

Diversity of *Cordyceps* Fungi in Nepal

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Abstract

Fungi are a part of the biodiversity that play a significant role in daily livelihood of the local communities. Yarsagumba (*Ophiocordyceps sinensis*) is one of the highly valued medicinal fungi that grow in the Tibetan Plateau of China and alpine grasslands of Nepal, Bhutan and India. Genus *Cordyceps* was recently revised and divided into four genera: *Cordyceps*, *Elaphocordyceps*, *Metacordyceps* and *Ophiocordyceps*, based on molecular phylogeny and morphology. The recent revision has consequently changed the scientific name of Yarsa gumba from *Cordyceps sinensis* (Berk.) Sacc. to *Ophiocordyceps sinensis* (Berk.) Sung *et al.* In Nepal, scientific study of *Cordyceps* species started about 60 years ago. During last 30 years, different *Cordyceps* species have been reported from Nepal. In this paper, *Cordyceps* species reported from Nepal have been discussed along with their synonyms, morphological characters, hosts and distributions in the global context.

Key words: *Cordyceps*, *Elaphocordyceps*, *Metacordyceps*, *Ophiocordyceps*, Yarsagumba

Introduction

More than 500 *Cordyceps* species have been reported in the world (<http://www.indexfungorum.org/Names/Names.asp>). *Cordyceps* species are regarded as medicinal fungi in the oriental societies of Asia including Nepal. Recently, Sung *et al.* (2007) revised the megagenus *Cordyceps* and separated it into 4 genera, namely, *Cordyceps* (fam. Cordycipitaceae), *Elaphocordyceps* and *Ophiocordyceps* (fam. Ophiocordycipitaceae) and *Metacordyceps* (fam. Clavicipitaceae) in the Order Hypocreales of Phylum Ascomycota of the Kingdom Fungi, based on molecular phylogeny. *Ophiocordyceps sinensis* (Berk.) Sung *et al.* (syn. *Cordyceps sinensis* (Berk.) Sacc.), popularly known as Yarsagumba in Nepal, is one of the most regarded medicinal fungi. Atreya Samhita has mentioned it as Bhu-Sanjibani that cures severe and incurable kidney and syphilis diseases (Shrestha 2010b,c, 2011, Shrestha *et al.* 2010). Chinese literatures have also mentioned different medicinal values of *O. sinensis* since last two thousand years and have

officially included it in Chinese pharmacopeia (Jones 1997, Zhu *et al.* 1998, Halpern 1999, Mizuno 1999, Li & Tsim 2004, Holliday *et al.* 2005, Li *et al.* 2006, Winkler 2008). It is popularly known as an aphrodisiac herb in folk herbal medicine in Nepal (Sacherer 1979, Bhattarai 1993). *O. sinensis* is naturally distributed in the northern alpine grasslands of Nepal, Bhutan and India and in Tibetan Plateau of China, ranging from 3000 to 5000 m above sea level (Balfour-Browne 1955, DMP 1970, Sacherer 1979, Kobayasi 1980, 1981, Otani 1982, Shrestha 1985, Adhikari & Durrieu 1996, DPR 1997, Chen *et al.* 1999, 2004, Mizuno 1999, Adhikari 2000, 2008, Kinjo & Zang 2001, Liu *et al.* 2001, Winkler 2004, 2010, Chhetri 2005, Holliday *et al.* 2005, Shrestha & Sung 2005, Canney 2006, Devkota 2006, 2008a,b, 2009, Li *et al.* 2006, Halpern 2007, Amatya 2008, Chhetri & Lodhiyal 2008, Shrestha *et al.* 2010, Singh *et al.* 2010, Weckerle *et al.* 2010). Besides *O. sinensis*, different *Cordyceps* species have been reported in Nepal during last 30 years. The reported *Cordyceps* species are described below.

I) FAMILY *Clavicipitaceae* (Lindau) Earle ex Rogerson, emend. Sung *et al.*, Stud. Mycol. 57:27, 2007.

1) *Metacordyceps liangshanensis* (Zang *et al.*) Sung *et al.*, Stud. Mycol. 57:35, 2007. (Fig. 1)

≡ *C. liangshanensis* Zang *et al.*, Acta Bot. Yunnanica 4:174, 1982.

Morphological characters: Stromata solitary or branched, light to dark brown, arising from the thorax of the host, 55~75 × 1.5~2.5 mm; head slightly wider than the stipe; perithecia semi-immersed, ellipsoid, ovoid or oval.

