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ENTOMOGENOUS CORDYCEPS AND RELATED GENERA FROM MEXICO WITH DISCUSSIONS ON THEIR HOSTS AND NEW RECORDS

by

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Abstract

Fifteen species of *Cordyceps* (Ascomycotina, Hypocreales, Clavicipitaceae) and related genera and their anamorphs parasitic on insects have been recorded from Mexico, of which *Cordyceps dipterigena* (from the State of Veracruz in a subtropical humid forest on flies of the genus *Eucalliphora*) and *C. pruinosa* (from Quintana Roo in a tropical rain forest on an unknown host) are first reported for the country. *Cordyceps militaris* presents the broadest distribution in the country. The confusion between *C. gracilis* and *C. entomorrhiza* is discussed. *Cordyceps melolonthae* var. *rickii* only previously known from Chiapas, is now reported from two new localities in Chiapas, and from the States of Oaxaca and Veracruz; in Oaxaca and Chiapas on larvae of *Enema endymion*, and in Veracruz on larvae of *Strategus aloeus* (both Coleoptera, Melolonthidae, subfam. Dynastinae, tribus Oryctini).

Key words: *Cordyceps dipterigena, C. pruinosa, C. melolonthae* var. *rickii*

Introduction

The first reports of fungi parasitic on insects in Mexico are from the XIX century (Urbina, 1881, and Sánchez, 1886). They described an "animal-planta" (animal-plant) as something rare in nature. Urbina's paper (1881) was a comment in a note from Milne-Edwards about *Sphaeria* (*Torrubia*) *sobolifera* (a synonym of *Cordyceps sobolifera*, see Table 1) growing on larvae of *Cicada* (Homoptera). Sánchez (1886) discussed about the "tlalomites", an indian name for insect larvae eaten by the Aztecs parasited by fungi. The fungus reported by Sánchez (1886) was identified by Pérez-Silva (1979) as *Isaria cosmopsaltria*. However, since both fungi illustrated by Sánchez (1886) and Pérez-Silva (1979) are infecting a scarab adult (Coleoptera), and not a tlalomite, then it seems that *I. cosmopsaltria* is an independent fungus of tlalomite larvae. Petch (1933-1934) commented in the discussion of *Cordyceps sobolifera* that the numerous specimens of *Isaria sinclairii* (the anamorph of *Cordyceps sobolifera*) from Mexico at the British Museum are known locally as "chicharra" or "animal-planta". Obviously, there is a mistake in the information, since "chicharra" is the common name of the cicadas. Probably these Mexican specimens were sent to England by Urbina according to his report (Urbina, 1881). Modern reports on *Cordyceps* from Mexico and related genera and its anamorphs are those of Pérez-Silva (1977, 1978, 1979), Blackwell and Gilbertson (1981, 1984), Ulloa and Benavides (1991), Rodríguez *et al.* (1993) and Rubio-Bustos *et al.* (1999). In this paper a bibliography and herbarium revision of the Mexican species of the group is presented. *Cordyceps melolonthae* var. *rickii* is first recorded from Oaxaca and Veracruz, and from two new localities in Chiapas, and two species of *Cordyceps* are reported as new from Mexico.

Materials and methods

The specimens studied were observed by light microscopy with the fungi mounted in KOH 5% and in Congo Red. The majority of the herbarium material is in XAL as dried specimens, but two specimens are in alcohol in the Entomological Collection of the Institute of Ecology (IE) at Xalapa, Veracruz.

