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## The genus *Gibellula* on spiders from Taiwan

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**Abstract:** Four species of *Gibellula* were found on spiders in Taiwan. *Gibellula leiopus* and *G. pulchra* are redescribed; *G. unica*, a new species, and *G. clavulifera* var. *major*, a new variety, are described. A key to the Taiwanese *Gibellula* species is given. The most distinguishing feature of *G. unica* is the concurrent or independent production of phialidic or polyblastic conidiogenous cells of, respectively, *Gibellula* and *Granulomanus* synanamorphs on the same well differentiated distinctly verrucose conidiophore. *Gibellula clavulifera* var. *major* is primarily characterized by a white, solitary, whiplashlike synnema arising from the tip of host abdomen, and from which the bi-, ter-, or rarely monoverticillate penicilli are initiated. The verticillate conidiogenous cells on the well differentiated conidiophores are of two types, one phialidic bearing catenate, fusiform to broadly fusiform conidia; the other holoblastic, with distinct denticles bearing solitary, long, bacilliform conidia. *Gibellula unica* is compared to the morphologically similar species *G. brunnea*, *G. clavata*, and *G. mirabilis*; and *G. clavulifera* var. *major* is compared to *G. clavulifera* var. *clavulifera*, and *G. clavulifera* var. *alba*.

**Key Words:** Araneae, Clavicipitales, *Granulomanus*, Hyphomycetes, systematics, taxonomy, *Torrubiella*

### INTRODUCTION

Spiders are naturally infected by a number of fungal pathogens, including species in the anamorph genera *Akanthomyces* Lebert, *Clathroconium* Samson & Evans, *Engyodontium* de Hoog, *Gibellula* Cavara, *Granulomanus* de Hoog, *Hymenostilbe* Petch, *Nomuraea* Maublanc, *Paecilomyces* Bainier, *Pseudogibellula* Samson & Evans, and the teleomorph genus *Torrubiella* Boudier (Evans and Samson, 1987; Samson et

al., 1988). The mechanisms of infection and mortality of the spiders by these pathogenic fungi are thought to be comparable to the mechanisms found in other other insect hosts (Evans and Samson, 1987). Since spiders are natural enemies of insect pests, mortality of spiders due to fungal infection may affect natural biocontrol of those pests, although the ecological significance of the spider mortality has not been comprehensively evaluated (Evans and Samson, 1987; Samson et al., 1988).

Among spider pathogens, the genus *Gibellula* was established by Cavara in 1894 to accommodate *G. pulchra* (Sacc.) Cavara because of its unusual conidiogenous cells. Since then, a number of species have been described on spiders (Petch, 1932; Mains, 1950; Samson and Evans, 1973, 1977; Humber and Rombach, 1987). Four new species of *Gibellula* were described by Samson and Evans (1992) from infected spiders collected in South America. They thoroughly discussed the taxonomy, host specificity, habitats and teleomorph connections (Hoog, 1980; Humber and Rombach, 1987), and presented a key to the nine accepted *Gibellula* species.

In Far Eastern Asia, Sawada conducted an extensive study of the fungal flora of Formosa from 1915 to 1945. He described four new *Gibellula* species, including *G. formosana* Sawada on pupae of moth, *G. araneicola* Sawada, and *G. araneae* Sawada on spiders, and *G. tropicalis* Sawada on an unspecified insect that inhabited the underside of leaves (Sawada, 1919, 1928, 1959). Kao (1981) reported finding *G. suffulta* Speare on Araneae from Fujian, People's Republic of China. *Gibellula suffulta* was suggested to be synonym of *G. pulchra* by Mains (1950).

During a survey of the insect- and spider pathogens from Taiwan that has been in progress since 1989, a total of 47 spiders associated with *Gibellula* species were collected. Of them, 20 were identified as *G. pulchra* and one as *G. leiopus* (Vuill.) Mains. Two collections were reminiscent of *G. clavulifera* var. *alba* Humber & Rombach in having white to yellowish white, solitary whiplike synnemata arising from the abdomen of host, and penicillately arranged conidiogenous cells. They differed from this variety in having much larger, broadly fusiform conidia, and verticillate cylindrical to flask-shaped polyblastic conidiogenous cells, and thus are the described as a new

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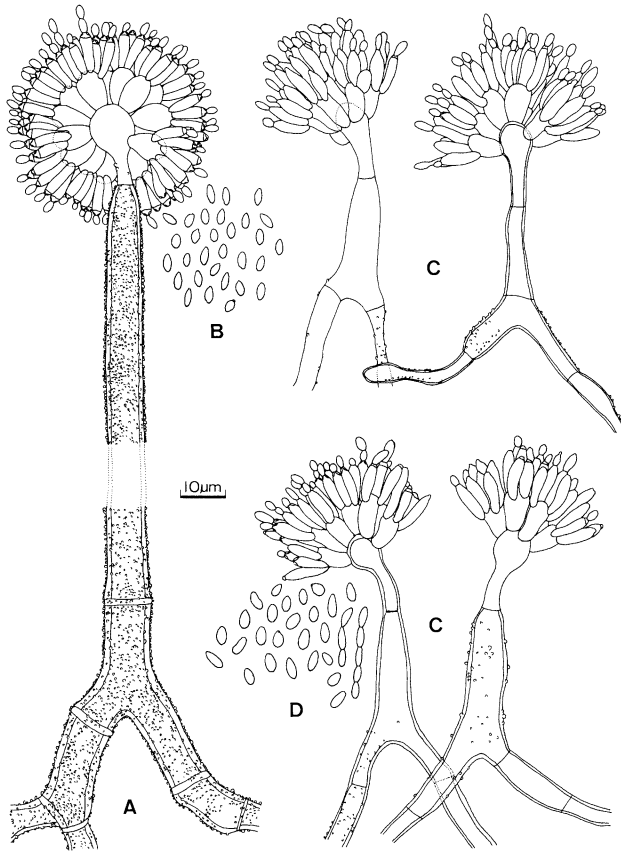


FIG. 1. Characteristics of conidiophores, conidiogenous cells, and conidia of *Gibellula* species. A, B. *G. pulchra* (Ar. 78). C, D. *G. leiopus* (Ar. 28).

variety (Humber and Rombach, 1987). Nine collections were similar to *G. brunnea* Samson & Evans. They differed from *G. brunnea* in gross morphology and pigmentation of synnemata, in the roughness of their conidiogenous cells, and particularly in the concurrence of phialidic and holoblastic conidiogenous cells on the same conidiophore (Samson and Evans, 1992). Because of these differences, they represent a new species.