Host: Lepidopteran larvae, vertically buried in the soil.

Distribution: China (Zang *et al.* 1982) and Nepal (Shrestha & Sung 2005, Adhikari 2008). *M. liangshanensis* described in Nepal differs from Chinese specimens in stromata length and other micro-morphological characters (Zang *et al.* 1982, Shrestha & Sung 2005, Adhikari 2008). Hence, further studies are required to verify the specimens collected in Nepal.

II) FAMILY *Cordycipitaceae* Kreisel ex Sung *et al.*, Stud. Mycol. 57:48, 2007.

2) *Cordyceps coccinea* Penz. and Sacc., Malpighia 11:524, 1897. (Fig. 2)

Morphological characters: Stromata gregarious, filiform, dark red, 4~35 × 0.3~0.5 mm; head wider than stipe, lanceolate, fusiform, cylindrical or clavate in shape, granular on the surface due to prominent perithecial ostiole; perithecia immersed to superficial, compact, ovoid or conic.

Hosts: Coleopterous grubs, lepidopterous larvae and chrysalides pupae. The chitinous covering of the host is somewhat black. The host is subterranean.

Distribution: Indonesia (Penzig & Saccardo 1897), Sri Lanka (Petch 1924), Japan (Kobayasi 1941), Congo (Moureau 1949) and Nepal (Tanda & Nagase 1994). Morphologically, this species is very similar to *C. pruinosa* (Teng 1936).

3) *C. ishikariensis* Kobayasi and Shimizu, Color Icon. Veg. Wasps Pl. Worms Pp. 176, 1994. (Fig. 3)

Morphological characters: Stromata gregarious, brown-yellow, arising from the thorax of the host, 45~65 1.5~2 mm; head continuous with the stipe and slightly broader than it; perithecia semi-immersed, ovoid to broadly ovoid.

Host: Cicada nymphs, vertically buried in soil.

Distribution: Japan (Shimizu 1994) and Nepal (Shrestha & Sung 2005). This species was described only in Japanese and has not yet been accompanied by Latin description. Hence, Latin description is necessary to validate its taxonomic status.

4) *C. militaris* (L.: Fr.) Link, Hand. Gew. 3:347, 1833. (Fig. 4)

Morphological characters: Stromata solitary or gregarious, yellow to orange, 20~110 × 1~6 mm; head continuous with the stipe, but wider than it, cylindrical or slightly spherical; perithecia immersed to semi-immersed, ovoid or flask-shaped.

Hosts: Lepidopteran, coleopteran, hymenoptera and dipteran larvae and pupae, horizontally buried in soil.

Distribution: Worldwide distribution. It was described from Kathmandu Valley of Nepal by Shrestha & Sung (2005). It is the type species of genus *Cordyceps* (Kobayasi 1941, Sung *et al.* 2007). This species has been successfully grown in artificial media.

5) *C. martialis* Speg., Bol. Acad. Nac. Ci. Córdoba 11:535, 1889. (Fig. 5)

Morphological characters: Stromata solitary or gregarious, sometimes branched, brownish orange, 35~65 × 1~3 mm; head broader than the stipe, rough and dotted due to the ostioles of the perithecia; perithecia obliquely immersed, ovoid or flask-shaped with long neck.

Host: Coleopteran grubs, horizontally buried in soil.

Distribution: Brazil (Spegazzini 1889), Trinidad (Petch 1933), China (Teng 1934), North America (Mains 1958), Russia (Koval 1974), Japan (Kobayasi & Shimizu 1982), Korea (Sung 1996) and Nepal (Shrestha & Sung 2005).

6) *C. pruinosa* Petch, *Trans. Brit. Mycol. Soc.* **10:38, 1924.** (Fig. 6)

Morphological characters: Stromata gregarious, bright red, 15~40 × 0.5~1.5 mm; head continuous with the stipe but broader than it, rough due to ostioles of perithecia; perithecia superficial

Host: Lepidopteran pupae, buried in soil.

Distribution: Sri Lanka (Petch 1924), China (Teng 1936), Japan (Kobayasi 1941), Congo (Moureau 1961), Russia

(Koval 1974), Korea (Sung 1996), Mexico (Guzman *et al.* 2001) and Nepal (Shrestha & Sung 2005, Adhikari 2008). This species is very similar to *C. coccinea* (Teng 1936). It is locally known as Aalu Chhyau in Nepal.

