

NOTE ON NEW FORMOSAN FOREST FUNGI
 VI. GENUS *CORDYCEPS* AND THEIR DISTRIBUTION
 IN TAIWAN⁽²⁾

ZUEI-CHING CHEN⁽¹⁾

Abstract: None of *Cordyceps* (Clavicitaceae, Sphaeriales, Pyrenomycetes, Ascomycotina) has been recorded from Taiwan up to date. Therefore, it is suspected that two distribution centers of *Cordyceps* in Asia, one in the equatorial tropic and the other in temperate Japan, may not be linked at Taiwan. To answer this question, the flora of genus *Cordyceps* in Taiwan has been studied through the wide range field survey since 1976. Up to this time, in total 16 species including 9 species of world new record have been discovered. The rest of 7 species are all new record to Taiwan flora, therefore, they are briefly described and their geographic distribution in Taiwan and Asia are discussed. The seven species of entomogenous *Cordyceps* are *C. dipterigena* Berk & Br., *C. grylloalpa* Lloyd, *C. militaris* (Fr.) Link, *C. myrmecophila* Ces., *C. nutans* Pat., *C. takaomontana* Yakusiji & Kumazawa, and *C. tuberculata* (Leb.) Maire.

Among them, *C. tuberculata* is cosmopolitan. *C. dipterigena* is a tropical species and Taiwan is the northern extremity of distribution in Asia. *C. militaris* is a subarctic-temperate species and was discovered from the high mountain zone of altitude about 2,000 m of the northern Taiwan. Thus, Taiwan is the southern extremity of its distribution. Both *C. grylloalpa* and *C. takaomontana* are endemic of the temperate Japan and Korea. They were discovered from the forest of about 1,250 m altitude of the central Taiwan and their southern extremity are also in Taiwan. Both *C. nutans* and *C. myrmecophila* are the tropic-temperate species and their populated presence in Taiwan suggested the close affinity between Taiwan flora and the tropic-temperate Asia continent. The hypothesis is proposed to announce the key stone value of Taiwan in the biogeographic distribution of *Cordyceps* in Asia. "Both temperate and tropical species of *Cordyceps* may be joined at the central part of Taiwan approximately between the Tropic of Cancer and the 24 degree of the northern hemisphere. In other words, two distribution centers of *Cordyceps* in Asia are linked at Taiwan."

INTRODUCTION

Despite the fact of having a rich flora of insects, only one species of the entomogenous *Cordyceps*, viz., *C. sinensis* (Berk.) Sacc., has been reported from Taiwan by Sawada (1931). Sawada's specimen was, in fact, not collected from Taiwan but was obtained from the imported Chinese medicine or drug from Mainland China. As far as the *Cordyceps* is concerned, Taiwan has been the unexploited area until recently. Near the end of 1975, two specimens of entomogenous *Cordyceps* were collected by students and sent to the author for the identification. Naturally, these specimens were the first record of *Cordyceps* directly collected from Taiwan.

- (1) 陳瑞青, Professor, Department of Botany, National Taiwan University, Taipei, Taiwan, Republic of China.
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Two specimens were identified as *C. nutans* and *C. myrmecophila*. Subsequently several field collecting trips were carried out during 1976 including one-month long trip with Japanese mycologists, Mr. Daisuke Shimizu and his associate, Mr. Yasuo Suzuki. In total, 16 species of *Cordyceps* with 9 new species, 4 new species of *Torubiella*, and several imperfect stage of *Cordyceps* belong to the genera of *Gibellula*, *Isaria*, etc. were discovered. The description and taxonomic treatments of new species obtained in this expedition will be published in future by Shimizu *et al.* In this report, biogeographic distribution of seven species of entomogenous *Cordyceps*, all new to Taiwan, will be discussed. The seven species are *C. dipterigena* Berk. & Br., *C. gryllotalpae* Lloyd, *C. militaris* (Fr.) Link, *C. myrmecophila* Ces., *C. nutans* Pat., *C. takaomontana* Yakusiji & Kumazawa, and *C. tuberculata* (Lebert) Maire. Only those species with the matured fruiting bodies shall be briefly described in this report.