Following is an account of the species of *Gibellula* for Taiwan. All herbarium specimens are deposited in the Plant Pathology and Entomology Department, National Taiwan University, Taipei, Taiwan, Republic of China. Kornerup and Wanscher (1978) were followed for color nomenclature.

#### DESCRIPTIONS OF THE SPECIES

*Gibellula pulchra* (Sacc.) Cavara, Atti Ist. Bot. Univ. Pavia Ser II, 3: 347. 1894. FIG. 1 A, B

Spider completely covered by a mat of white, yellowish white (4A2), pale, pastel to light or grayish yellow (2A3–4, 3A4–6, 3B5–6), occasionally orange

white, pale to light orange (5A2–4) mycelium. Synnemata solitary to numerous, arising from all parts of the host, cylindrical, attenuated, 4–7 mm long, 120–144 µm diam, consisting of parallel multiseptate longitudinal hyphae. Hyphae of synnemata hyaline, verrucose, 3.2–5.5 µm wide. Conidiophores greenish white to pale green (30A2–3), arising from the mycelium covering the host or from the synnemata, 110–640 × 7.9–10.3 µm, septa conspicuous, thickened and often darkly pigmented, distinctly roughened at the basal 3–5 cells, narrowing abruptly to a slender apex, 2.8–4.0 µm wide, and terminating in a swollen vesicle. Conidial head 40–48 µm diam. Vesicle mostly ellipsoidal to globose, 8.7–10.3 × 7.9–8.7 µm. Phialides cylindrical to narrowly clavate, with a short neck, often apically thickened, hyaline, 6.4–10.3 × 2.0–2.4 µm, up to 10, borne on metulae. Metulae broadly obovoid, hyaline, 7.9–9.9 × 5.2–6.4 µm, up to 20, borne on a vesicle. Conidia hyaline, ellipsoidal, sometimes fusoid, smooth, single or catenulate, 4.0–6.0 × 2.0–2.4 µm. Teleomorph and *Granulomanus* synanamorphs not observed.

*Specimens examined.* REPUBLIC OF CHINA. TAIWAN: Ilan County, Yuanshan, Fushan Herbarium, on spider Ar. 6, 9 Aug. 1989; Taipei County, Wulai, Hapen, on spider Ar. 7, 9 Aug. 1989; Taichung County, Hoping, Tashueshan, on spider Ar. 9, 24 Oct. 1989; Nantou County, Wushe, on spider Ar. 10, 24 Oct. 1989; Pingtung County, Manchow, Nanjenshan, on spider Ar. 13, 24 Feb. 1990; Taipei County, Wulai, on spider Ar. 17, 1 Jun. 1990; Taipei City, Mientienshan, on spider Ar. 21, 12 Jun. 1990; Taipei City, Yangmingshan National Park, on spider Ar. 27, 16 Aug. 1990; Nantou County, Puli, Lienhuachih, on spiders Ar. 31, Ar. 32, Ar. 34, 29 Sep. 1990; Nantou County, Luku, Chitou, on spider Ar. 38, 22 Dec. 1990; Nantou County, Puli, Lienhuachih, on spider Ar. 53, 10 Jul. 1991; Taitung County, Yenping, on spiders Ar. 62, Ar. 63, 30 Jul. 1991; Nantou County, Puli, Lienhuachih, on spider Ar. 71, 9 Sep. 1994; Ilan County, Tatung, Taipingshan, on spider Ar. 72, 28 Aug. 1993; Kahoisiung County, Liukui, Shanping, on spider Ar. 78, 22 Oct. 1994; Taipei County, Sanhsia, Manyuehyuan, on spider Ar. 97, 20 Jan. 1995; Pingtung County, Manchow, Nanjenshan, on spider Ar. 102, 1 Mar. 1995.

*Gibellula leiopus* (Vuill.) Mains, Mycologia 42: 318. 1950. FIG. 1 C, D

Spider covered by dense white to yellowish white (3A2) mycelium. Synnemata arising from the whole host, erect, cylindrical, or slightly clavate, with a short stipe, white, becoming orange white to pale orange (5A2–3) in age, pulverulent when sporulating, 0.7–

1.0 mm long, 280–430  $\mu\text{m}$  diam, composed of parallel densely compact hyphae. Hyphae of synnemata septate, hyaline to yellowish white (2A2) to grayish yellow (1B3), mostly smooth, 1.8–4.8  $\mu\text{m}$  wide, but becoming arched, wider, and distinctly verrucose, near the points of origin of conidiophores. Conidiophores arising at the ends of hyphae of the synnemata or laterally from the arched hyphae of the synnemata, crowded, especially on the upper portion, 24–80  $\times$  4.4–11.1  $\mu\text{m}$ , mostly smooth, occasionally slightly verrucose at the base, narrowing to a slender apex, and terminating in a swollen vesicle. Conidial head wedge-shaped, hemispherical to spherical, (16–) 24–56  $\mu\text{m}$  diam. Vesicle mostly ellipsoidal to globose, smooth, hyaline, 5.6–9.2  $\mu\text{m}$  diam, bearing a number of metulae on the upper portion. Metulae ellipsoidal, broadly cylindrical to obovoidal, hyaline, smooth, 7.5–10.7  $\times$  3.7–6.4  $\mu\text{m}$ , bearing up to 13 phialides at the apices. Phialides narrowly clavate to subcylindrical, tapering towards the thickened apex, smooth, hyaline, 7.9–11.5(–14.0)  $\times$  2.4–3.4  $\mu\text{m}$ . Conidia mostly ovoid, ellipsoidal, often cylindrical to fusiform, sometimes obclavate, occasionally apiculate, hyaline, smooth, single or in a long chains, 3.0–5.4  $\times$  1.6–2.5  $\mu\text{m}$ .