III) FAMILY Ophiocordycipitaceae Sung *et al.*, Stud. Mycol. **57:35, 2007.**

7) *Ophiocordyceps formicarum* (Kobayasi) Sung *et al.*, *Stud. Mycol.* **57:43, 2007.** (Fig. 7)

≡ *C. formicarum* Kobayasi, *Bull. Biogeogr. Soc. Japan* **9:286, 1939.**

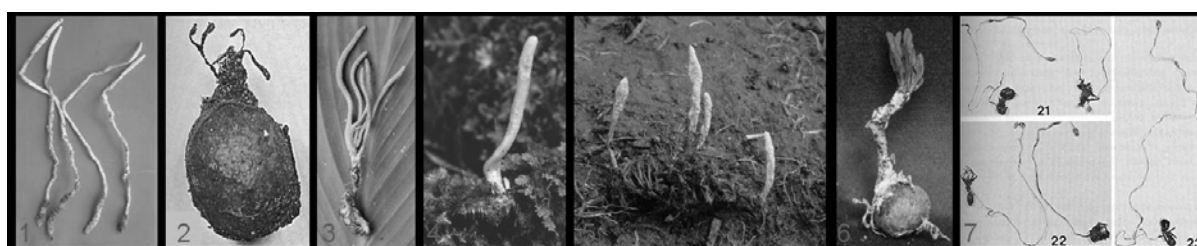


Fig. 1. *Metacordyceps liangshanensis*. Fig. 2. *Cordyceps coccinea*. Fig. 3. *Cordyceps ishikariensis*. Fig. 4. *Cordyceps militaris*. Fig. 5. *Cordyceps martialis*. Fig. 6. *Cordyceps pruinosa*. Fig. 7. *Ophiocordyceps formicarum*. (Sources: Figs. 1, 3, 4, 5 and 6 from Shrestha & Sung 2005; Figs. 2 and 7 from Tanda & Nagase 1994).

Morphological characters: Stromata solitary, filiform arising from abdomen and thorax of the host, 30~90 × 0.2~0.3 mm; head distinct, ovate or fusiform, 1.4~2.1 × 0.8~1.4 mm; perithecia obliquely immersed.

Host: Hymenopteran adults (ants), covered by decaying leaves or attached to them.

Distribution: Japan (Kobayasi 1939), Nepal (Tanda & Nagase 1994), Korea (Sung 1996) and China (Li *et al.* 2002).

8) *O. gracilis* (Grev.) Sung *et al.*, *Stud. Mycol.* **57:43, 2007.** (Fig. 8)

≡ *Xylaria gracilis* Grev., *Scot. Crypt. Fl.* **2. t. 86, 1824.**

≡ *C. gracilis* (Grev.) Durieu and Mont., *Fl. Algérie Crypt.* **1:449, 1846.**

Morphological characters: Stromata solitary, occasionally two, stout, creamy white, smooth, arising from thorax, 30~60 × 1~3 mm; head distinct, ovoid to subglobose, pinkish or brown-colored, punctate with ostioles of perithecia, 3~6 × 3~4 mm; perithecia completely immersed.

Host: Lepidopteran larvae, horizontally or vertically buried in soil.

Distribution: United Kingdom (Greville 1824), Algeria (Durieu 1846), France (Montagne 1856), North America (Ellis & Everhart 1892), Brazil (Möller 1901), Australia (Lloyd 1915), China (Teng 1934), Czech (Fassatiová 1954), Korea (Sung 1996), Nepal (Shrestha & Sung 2005) and Slovakia (Kautman & Kautmanová 2009).

9) *O. kangdingensis* (M. Zang and N. Kinjo) Sung *et al.*, *Stud. Mycol.* **57:44, 2007.**

≡ *C. kangdingensis* M. Zang and N. Kinjo, *Mycotaxon* **66:221, 1998.**

Morphological characters: Stromata solitary, simple, clavate, purplish brown to dark violet, arising from the thorax of the host, 62~75 × 2~4 mm; head abruptly enlarged from stipe with a sterile tip, rough or punctate with ostioles of perithecia; perithecia globoid or ovoid, almost immersed.

Host: larvae of *Thitarodes* spp., vertically buried in soil.

Distribution: China (Zang & Kinjo 1998) and Nepal (Adhikari 2008). These species resemble to *O. sinensis*, but differ in micromorphological characters (Zang & Kinjo 1998).

10) *O. multiaxialis* (M. Zang and N. Kinjo) Sung et al., Stud. Mycol. 57:45, 2007.

≡ *C. multiaxialis* M. Zang and N. Kinjo, Mycotaxon 66:224, 1998.

