 KJ878924 KJ878921 KJ878970 KJ879004 KJ878948 Ophiocordyceps longissima EFCC 6814 Hemiptera EF468817 EF4688757 EF468865 Ophiocordyceps nymincarum CG1357 Hymenoptera MG922559 MG922551 MG922554 MG922556 Ophiocordyceps nymincarum OSC 151914 Doptizera EF468973 EF468818 EF468758 EF468930 Ophiocordyceps ravenelii OSC 151914 KJ878932 KJ878978 KJ878978 KJ878978 KJ878978 KJ878912 KJ878950 Ophiocordyceps sinensis EFCC 7287 Lepidoptera EF468970 EF468825 EF468767 EF468874 EF468924 Ophiocordyceps spendocordyceps sp. OSC 151904 KJ878935 KJ878990 KJ878980 KJ878980 KJ878980	Ophiocordyceps konnoana	EFCC 7295	Coleoptera	EF468958			EF468862	EF468915
Ophicordyceps Ionpingensis YHOS 0705 Lepidoptera KC417458 KC417460 KC417462 KC417464 KC456333 Ophicocrdyceps Iongissima EFCC 6814 Hemiptera EF468817 EF468817 EF468757 EF468865 Ophicocrdyceps nigrella EFCC 9247 EF468963 EF468818 EF468758 EF468866 EF468920 Ophicocrdyceps nutrans OSC 110994 DQ522549 DQ518763 DQ522333 DQ5223378 Ophicocrdyceps nutans OSC 151914 KJ878970 EF468818 EF468758 EF468930 Ophicocrdyceps ravenelii OSC 151914 KJ878932 KJ878978 KJ878978 KJ878970 KJ878970 KJ878970 KJ878970 KJ878973 EF468930 Dp522378 Dp522378 Dp522378 Dp522378 Dp522378 Dp522378 EF46875 EF46875 EF468930 KJ878932 KJ878970 EF468873 EF468930	Ophiocordyceps konnoana	EFCC 7315	Coleoptera	EF468959		EF468753	EF468861	EF468916
Ophiocordyceps Ioydii OSC 151913 K1878924 K1878924 K1878970 K1879004 K1878948 Ophiocordyceps longissima EFCC 6814 Hemiptera EF468817 EF4688757 EF468865 Ophiocordyceps myrmicarum CG1357 Hymenoptera MG922559 MG922551 MG922554 MG922550 Ophiocordyceps nigrella EFCC 9247 EF468863 EF468813 EF468758 EF468866 EF468920 Ophiocordyceps nigrella OSC 110994 DQ522549 DQ518763 DQ522333 DQ522378 EF468875 EF468875 EF468875 EF468970 EF468874 EF468970 EF468874 EF468970 EF468874 EF468873 EF468874 EF468874 EF468874 EF468874	Ophiocordyceps lanpingensis	YHOS 0705	Lepidoptera	KC417458	KC417460	KC417462	KC417464	KC456333
Ophiocordyceps EFCC 6814 Hemiptera EF468817 EF468817 EF468857 EF468805 Ophiocordyceps mymicarum CG1357 Hymenoptera MG922559 MG922554 MG922554 MG922556 Ophiocordyceps nigradia EFCC 67247 EF468963 EF468818 EF468758 EF468866 EF468890 Ophiocordyceps nutans OSC 110994 DQ522549 DQ518763 DQ522333 DQ522378 Ophiocordyceps pseudocommunis NHJ 12581 Isoptera EF468973 EF468831 EF46875 EF468873 EF468970 Ophiocordyceps revenelii OSC 151914 KJ878932 KJ878978 KJ879012 KJ878950 Ophiocordyceps NBRC 106966 JN941704 JN941437 AB968582 JN992438 AB968544 rubigionsiperitheciata Ophiocordyceps sinensis EFCC 7287 Lepidoptera EF468971 EF468827 EF468876 EF468875 EF468875 EF468875 Ophiocordyceps sp. OSC 151904 KJ878937 KJ878980 KJ878980 <t< td=""><td>Ophiocordyceps lloydii</td><td>OSC 151913</td><td>Hansintana</td><td>KJ878924</td><td>KJ8/8891</td><td>KJ8/89/0</td><td>KJ8/9004</td><td>KJ878948</td></t<>	Ophiocordyceps lloydii	OSC 151913	Hansintana	KJ878924	KJ8/8891	KJ8/89/0	KJ8/9004	KJ878948