The known entomogenous *Cordyceps* and related genera including their anamorph stages from Mexico

According to revisions of ascomycetes from Mexico (Chacón and Guzmán, 1983, García-Romero *et al.*, 1970, Medel *et al.*, 1999), and the reports of Blackwell & Gilbertson (1981, 1984), Díaz-Barriga *et al.* (1988), Duges (1924), Guzmán (1977), Mains (1951, 1955, 1958, 1959), Pérez-Silva (1977, 1978, 1979), Rodríguez *et al.* (1993), Rubio-Bustos *et al.* (1999) and Ulloa and Benavides (1991), there are fifteen species of *Cordyceps* and related genera and its anamorph stages in Mexico. These latter belong to the genera *Aschersonia, Cordycepioideus, Hirsutella, Hymenostilbe, Isaria, Paecilomyces* and *Paraisaria* (Table 1). The oldest references are those of Urbina (1881), Sánchez (1886) and Petch (1933-1934) as previously discussed.

Of the known entomogenous *Cordyceps* species, *C. militaris,* distinguished by its cylindric and orange-red stromata with a finely roughened surface at the apex, as was observed in several specimens at XAL and IBUG (Fig. 11), has the broadest distribution through ten states of the country (Chiapas, Hidalgo, Jalisco, Michoacán, Morelos, Nuevo León, Oaxaca, Sinaloa, State of Mexico and Veracruz) (see Table 1). However, *C. sobolifera*, only known from Coahuila, Guanajuato and Jalisco, is the species most

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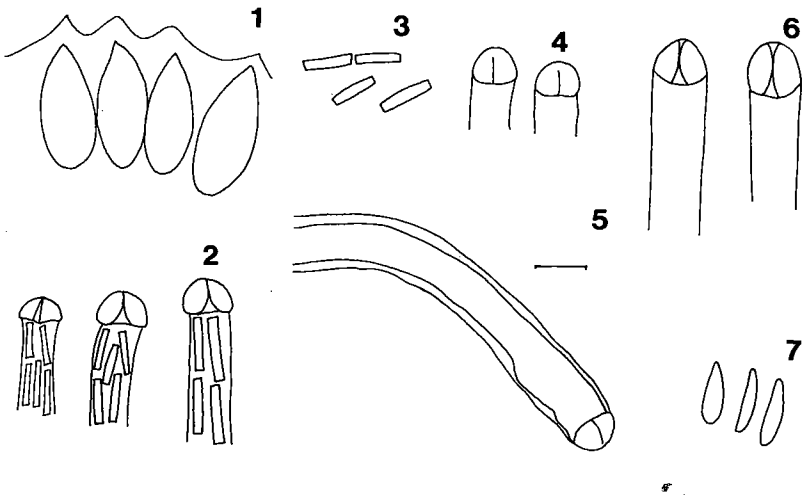
recorded, in nine references as against seven for *C. militaris*. *Cordyceps entomorrhiza* in Mexico was only reported from the State of Veracruz (Pérez-Silva, 1978; Chacón & Guzmán, 1983, 1995; Chacón *et al.*, 1995; Rubio-Bustos *et al.*, 1999). This species is very close to *C. gracilis* (Fig. 12), with which it has been confused previously as pointed out



Figs. 1-7.- *Cordyceps melolonthae* var. *rickii* and *Cordyceps dipterigena*. 1-5: *C. melolonthae* var. *rickii*, 1: Perithecia, 2:Asci, 3: Secundary ascospores, 4: Caps of the asci, 5: An asci without ascospores. 6-7: *C. dipterigena*, 6: Caps of the asci, 7: Secundary ascospores (1-5: *Wolf 2559-1*; 5: *Robles*; 6-7: *Ramírez-Guillén 15*). Scale bar: 1= 160 µm; 2-7 = 6 µm.