DESCRIPTION OF FUNGI

1. *Cordyceps dipterigena* Berk. & Br. Jour. Linn. Soc. 14:111. 1875. (Plate I, Fig. 1.)

Synonyms: *Cordyceps muscicola* Müller. Phyco. u Asco. 221, 1901.

Cordyceps oumensis Höhnelt. Sitz. Akad. Wiss. Wien. 118: 309, 1909.

Cordyceps opposita Syd. Engler Bot. Jahrb. 57: 325, 1922.

Stromata one to three from the host, one each from both side of neck and the third from tail or anus, the first one from the neck of host usually mature first, 4-5 mm long, capitate, the head flattened globoid or flattened turbinate, 1-2 mm wide, 0.8-1.5 mm thick, light yellow to brownish yellow, rough on the upper surface from apices of the perithecia, the stipes cylindrical, 0.2-0.5 mm thick, brown to orange cinnamon, dark brown to black on the upper 1 mm portion just below the head; the second stroma from the opposite side of the first one, slender, 5-7 mm long, 0.2-0.4 mm wide, simple or capitate, the capitate head sometimes grow branches 1 to 2, the branches capitate, heads hemispherical or oblate globoid, 0.8-1.0 mm wide or 0.8-1.2 × 0.5 mm, surface smooth; the third stroma from the tail of the host, slender, cylindrical, up to 18 mm, 0.1-0.2 mm thick, with apices acute, brown; the stipes of stromata consisting of compact longitudinal somewhat interwoven hyphae continuing into the base of the head, becoming very loosely interwoven in the medullary excipulum, hyphae 2-3 μ in diameter, cortex or ectal excipulum consisting of 35-50 μ thick, brown pseudoparenchyma and the ectal layer composed of palisade of hyaline or brown, oblong to rectangular cells, 10-16 μ thick; perithecia narrowly ovoid or conoid, 700-1,150 × 150-200 μ , completely embedded in a stroma vertically, ostioles opening on the upper surface of the heads, perithecial wall brownish, thin, 20-25 μ ; asci not seen.

Host: Diptera.

Hab.: On adult beetles that are stickened on the lower surface of leaves of hardwood near the stream.

Specimens examined: Nantou Hsien, Len-Hua-Tsu, Shimizu T. A. No. 15 (TAI 4605), July 17, 1976; Z. C. Chen TAI 3905, November 13, 1976.

Distribution: North America, Cuba, Costa Rica, Nicaragua, Puerto Rico, Brazil, British Guiana, Trinidad, New Guinea, Java, Japan, Taiwan.

Notes: The specimens of this fungus have been collected abundantly from the place near the collecting site of *C. myrmecophila*. Although the fruiting bodies of our specimens seems more similar to those of *C. Lloydii* Fawcett on ants, both Shimizu and the author agree to assign this species to *C. dipterigena* based on different host species.

2. *Cordyceps gryllotalpae* Lloyd. Myc. Writ. 6: 913. 1922 (1920) (Plate I, Fig. 2)

Stromata two from the host, slender, cylindrical, simple or branched, apices acute, white to gray, dark gray after dry, 6-8 cm long, 1-2 mm thick, sterile.

Habitat and Host: On adult body of formosan gryllotalpae (Orthoptera), under the forest floor of mixed hardwoods.

Specimens examined: Nantou Hsien, Chi-Tou, altitude 1,250 m, Shimizu T. A. No. 1 (TAI 4606), July 12, 1976.

Distributions: Korea, Japan, Taiwan.

3. *Cordyceps militaris* (Fr.) Link, Handbuch 3: 347. 1833. (Plate I, Figs. 3-4, Plate II, Figs. 9-12)

Synonyms: *Sphaeria militaris* Fr. Sys. Myc. 2: 322, 1823.

Cordylia militaris Fr. ex Ficus & Schubert, Fl. Dresden 2 ed. 2: 331, 1823.

Kentrosporium militare Wallroth. Beitr. Bot. Fasc. 2: 166, 1844.

Torrubia militaris Tul. Sel. Fung. Carp. 3: 6, 1865.

