What is the Chinese caterpillar fungus *Ophiocordyceps sinensis* (Ophiocordycipitaceae)?

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*Ophiocordyceps sinensis* is a well-known insect fungus, naturally distributed in the Tibetan Plateau of Asia. It has been long known by its synonym *Cordyceps sinensis* both in scientific and non-scientific communities but was recently transferred to *Ophiocordyceps*. Over the last 300 years, the morphological characters of this taxon have been studied by different professionals and experts, such as religious persons, travelers, entomologists, pharmacologists and mycologists. Morphological descriptions of mature *O. sinensis* stroma based on recent studies are compared in this study with those of the type specimens of Berkeley (Lond J Bot. 2:205–211;1843). A literature review indicates that the specimens of Berkeley (1843) are immature. New names have been proposed for *O. sinensis*-like species from alpine regions, such as *O. gansuensis*, *O. crassispora*, *O. kandingensis*, *O. multiaxialis* and *O. nepalensis*, and it is not obvious how these differ from *O. sinensis*. Epitypification and revision of *O. sinensis* is, therefore, essential to resolve the taxonomic ambiguity of *O. sinensis* and related species.

**Keywords:** Chong Cao; *Cordyceps sinensis*; Dong Chong Xia Cao; Dong Chung Ha Cho; emendation; epitypification; *Sphaeria sinensis*; taxonomic revision; Tochu-Kaso, Yarsa Gumba

**Introduction**

*Ophiocordyceps sinensis* (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora is a well-known medicinal fungus, endemic to the alpine regions of the Tibetan Plateau. The medicine is derived from parasitism of the fungus *O. sinensis* on insect larvae within the family Hepialidae. Historically, this medicine was mentioned as Bhu-Sanjivani in old Ayurvedic literature, such as Atreya Samhita and Charak Samhita, which were written about 3000 years ago. The fungus has been recognized as a medicinal product in China for at least 2000 years (Zang et al. 1990; Jones 1997; Zhu et al. 1998; Halpern 1999; Kinjo and Zang 2001; Liu et al. 2001; Li et al. 2006), the northern range of Nepal (Balfour-Browne 1955; Department 1976; Kobayasi 1981; Otani 1982; Adhikari and Durrieu 1996; Holliday et al. 2005; Shrestha and Sung 2005; Devkota 2006, 2008, 2009; Halpern 2007; Adhikari 2008; Chhetri and Lodhiyal 2008), northern Bhutan (Balfour-Browne 1955; Cannon et al. 2009) and the northern states of India (Sharma 2004). It is generally distributed between 3000 and 5000 m elevation, depending on locality. McKenna et al. (2002) mistakenly included other countries and continents where *O. sinensis* grows, such as Japan, Australia, New Zealand, Canada, the United States, Mexico, Russia, Norway, the Netherlands, Italy, Kenya, Tanzania and Ghana.

**Origin of scientific name of O. sinensis**

Westwood (1842) misidentified *O. sinensis* as *Clavaria entomorrhiza* (Dicks.) Westwood. *Clavaria entomorrhiza* was reported by Dickson (1785) from England as *Sphaeria entomorrhiza* Dicks. and was well known at that time. The following year, *Clavaria entomorrhiza* of Westwood
(1842) was identified as a new fungal species by Berkeley (1843) and named *Sphaeria sinensis* Berk. Berkeley described *S. sinensis* in Latin as “fusca, stipte cylindraceo deorsum subincrasato; capitulo cylindrico cum stipte confluentu apiculato; apiculo sterilii” which means “it is dark, the stem is cylindrical, somewhat thicker downwards, the head is cylindrical and pointed, confluent with the stem and the tip being sterile”. Identification was based on specimens bought and sent by Reeves to the Linnean Society of England from Guangzhou, then known as Canton, the capital city of Southeast Chinese Province of Guangdong (Westwood 1842; Berkeley 1843). At that time, the mushroom fungus to be brought to Guangzhou from the western Provinces of China such as Tibet and Sichuan for sale. The specimens sent by Reeves are said to have been collected from western Sichuan (Zang et al. 1990), but the locality was mentioned only as China (Berkeley 1843). The specimens have been preserved in Royal Botanical Garden, Kew, UK (K) (Berkeley 1843; Massée 1895; Zang and Kinjo 1996). Some of the *O. sinensis* specimens maintained in K have also been collected from Nepal and Bhutan (Dr. Begona Aguirre-Hudson, 2010, personal communication).