by Petch (1933-1934), Mains (1951) and Brady (1984). *Cordyceps gracilis* according to Mains (1951, 1958), Eckblad (1967), Smith & Smith (1973), Dennis (1978), Brady (1984), Allard (1998) and Zang & Kinjo (1998), has globose red, orange or ochraceous heads, with numerous dark perithecial ostioles on the surface. The perithecia are completely embedded, and the stipe is yellow or yellowish, in contrast to *C. entomorrhiza* which has globose light vinaceous drab, violaceous gray or brown grayish heads, with a verrucose surface due to the projecting perithecia; the stipe being pallid brownish above to deep brown below. *Cordyceps gracilis* is most common on larvae of Lepidoptera and probably restricted to this order, while *C. entomorrhiza* is probably specific to beetle larvae.
Revising the collections of "*C. entomorrhiza*" at XAL, including those reported by Chacón and Guzmán (1983, 1995), Chacón *et al.* (1995) and Rubio-Bustos *et al.* (1999), all of them from Veracruz agree well with the concept of *C. gracilis* as discussed above. The material of *C. entomorrhiza* reported by Pérez-Silva (1978) and illustrated (Fig. 2, page 20) cleary belongs to *C. entomorrhiza*, but she described dark red heads and a brownish stipe for the stromata, which is more typical of *C. gracilis*. Rubio-Bustos *et al.* (1999) considered *C. entomorrhiza* to have brownish-orange or reddish heads, and a brownish stipe. They based their descriptions on the collections at XAL. *Cordyceps gracilis* reported by Rubio-Bustos *et al.* (1999) from Jalisco was based on the specimens: *Álvarez 45, Brown 182, Gutiérrez-Torres 14, Guzmán-Dávalos 4857* and *Vázquez 127*, which were studied in present work; these agree well with the species concept. It is concluded that *C. entomorrhiza* has been confused with *C. gracilis* in Mexico but that *C. gracilis* is a common entomogenous fungus on Lepidoptera, known from Veracruz and Jalisco. It is recorded here from three new localities in Veracruz, based on the XAL specimens: 1) Xico Municipio, Cofre de Perote Region, Los Gallos, *Bandala 661*; 2) Banderilla Municipio, Cerro La Martinica, *Guzmán 12458*; and 3) Xalapa Municipio, Rio Coapexpan, *Bandala 1357*. The anamorph of *C. gracilis* according to Brady (1984) is *Paraisaria dubia* (Table 1). It is interesting to observe that of the known localities of *C. gracilis* in Veracruz, the Botanical Garden at IE, presents the highest number of specimens. Chacón and Guzmán (1995) reported 57 collections between 1987 and 1990. Of the 10 species of fungi studied by Chacón and Guzmán (1995) in the Botanical Garden, "*Cordyceps entomorrhiza*" was the most common (57 collections again 31-49 the others). From 1991 to the present, however, only a few records of *C. gracilis* have been found, in spite of the frequent mycological explorations in this locality. Allard (1998) found in France a new record of *C. gracilis* after 30 years of the last in the same place.

There is another species of *Cordyceps* recorded in the Botanical Garden at Xalapa, this is *C. dipterigena* (Table 1), a new record for Mexico. This fungus is parasitic on flies probably of the genus *Eucalliphora* (Diptera, Calliphoridae), which are parasites of larvae of Lepidoptera. The stromata are cinnamon orange or cinnamon brown, with the heads around 1-2.5 mm wide, hemisphaerical or subgloboid. The asci are delicate, hyaline, more than 320 µm long, by 6-10 µm wide, with prominent hyaline caps, 5-7 x 6-6.5 µm. The ascospores are filiform, multiseptate, breaking up into cylindrical or fusiform-elliptical fragments, hyaline, 6-8 x 1-1.5 µm (Figs. 6-7 & 14-16). Conidial stage not observed. Mains (1958) and Brady (1979) reported *C. dipterigena* from Eastern U.S.A., Costa Rica, Panama, British Guiana, Brazil, Puerto Rico, Trinidad, Sri Lanka, Indonesia, New Guinea, Japan and Ghana. The anamorph of *C. dipterigena* according to Brady (1979) is *Hymenostilbe dipterigena* (Table 1).