Ophiocordyceps nignila EFCC 9247 Infinenoptena Infinenoptena <thinfinenoptena< th=""> Infinenoptena Infi</thinfinenoptena<>	Ophiocordyceps iongissima	CG1357	Hemiplera	MG022550	EF408817 MG022561	EF408/3/ MC022554	EF408803 MG022556	
Ophiocordyceps nutans OSC 110994 DQ522549 DQ518763 DQ522333 DQ522338 Ophiocordyceps pseudocommunis NHJ 12581 Isoptera EF468973 EF468831 EF468775 EF468970 Ophiocordyceps ravenelii OSC 151914 KJ878932 KJ878978 KJ879012 KJ878950 Ophiocordyceps ravenelii OSC 151914 KJ878932 EF468875 EF468873 EF468873 Ophiocordyceps rhizoidea NHJ 12522 EF468970 EF468825 EF468764 EF468873 EF468923 Ophiocordyceps rubicordyceps NBRC 106966 JN941704 JN941437 AB968582 JN992438 AB968544 rubiginosiperitheciata Ophiocordyceps sinensis EFCC 7287 Lepidoptera EF468971 EF468827 EF468876 EF468875 EF468875 EF468875 EF468875 EF468875 EF468875 EF468970 EF468875 EF468875 EF468970 EF468875 EF468875 EF468974 EF468972 EF468767 EF468875 EF468974 EF468972 EF468972 EF468875 EF468975 EF4689726	Ophiocordyceps nigrificaram Ophiocordyceps nigrella	FFCC 9247	nymenoptera	FF468963	FF468818	FF468758	FF468866	FF468920
Ophiocordyceps pseudocommunis NHJ 12581 Isoptera EF468973 EF468831 EF468775 EF468970 Ophiocordyceps ravenelii OSC 151914 KJ878932 KJ878978 KJ878978 KJ879012 KJ878950 Ophiocordyceps rhizoidea NHJ 12522 EF468970 EF468825 EF468764 EF468873 EF468873 Ophiocordyceps NBRC 106966 JN941704 JN941437 AB968582 JN992438 AB968544 rubiginosiperitheciata 0 EFCC 7287 Lepidoptera EF468971 EF468827 EF468876 EF468874 EF468874 EF468875 EF468875 <t< td=""><td>Ophiocordyceps nutans</td><td>OSC 110994</td><td></td><td>D0522549</td><td>DO518763</td><td>D0522333</td><td>D0522378</td><td>21 100920</td></t<>	Ophiocordyceps nutans	OSC 110994		D0522549	DO518763	D0522333	D0522378	21 100920
Ophiocordyceps ravenelii OSC 151914 KJ878932 KJ878978 KJ879912 KJ878950 Ophiocordyceps rhizoidea NHJ 12522 EF46870 EF46825 EF468764 EF468873 EF468923 Ophiocordyceps NBRC 106966 JN941704 JN941437 AB968582 JN992438 AB968544 rubiginosiperitheciata EF468971 EF468827 EF468876 EF468874 EF468924 Ophiocordyceps sinensis ARSEF 6282 Lepidoptera EF468971 EF468827 EF468875 EF468970 EF468971 EF468875 EF468971 EF468875 EF468875 EF468974 EF468875 EF468875 EF468970 EF468875 EF468970 EF468972 EF468875 EF468970 EF468972 EF468972 EF468972 EF468972 EF468972 EF468972 EF468972 EF468973 EF468972	Ophiocordyceps pseudocommunis	NHJ 12581	Isoptera	EF468973	EF468831	EF468775		EF468930
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Opniocorayceps unituberculata YFCC HU I 301 KY923214 KY923216 KY923218 KY923220	Ophiocordyceps unituberculata	YHH HU1301		KY923213		KY923215	KY923217	KY923219
	Opniocorayceps unituberculata	TECC HU1301		K1923214		K1923216	K1923218	KY923220