It is well known that Saccardo (1878, 1883) listed the scientific name from *Sphaeria sinensis* to *Cordyceps sinensis* (Berk) Sacc. However, Berkeley (1857) had already named it as *C. sinensis*, while revising *Cordyceps* diversity of the United States, but he did not justify the name change. Later, Soubeiran and Thiersant (1874) and Bretschneider (1881) also named it as *C. sinensis*, but did not give any reference nor did they justify the new name. Saccardo (1878) listed *C. sinensis* and simply referred to Berkeley (1843), but did not provide any further description. Saccardo (1883), however, gave the full description of Berkeley (1843) in Latin along with its synonym. Not only that, he grouped *C. sinensis* as an imperfectly identified *Cordyceps* species due to lack of information on micromorphological characters. In the true sense, Berkeley’s (1843) specimens do not serve to identify *C. sinensis*, as his specimens are immature (Massée 1895; Zang and Kinjo 1996). The taxonomy of *C. sinensis* has been generally conceived as problematic and controversial, based on type specimens (Chen et al. 1999; Kang et al. 2000; Kinjo and Zang 2001; McKenna et al. 2002; Chen et al. 2004). Some authors have even gone so far as to think that there is no type specimen of *C. sinensis* or even wonder what *C. sinensis* actually is. An appropriate epitype should be designated to stabilize the use of the name (Hyde and Zhang 2008).

Based on molecular phylogenetic study, Sung et al. (2007) separated the megagenus *Cordyceps* into four genera, viz. *Cordyceps* (40 spp.), *Ophiocordyceps* (146 spp.), *Metacordyceps* (6 spp.) and *Elaphocordyceps* (21 spp.), while the remaining 175 spp. were left in the *Cordyceps* group. As a result, *C. sinensis* was transferred to *Ophiocordyceps*, hence renamed as *O. sinensis*.

### Names of natural *O. sinensis* in different countries/regions

Old Chinese names of *O. sinensis* are as diverse as the authors. Father Parennin was the first to introduce it to the Western world. He sent a few specimens to the Academy of Sciences in Paris in 1723 with some explanatory notes. Three years later, Réaumur (1726) published an article based on the specimens and named it as “Hia tsao tom tchom”, which was based on the Chinese name “冬虫夏草” but the first two words were reversed with last two, as a result meaning “plant in summer and worm in winter”. He also coined the term “plante ver” in French, meaning “plant worm”. Ten years later, Father Parennin himself named it as Hia tsao tong tchong (du Halde 1736). In China, it was believed to be a plant during the summer that changed into a worm in the winter (Réaumur 1726; du Halde 1736).

Other names are Hia tsao tom tchom and Hiastotomtchom according to Rees’s Encyclopaedia (Westwood 1842; Berkeley 1843). Rennie (1835) named it as Hiastirotetocheon and first identified the plant as a fungus. According to Westwood (1842), the name given by Reeves was Hea Tsaon Taong Chung, but Pereira (1854) mentioned it as Tong Chong Ha Cho, which is very similar to general Korean name for *Cordyceps*. Pegler et al. (1994) gave a slightly different name Hea Tsao Tsong Chung referring to Reeves. Besides that, Robin (1853) and Pereira (1854) mentioned the name as Hea Tsao Taong Chung and Hea Tsao Taung Chung, respectively, referring to Westwood (1842). Actually, Westwood (1842) did not give any name, but only referred to different sources, such as du Halde (1736), Rees’s Cyclopaedia and personal communication with Reeves. However, he mentioned another name Ting Ching Hea Tsam as more commonly used name in Guangdong (Westwood 1842). Actually, all these names originated from the Chinese name “冬虫夏草” and translated from Chinese in different languages with different spellings or word orders.

Other Chinese names include Siao-cao-dun-czun, Hias’-au-tung-ch’ung and Tchong-tsao (Soubeiran and Thiersant 1874), Hia tsao tum chom (Bretschneider 1881), Hea-Tsao-Taog-Chung (Saccardo 1883), Thêong-Tsäo (Pratt 1892), Hsia-ts‘ao-tung-ch‘ung (Stuart 1911), Ch‘ung-tsao (Wilson 1913), Hia-tsao-tong-tchong and Hia tsao-tenchung (Brewster and Alsberg 1917), Hia Tsao Tchong (Lloyd 1918), tung-chhung -hsia-tsiao (Ainsworth 1976) and Dong zhong chang cao and Zhong cao (McKenna et al. 2002). Currently, the Chinese name is Dong Chong Xia Cao (Liu et al. 1989), also known as Chong Cao in short. However, Chong Cao sometimes refers to the common name for all *Cordyceps* species.