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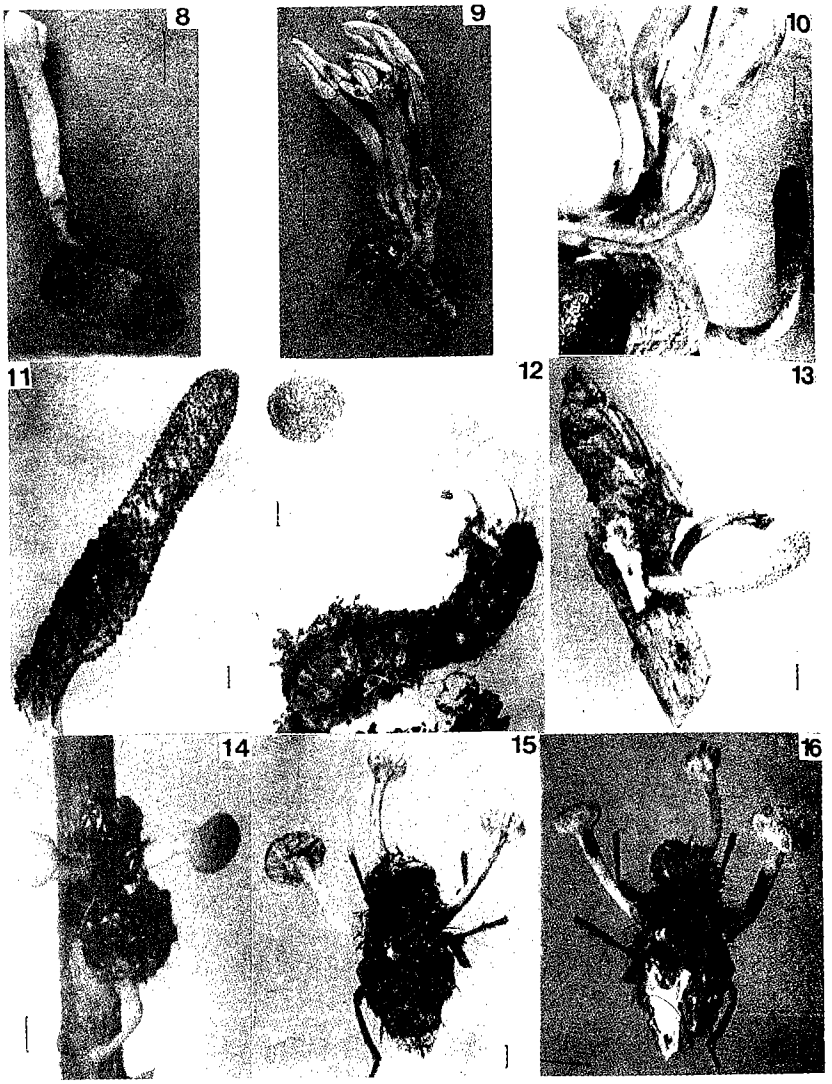
Another new record of a *Cordyceps* from Mexico, is *C. pruinosa* (Table 1), collected in Quintana Roo and deposited in XAL Herbarium (identified by Evans in 1990). The species was previously only known from Asia (Sri Lanka and Japan) and Africa (Congo, today know as Ruanda) (Moureau, 1961) (Table 1). The host of the Mexican specimen is unknown. This species has reddish and roughened stromata (Fig. 13).

New records of *Cordyceps melolonthae* var. *rickii* in Chiapas, Oaxaca and Veracruz

