
Studies on the genus *Paecilomyces* in China. I

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Thirty-two taxon of *Paecilomyces* known to China are briefly reviewed. *Paecilomyces cylindricosporus* sp. nov from the soil of ShenLongJia Mountains, Hubei Province is described and illustrated and compared with similar species. This fungus can be distinguished by narrowly cylindrical conidia, obtuse ends and phialides consisting of a narrowly cylindrical basal portion and fusiform or cylindrical middle portion from allied species. Biotechnological research and applications are discussed. A key to Chinese *Paecilomyces* species is provided.

Key words: Biotechnology, China, new species, vitamin.

Introduction

Paecilomyces incorporates many species that have potential broad biotechnological application. Species occur on a great variety of organic substrates. For example, *Paecilomyces variotii* can cause destruction of wood, leather, wood chips, books, cotton yarn and jute. Some *Paecilomyces* species are correlative with human diseases and other species are important entomopathogens and can induce insect diseases. It is important to note that the anamorphs of some *Cordyceps* applied in medications and health foods are *Paecilomyces* species (Liang *et al.*, 2003a).

Some *Paecilomyces* species are thermophilic, for example, the optimum temperature of *Paecilomyces fulvus* is 45°C and *Paecilomyces crustaceus* is up to 55°C (Samson, 1974). They are familiar moulds leading to food deterioration and are also important fungi producing thermotolerant enzymes. Recent studies have shown that some species of *Paecilomyces* can produce very useful bioactive compounds (Liang *et al.*, 2003a).

We are systematically investigating the resources of the genus *Paecilomyces* in China supported by the National Natural Science Foundation of China. This paper will introduce Chinese species of *Paecilomyces* and a new species, *Paecilomyces cylindricosporus* Z.Q. Liang & Y.F. Han.

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Materials and methods

Collection of strain and isolation

Paecilomyces cylindricosporus GZDX-IFR-105 was isolated from soil of ShenLongJia Mountains, Hubei Province, China, in February 2003. Two grams of soil were added into a flask containing 20 ml sterilized water and some glass balls. The soil suspension was diluted into concentrations of 10^{-1} - 10^{-3} after shaking for 10 minutes. Then one ml of soil suspension at concentration of 10^{-3} was mixed with Martin medium in a sterilized 9 cm diam. Petri dish and incubated at 25°C for 5 days. Colonies with conidiogenous structure of *Paecilomyces* were transplanted on Martin's slant for purification.

Identification for strains

The strains studied were transplanted on Czapek agar, potato dextrose agar (PDA) and Sabouraud agar. After incubating at 25-26°C for 14 days, strains studied were identified classically based on colony characters, conidiogenous structures and some biological features (Brown and Smith, 1957; Samson, 1974).

The type culture and holotype, a dried plate culture on Czapek agar of *P. cylindricosporus*, were deposited in the Institute of Fungus Resources, Guizhou University, China.

Description

Paecilomyces amoeneroseus (Henn.) Samson, Studies in Mycology 6: 37 (1974).

Colonies on Czapek were rose-coloured and always formed synnemata consisting of a rose-coloured base and pale red to pruinulose upper portion on Sabouraud agar (Liu and Liang, 2003).

Habitat: An adult of Coleoptera.

Distribution: Guizhou (Liu and Liang, 2003).

Paecilomyces sp.

Zhang *et al.* (1998) used the name *Paecilomyces arovirens* without a Latin diagnosis in reporting a species of *Paecilomyces* and it is therefore invalid. It was isolated from an aphid of peach found in a green house. It can produce metabolites which exhibit insecticidal activity against many insect pests including *Aphis gossypii*, *Tetranychus viennensis* and larvae of *Pietis rapae*. Bioassays on the physiological effects of metabolites from this fungus

on *Triticum aestivum* and *Cucumis sativus* and also naphthye acetic acid (NAA) showed that physiologically active metabolite(s) from this fungus are similar to NAA, while others are different. The results indicate that the metabolites of this fungus comprise a new type or many types of plant growth regulators. The fungus may be useful for developing a new insecticide that can not only control insect pests, but also can stimulate plant growth (Zhang *et al.*, 1998).