Stromata several (five in our specimen) from various parts of the host, long cylindrical to clavate, terete at first, compressed in mature part, frequently with a longitudinal furrow at the compressed side, 3.5-6.5 cm long, 1-3 mm thick for stipes, 2-4 mm thick for the upper part of stroma, Orange Buff, Orange, Cadmium Orange, to Mikado Orange, fading after dry, fertile part 0.5-1.2 cm long, thicker than the stipes, surface rough by protruding upper part of perithecia, no well differentiated cortex; perithecia ovoid, 400-630 × 230-400 μ, with a pseudoparenchymatous wall 20-23 μ thick, embedded at right angles to the surface except for apices, becoming half embedded or superficial after shrink by drying of stroma tissue; asci narrowly cylindrical, 300-500 × 3-4 μ, with a 2-2.5 μ thick cap; ascospores filiform, multiseptate, part cells 1-1.5 × 3-4 μ, rectangular; conidial state not seen.

Habitat and host: On larvae of Lepidoptera, on the forest floor of *Pinus morrisonicola* Hay. at about altitude 2,000 m.

Specimens examined: Ilan Hsien, Nanshan Hsiang, Nan-Hu-Ta-Shan, TAI 8973, collected by Ming-Jou Lai, Nov. 13, 1976.

Distribution: North America, Puerto Rico, Dominica Republic, Europe, U. S. S. R., Ceylon, Japan, Mainland China, Taiwan.

4. *Cordyceps myrmecophila* Cessati, Bot. Zeit. 4: 877. 1846. (Plate I, Figs. 5-6, Plate II, Figs. 13-15)

Synonym: *Torrubia myrmecophila* Tul. Sel. Fung. Carp. 3: 18, 1865.

Stromata solitary, about 4-7 cm, rarely up to 20 cm long, capitate, the heads ovoid, 2.5 × 1.2 mm, Ochraceous Buff, longitudinally rugose when dry, ridges formed by the papillate ostioles of perithecia, the stipes 0.5 mm thick, concolours with the head or slightly yellow, consisting of compact longitudinal hyphae about 5.7-6.5 μ diameter, diverging and becoming loosely interwoven in the head; perithecia narrowly ovoid to conoid, 600-1,150 × 200-230 μ, with the wall 20 μ thick, completely embedded obliquely to the surface of the head, ostioles slender up to 100 μ long, curved and slightly protrude from the surface as papillate when dry, embedded in a cortex; Cortex composed by slightly brownish pseudoparenchyma tissue; the ectal layer composed by a palisade of hyaline, septate hyphae, about 50 μ thick; asci cylindrical, 200-650 × 6-7.4 μ, with a cap 6.5-8 μ wide, 4-5 μ thick, hemispherical; ascospores filiform, multiseptate, breaking into one-celled fragment, 8.2-9 × 1.6 μ; conidial state unknown.

Host: Ants (Formicidae, Hymenoptera).

Specimens examined: Taipei Hsien, Wu-Lai Hsiang, Wa-Wa Valley, TAI 4126, collected by S. C. Lyu, Dec. 25, 1975. Nantou Hsien, Len-Hua-Tsu, TAI 3335, collected by Shimizu, July 15, 1976; TAI 3337, collected by Z. C. Chen, Nov. 13, 1976.

Distribution: North America, Brazil, Europe, Ceylon, Annam, Mainland China, Taiwan.

Notes: The specimens on ants collected from Taiwan have been identified as *C. japonensis* Hara by Shimizu. The present author disagree with this decision based on the following reasons: (1) the perithecia of *C. myrmecophila* are obliquely embedded in the stroma, for