*Specimen examined.* REPUBLIC OF CHINA. TAIWAN: Taipei City, Yangmingshan National Park, on spider *Ar.* 28, 16 Aug. 1990, *W. J. Wu*.

***Gibellula clavulifera* var. *major*** Tzean, Hsieh, Liou, et Wu, var. nov. FIGS. 2, 3

Mycelium hospitem cooperiens, album vel flavido-album. Synnemata solitaria, alba vel flavido-alba, dorso abdominis hospitis enata, exilia, cylindrica, apicem versus aliquando arcuata, 10–15 mm longa, 400–500  $\mu\text{m}$  lata, e fascibus compactis hyphas parallelas contentibus constantia. Conidiophora proxime aut e mycelio, aut ex apice aut e latere synnematum orientia, hyalina, penicillata, plerumque bi- vel triverticillata, raro univerticillata, robusta, glabra vel subaspera, 140  $\mu\text{m}$  longa, 4.8–7.1  $\mu\text{m}$  lata. Vesiculae absentes vel aegre effectae. Rami cylindrici, aliquando septati, 25.0–34.0  $\times$  4.8–6.0  $\mu\text{m}$ . Ramuli cylindrici 15.9–20.6  $\times$  4.4–6.4  $\mu\text{m}$ , metulas 3–10 gerentes. Metulae clavatae vel cylindricae, 12.7–19.8  $\times$  4.0–5.6  $\mu\text{m}$ , phialides 2–8 gerentes. Phialides ampulliformes vel cylindricae, 12.7–19.8  $\times$  3.6–4.8(–5.3)  $\mu\text{m}$ , in apice exigue incrassatae, collis indistinctis praeditae vel collis carentes. Conidia catenata, hyalina, exigue crassitunicata, 7.1–12.0(–13.9)  $\times$  2.4–4.0(–5.6)  $\mu\text{m}$ , unicellularia, late fusiformia vel fusiformia, aut apiculata aut in polis exigue rotundata. Status *Granulomanus* synanamorphicus adest. Conidiophora e stipite synanamorphae *Gibellula* orientia, hyalina, glabra vel leviter as-

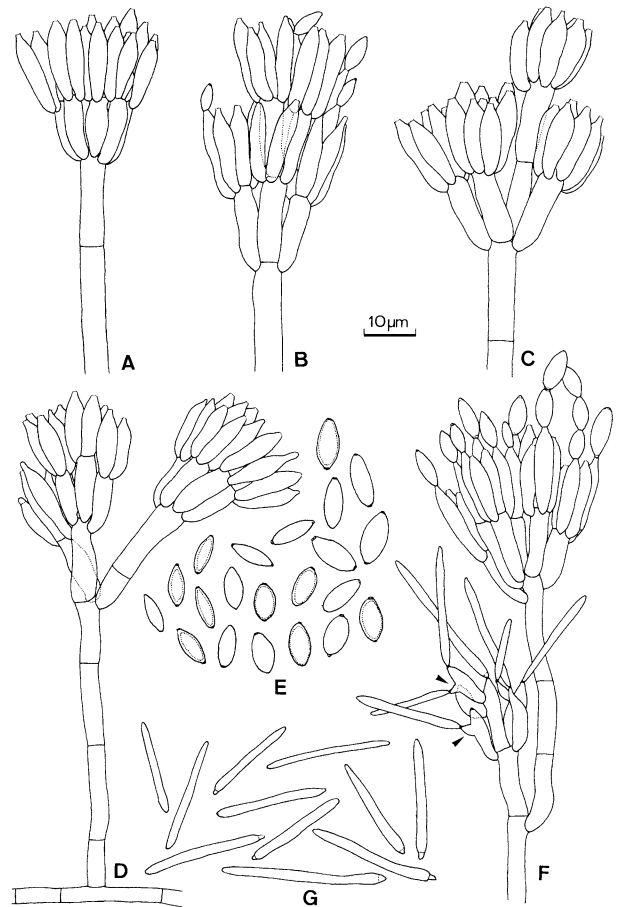


FIG. 2. *Gibellula clavulifera* var. *major*. Characteristics of conidiophores, conidiogenous cells and conidia in the synanamorphs. A-E. *Gibellula* stage. F, G. *Granulomanus* stage. Distinct denticles on holoblastic conidiogenous cells indicated by arrow heads. (F). On spider *Ar.* 76.

pera, cellulas conidiogenas in apice verticillatas holoblasticas gerentia. Cellulae conidiogenae cylindricae vel ampulliformes, denticulis 1–2 conspicuis armatae, 9.5–14.6  $\times$  2.7–4.4  $\mu\text{m}$ , conidio unico ex omni denticulo oriente instructae. Conidia prosenchymata, filiformia vel bacilliformia, 15.9–26.2(–34.1)  $\times$  1.3–2.4  $\mu\text{m}$ , interdum in polo uno subtumida apiculataque, unicellularia glabritunicata, hyalina. Status teleomorphicus ignotus.

**HOLOTYPUS.** REPUBLIC OF CHINA. TAIWAN: Kaohsiung County, Liukui, Sanping, on spiders, *Ar.* 76, *Ar.* 88, 22 Oct. 1994, *J. Y. Liou* (PPH 25, deposited in Department of Plant Pathology and Entomology, National Taiwan University, Taipei, Taiwan, Republic of China).