The fungus is called Totsu kaso (Thumberg 1796), Tatsou Kaso (Kobayasi 1941), totsu kasu or tochukaso (Hølpern 1999), Tochu-Kaso (Kinjo and Zang 2001), tochukasu (Holliday et al. 2005) and Tochucaso (Holliday et al. 2005).
Table 1. Names of *Ophiocordyceps sinensis* based on Chinese characters.

| Name                          | Chinese characters (English translation) | 冬 | 夏 | 蟲 | 草 |
|-------------------------------|------------------------------------------|----|----|----|----|
| Hia tsao tom tchom (Réamur 1726) | Tom Hia Tchom Tsao                        |    |    |    |    |
| Hia tsao tong tchong (du Halde 1736) | Tong Hia Tchong Tsao                      |    |    |    |    |
| Hea Tsaon Taong Chung (Westwood 1842) | Taong Hea Chung Tsao                      |    |    |    |    |
| Tong Chong Ha Cho (Pereia 1854)  | Tong Ha Chong Cho                         |    |    |    |    |
| Dong Chong Xia Cao (in modern Chinese) | Tong Xia Chong Cao                       |    |    |    |    |
| Dung Tsung Ha Chou (in Guangdong Chinese) | Dung Ha Tsung Chou                       |    |    |    |    |
| Chong Cao (short form in modern Chinese) | Chong Cao                                 |    |    |    |    |
| Tochu-Kaso (in modern Japanese)   | To Ka Chu So                               |    |    |    |    |
| Dong Chung Ha Cho (in Korean)     | 동(dong) 安(ha) 충(chung) 쏘(cho)            |    |    |    |    |

and Cleaver (2008) in Japanese. McKenna et al. (2002) also mentioned another Japanese name, semitake, which is actually the Japanese name for another *Ophiocordyceps* species, *O. sobolifera* (Dr. Eiji Tanaka, 2010, personal communication). The common name of *Cordyceps* in Korean is Dong Chung Ha Cho (Lim and Kim 1973; Sung 1996). As mentioned earlier, these various alphabetic names are based on four Chinese characters that mean winter, summer, insect and plant (Table 1). The translations depend on pronunciation of the region or country.

Yartsa gunbu is the Tibetan name for *O. sinensis* given by Nyammyi Dorje (1439–1475) in the 15th century (Winkler 2008). Chaudhuri (1931) mentioned that the local name is yartsa gumba in Sikkim and Tibet. This is also the most common name in Nepal, Bhutan and India. As in the Chinese name, this name has different forms such as yarsa gumba, yarsagomba, yarsha gumba, yarcha gumba, yarchagunbu, yarcha, yartsa guenbub and yartsa gunbu. A few other names are also popular in Nepal, such as Jingani, Jivan Buti, Kira Chhyau, Kira Jhar, Saram Buti and Saram Buti Jadi. Tsa daji is also another Tibetan name (Winkler 2008).

**Morphological characters of *O. sinensis***

**Macromorphological characters**

As in other *Cordyceps* species, the complete specimen of *O. sinensis* consists of two parts, the basal caterpillar containing fungal endosclerotium and the upper fungal part (stroma). The caterpillar is usually yellowish, while the stroma is dark brown or black. The caterpillar is usually 3.5–4 cm long, but the stroma is longer, usually 4–10 cm. A single stroma grows from the head region of the caterpillar, with its tip rarely bifurcating. The caterpillar is solid, intact and its body parts, such as head, neck, body segments and legs (thoracic, ventral and anal), are all clearly visible. The stroma is further distinguished into two parts, the basal stem and upper head. The stem is 2.5–8.5 cm long and 2–3 mm wide, while head is 1–2.5 cm long and 3–5 mm wide. The stem is also slender, glabrous, but longitudinally furrowed or ridged; the head is slightly swollen, sublanceolate or fusiform, and distinct from the stem. The head is the fertile region of the stroma, of which the apex is distinct and sterile, laterally compressed and furrowed; 2–4 mm long and 2–4 mm wide. The surface of the head is granular due to projecting openings or ostioles of perithecia. *O. sinensis* is the name given to the stroma (fungal part), whereas the caterpillar belongs to different species of *Thitarodes* (*Hepialus*) and other similar genera of the family Hepialidae, commonly known as the ghost moth, bat moth or swift moth (for details, see the hosts of *O. sinensis* section below).