(continued)

Table 1. Continued.

	leolato no /			Ger	Bank accession	no.	
Species	specimen no.	Host	nrSSU	nrLSU	tef1-α	rpb1	rpb2
Ophiocordyceps variabilis	ARSEF 5365	Diptera	DQ522555	DQ518769	DQ522340	DQ522386	DQ522437
Ophiocordyceps variabilis	OSC 111003	Diptera	EF468985	EF468839	EF468779	EF468885	EF468933
Ophiocordyceps yakusimensis	HMAS 199604	•	KJ878938	KJ878902		KJ879018	KJ878953
Ophiocordyceps pulvinata	TNS-F-30044			GU904208	GU904209	GU904210	
Ophiocordyceps crinalis	GDGM 17327		KF226253	KF226254	KF226256	KF226255	
Cordyceps militaris	OSC 93623		AY184977	AY184966	DQ522332	DQ522377	
Cordyceps tenuipes	TBRC 7265			MF140707	MF140827	MF140776	MF140800

Ophiocordyceps, designated here as Ophiocordyceps clades A (the Hirsutella clade), B (the O. sobolifera clade), C (the O. ravenelii clade), and D (the O. sphecocephala clade) (Figure 1). The Ophiocordyceps clade A (Hirsutella clade) consisted of six major subclades, i.e., H. nodulosa, H. citriformis, H. thompsonii, H. guyana, H. sinensis, as well as Hirsutella ant pathogen clades. As revealed from phylogenetic analyses, the new species O. alboperitheciata clustered into the H. citriformis subclade and isolated a distinct clade from other related species with 100% statistical support.

3.2. Taxonomy

Ophiocordyceps alboperitheciata H. Yu, Q. Fan & Y.B. Wang, sp. nov. (Figure 2).

MycoBank: MB 834082

Etymology: alboperitheciata, indicating to the color of perithecia from the type specimen, "*albo*" means white.

Typus: China. Yunnan Province: Kunming City, the Wild Duck Forest Park, at 25°13′N, 102°87′E, alt. 2100 m, on a larva of Noctuidae (Lepidoptera) buried in fallen leaves, 12 August 2018, Hong Yu (holotype, YHH 16755; ex-holotype living culture, YFCC 7203).

Sexual morph: Stromata arising in pairs from the larva of Noctuidae buried in fallen leaves, cylindrical, flexible, light brown to dark brown, unbranched, gradually tapering toward the apex, $69-71 \times 0.6-1.2$ mm, with a sterile tip, remaining unchanged in 3% KOH. Stipes cylindrical, smooth, dark brown, 0.6-1.2 mm wide. Fertile parts clavate, pale brown, covered by a spinous surface, reaching up to $4.1-4.5 \times 0.8-1.4$ mm. Perithecia superficial, subtranslucent, scattered or crowded, nearly ovoid, white to pale brown, exhibiting an unequal distribution on the middle of the stromata, covering densely the lower part and aggregating loosely at the upper of stromata, arranged in a disordered manner, $408-549 \times 233-321 \,\mu\text{m}$. Asci hyaline, cylindrical, eight-spores, $144-246 \times 3.5-4.7 \,\mu\text{m}$, with a hemispheric apical cap of $3.2-4.2 \times 2.3-2.5 \,\mu\text{m}$. Ascospores cylindrical, multiseptate, hyaline,

 $0.5-0.6\,\mu\text{m}$ diameter, with septa of $1.1-1.3\,\mu\text{m}$ long. Part-spores were not examined.

Asexual morph: Colonies on PDA growing very slowly, exhibiting 3.0–3.6 cm diameter in 21 days at 25 °C, fan split, dark brown at the centrum, and white at the edge. Reverse dark brown. Hyphae hyaline, branched, septate, smooth-walled, $1.37-2.05 \,\mu\text{m}$ wide. Conidiogenous cells and conidia were not detected.

Host: Larva of Noctuidae (Lepidoptera).

Habitat: Buried in fallen leaves.

Type locality: The Wild Duck Lake Forest Park, Kunming City, Yunnan Province, China.