Mycelium covering the host, white to yellowish white (4A2). Synnemata solitary, white to yellowish white (4A2), arising from the posterior of the host abdomen, slender, cylindrical, sometimes curved towards the end, 10–15 mm long, 400–500  $\mu\text{m}$  wide,

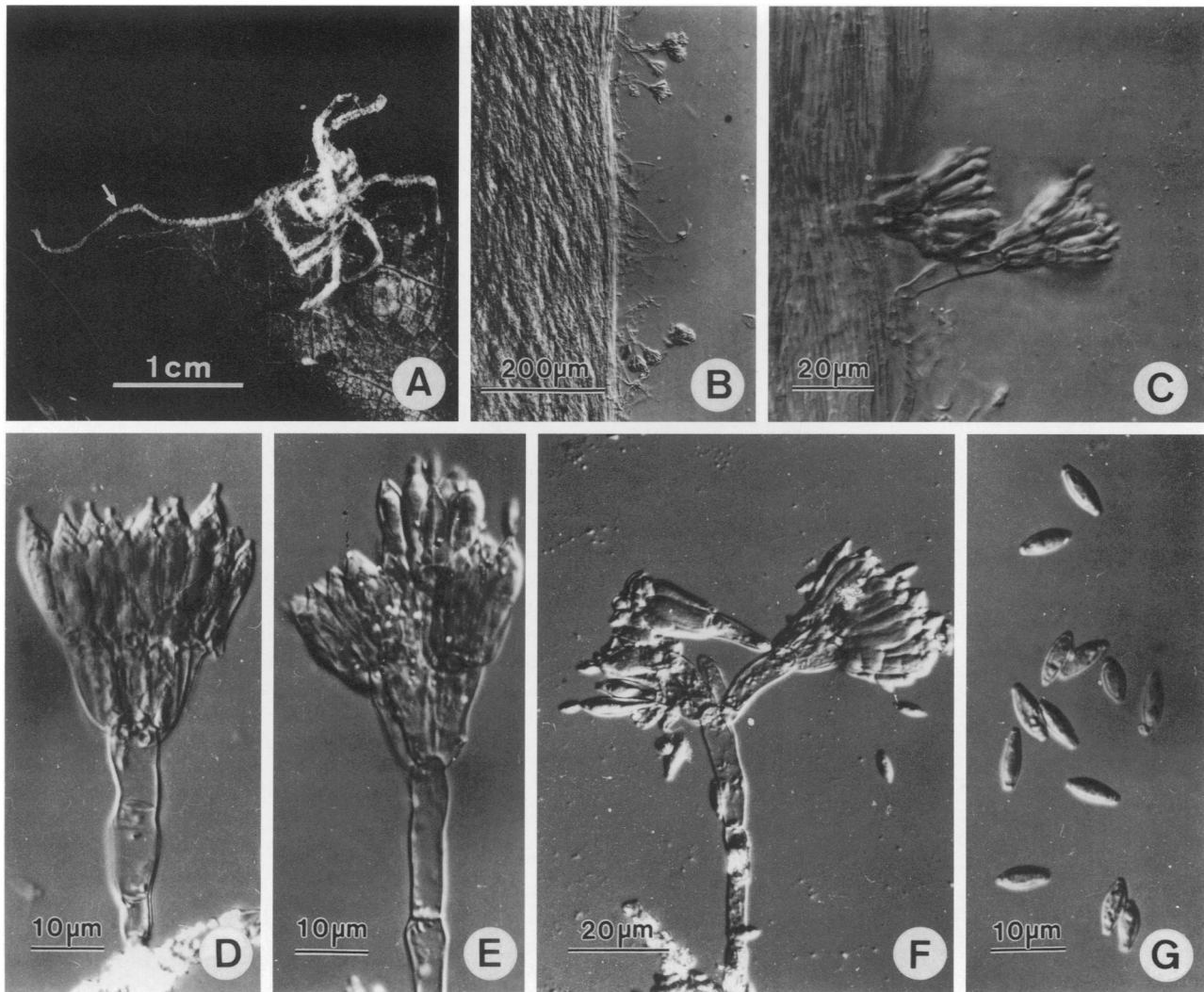


FIG. 3. *Gibellula clavulifera* var. *major*. A. Habit. A solitary synnema arising from the tip of the abdomen of the infected spider (arrow head). B. Synnema composed of compact parallel hyphae. C. Penicillate conidiophores arising from the synnema. D, E. Biverticillate conidiophore and conidiogenous cells. F. Terverticillate conidiophore. G. Conidia.

consisting of a compact bundle of parallel hyphae. Conidiophores directly arising from aerial mycelium, or apically or laterally from synnemata, hyaline, mostly biverticillate or terverticillate, occasionally monov-  
 erticillate, stout, smooth or slightly roughened, to 140  $\mu\text{m}$  long, 4.8–7.1  $\mu\text{m}$  wide. Vesicles absent or hardly developed. Rami cylindrical, sometimes septate, 25.0–34.0  $\times$  4.8–6.0  $\mu\text{m}$ . Ramuli cylindrical, 15.9–20.6  $\times$  4.4–6.4  $\mu\text{m}$ , bearing 3 to 10 metulae. Metulae clavate to cylindrical, 12.7–19.8  $\times$  4.0–5.6  $\mu\text{m}$ , bearing 2 to 8 phialides. Phialides ampulliform to cylindrical, 12.7–19.8  $\times$  3.6–4.8(–5.3)  $\mu\text{m}$ , apex slightly thickened, neck absent or indistinct. Conidia in chains, hyaline, slightly thick-walled, 7.1–12.0 (–13.9)  $\times$  2.4–4.0(–5.6)  $\mu\text{m}$ , one-celled, broadly fusiform to fusiform, either apiculate or with slightly rounded ends. *Granulomanus* synanamorph present.