**Micromorphological characters of the teleomorph**

**Perithecium**

Perithecia are crowded and distributed around the swollen head. They are globose (Rehm 1904) or ellipsoid, ovoid, subtruncate or obl ate (Teng 1939; Kobayasi 1941; Kinjo and Zang 2001). The globose shape could be due to the immaturity of the specimen. They are superficial or slightly immersed in the stroma cortex (Chaudhuri 1931; Teng 1939; Kobayasi 1941; Kinjo and Zang 2001) but, in old literature, they are reported as immersed and hardly projecting (Rehm 1904; Lohwag 1923). In *Cordyceps*, generally, perithecia are immersed when young but appear subsuperficial or superficial when mature. Kobayasi (1941) described the inner layer of perithecia as pale yellow, 20–25 μm wide, and the outer layer as dark black.

Lohwag (1923) reported the smallest perithecial size, followed by Zang and Kinjo (1996), Chaudhuri (1931), and Shrestha and Sung (2005) (Table 2). Zang and Kinjo (1996) and Teng (1939) reported the longest perithecia, followed by Xiao et al. (1983) and Vassiljeva and Koval (1961) (Table 2).

**Asci**

Asci are cylindrical or slightly tapering at both ends, straight or curved, with a capitake and hemispherical apex. Massee (1895) and Lohwag (1923) reported the base of asci narrows into a slender pedicel. Lohwag (1923) also reported narrow central canal in asci.
Previously, asci were described as eight-spored (Massee 1895; Chaudhuri 1931; Zang and Kinjo 1996), but subsequently they are reported as two- to four-spored (Teng 1939; Kobayasi 1941; Koval 1974; Xiao et al. 1983; Liang et al. 1995; Zang and Kinjo 1996; Kinjo and Zang 2001). It is possible that, at the initial stage, there are eight ascospore primordia in an ascus, and only two to four develop to maturity (Liang et al. 1995; Liu et al. 2003b).

Lohwag (1923), Xiao et al. (1983), Zang and Kinjo (1996), and Shrestha and Sung (2005) reported smaller ascus size (Table 3). As in perithecial size, Zang and Kinjo (1996) and Teng (1939) reported the longest ascus (Table 3), similar to Vassiljeva and Koval (1961), and Zhang et al. (1999). Chaudhuri (1931) reported the length of asci same as perithecia, which is very unnatural (Table 3). Also, he gave abnormally wide asci. Lohwag (1923) and Zang and Kinjo (1996) reported very thin asci, followed by Shrestha and Sung (2005) (Table 3). Although Xiao et al. (1983) gave short asci, its width is comparable to others (Table 3).

Ascus length is not a suitable character for identification of *Cordyceps* species, as asci are found in the same perithecia at different stages of development. Young asci tend to have their posterior end tapering into a long slender pedicel connected with the ascogenous cell. Young asci also possess narrow central canal connected with the capitule apex, as mentioned by Lohwag (1923).

Only Lohwag (1923), Kobayasi (1941) and Kinjo and Zang (2001) have described the size of the ascus cap (Table 3). The measurements do not differ widely. Lohwag (1923) and Kobayasi (1941) reported almost the same cap width, while Kinjo and Zang’s (2001) size is within that of Kobayasi (1941). Rehm (1904) described filiformis, hyaline, 1 μm wide paraphyses in perithecia and also mentioned that the spores disappeared in asci. It is highly probable that he mistook paraphyses for asci.

### Ascospores

Ascospores are hyaline, filiform, multisepitate and slightly tapering at both ends. Cooke (1884, 1892) described that the ascospores of *Ophiocordyceps* as fragmented in truncate joints, which was followed by Saccardo (1891), Zang et al. (1983), Kinjo and Zang (1998; Kinjo and Zang 2001). Massee (1895), however, correctly observed that the ascospores of *Ophiocordyceps* do not fragment into part-spores, which has been shown by many recent authors (Teng 1939; Kobayasi 1941; Zang and Kinjo 1998; Kinjo and Zang 2001).