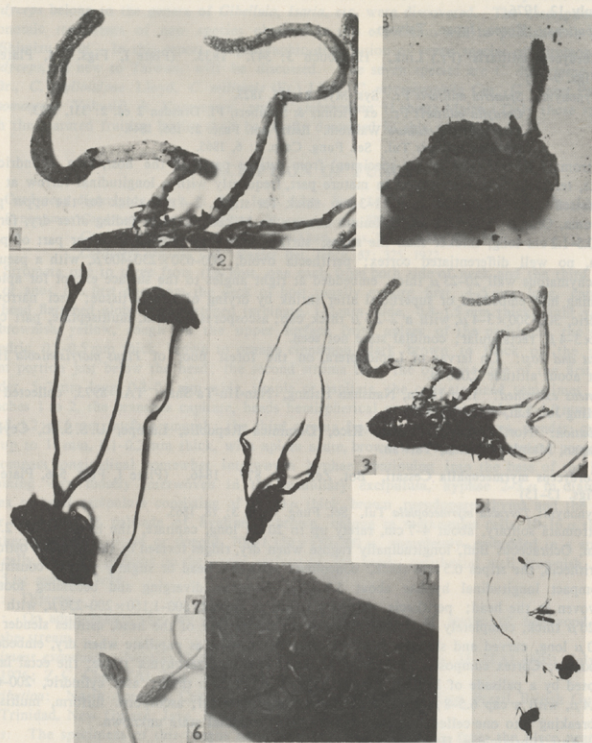


Plate I. Figure 1. *C. dipterigena*, 2.5 \times .

3. *C. militaris*, 0.9 \times .

5. *C. myrmecophila*, 0.9 \times .

7. *C. nutans*, 0.8 \times .

2. *C. gryllotalpae*, 0.9 \times .

4. *C. militaris*, fertile part, 2.2 \times .

6. *C. myrmecophila*, fertile part, 3.6 \times .

8. *C. takaomontana*, 2.4 \times .

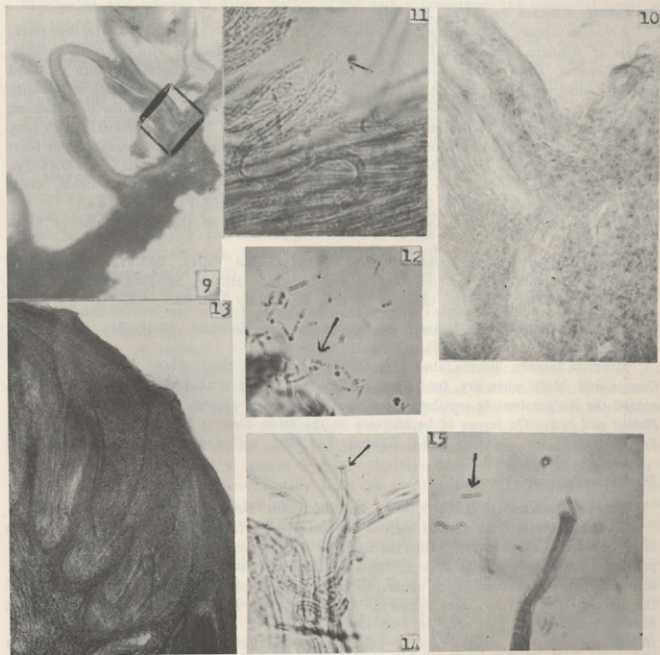


Plate II. Figure 9, *C. militaris*, perithecia & main stem of stroma. A portion inside a frame is enlarged at Figure 10. 100 \times .

10. *C. militaris*, perithecial wall. 500 \times .

11. *C. militaris*, arrow shows ascus cap, 600 \times .

12. *C. militaris*, arrow shows part cells, 1,000 \times .

13. *C. myrmecophila*, longitudinal section of stroma head shows perithecia in obliquely embedded. 70 \times .

14. *C. myrmecophila*, arrow shows ascus cap, 300 \times .

15. *C. myrmecophila*, arrow shows part cells, 700 \times .

those of *C. japonensis* are not; (2) the size of our specimens, in many respects, are larger than that of *C. japonensis*, for instance, the asci of latter species are $130-170 \times 5-6 \mu$, smaller than our specimens and the size described by Mains (1958), $480-720 \times 4-6 \mu$.

5. *Cordyceps nutans* Pat. Bull. Soc. Myc. Fr. 3: 127. 1887. (Plate I, Fig. 7)

Stromata solitary, 1-2 arising from both sides of throat, 8-11 cm long, 0.8-1.0 mm thick, clavate or subulate, sometimes branched dichotomously as fork-shape with unequal branches, stipes flexuous, about 1 mm thick, black but the upper portion concolours with the head (stromata bicolored), head clavate or fusoid, Scarlet Red in fresh, becoming orange at maturity and fading to yellow with age, Warm Buff when dry, $13-16 \times 1.5-2.5$ mm; perithecia immersed, obliquely to the surface of the head, narrowly ovoid to conoid, $700-900 \times 140-280 \mu$, with long neck up to 300μ long, ostioles never protruding from the surface, but the pores evident from the surface view by low power microscope, perithecial wall $15-20 \mu$ thick; asci $260-400 \times 6-7 \mu$, with the caps $6-8 \mu$ wide, $5-7 \mu$ thick, spherical to hemispherical; ascospores filiform, multi septate, breaking into part cells, $7-10 \times 1.2-2 \mu$, rectangular; conidial state unknown.