Morphological characters: Stromata clavate, in cluster from two to four, purplish brown to dark brown, arising from thorax of host, 4~52 × 1.5~3 mm; head abruptly enlarged from the stipe with a sterile tip, long cylindrical, slender, punctate with ostioles of perithecia; perithecia globoid, slightly projecting.

Host: larvae of *Thitarodes* spp., vertically buried in soil.

Distribution: China (Zang & Kinjo 1998) and Nepal (Adhikari 2008). It has some resemblance with *O. kangdingensis* in color and host, but differ from the latter in micromorphological characters (Zang & Kinjo 1998).

11) *O. nepalensis* (M. Zang and Kinjo) Sung et al., Stud. Mycol. 57:45, 2007. (Fig. 9)

≡ *C. nepalensis* M. Zang and N. Kinjo, Mycotaxon 66:224, 1998.

Morphological characters: Stromata solitary, simple, clavate with a sterile tip, purplish brown to dark brown, arising from the thorax of the host, 41~45 × 2~5 mm; head gradually enlarged from stipe, almost smooth; perithecia globoid or ovoid, immersed.

Host: larvae of *Hepialus nebulosus*, vertically buried in soil.

Distribution: Endemic to Nepal (Zang & Kinjo 1998, Adhikari 2008). It resembles with *O. sinensis* in color and is often misidentified, but differs from the latter in micromorphological characters (Zang & Kinjo 1998).

12) *O. nutans* (Pat.) Sung et al., Stud. Mycol. 57:45, 2007. (Fig. 10)

≡ *C. nutans* Pat., Bull. Soc. Mycol. France 3:127, 1887.

Morphological characters: Stromata solitary to few, filiform, erect or somewhat curved, pallid, mainly arising from the thorax region of the host, black except orange yellow or reddish head, glabrous, 50~100 × 0.8~1.5 mm; head distinct, pod-like structure, fusiform or clavate, punctate with ostioles of perithecia; perithecia obliquely immersed with a long neck.

Host: Adults of hemipteran bugs, covered by decaying leaves and sometimes piercing through them.

Distribution: Japan (Patouillard 1887), New Guinea (Sydow 1922), China (Teng 1934), Congo (Moureau 1949), Korea (Lim & Kim 1973), Russia (Koval 1974) and Nepal (Otani 1982, Shrestha 1985, Tanda & Nagase 1994, Shrestha & Sung 2005).

13) *O. sinensis* (Berk.) Sung et al., 57:46, 2007. (Fig. 11)

≡ *Sphaeria sinensis* Berk., J. Bot. (Hooker) 2:207, 1843.

≡ *C. sinensis* (Berk.) Sacc., Michelia 1:320, 1878.

Morphological characters: Stromata solitary, rarely branched, dark brown to black, arising from the prothorax of the host, 40~100 × 2~5 mm; head continuous with the stipe with acuminate sterile tip, broader than stipe, punctate to rough due to ostioles of perithecia; perithecia semi-immersed

Hosts: Larvae of *Thitarodes* (*Hepialus*) spp., *Hepialiscus* spp., *Forkalus* spp., *Bipectilus* spp., usually vertically buried in soil.

Distribution: Endemic to Tibetan Plateau and alpine grasslands of China, Nepal, Bhutan and India ranging from 3000 to 5000 m above sea level. Its historical records, geographical distributions, morphological variations and taxonomic complexities especially in light of discovery of similar species such as *O. crassispora*, *O. gansuensis*, *O. kangdingensis*, *O. multiaxialis* and *O. nepalensis* have been recently reviewed (Shrestha et al. 2010). Many recent authors have opined that they are not distinct species; rather they are conspecific with *O. sinensis* and can be treated as its subspecies or forms or clades (Shrestha et al. 2010).

14) *O. sphecocephala* (Klotzsch ex Berk.) Sung et al. 57:47, 2007. (Fig. 12)

≡ *Sphaeria sphaecocephala* Klotzsch ex Berk., J. Bot. (Hooker) 2:206, 1843.

≡ *C. sphaecocephala* (Klotzsch ex Berk.) Berk. and M.A. Curtis, J. Linn. Soc. Bot. 10:376, 1869.