Massee (1895) and Zang and Kinjo (1996) reported the shortest ascospores (Table 4). Although they examined Berkeley’s collection, there is a wide difference between the ascospore sizes. Probably, no single specimen was designated as a holotype, but rather there is more than one specimen in Berkeley’s collection, as in ascus width, Chaudhuri (1931) showed abnormally wide ascospores (Table 4). Teng (1939) reported the longest ascospore

### Table 2. Perithecial sizes recorded in *Ophiocordyceps sinensis*.

| Author             | Perithecial size (μm) |
|--------------------|-----------------------|
| Lohwag (1923)      | 200–300 × 140–170     |
| Chaudhuri (1931)   | 300–360 × 150–180     |
| Teng (1939)        | 350–550 × 140–240     |
| Kobayasi (1941)    | 400–430 × 200–290     |
| Vassiljeva and Koval (1961) | 500 × 200 |
| Xiao et al. (1983) | 400–520 × 180–280     |
| Zang and Kinjo (1996) | 150–380 (550) × 110–240 |
| Kinjo and Zang (2001) | 360–440 × 240–280 (~320), |
| Shrestha and Sung (2005) | 360–420 × 240–320 |
|                    | 330–370 × 170–270     |

### Table 3. Ascus sizes recorded in *Ophiocordyceps sinensis*.

| Author             | Ascus size (μm) | Cap size (μm) and shape |
|--------------------|-----------------|------------------------|
| Lohwag (1923)      | 190–200 × 6     | 8 wide                 |
| Chaudhuri (1931)   | 300–350 × 30–35 |                       |
| Teng (1939)        | 240–485 × 12–16 |                       |
| Kobayasi (1941)    | 220–280 × 11.5–13 | 3.5–7 long, 7.7–8 wide |
| Vassiljeva and Koval (1961) | 260–420 × 11.6–14.6 |
| Xiao et al. (1983) | 100–250 × 10–12 |                       |
| Zang and Kinjo (1996) | 160–240 (400) × 5.2–6.5 (12) |
| Zhang et al. (1999) | 220–420 × 11–15 |                       |
| Kinjo and Zang (2001) | 350–380 × 9.5–13, | 4.8–5.6, globose |
| Shrestha and Sung (2005) | 200–210 × 7–8 |                       |

### Table 4. Ascospore and septation sizes recorded in *Ophiocordyceps sinensis*.

| Author         | Ascospore size (μm) | Length between septa (μm) |
|----------------|---------------------|----------------------------|
| Massee (1895)  | 85–90 × 1.5         | 4                          |
| Lohwag (1923)  | 1.5 wide            | 4                          |
| Chaudhuri (1931)| 250–300 × 8–10    | 5                          |
| Teng (1939)    | 160–470 × 5–6.5     |                            |
| Kobayasi (1941)| 215–265 × 4–5      | 5–12                       |
| Vassiljeva and Koval (1961) | 180–350 × 5.8 |                       |
| Xiao et al. (1983) | 8–240 × 4–5.5    |                           |
| Zang et al. (1990) | 9–15               |                           |
| Liang et al. (1995) | 120–190 × 0.6–1.3 |                           |
| Zang and Kinjo (1996) | 200–320 × 4.6–6.4  |                           |
| Kinjo and Zang (2001) | 310–350 × 4–7, 51–93 irregularly septate | |

Note: *Probably, the ascospore length is 80–240 μm.*
length followed by Vassiljeva and Koval (1961), and Kinjo and Zang (2001).

Very few authors have reported the length between septa of each cell in ascospores. Massee (1895) and Lohwag (1923) showed the shortest length between septa, whereas Kobayasi (1941) and Liang et al. (1995) showed longer ones, ranging from 5 to 12 μm long (Table 4). Kinjo and Zang (2001) have indicated the shorter range of ascospores and smaller lengths between septa and, thus, their measurements do not represent the micromorphological characters of mature O. sinensis (Massee 1895; Rehm 1904; Lohwag 1923; Xiao et al. 1983; Zang and Kinjo 1996; Shrestha and Sung 2005). Ascus and ascospore length are particularly difficult to measure as they vary a lot depending upon the developmental stage. Ascospore length is more difficult to measure in the case of fragmenting ascospores, as they fragment very easily even upon slight press. Hence, in case of fragmenting ascospores, part-spore size, instead of whole ascospore length, can be used to distinguish between species, as pointed out by Ginns (1988).