Habitat and host: On adults of Pentatomidae, Hemiptera, on the forest floor of hardwoods.

Specimens examined: Taipei Hsien, Ping-Lin Hsian, Orchid Valley, TAI 4125, collected by S. H. Chen, fall, 1975. Kao-Hsiung Hsien, Lyo-Kuei Hsian, Sen-Ping, Nan-Pau Shan, altitude 1,500 m, TAI 3719, collected by Z. C. Chen, July 21, 1976.

6. *Cordyceps takaomontana* Yabusiji & Kumazawa. in Kobayasi. Bull. Bot. Inst. Tokyo Bunrika Univ. 5: 108. 1941. (Plate I, Fig. 8)

Stromata solitary, clavate, about 2 cm long, 0.5-1.0 mm thick, Light Ochraceous Buff to Orange Buff, black when dry, fertile part on terminal of stipes, 0.8-1.0 cm long, 1-2 mm thick, around the surface bearing perithecia; perithecia superficial, oblong to pear shape, sterile.

Habitat and host: On larvae of Lepidoptera on the forest floor of hardwood.

Specimens examined: Nantou Hsien, Chi-tou, TAI 4604, collected by Shimizu (Shimizu T. A. No. 3), July 12, 1976.

Distribution: Japan, Taiwan.

7. *Cordyceps tuberculata* (Lebert) Maire, Bull. Soc. Hist. Nat. Afrique Nord. 8: 165. 1917.

Stromate several from various parts of the host, short cylindric, clavate, acuminate, 4-9 mm long, 1.5-2.0 mm thick above, yellowish white or gray above, stipe brown, 0.5-1.0 mm thick; perithecia narrowly ovoid or conoid, $500-870 \times 200-350 \mu$, dark brown, crowded in groups or scattered, partly embedded in the upper part of the stroma or superficially on the mycelium of the stroma after drying; asci cylindric, $350-600 \times 4-5 \mu$, with a 4μ thick cap; ascospores filiform, multiseptate, part cells $2-6 \times 0.5-1.0 \mu$.

Habitat and host: On adult moths of Lepidoptera, on the forest floor Hardwoods, Nantou Hsien, Sun-Moon Lake.

Specimens examined: Nantou Hsien, Sun-Moon Lake, Shimizu T. A. No. 19, July 13, 1976; TAI 1598, July 28, 1977.

Distribution: Europe, North America, West Indies, Guiana, Venezuela, Brasil, India, Ceylon, Central America, New Guinea, New Zealand, Pacific Islands, South China, Japan, and Taiwan.

GEOGRAPHICAL DISTRIBUTION IN TAIWAN

More than 300 species of *Cordyceps* have been reported from the world. Current estimation, they may be reduced to no more than 120 biological species. Since the majority of *Cordyceps* were discovered from the equatorial area of the world, it has been considered that