4. Discussion

The particularity of O. alboperitheciata is revealed by morphological and ecological comparisons with eight other closely related species that possess Hirsutella morphs (Table 2). Ophiocordyceps alboperitheciata is noticeably inconsistent with eight other related species of H. citriformis clade in five aspects: (1) its fertile parts are long, rod-shaped, $4.1-4.5 \times 0.8-1.4$ mm; (2) its perithecia are superficial and scattered or crowded, which is nearly white; (3) its asci are slender; (4) its septa of ascospores are smaller; (5) it is associated with the larva of Noctuidae buried in fallen leaves. In the H. citriformis clade, sexual morphs of species have been rarely reported, except for O. elongata and O. humbertii Petch [13,28,29]. It is noteworthy, O. alboperitheciata and O. elongata are closely clustered together, whereas the latter exhibits greater sizes of stromata (110 mm long), asci (220 \times 8 µm), ascospore septa long), immersed (4–12 μm and perithecia. Ophiocordyceps alboperitheciata synthesizes relatively shorter stromata (54-65 mm long) with sterile tips and fertile parts, stromata in pairs, superficial perithecia, shorter asci $(144-246 \times 3.5-4.7 \,\mu\text{m})$, as well as ascospore septa (1.1–1.3 μ m). As revealed from the mentioned distinct features above indicated that O. alboperitheciata was considerably different from other related species. The hosts comprised five orders of insects in the H. citriformis clade, in which O. alboperitheciata, O. elongate, and H. gigantean



Figure 1. Phylogenetic placement of *Ophiocordyceps alboperitheciata* infered from BI and ML analyses based on five-gene (nrSSU, nrLSU, tef-1 α , rpb1, and rpb2) sequence dataset. Values at the nodes before and after the backslash are BI posterior probabilities and ML bootstrap proportions, respectively. Support values of ML bootstrap proportions greater than 40% are indicated at the nodes.

clustered together and linked to Lepidoptera, other six species displayed the respective association with Hymenoptera, Hemiptera, Diptera, Orthoptera, Dermaptera, and Anoplura. The family Ophiocordycipitaceae was proposed according to the type genus *Ophiocordyceps* with the sexual morph characterized by the production of whole septate ascospores, which usually did not



Figure 2. Morphological characteristics of *Ophiocordyceps alboperitheciata*. (a, b) Stromata on a larva of Noctuidae; (c) Fertile part; (d) Sterile tip; (e–g) Perithecia; (h–j, l) Asci; (k) Ascospores; (m) Clony on PDA. Scale bars: a, b = 1 cm; $c = 600 \text{ }\mu\text{m}$; d = 1 mm; $e-f = 100 \text{ }\mu\text{m}$; $g-j = 50 \text{ }\mu\text{m}$; k, $l = 20 \text{ }\mu\text{m}$; m = 1 cm.

disarticulate into part-spores at maturity, and asci had an apical hemispheric cap. The Hirsutella, as the old name associated asexual generic with the Ophiocordyceps, is synonymized under Ophiocordyceps, most species occurring from adult insects are formerly employed in the Ophiocordyceps clade A [1,3,5]. Phylogenetic studies of Hirsutella species from the USA were conducted by three loci providing evidence for taxonomic revisions under novel rules [14,15]. The available molecular data have facilitated the use of the mentioned fungi and associated data to conduct indepth phylogenetic classification studies on Hirsutella and *Ophiocordyceps*. The phylogenetic tree of *Hirsutella* and *Ophiocordyceps* of this study complies with the existing studies of Ophiocordycipitaceae [5,10,14,15]. The genus *Ophiocordyceps* with *Hirsutella* morph comprises six distinct groups, i.e., *H. citriformis*, *H. thompsoni*, *H. nodulosa*, *H. guyana*, *H. sinensis*, and *Hirsutella* ant pathogen clades. The insect pathogen *O. alboperitheciata* pertains to the *H. citriformis* clade, which is obviously separated from other allied species.