Identification of O. sinensis based on asexual state and molecular study

The life cycle of O. sinensis consists of teleomorphic and anamorphic phases. The anamorph usually results from the culture of teleomorph. Given the importance of cultivation of O. sinensis, it is very essential that cultures are pure and homogenous. Over the last 30 years, many mycologists have cultured natural O. sinensis specimens and reported different asexual structures (Jiang and Yao 2002, 2003). Kobayasi (1981) first described Stachybotrys sp. as the asexual stage of O. sinensis in culture, using the specimens collected from Dolpa district of Nepal. From his figure and description, it seems that the identification was based on a fungal contaminant. Hirustella sinensis X.J. Liu, Y.L. Guo, Y.X. Yu & W. Zeng reported by Liu et al. (1989) has been accepted as the asexual stage of O. sinensis by many authors, based on the evidences of microcycle conidiation from ascospores and molecular studies (Zhao et al. 1999, 2006; Li et al. 2000; Liu et al. 2001, 2003a; Chen et al. 2001a,b, 2004; Zhang et al. 2002). Hirustella is one of the common anamorphic genera of Ophiocordyceps (Sung et al. 2007; Kurihara et al. 2009).

Chen et al. (1999) showed that C. crassispora M. Zang, D.R. Yang & C.D. Li is a different form of O. sinensis on the basis of RAPD markers. C. nepalensis M. Zang & N. Kinjo had the same ITS sequences as O. sinensis, while C. multiaxialis M. Zang & N. Kinjo had similar ITS sequences (Liu et al. 2001). Kinjo and Zang (2001) showed that C. gansuensis K. Zhang, C. Wang & M. Yan and C. crassispora might be the same species, assignable as O. sinensis, based on molecular phylogeny. Moreover, Jiang and Yao (2004) showed that C. gansuensis, C. crassispora, C. multiaxialis, C. nepalensis and O. sinensis share similar ITS sequences; hence, are the same species. RAPD and ITS analyses however, showed genetic variation among different populations of O. sinensis (Jiang and Yao 2004). However, 5.8S rDNA and ITS regions show that different populations of O. sinensis are related to each other (Jiang and Yao 2004). Kuo et al. (2005) even confused O. sinensis and C. pseudomilitaris Hywel-Jones & Sivichai as sharing the same patterns based on SSCP.

Recently, more molecular studies have been carried out to understand the diversity of O. sinensis (Liang et al. 2008; Zhang et al. 2009).

Hosts of O. sinensis

Identification of host is very important, especially in relation to the pathogenic organisms. It is very difficult to identify the hosts of entomopathogenic fungi for two reasons. Firstly, the host insects are mostly immature, such as larvae or pupae. Secondly, the fungal pathogens might have deformed the hosts’ shape, size and color. Fortunately, the latter is not so severe, as the fungus grows inside the host, with the external features almost intact.

Despite the notion that O. sinensis was a plant in the summer and an insect in the winter, Réamur (1726) showed that the worm was truly a larva, with nine lines and yellow in colour; the head, eyes, legs, belly and back all being very clear. However, he stated that the plant was added to the anal portion of the larva. Rennie (1835) reasoned that, due to lack of keen observation, the insect had been regarded as a part of the plant in olden times. He showed that the whole interior portion of the larva was filled with fungus and also explained the infection process of the caterpillar by O. sinensis. He truly pointed out that the fungus grew from the head. Pereira (1843) more accurately described that the “plant” grew from the back part of the neck (Cooke 1892).

Pereira (1854) first classified the host larva as a lepidopteran insect and reported that, according to Mr. Doubleday, the insect was a species of Agrotis. Later, Gray (1858) classified the insect as Gortyna belonging to the family Noctuidae. Soubeiran and Thiersant (1874) again identified the insect as Hepialus. After that, Lohwag (1923) ascribed the larva to Hepialus and Phassus of Hepialidae.

Different species of Hepialus, such as H. armoricanus, H. obliterus, H. biruensis, have been identified as hosts of O. sinensis (Chu 1965; Gao et al. 1992; Chen et al. 2002). Recent studies show that 50–70 species of moths, mostly Thitarodes (Hepialus) species and few Hepialiscus, Forkalus and Bipectilus species, are the hosts of O. sinensis (Li and Tsim 2004; Liu et al. 2005; Cheng et al. 2007).
Maczev et al. (2010) also recently identified two new species of *Thitarodes* (*Hepialus*) as host species of *O. sinensis* from Bhutan. Host larvae are infected from the middle of July to the end of August (Yang et al. 1989). The fourth and fifth instar larvae are most suitable for infection, while the larvae below the third instar are not suitable (Yang et al. 1989).