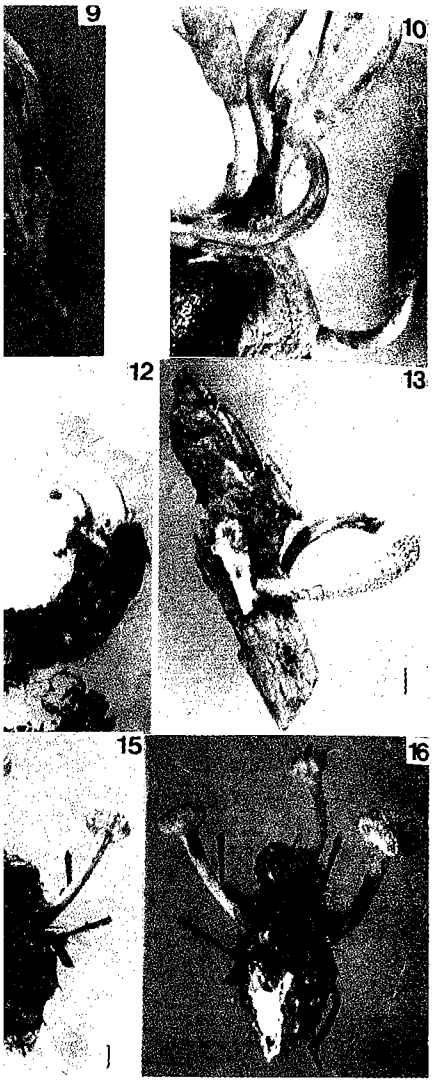
Figs. 1-5 & 8-10

Cordyceps melolonthae var. *rickii* was thus far known in Mexico only from two collections at Tuxtla Gutiérrez, Chiapas (Pérez-Silva, 1977) (at MEXU and at P). They were found on unidentified Coleoptera larvae (Melolonthidae). We are reporting here four new localities from Chiapas, Oaxaca and Veracruz. The specimens studied agree well with Pérez-Silva (1977) and Mains (1958). The latter reported the fungus from Nicaragua, Brazil, Guyana and probably from Ecuador. The var. *melolonthae* ocurrs only in the U.S.A. on *Phyllophaga* larvae (Mains, 1958). Evans *et al.* (1999) discussed the fungi parasitic on *Cochliotus melolonthoides* (Gerst.) a Scarabaeidae from Tanzania, misidentified in Sri Lanka as *Cordyceps melolonthae*. They identified the fungus as *Cordyceps barnesii* Thw. These authors following Mains (1958), concluded that *C. melolonthae* is confined to America, of which var. *melolonthae* occurs only on *Phyllophaga* spp. in the U.S.A. and the var. *rickii* on lamellicorn beetles in tropical North and South America. Mains (1957) first considered *C. rickii* as an independent species, and separated it from *C. melolonthae* by the perithecial layer, which completely covers the upper portion of the stroma in the former, in contrast with the latter, where the perithecial layer develops as irregular patches. Evans *et al.* (1999) illustrated *C. melolonthae* var. *rickii* on a melolonthid larvae buried in forest soil in Amazonian Ecuador, that agrees well with the specimens studied here. Lloyd (1920) described *C. rickii* Lloyd from Brazil, based on a collection by Rick, "growing from the head of some larva", with subcylindric or globose stromata, about 20 mm long, yellow, but with the added observation that they were probably orange when fresh. According to Evans *et al.* (1999), one of the differences between *C. barnesii* and *C. melolonthae* var. *rickii* is the color of the stroma, drab orange to ginger-brown in the former and conspicous sulphur-yellow to yellow-brown in the latter. In addition, the part-spores are larger in *C. barnesii*, 9.4 x 2 µm, and only 4.8 x 1.5 µm in *C. melolonthae* (Evans *et al.*, 1999). Mains (1958) described the 1-celled fragment spores, 4-8 x 1-1.5 µm and the stromata 30-130 x 5-15 mm.

In the dried material, the stromata are 20-58 x 2-5 mm, subcylindric, sulphur-yellow to yellowish-brownish, perithecia brown reddish and stipe pale yellowish, 1-1.5 mm wide, occurring solitary or more commonly gregarious. Perithecia 350-450 x 120-200 µm, yellowish, embedded except for the apices, ovoid with acute apex. Asci 200-220 x 5-5.5 µm, cylindric, with globose caps, 5-6 µm diam. Ascospores filiform, multiseptate, breaking into secondary spores, 1-celled fragments, (4.5-) 5-7 (-8) (-10.5) x 1-1.5 (-2) µm, pale olivaceous and thin walled. The microscopic features were observed in the specimens from Oaxaca. The specimen from Veracruz is immature, without asci, and the specimen from Chiapas is conserved in alcohol and has empty asci.