the biogeographical distribution of *Cordyceps* may centered in this tropical area. Since 1948, Shimizu (1974) has discovered more than 100 new species of *Cordyceps* from the temperate Japan. Although majority of them have not yet been published, sudden exposure of having the rich flora of *Cordyceps* in Japan, brought the suspicion that there may be two centers of distribution of *Cordyceps* in Asia. As far as the Asia is concerned, the equatorial tropic and the temperate Japan are linked by a chain of islands including Borneo, Philippines, Taiwan, and Lyu-Kyu, etc. Naturally, Taiwan is a key stone for the distribution of *Cordyceps* between two centers. On these chain of islands, *Cordyceps* have been recorded from Java (17 species), Borneo (4 species), Philippines (3 species), and Lyu-Kyu islands (17 species) except Taiwan. Whether the linkage of distribution being cut down at Taiwan or continuous between two centers are matter of question. Current survey of *Cordyceps* in Taiwan provided the evidence of floristic distribution in this island, and thus, enable us to discuss the insight of the problems mentioned above. Among the seven species of newly recorded *Cordyceps* from Taiwan, only *C. tuberculata* is cosmopolitan. The typical tropical species is *C. dipterigena*. The subarctic—temperate species is *C. militaris*. The subtropic—temperate species are *C. nutans*, *C. myrmecophila*, *C. gryllotalpae*, and *C. takaomontana*. The latter two species have been recorded from Japan and her vicinity, Korea, and are considered to be the endemic species in the temperate Japan and Korea. Although, Kobayasi (1941) added North America as the distribution zone of *C. gryllotalpae*, Mains (1958) has rejected the idea. It is evident that the majority of species distributed in Taiwan could be categorized as the subtropic—temperate species. The detailed distribution map of each species of *Cordyceps* in Taiwan are shown in Figs. 1 and 2. *Cordyceps militaris*, the only one subarctic-temperate species, was discovered from the high mountain area of northern Taiwan. The collection site was on the forest floor of *Pinus morrisonicola* Hay., which belongs to the sub-tropical zone by the vertical distribution of plant flora in Taiwan. Probably Taiwan is the southern extremity of distribution of *C. militaris* in Far East Asia. While the only one tropical species, *C. dipterigena*, was found in the low-land mountain area of the central part of Taiwan. The collection site, Len-Hua-Tsu, is vegetated with the subtropical rain forest and probably the northern extremity of distribution as the endemic tropical habitat of the species in Asia. However, Shimizu (1976a) indicated that *C. dipterigena* has been found in occasionally from the area north of Tokyo, in Japan. The two temperate species endemic in Japan and Korea, *C. takaomontana* and *C. gryllotalpae*, were discovered from the hardwood floor of about 1,250 m altitude of Chi-Tou area which is located in the central part of Taiwan. It is interesting to notice the difference of southern limit of distribution of both the subarctic-temperate species and two temperate species from Japan area. The subarctic—temperate species distributed in 2,000 m altitude of northern Taiwan, while the temperate species went down south to the central Taiwan and even to the lower altitude of 1,250 m. The most commonly found tropical—temperate species of *Cordyceps* in Taiwan are *C. nutans* and *C. myrmecophila*. According to Shimizu (1974), the stromata of *C. nutans* distributed in Japan and Mainland China have the beautiful Scarlet Red color which distinct from those found in Africa and New Guinea by having a light colored heads. The temperate form of *C. nutans* and the tropical form differ in the stroma color. Thus, it is anxious to see which form the formosan collections of *C. nutans* will be belong to. The specimens of *C. nutans* have been collected so far from Taiwan show the red color in the fresh condition and naturally belong to the temperate form. It is evident that *C. nutans* in Taiwan has a close affinity with Mainland China and Japan. The in-island distribution of *C. nutans* in Taiwan is characterized by that the more the south, the higher the altitude of the collection sites. (Fig. 2). This species has been recorded from Hai-nan Island, the southern edge of Mainland China. And no doubt, it is the southern extremity of distribution of *C. nutans* in Asia continent. At the same time, Taiwan could be considered to be the southern