**Synonymy of *O. sinensis***

Different *O. sinensis*-like species were recently reported from alpine regions of China and Nepal, such as *C. gansuënsis* K. Zhang, C. Wang & M. Yan (Zhang et al. 1987, 1989), *C. crassispora* M. Zang, D.R. Yang & C.D. Li (Zang et al. 1990), and *C. kangdingensis* M. Zang & N. Kinjo, *C. multiaxialis* M. Zang & N. Kinjo and *C. nepalensis* M. Zang & N. Kinjo (Zang and Kinjo 1998). Sung et al. (2007) recognized them as distinct species and revised them as *O. gansuënsis* (K. Zhang, C. Wang & M. Yan) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, *O. crassispora* (M. Zang, D.R. Yang & C.D. Li) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, *O. kangdingensis* (M. Zang & N. Kinjo) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, *O. multiaxialis* (M. Zang & N. Kinjo) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora and *O. nepalensis* (M. Zang & N. Kinjo) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora. However, based on the cytological, morphological and molecular studies, *O. gansuënsis*, *C. crassispora*, *C. multiaxialis* and *O. nepalensis* have been recognized as conspecific with *O. sinensis* (Liang et al. 1995; Chen et al. 1999, 2004; Kang et al. 2000; Kinjo and Zang 2001; Liu et al. 2001, 2002, 2003b; Jiang and Yao 2004; Stensrud et al. 2007). Liang (2007), however, recognized *O. crassispora* as a distinct species. It is very interesting to note that the taxonomic status of *C. kangdingensis* remains largely unclear.

*Ophiocordyceps sinensis* (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57:47, 2007, is a fungus with a peculiar habitat from the alpine regions of the Tibetan plateau. This paper provides a comprehensive, historical understanding on the name, morphology and taxonomy of *O. sinensis*. However, the type specimens of *O. sinensis* of Berkeley (1843) are immature (Massic 1895; Zang and Kinjo 1996) and, hence, do not represent the morphological characters of mature specimens (Kang et al. 2000; McKenna et al. 2002). Kobayasi’s (1941) description and illustrations seem to be the most complete and detailed, and represent the salient features of *O. sinensis* (Tables 2–4). He described the morphological characters both in Latin and English; also many other recorded measurements fall within his range (Tables 2–4). However, to date, no epitype has been designated to replace the holotype of Berkeley (1843). Many *O. sinensis*-like species have been reported. Although many attempts have been conducted to establish the relationship between these species and *O. sinensis*, it is difficult to deal with this taxonomic problem until *O. sinensis* is epitypified. In addition, genetic diversity has been observed among different populations of *O. sinensis*; hence, it is necessary to evaluate the divergence and differentiation of *O. sinensis* among those populations at the species or infraspecies levels. The species circumscription of *O. sinensis* based on a new epitype is urgently required to answer the question as to what is the Chinese caterpillar fungus.

**Conclusions**

*O. sinensis* is a fungus with a peculiar habitat from the alpine regions of the Tibetan plateau. This paper provides a comprehensive, historical understanding on the name, morphology and taxonomy of *O. sinensis*. However, the type specimens of *O. sinensis* of Berkeley (1843) are immature (Massic 1895; Zang and Kinjo 1996) and, hence, do not represent the morphological characters of mature specimens (Kang et al. 2000; McKenna et al. 2002). Kobayasi’s (1941) description and illustrations seem to be the most complete and detailed, and represent the salient features of *O. sinensis* (Tables 2–4). He described the morphological characters both in Latin and English; also many other recorded measurements fall within his range (Tables 2–4). However, to date, no epitype has been designated to replace the holotype of Berkeley (1843). Many *O. sinensis*-like species have been reported. Although many attempts have been conducted to establish the relationship between these species and *O. sinensis*, it is difficult to deal with this taxonomic problem until *O. sinensis* is epitypified. In addition, genetic diversity has been observed among different populations of *O. sinensis*; hence, it is necessary to evaluate the divergence and differentiation of *O. sinensis* among those populations at the species or infraspecies levels. The species circumscription of *O. sinensis* based on a new epitype is urgently required to answer the question as to what is the Chinese caterpillar fungus.

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