Conidiophores arising from the stipe of *Gibellula* synanamorph, hyaline, smooth or inconspicuously roughened, bearing apically whorled polyblastic conidiogenous cells. Conidiogenous cells cylindrical to flask-shaped, with one to two conspicuous denticles, 9.5–14.6  $\times$  2.7–4.4  $\mu\text{m}$ , each denticle giving rise to a solitary conidium. Conidia filiform to bacilliform, 15.9–26.2(–34.1)  $\times$  1.3–2.4  $\mu\text{m}$ , sometimes slightly swollen and apiculate at one end, one-celled, smooth, hyaline. Teleomorph not observed.

***Gibellula unica*** Tzean, Hsieh et Wu, sp. nov. FIGS. 4, 5

Hospes arachnoideus tegete alba myceliali coopertus. Synnemata catervas 5–6 formantia, proxime e latere dorsali hospitis orientia, exilia, cylindrica, attenuata, flavido-grisea (4B2), 4–5 mm longa, 96–184  $\mu\text{m}$  lata, e hyphis dense com-

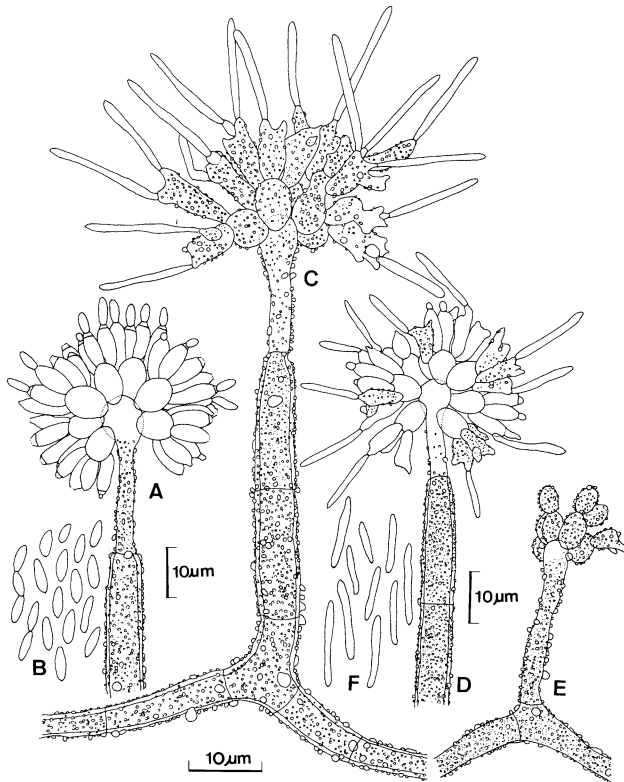


FIG. 4. *Gibellula unica*. Characteristics of conidiophores, conidiogenous cells, and conidia in the synanamorphs. A, B. *Gibellula* stage. C–F. *Granulomanus* stage. On spider *Ar. 55*.

pactis parallelis constantia. Hyphae hyalinae, verrucosae, 3.2–6.1  $\mu\text{m}$  latae. Conidiophora hyalina, septata, synnematus enata, dispersa vel dense compacta, 112–244  $\mu\text{m}$  longa, 6.4–13.5  $\mu\text{m}$  lata, longitudinaliter aspera, in apicem gracilem abrupte decrescentia, diametro 2.4–4.0  $\mu\text{m}$ , in vesiculam inflatam terminantia. Capitulum conidicum diametro 40–52  $\mu\text{m}$ . Vesicula ellipsoidea, subglobosa vel globosa, glabritunicata, interdum subverrucosa, hyalina, 7.1–9.9  $\times$  5.6–7.9  $\mu\text{m}$ . Phialides late cylindricae vel ellipsoideae, glabritunicatae, raro asperae, colo brevi praeditae, plerumque in apice incrassatae, hyalinae, 6.4–9.5  $\times$  2.8–4.2  $\mu\text{m}$ , in verticillum ex phialidibus 3–12 compositum dispositae, in metulis portatae. Metulae late ellipsoideae, obovoideae, hyalinae, glabritunicatae, interdum 5.6–9.1  $\times$  4.8–7.0  $\mu\text{m}$ . Conidia fusiformia, interdum apiculata, hyalina, glabritunicata, brevicatenata, 4.0–6.8  $\times$  1.6–2.2  $\mu\text{m}$ . Cellulae conidiogenae synanamorphae *Granulomanus* holoblasticae, cylindricae, clavatae, ampullaecae vel in ambitu irregulares, maximam partem verrucosae, raro glabrae, denticulis conspicuis 1–3 armatae, 6.8–11.9  $\times$  3.2–4.0  $\mu\text{m}$ , conidia solitaria, longa, filiformia gerentes. Conidia glabritunicata, hyalina, 11.1–17.5  $\times$  1.0–1.6  $\mu\text{m}$ . Status teleomorphicus ignotus.

HOLOTYPE. REPUBLIC OF CHINA. TAIWAN: Nantou County, Puli, Lienhuachih, on a spider *Ar. 55*, 10 July, 1992, L. S. Hsieh (PPH 23, deposited in Department of

Plant Pathology and Entomology, National Taiwan University, Taipei, Taiwan, Republic of China).