Figs. 8-16.- *Cordyceps melolonthae* var. *rickii*, *C. militaris*, *C. gracilis*, *C. pruinosa*, and *C. dipterigena*. 8-10: *C. melolonthae* var. *rickii*. 8 & 10: Stroma on a larva of *Enema endymion*, 9: Stroma on a larva of *Strategus aloeus*. 11: *C. militaris*, head of the stroma. 12: *C. gracilis*, a stroma on a larva of Lepidoptera. 13: *C. pruinosa*, a stroma growing on a unknown host within wood. 14-16: *C. dipterigena*, three stromata on flies of the genus *Eucalliphora* (8: *Robles s.n.*; 9: *Chacón 4001*; 10: Wolf 2259-1; 11: *Villarreal, s.n.*. IBUG 815; 12: *Brown 182*; 13: *Guzmán 20626*; 14: *Jarvio 456*; 15-16: *Ramírez-Guillén 15*). Scale bar = 1 cm.



/ar. *rickii*, *C. militaris*, *C. gracilis*, *C. pruinosa*, var. *rickii*. 8 & 10: Stroma on a larva of *Enema gus aloeus*. 11: *C. militaris*, head of the stroma. ɔidoptera. 13: *C. pruinosa*, a stroma growing on *dipterigena*, three stromata on flies of the genus *001*; 10: Wolf2259-1; 11: *Villarreal, s.n.*. IBUG ɔ; 14: *Jarvio 456*; 15-16: *Ramírez-Guillén 15*).

Habitat. The material from Chiapas and Oaxaca is on larvae of *Enema endymion* Chevrolat (Coleoptera, Melolonthidae, subfam. Dynastinae, tribus Oryctini). That from Oaxaca was buried c.5 cm in the soil, in a subtropical humid forest (mesophytic forest), with *Calophyllum, Tapirira, Laplacea, Terminalia, Mosquitoxylum, Vochysia, Enterolobium, Quercus, Podocarpus* and scattered *Pinus chiapensis* (Mart.) Andersen. The material from Veracruz was found on larvae of *Strategus aloeus* (L.), also belonging to the tribe Oryctini, in a disturbed tropical evergreen forest and in a subdeciduous tropical forest. The specimens from Chiapas were found in a coffee plantation where the host *Enema endymion* is a scarab root pest, 32-36 mm long, common in tropical regions of Mexico through Brazil and Bolivia. In Mexico it is known from the States of Campeche, Chiapas, Hidalgo, Oaxaca (Chiltepec, Ixtepec, Santo Domingo, Tuxtepec and Valle Nacional), Puebla, Quintana Roo, Tabasco, Tamaulipas and Veracruz (Morón *et al.* 1997). In Ocozocuautla (Chiapas), one of the authors (MAM) has once observed thousands of flying adults around the light source. The larvae of this beetle may also occur in high densities and large groups of thousand of individuals have been reported as displacing themselves in one direction over the forest floor in Campeche (Mexico) and Guatemala. This insect feeds exclusively on descomposing plant litter. *Strategus aloeus* has also a broad distribution from Mexico to the Amazonian region. Near Villa Las Rosas, Chiapas, a large population of these larvae was observed in seasonaly flooded soil. Nine specimens of *Cordyceps melolonthae* var. *rickii* were collected there.