The present phylogenetic tree covers nine species cluster in the *H. citriformis* clade. Our result is

	References	This study	[28]	[29]	[28]	[13]	[28]
	Conidia	Undetermined	Unknown	Unknown	The spore cluster is lemon-shaped, $10 \times 6 \mu m$, $10 \times 6 \mu m$, becoming globose 10 μm diameter, and the separate conidia are broadly cymbiforr with obtuse tips, $9-10 \times 3-4 \mu m$	Spores fusoid, hyaline, 5.5–8.5 × 1.5–18 μm	The spore cluster is oval, 9–11 \times 6-7 μ m, and the individual conidia are cymbiform, 6–9 \times 2–2.5 μ m, o oval, 7–8 \times 3–4 μ m
	Conidiogenous cells	Undetermined	Unknown	Unknown	Phialider up to 40 μ m high, with a flask- shaped base, 16–20 \times 8–9 μ m, and a long, stout sterigma, 1 μ m diameter.	Sporophores simple, sessile or subsessile, with rather short, delicate sterigmata 20–30µm	The phialides have a conical base, 5-8 × 3-4 µm, merging into a stout sterigmata, 9-14 µm long, or a cylindrical base, 6-18 × 2 µm, with a sterigmata 6 µm long
	Ascospores	Ascospores hyaline, cylindric, multiseptate, 0.5–0.6 µm diameter, with septa 1.1–1.3 µm apart. part-spores were not seen.	Ascospores cylindric, 2 μm diameter, with septa 4–12 μm apart. Part-spores were not seen.	Ascospores are 75 µm long, 25 µm diameter, narrow-fusoid, septate at intervals of 6–16 µm, not dividing into part-spores.	None	None	None
	Asci	Asci hyaline, cylindrical, 8-spores, 144–246 × 3.5–4.7 μm, with a hemispheric apical cap, 3.2–4.2 × 2.3–2.5 μm.	The asci are 220 μm long, 8 μm diameter.	The asci are 130 µm long, 10 µm diameter, capitate, fusoid or narrow-clavate.	None	None	None
nu nus relateu species.	Perithecia	Perithecia superficial, scattered or crowded, size 0.41–0.55 × 0.23–0.32 mm, nearly ovoid, white nearly light brown.	The perithecia are immersed, scattered or crowded, ovato- conoid, size 0.5 × 0.3 mm, apex subacute, wall wellow by transmitted light.	Perithecia, scattered, dark amber, subtranslucent, flask- shaped with a truncate apex, 275 × 120 µm.	None	None	None
серь агоорегипесиана аг	Synnemata/stromata	Stromata in pairs, rigid, the stalk is smooth, unbranched, long 54-65 mm, light brown to dark brown, with a clavate fertile part, white o light brown, $4.1-4.5 \times$ 0.8-14 mm, and a sterile tip.	The stalk is flexuose, longitudinally sulcate and twisted, 110 mm long, pale brown.	Several, 7 mm long, dark brown, with an oval swelling, 1 × 0.4 mm.	Branched, longitudinally sulcate, glabrous, ashy and minutely setose above, size 40 × 0.6 mm, brown below.	Synnemata usually long, flexible, simple or branched, branches often short and often short and detached, brown in color	Rrigid, branched, size 18–19 mm, dark brown or rufous brown, cinercous toward the tips, with a matt surface
и ог <i>ортиосога</i>)	Habitat	Buried in fallen leaves	Unknown	Unknown	Doow nO	Unknown	Unknown
поюдісаї соппральо	Host	Larva of Noctuidae (Lepidoptera)	Pupae and larvae of <i>Apalela</i> <i>americana</i> (Lepidoptera).	Hymenoptera	Pupae and larvae of Apatela Americana (Lepidoptera)	Adult of Fulgoridae (Hemiptera)	Fly (Diptera)
I able 2. A morp	Species	0. alboperitheciata	0. elongata	0. humbertii	H. gigantea	H. citriformis	H. radiata

Table 2. A morphological comparison of Ophiocordyceps alboperitheciata and its related species.