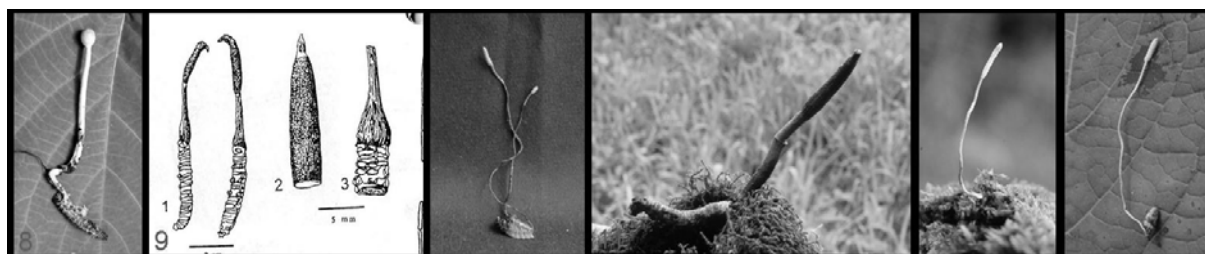
Morphological characters: Stromata solitary or rarely two, filiform, arising from thorax to abdomen region of the host, erect or curved, pale-yellow to brownish-yellow, glabrous, 14~70 × 0.5~1 mm; head distinct, abruptly enlarged from stipe, cylindrical or fusiform or spherical; perithecium obliquely immersed with long neck.

Host: Adult wasps, covered by decaying leaves and sometimes attached to them.

Distribution: Cuba (Torrubia 1754), West Indies (Edwards 1764), Jamaica (Berkeley 1843), St. Vincents (Berkeley 1843), Guadeloupe (Tulasne & Tulasne 1865), Argentina (Spegazzini 1881), Japan (Miyoshi 1888), Indonesia (Penzig & Saccardo 1897), Brazil (Mçller 1901), North America (Seaver 1910), Guyana (Petch 1934), China (Teng 1934), Britain (Petch 1938), Czech (Šmarda 1941), Congo (Moureau 1949), India (Sen 1949), Korea (Lim & Kim 1973), Russia (Koval 1974), Nepal (Tanda & Nagase 1994, Shrestha & Sung 2005) and Slovakia (Kautman & Kautmanová 2009).

15) *O. tricentri* (Yasuda) Sung *et al.*, 57:47, 2007. (Fig. 13)

≡ *C. tricentri* Yasuda in Lloyd, Mycol. Writ. 4:568, 1916.



Figs. 8. *Ophiocordyceps gracilis*. **Fig. 9.** *Ophiocordyceps nepalensis*. **Fig. 10.** *Ophiocordyceps nutans*. **Fig. 11.** *Ophiocordyceps sinensis*. **Fig. 12.** *Ophiocordyceps sphaecocephala*. **Fig. 13.** *Ophiocordyceps tricentri*. (Sources: Figs. 8, 10, 11, 12 and 13 from Shrestha & Sung 2005; Fig. 9 from Zang & Kinjo 1998).

Morphological characters: Stromata solitary, yellow, filiform, erect or curved, glabrous, arising from thorax region of the host, 35~50 × 0.25~0.3 mm; head distinct, cylindrical, fusiform or spherical; perithecia obliquely immersed.

Host: Adults of *Aphrophora* spp., covered by decaying leaves and sometimes attached to them, very easy to loose the host during collection due to its tiny size.

Distribution: Japan (Lloyd 1916), China (Teng 1934), Korea (Lim & Kim 1973) and Nepal (Shrestha & Sung 2005). It resembles pretty well with *O. sphaecocephala* except the host.

Besides *Cordyceps* species, many other entomopathogenic fungi such as *Beauveria* spp., *Hirsutella* spp. and *Isaria* (*Paecilomyces*) spp. such as *I. cicadae* and *I. japonica* have been recorded in Nepal (Kobayasi 1965, Otani 1982, Mizuno 1999, Tanda & Nagase 1994, Shrestha & Sung 2005, Shrestha 2010a). The results described above show the richness of valuable entomopathogenic fungi in Nepal, mainly due to its diverse unique eco-geographical regions.

To date, 15 *Cordyceps* spp., recently classified as *Cordyceps* (5 spp.), *Metacordyceps* (1 sp.) and *Ophiocordyceps* (9 spp.), have been reported from Nepal. However, further collections are required to explore the hidden diversity of *Cordyceps* species. Nature conservation is of utmost importance to preserve *Cordyceps* species that depend upon living insects to complete their life cycle. Green Energy Mission/Nepal (GEM/Nepal), a non-profit research and development-oriented non-governmental organization, has been involved in scientific studies and public awareness of *Cordyceps* fungi and their medicinal values in Nepal.

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