Spider host covered by white mycelial mat. Synnemata in groups of 5 or 6, arising directly from the dorsal side of the host, slender, cylindrical, attenuated, yellowish gray (4B2), 4–5 mm long, 96–184  $\mu\text{m}$  wide, composed of parallel, densely compacted hyphae. Hyphae of synnemata hyaline, verrucose, 3.2–6.1  $\mu\text{m}$  wide. Conidiophores hyaline, septate, arising from arches in hyphae of the aerial mycelium or from synnemata, scattered or densely compacted, 112–244  $\mu\text{m}$  long, 6.4–13.5  $\mu\text{m}$  wide, distinctly roughened along the length, narrowing abruptly to a slender apex, 2.4–4.0  $\mu\text{m}$  diam and terminating in a swollen vesicle. Conidial head 40–52  $\mu\text{m}$  diam. Vesicle ellipsoidal, subglobose to globose, smooth, occasionally slightly verrucose, hyaline, 7.1–9.9  $\times$  5.6–7.9  $\mu\text{m}$ . Phialides broadly cylindrical to ellipsoidal, smooth, rarely roughened, with a short neck, often apically thickened, hyaline, 6.4–9.5  $\times$  2.8–4.2  $\mu\text{m}$ , in a whorl of 3–12, borne on metulae. Metulae broadly ellipsoidal, obovoidal, hyaline, smooth, occasionally 5.6–9.1  $\times$  4.8–7.0  $\mu\text{m}$ . Conidia fusiform, occasionally apiculate, hyaline, smooth, in short chains, 4.0–6.8  $\times$  1.6–2.2  $\mu\text{m}$ . Conidiophores of *Granulomanus* synanamorph present, well differentiated, roughened to distinctly verrucose, particularly around the base of the synnemata. Conidiogenous cells of *Granulomanus* synanamorph holoblastic, cylindrical, clavate, flask-shaped, to irregularly shaped, mostly verrucose, rarely smooth, with one to three conspicuous denticles, 6.8–11.9  $\times$  3.2–4.0  $\mu\text{m}$ , bearing solitary, long, filiform conidia. Conidia smooth, hyaline, 11.1–17.5  $\times$  1.0–1.6  $\mu\text{m}$ . Teleomorph not observed.

#### DISCUSSION

*Gibellula* species associated with spiders were not uncommon, particularly in humid and shaded areas. Usually the infected spider cadavers were collected from the lower side of broad leaved shrubs at elevations of 200 to 2500 m. Of the 47 specimens of *Gibellula* species associated with spiders, *G. pulchra* was the predominant species encountered in all seasons and habitats. *Gibellula leiopus* was recorded only once in our survey in Taiwan, and was considered to be rare. *Gibellula suffulta*, which was recorded from Fujian (People's Republic of China) by Kao (1981), resembled *G. leiopus* in its conidiogenous structures and very short conidiophores. Sawada described four new species of *Gibellula* from Taiwan, unfortunately type specimens are not available (Sawada, 1919, 1928, 1959; Kobayasi and Shimizu, 1976). However, judging from their illustrations and diagnoses, these four species are either synonymous with previously described *Gibellula* species, or can be excluded from *Gibellula*. *Gibellula formosana* Sawada is probably conspecific with *Paecilomyces tenuipes* (Petch) Samson, *G. tropicalis* Sawada is a synonym of *G. pulchra*, and *G. araneae* Sawada is a typical *G. leiopus*. No illustration was provided for *G.*