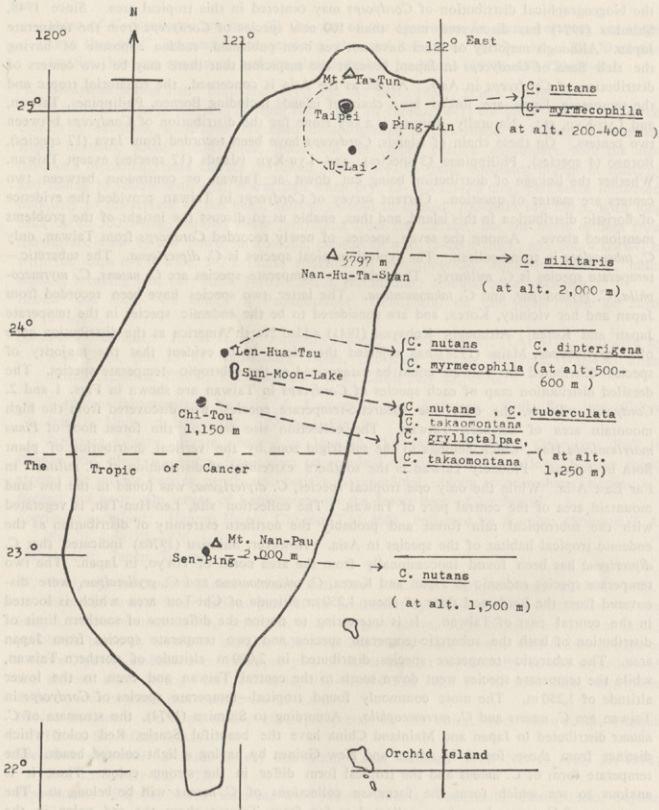


Fig. 1. The distribution map of *Cordyceps* in Taiwan.

extremity of distribution in a chain of Asian islands. The ant *Cordyceps*, *C. myrmecophila* in Taiwan is the most populated species and it is not uncommon to collect hundreds of specimens at one location. Although it has the same range of geographic distribution in the world with *C. nutans*, surprisingly it has never recorded from temperate Japan. Both species distribute at

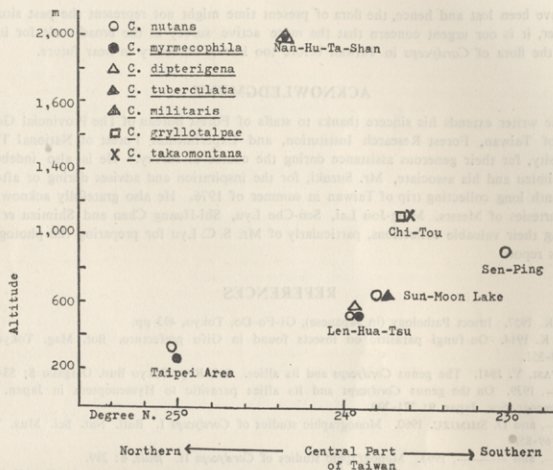


Fig. 2. The vertical distribution of *Cordyceps* in Taiwan.

the same location in both northern and central parts of Taiwan but *C. myrmecophila* has not yet been discovered from the southern Taiwan. Although this ant *Cordyceps* is widely distributed in Mainland China and Asia Tropic, it probably has its northern limit of distribution in Taiwan.

Comparing the nature and number of common species of *Cordyceps* in the regions surrounding Taiwan, it is recognized that Japan including Korea have six species out of more than 150 recorded species common with Taiwan, i. e., *C. dipterigena*, *C. militaris*, *C. gryllotalpae*, *C. takaomontana*, *C. tuberculata*, and *C. nutans*; Mainland China has four species, i. e., *C. nutans*, *C. militaris*, *C. tuberculata*, and *C. myrmecophila*, out of their 24 recorded species; while the Hai-Nan Island, only two species, i. e., *C. nutans* and *C. myrmecophila*, out of seven recorded species are common with Taiwan. Therefore, the flora of Taiwan, as far as the *Cordyceps* is concerned, has received the influences come from three parts: the first from South East Asia for the tropical species, the second from the Mainland China, and the third from Japan area. The distribution map of Taiwan has shown that both the tropical species, *C. dipterigena*, and the tropical-temperate species, *C. nutans* and *C. myrmecophila*, were found at the same location, Len-Hua-Tsu, the central low-mountain area of Taiwan. While the endemic Japanese species, *C. takaomontana* and *C. gryllotalpae* were found from Chi-Tou Area, about 40 km south of Len-Hua-Tsu. It is suspected that both the temperate and the tropical species may be joined at the central part of Taiwan approximately between the Tropic of Cancer to the 24 degree of the northern hemisphere. Since the specimens of *Cordyceps* so far have been collected from Taiwan were discovered from the natural forests, and many of them have been destroyed for the reforestation during this century. Evidently the huge area of surviving sites of *Cordy-*

ceps have been lost and hence, the flora of present time might not represent the past situation. However, it is our urgent concern that the more active survey in the broad scale for investigating the flora of *Cordyceps* in Taiwan before too late is necessary in near future.

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