Material studied. Mexico, State of Chiapas, Tenejapa, Patekton splot, alt. 1600 m, Nov. 1999, *Robles* (in alcohol in the Entomological Collection at the IE). Villa Las Rosas, alt. 1240 m, Oct. 23, 1999, *Alcazar* (in alcohol in the Entomological Collections at IE and ECOSUR at San Cristóbal de las Casas). State of Oaxaca, W of Sierra Madre del Sur, E of Tehuantepec Isthmus, 31 km NE of Lázaro Cárdenas and Escuilapa, road to Santa María Chimalapa (no San Miguel Chimalapa), ca. 9 km from the town, West of Cerro Azul, 16° 51, 45" N, 94° 43, 40" 16°51"W, alt. 400 m, October 27, 1998, *Wolf 2559-1, 2559-2, 2559-3, 2559-4, 2559-5, 2559-6, 2559-7, 2559-8, 2559-9, 2559-10, 2559-11, 2559-12, 2559-13, 2559-14, 2559-15* (all in XAL, except 2559-8, 9 & 13 that are also in the ECOSUR Herbarium, and 2559-2 and 2559-7 that are also in K and NY, respectively). Veracruz, Municipio Catemaco, Ejido López Mateos, alt. 150 m, June 28, 1987, *Chacón 4001* (XAL).

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Table 1. Species of entomogenous *Cordyceps* and related genera including their anamorph stages reported from Mexico and new records in XAL Herbarium

Species	Distribution
Aschersonia viridula Sacc. = *A. viridans* (Berk. & M.A. Curtis) Pat.	Veracruz (Mains, 1959).
Cordycepioideus octosporus Blackwell & Gilbn. emend. Blackwell & Gilbn.	Jalisco (Blackwell & Gilbertson, 1981, 1984).
Cordyceps dipterigena Berk. & Broome **anamorph**: *Hymenostilbe dipterigena* Petch	**First record for Mexico**: Veracruz, Botanical Garden of the Instituto de Ecología at Xalapa, a mesophitic forest, Jan. 23, 1997, *Ramírez-Guillén 15*; Jan. 17, 2000, *Jarvio 456* (both in XAL) (Figs. 6-7 & 14-16).
C. entomorrhiza (Dicks. : Fr.) Link sensu Pérez-Silva, 1978	Veracruz (Pérez-Silva, 1978).
C. gracilis Durieu & Mont. = *C. entomorrhiza* sensu Chacón & Guzmán (1983, 1995), Chacón *et al.* (1995) and Rubio-Bustos *et al.* (1999) **anamorph**: *Paraisaria dubia* (Delacr.) Samson & B.L. Brady (= *Isaria dubia* Delacr.)	Jalisco (Medel *et al.*, 1999; Rodríguez *et al.*, 1993; Rubio-Bustos *et al.*, 1999); Veracruz (Chacón & Guzmán, 1983, 1995; Chacón *et al.*, 1995; Rubio-Bustos *et al.*, 2000) (Fig. 12).
C. melolonthae var. *rickii* (Lloyd) Mains	Chiapas and Jalisco (Chacón & Guzmán, 1983; Pérez-Silva, 1977; Rubio-Bustos *et al.*, 1999); Oaxaca and Veracruz (**new records**); without locality (Herrera & Ulloa, 1998) (Figs. 1-5 & 8-10).
C. militaris (Fr.) Link	Chiapas, Jalisco, Nuevo León (in XAL), Hidalgo, Michoacán, Morelos, Oaxaca, Sinaloa, State of Mexico and Veracruz (Chacón & Guzmán, 1984; Díaz-Barriga *et al.*, 1988; Frutis & Guzmán, 1983; Pérez-Silva, 1977; Rubio-Bustos *et al.*, 1999; Welden & Guzmán, 1978); without locality (Guzmán, 1977; Herrera & Ulloa, 1998) (Fig. 11).
C. polyarthra Möller	Jalisco (Rubio-Bustos *et al.*, 1999)

eps and related genera including their anamorph
and new records in XAL Herbarium

Cont. Table 1.