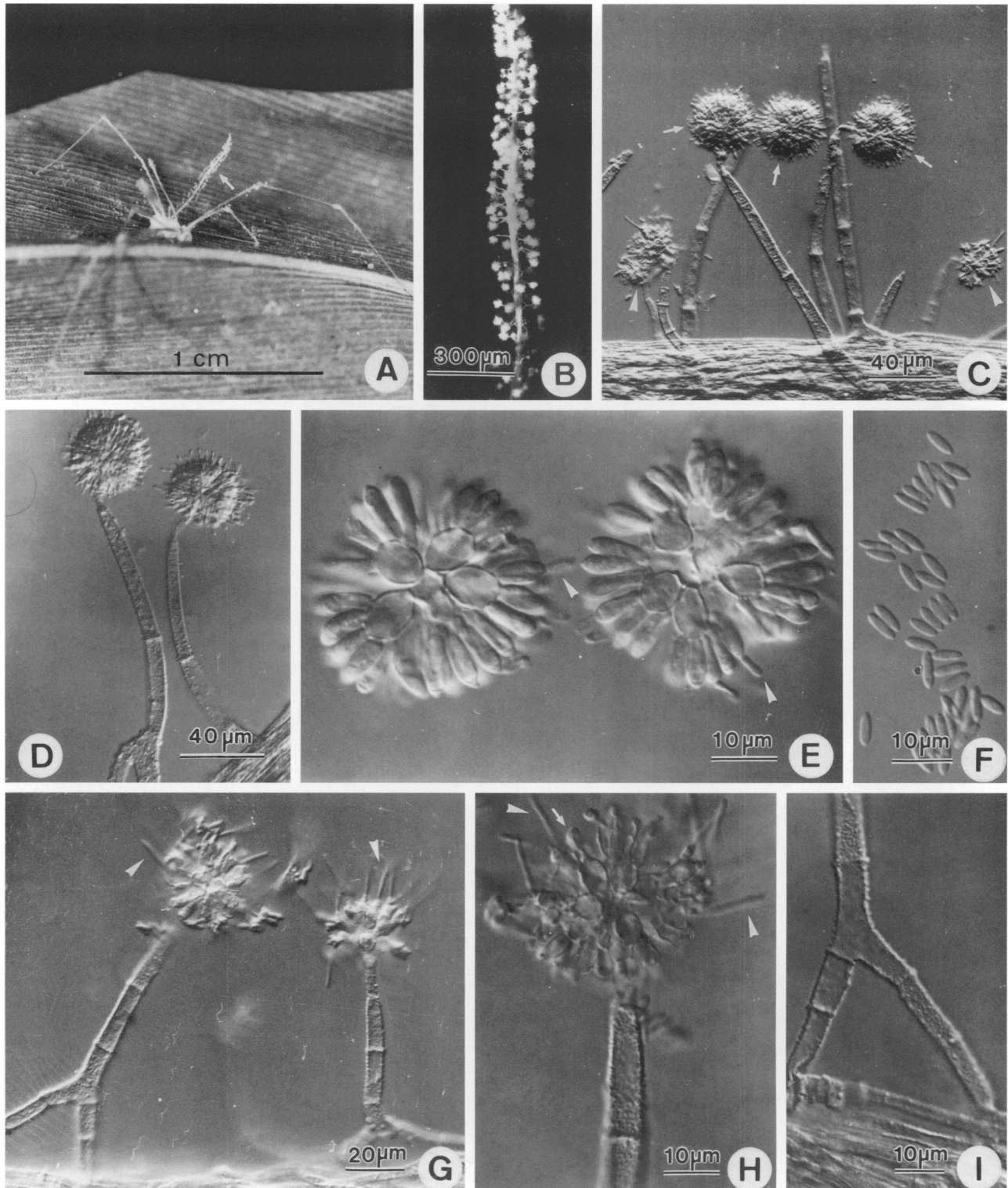


FIG. 5. *Gibellula unica*. A. Habit. A synnema (arrow) arising directly from the abdomen of host. B. Conidiophores dispersed along the whole length of the synnema. C. *Gibellula* (arrows) and *Granulomanus* (arrow heads) synanamorphs located near the base of the synnema. D-F. *Gibellula* synanamorph, conidiophores and conidiogenous cells and conidia. D. Conidiophores with globose conidial heads are conspicuously warted. E. Vesicles bearing metulae and phialides. Conidial initials indicated by arrow heads. F. Conidia. G-I. *Granulomanus* synanamorph. G. The distinctly roughened conidiophores bearing conidial heads and filiform conidia (arrow heads). H. Conidiogenous cells of *Gibellula* and *Granulomanus* synanamorphs concurrently initiated on the vesicle of the same conidiophore, bearing fusiform (arrow) and filiform (arrow heads) conidia. I. Conidiophore with distinct septation and arched base.

TABLE I. Comparison of three varieties of *Gibellula clavulifera* with penicillate conidiophores<sup>a</sup>

Species and variety	<i>Gibellula</i> morph						<i>Granulomanus</i> morph		
	Mycelium	Synnemata	Conidiophores	Metulae	Phialides	Conidia	Conidiogenous cells	Conidia	Teleomorph
<i>G. clavulifera</i> var. <i>clavulifera</i>	Lilac	Grayish to purple, stout, short, cylindrical	Up to 97.3 µm long, 5.4 µm wide, brown, smooth	Cylindrical, 11.6-15.4 × 3.8-5.0 µm	Cylindrical, in groups of 2-4, 1.3-1.7 × 3.0-3.5 µm	Purplish in mass, 6-9 × 1.7-2 µm, fusiform to cylindrical	Holoblastic, cylindrical or irregular, pigmented, 10-18 × 3-4 µm, arising from hyphae	Filiform, 11-17 × 1.2-1.5 µm, smooth, hyaline	Unknown
<i>G. clavulifera</i> var. <i>alba</i>	White	Not formed	100 µm long, stout, hyaline, smooth to asperulate	Cylindrical or clavate, 9-15 × 3-4 µm	Cylindrical, in groups of 2-6, 10-12.4 × 1.5-2.5 µm	Pure white in mass, 5-7.5 × 1.5-2 µm, fusiform	Holoblastic, irregular, smooth, 9-15 × 3-5 µm, arising from hyphae	Bacilliform, 20-30 × 0.5-1.5 µm, smooth, hyaline, often swollen at one end	<i>Torrubiella raticaudata</i>
<i>G. clavulifera</i> var. <i>major</i>	White to yellowish-white	White to yellowish-white, whip-like	Up to 140 µm long, 4.8-7.1 µm wide, hyaline, smooth to slightly roughened	Clavate to cylindrical in groups of 3-10, 12.7-19.8 × 4.0-5.6 µm	Amphulliform to cylindrical, in groups of 2-8, 12.7-19.8 × 3.6-6.0 µm	Pure white in mass, 7.1-13.9 × 2.4-5.6 µm, fusiform to broadly fusitinctly apiculate at both ends	Verticillate, holoblastic, cylindrical to flask-shaped, 9.5-14.6 × 2.7-4.4 µm, arising from stipe	Bacilliform to filiform, 15.9-34.1 × 1.3-2.4 µm, smooth, hyaline, apiculate or round end	Unknown

<sup>a</sup> Data compiled in part from Samson and Evans (1977, 1992) and Humber and Rombach (1987).



TABLE II. Comparison of the morphological characters of *Gibellula unica* and related species<sup>a</sup>