Continue	d.								
	Host	Habitat	Synnemata/stromata	Perithecia	Asci	Ascospores	Conidiogenous cells	Conidia	Reference
	Cricket adult (Orthoptera)	Unknown	Synnemata erect, straight, unbranched, uniform in height, measuring 4–5 mm, nearly black in color	None	None	None	Sporophores simple, sessile, the inflated basal portion tapering gradually to rather short 25–35 µm sterigmata	Spores fusoid cylindrical, hyaline, size 9–10 × 2 μm	[28]
sis	Earwigs (Dermaptera)	Unknown	Synnemata cylindrical, size 60.0 × 1.0-2.0 mm, brown	None	None	None	Conidiogenous cells solitary, phialides cylindrical or awl- like, 14.4–26.1 or 6.3–14.4 μm	Conidia hyaline, aseptate, smooth, sausage-shaped, single or double from the apex of the neck, 6.3–10.8 × 3.6–6.3 um	[30]
_	Colaoptera (Anoplura)	Unknown	Synnemata simple or branching, 3–5 mm, cinereous to violaceous gray to dull brown, often paler at the apex	None	None	None	Conidiogenous cells ellipsoid, base $8-10 \times 5-6 \mu m$, tapering rather abruptly into a long neck, $30-35 \mu m$ long	Conidia cymbiform to narrow ellipsoid, $4-7 \times 1-2 \mu m$, forming citriform clusters $8 \times 6 \mu m$	[31]

consistent with existing findings, i.e., *H. radiata, H. fusiformis*, and *O. shennongjiaensis*, and *H. gigantean* and *O. elongate* group cluster closely, respectively [14,15,32]. Three species, i.e., *O. alboperitheciata, O. elongate*, and *H. gigantea*, are closely clustered together, whereas they are noticeably inconsistent with each other in morphological and ecological characteristics. According to both molecular phylogeny and morphology, a consistent relationship between *O. alboperitheciata* and other relatives in the *H. citriformis* clade is evidenced. Thus, the novel species *O. alboperitheciata* is proposed in genus *Ophiocordyceps*.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

- Wijayawardene NN, Hyde KD, Rajeshkumar KC, et al. Notes for genera: Ascomycota. Fungal Divers. 2017;86(1):1–594.
- [2] Araújo JPM, Evans HC, Kepler RM, et al. Zombieant fungi across continents: 15 new species and new combinations within *Ophiocordyceps*. I. Myrmecophilous hirsutelloid species. Stud Mycol. 2018;90:119–160.
- [3] Luangsa-Ard JJ, Tasanathai K, Thanakitpipattana D, et al. Novel and interesting *Ophiocordyceps* spp. (Ophiocordycipitaceae, Hypocreales) with superficial perithecia from Thailand. Stud Mycol. 2018;89: 125–142.
- [4] Petch T. Notes on entomogenous fungi. Trans Br Mycol Soc. 1931;16(1):55–75.
- [5] Sung GH, Hywel-Jones NL, Sung JM, et al. Phylogenetic classification of *Cordyceps* and the clavicipitaceous fungi. Stud Mycol. 2007;57:5–59.
- [6] Spatafora JW, Quandt CA, Kepler RM, et al. New 1F1N species combinations in Ophiocordycipitaceae (Hypocreales). IMA Fungus. 2015;6(2):357–362.