	Distribution
C. pruinosa Petch	**First record for Mexico**: Quintana Roo, Chunyaxche Zone, near to the road Puerto Morelos to Carrillo Puerto, a tropical rain forest, Nov. 4, 1981, *Guzmán 20626*, XAL; det. H.C. Evans in 1990 (Fig. 13).
C. sobolifera (Berk.) Berk. & Broome = *Sphaeria* (*Torrubia*) *sobolifera* Berk. **anamorph**: *Isaria cicadae* Miq.; = *I. sinclairii* (Berk.) Petch; = *I. cosmopsaltria* Yasuda; = *Paecilomyces cicadae* (Miq.) Samson (Mains, 1958; Samson, 1974; Urbina, 1881).	Coahuila, Guanajuato and Jalisco (Chacón & Guzmán, 1983; Duges, 1924; García-Romero *et al.*, 1970; Guzmán & García-Saucedo, 1973; Mains, 1958; Pérez-Silva, 1979; Rubio-Bustos *et al.*, 1999); without locality (Mains, 1951, 1955, 1958; Pérez-Silva, 1979; Petch, 1933-1934; Urbina, 1881).
C. sphecocephala (Klotzsch) Sacc. non *C. sphecocephala* (Berk.) Sacc.	Jalisco (Chacón & Guzmán, 1983; Pérez-Silva, 1977; Rubio-Bustos *et al.*, 1999).
C. stylophora Berk. & Broome **anamorph** : *Hirsutella stylophora* Mains	Jalisco (Pérez-Silva, 1978, in both stages; Rubio-Bustos *et al.*, 1999); without locality (Herrera & Ulloa, 1998).
Hirsutella saussurei (Cooke) Speare = *Isaria crinita* Lloyd **teleomorph**: *Cordyceps humberti* Robin ex Saussure?	Oaxaca (Ulloa & Benavides, 1991).
H. thompsonii Fisher	without locality (Mier *et al.*, 1989, 1992; Sampedro & Rosas, 1989).
Isaria farinosa Fr. = *Paecilomyces farinosus* (Holm. ex S. F. Gray) Brown & Smith (Samson, 1974)	Morelos and Oaxaca (Pérez-Silva, 1977); without locality (Pérez-Silva, 1979).
	Veracruz (Mains, 1959).
	Jalisco (Blackwell & Gilbertson, 1981, 1984).
	First record for Mexico: Veracruz, Botanical Garden of the Instituto de Ecología at Xalapa, a mesophitic forest, Jan. 23, 1997, *Ramírez-Guillén 15*; Jan. 17, 2000, *Jarvio 456* (both in XAL) (Figs. 6-7 & 14-16).
	Veracruz (Pérez-Silva, 1978).
	Jalisco (Medel *et al.*, 1999; Rodríguez *et al.*, 1993; Rubio-Bustos *et al.*, 1999); Veracruz (Chacón & Guzmán, 1983, 1995; Chacón *et al.*, 1995; Rubio-Bustos *et al.*, 2000) (Fig. 12).
	Chiapas and Jalisco (Chacón & Guzmán, 1983; Pérez-Silva, 1977; Rubio-Bustos *et al.*, 1999); Oaxaca and Veracruz (**new records**); without locality (Herrera & Ulloa, 1998) (Figs. 1-5 & 8-10).
	Chiapas, Jalisco, Nuevo León (in XAL), Hidalgo, Michoacán, Morelos, Oaxaca, Sinaloa, State of Mexico and Veracruz (Chacón & Guzmán, 1984; Díaz-Barriga *et al.*, 1988; Frutis & Guzmán, 1983; Pérez-Silva, 1977; Rubio-Bustos *et al.*, 1999; Welden & Guzmán, 1978); without locality (Guzmán, 1977; Herrera & Ulloa, 1998) (Fig. 11).
	Jalisco (Rubio-Bustos *et al.*, 1999)

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