Species	<i>Gibellula</i> morph					<i>Granulomanus</i> morph			
	Synnemata	Conidiophores	Vesicles	Metulae	Phialides	Conidia	Conidiophores	Conidiogenous cells	Conidia
<i>G. unica</i>	In a group of 5, arising all over the host, cylindrical, slender acuminate towards the apex, yellowish gray, 4–5 mm × 96–184 µm, fertile along the length	112–244 µm long, distinctly verrucose at the base	Subglobose to globose, smooth, hyaline, 7.1–9.9 µm diam	Ellipsoidal to obovoidal, hyaline, smooth, 5.6–9.1 × 4.8–7.0 µm	Broadly cylindrical to ellipsoidal, smooth hyaline, 6.4–9.5 × 2.8–4.2 µm	Fusiform, 4.0–6.8 × 1.6–2.2 µm	Mostly arising from the base of synnemata, verrucose, bearing 3–6 conidiogenous cells	Cylindrical, clavate, flask- or irregularly-shaped, verrucose, with 1–3 conspicuous denticles, 6.8–11.9 × 3.2–4.0 µm rough-walled	Filiform, 11.1–17.5 × 1.0–1.6 µm
<i>G. brunnea</i>	Multiple, with a stout yellow-tan stipe, 0.2–0.8 × 0.2–0.4 cm, broadening into globose to pyriform fertile area, 0.5–0.8 × 0.8–1.4 cm, and narrowed into a pale brown compact acuminated sterile tip	350 µm long, distinctly verrucose at the base	Ellipsoidal to globose, verrucose, pigmented, 10–15 µm diam	Ellipsoidal to obovoidal, smooth to roughened walled, hyaline, 10–12 × 6–9 µm	Mostly cylindrical also ellipsoidal, pigmented, smooth to verrucose, 10–13 × 3–4 µm	Fusiform, 8–10 × 2–2.5 µm	Mostly arising from the base of synnemata, verrucose, darkly pigmented, bearing 2–5 conidiogenous cells	Cylindrical, ellipsoidal, with 1–3 distinctly denticles, smooth-walled	Filiform, 10–21 × 1–1.5 µm
<i>G. mirabilis</i>	Paired, pale to golden yellow, 1.5–2 × 0.6–1 mm, consisting of a short stipe and clavate brush-like fertile area, terminating in a short, golden brown sterile tip	80 µm long, slightly verrucose at the base	Ellipsoidal to globose, smooth to verrucose, 8–10 µm diam	Ellipsoidal to obovoidal, smooth, hyaline, 6–9 × 5–8 µm	Broadly cylindrical to ellipsoidal, smooth, hyaline, 5.5–7.5 × 3–4 µm	Fusiform, 5–7 × 2–3.5 µm	Arising from irregularly branched hyphae, bearing solitary or densely whorled conidiogenous cells	Flask- or irregularly shaped with 1–2 distinctly denticles, 5–12 × 3–4 µm, smooth-walled	Filiform, 14–25 × 1–1.5 µm
<i>G. clavata</i>	Single, rarely paired, broadly clavate, 4–6 mm long, with a compact stipe, 1.5–2 × 0.1–0.2 mm, broadening into an ellipsoidal, pink to lilac fertile area	30–50 µm long, slightly verrucose at the base	Ellipsoidal to globose, verrucose, 5–8 µm diam	Ellipsoidal to obovoidal, smooth, hyaline, 6–7.5 × 4–5 µm	Cylindrical, smooth, hyaline, 5.5–7.5 × 2–3 µm	Fusiform, 6–7 × 2–2.7 µm	Arising from irregularly branched solitary conidiogenous cells	Flask or irregularly shaped, with 1–2 distinctly denticles, 5–15 × 3–5.5 µm, smooth-walled	Filiform, 12–15 × 1–1.5 µm

<sup>a</sup> Data compiled in part from Samson and Evans (1992).

*araneicola* Sawada and its diagnosis is not adequate to characterize it. However its entomopathogenic habit indicates that it is probably not a *Gibellula* species, but perhaps a species of *Paecilomyces* Bainier.

*Gibellula clavulifera* is the only *Gibellula* species on spiders known to produce penicillately branched conidiophores. Its three varieties, vars. *clavulifera*, *alba*, and *major*, are distinguished through microscopic and macroscopic characters (TABLE I). Varieties *clavulifera* and *major* produce synnemata whereas var. *alba* is the only known *Gibellula* that does not form synnemata. *Gibellula clavulifera* var. *alba* is recognized most readily by the rat-tail like stroma that arises from the posterior tip of the host's abdomen (Humber and Rombach, 1987). Of the three varieties, only var. *alba* has been linked to a teleomorph, *Torrubiella ratticaudata* Humber & Rombach (Humber and Rombach, 1987).

In its microscopic characters, *G. unica* resembles *G. brunnea*, *G. clavata*, and *G. mirabilis* (TABLE II). However, these *Gibellula* species are easily separated through their synnemata (TABLE II). It is particularly worth noting that *G. unica* and *G. brunnea* are the only species known to produce polyblastic, denticulate conidiogenous cells on well-differentiated conidiophores (TABLE II). Also *G. unica* is the only species that produces *Gibellula* and *Granulomanus* conidiogenous cells, respectively, enteroblastic and apparently holoblastic, on the same vesicle of a conidiophore (FIG. 4 D).

Attempts to culture *G. pulchra*, *G. leiopus*, *G. unica*, and *G. clavulifera* var. *major* collected in Taiwan from single or mass conidia or mycelium on artificial media [potato dextrose agar, 2% malt extract agar, or Sabouraud dextrose agar + 1% yeast extract (SDAY) at 25°C in darkness] failed. Most attempts at culturing *Gibellula* species have not been successful, indicating that they may have specialized growth requirements (Samson and Evans, 1992). However, *Gibellula clavulifera* var. *clavulifera* from Ghana, and *G. pulchra* from Ecuadorian and Brazilian specimens have been grown on mealworm agar or general culture media (Samson and Evans, 1992). Their growth was slow and produced only rudimentary synnemata. *Gibellula clavulifera* var. *alba* (teleomorph *Torrubiella ratticaudata*), from the Solomon Islands, was isolated on SDAY by Humber and Rombach (1987). It sparsely produced penicilloid conidiophores, holoblastic, denticulate polyblastic conidiogenous cells, and a limited number of ovoid, fusiform to bacilliform conidia of *Gibellula* and *Granulomanus* synanamorphs.

#### KEY TO THE *GIBELLULA* SPECIES FROM TAIWAN

1. Conidiophores penicillate; synnemata white, whip-lashlike, arising from the tip of host abdomen . . .

- ..... *Gibellula clavulifera* var. *major*
1. Conidiophores aspergillate; synnemata yellowish, pale orange or grayish purple, multiple, cylindrical, arising from all over the host . . . . . 2
2. Sporulating structures consisting of *Gibellula* and *Granulomanus* morphs . . . . . *Gibellula unica*
2. Sporulating structures consisting of *Gibellula* morph only . . . . . 3
3. Conidiophores 24–80 µm long, mostly smooth, rarely verrucose at the base . . . . . *Gibellula leiopus*
3. Conidiophores 110–640 µm long, distinctly roughened, prominently verrucose at the base . . . . . *Gibellula pulchra*

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