I SI

- [7] Khonsanit A, Luangsa-Ard JJ, Thanakitpipattana D, et al. Cryptic species within *Ophiocordyceps myrmecophila* complex on formicine ants from Thailand. Mycol Prog. 2019;18(1–2):147–161.
- [8] Mains E. North American entomogenous species of *Cordyceps*. Mycologia. 1958;50(2):169–222.
- [9] Ban S, Sakane T, Nakagiri A. Three new species of Ophiocordyceps and overview of anamorph types in the genus and the family Ophiocordyceptaceae. Mycol Prog. 2015;14(1):1017.
- [10] Quandt CA, Kepler RM, Gams W, et al. Phylogenetic-based nomenclatural proposals for Ophiocordycipitaceae (Hypocreales) with new combinations in *Tolypocladium*. IMA Fungus. 2014;5(1):121–134.
- [11] Sanjuán T, Franco-Molano AE, Kepler RM, et al. Five new species of entomopathogenic fungi from the Amazon and evolution of neotropical *Ophiocordyceps*. Fungal Biol. 2015;119(10): 901–916.
- Mains EB. Entomogenous species of *Hirsutella*, *Tilachlidium* and *Synnematium*. Mycologia. 1951; 43(6):691–718.
- [13] Speare AT. On certain entomogenous fungi. Mycologia. 1920;12(2):62–76.
- [14] Simmons DR, Kepler RM, Rehner SA, et al. Phylogeny of *Hirsutella* species (Ophiocordycipitaceae) from the USA: remedying the paucity of *Hirsutella* sequence data. IMA Fungus. 2015;6(2):345–356.
- [15] Simmons DR, Lund J, Levitsky T, et al. Ophiocordyceps myrmicarum, a new species infecting invasive Myrmica rubra in Maine. J Invertebr Pathol. 2015;125:23–30.
- [16] Wang YB, Nguyen TT, Dai YD, et al. Molecular phylogeny and morphology of *Ophiocordyceps unituberculata* sp. nov. (Ophiocordycipitaceae), a pathogen of caterpillars (Noctuidae, Lepidoptera) from Yunnan, China. Mycol Prog. 2018;17(6):1–9.
- [17] Fan Q, Wang YB, Tang DX, et al. Species diversity of *Cordyceps sensu lato* in the wild duck lake forest park of Kunming (in Chinese). Acta Edulis Fungi. 2020;27(2):101–108.
- [18] Wang YB, Yu H, Dai YD, et al. Polycephalomyces yunnanensis (Hypocreales), a new species of Polycephalomyces parasitizing Ophiocordyceps nutans and stink bugs (hemipteran adults). Phytotaxa. 2015;208(1):34.
- [19] Wang YB, Yu H, Dai YD, et al. *Polycephalomyces* agaricus, a new hyperparasite of *Ophiocordyceps*

sp. infecting melolonthid larvae in southwestern China. Mycol Prog. 2015;14(9):70–78.

- [20] Wang YB, Wang Y, Fan Q, et al. Multigene phylogeny of the family Cordycipitaceae (Hypocreales): new taxa and the new systematic position of the Chinese cordycipitoid fungus *Paecilomyces hepiali*. Fungal Divers. 2020;103(1):1–46.
- [21] Liu ZY, Liang ZQ, Whalley AJS, et al. Cordyceps brittlebankisoides, a new pathogen of grubs and its anamorph, Metarhizium anisopliae var. majus. J Invertebr Pathol. 2001;78(3):0–182.
- [22] Rehner SA, Samuels GJ. Taxonomy and phylogeny of *Gliocladium* analysed from nuclear large subunit ribosomal DNA sequence. Mycol Res. 1994;98(6): 625-634.
- [23] Bischoff JF, Rehner SA, Humber RA. Metarhizium frigidum sp. nov.: a cryptic species of M. anisopliae and a member of the M. flavoviride complex. Mycologia. 2006;98(5):737–745.
- [24] Tamura K, Peterson D, Peterson N, et al. MEGA5: molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. Mol Biol Evol. 2011;28(10):2731–2739.
- [25] Ronquist F, Huelsenbeck JP. MrBayes 3: Bayesian phylogenetic inference under mixed models. Bioinformatics. 2003;19(12):1572–1574.
- [26] Stamatakis A. RAxML-VI-HPC: maximum likelihood-based phylogenetic analyses with thousands of taxa and mixed models. Bioinformatics. 2006; 22(21):2688–2690.
- [27] Darriba D, Taboada GL, Doallo R, et al. jModelTest 2: more models, new heuristics and parallel computing. Nat Methods. 2012;9(8):772.
- [28] Petch T. Notes on entomogenous fungi. Trans Br Mycol Soc. 1937;21(1-2):34-67.
- [29] Petch T. Notes on entomogenous fungi. Trans Br Mycol Soc. 1935;19(3):161–194.
- [30] Zou X, Zhou JX, Liang ZQ, et al. *Hirsutella shen-nongjiaensis*, a new entomopathogenic species infecting Earwig (Dermaptera). Mycosystema. 2016;35(9):1070–1079.
- [31] Petch T. Notes on entomogenous fungi. Trans Br Mycol Soc. 1932;16(4):209–245.
- [32] Hodge KT. Revisionary studies in *Hirsutella* (Anamorphic Hyphomycetes: Clavicipitaceae)
 [Ph.D. dissertation]. America: Cornell University; 1998.