Habitat: Aphids of peach in green house.

Distribution: Beijing.

Paecilomyces atrovirens Z.Q. Liang & A.Y. Liu, Acta Mycologica Sinica 12: 110 (1993). (Fig. 3)

Colonies on Czapek agar limited, after 14 days at 25°C diam. 6-7 mm, dark green, white near margin; reverse pale brown. *Hyphae* 1.8-2 µm wide. *Phialides* 5.3-8 × 2.5 µm, the basal portion lecythiform. *Conidia* smooth, cylindrical, (4.2-)5.4-7.2 × 2.4(-3) µm, always congregating into a long imbricate chain. *Macro-conidia* smooth, ellipsoidal, 3.6 × 2.5 µm, or subglobose, 4.2-6 µm diam.

Liang *et al.* (1993) collected and isolated the fungus from *Telligonia* sp. in Fanjing Mountain Preserve in Guizhou Province. The fungus can be distinguished from the other species as (1) colony on Czapek growing rather slowly and being dark green; (2) the basal portion of phialides being lecythiform, and (3) cylindrical conidia forming imbricate chains (Fig. 3).

Habitat: An adult of *Telligonia* sp.

Distribution: Guizhou (Liang *et al.*, 1993).

Paecilomyces breviramossus Bissett, Fungi Canadenses 159: 1 (1979).

Host covered by white to yellowish-white mycelia, powdery. *Conidiophores* smooth-walled, bearing groups of swollen lateral cells, globose, ellipsoidal to cylindrical, 3.2-5.6 × 2.8-4.8 µm, further branching, giving rise to 1-5 smaller swollen cells or 1-6 phialides in the first or second order, occasionally the phialides solitarily arising from hyphae. *Phialides* smooth-walled, 3.2-2.5 × 2-3.2 µm, flask-shaped, with a globose to subglobose basal portion, tapering into a long thin neck. *Conidia* ovoid to ellipsoidal, often asymmetrically apiculate, sometimes lemon-shaped, one-celled, catenulate, 2.4-3.2 × 1.6-2.1 µm (Tzean *et al.*, 1997).

Habitat: A larva of Lepidoptera.

Distribution: Taiwan (Tzean *et al.*, 1997).

Paecilomyces carneus (Duché & Heim) Brown & Smith, Trans. Br. Mycol. Soc. 40: 70 (1957).

This fungus is collected from Hunan Province, China. Its conidia have been used to control 2, 5 and 6 generations of whitefly. The population of pests can be reduced to 47-81% after 12 days (Pu and Li, 1996).

Habitat: Soil.

Distribution: Hunan (Pu and Li, 1996).

Paecilomyces cateniannulatus Z.Q. Liang, Acta Microbiologica Sinica 21: 32 (1981). (Fig. 1)

Colonies on Czapek agar appear consistently white. *Conidiophores* short, arising primarily from the aerial hyphae. *Phialides* consisting of a globose or ellipsoidal inflated basal portion and a thin long neck. *Conidia* small, oval to ellipsoidal, $2-3.5 \times 1-1.5 \mu\text{m}$, the conidial chains usually lying broadside to each other and sliming to form a ring or irregular mass.

Paecilomyces cateniannulatus can easily be distinguished from closely related species such as *P. farinosus* and *P. fumosoroseus* by the white colour of its colony and the specific ring, in imbricate conidial chains. This fungus was isolated from many insects in Guizhou (Liang, 1981a) and Anhui (Huang *et al.*, 2002). Recently we isolated it from some dead insects in Yunnan Province and soil in Beijing.

The genetic variation of 12 species of *Paecilomyces* by RAPD has been reported (Huang *et al.*, 2002). The experimental results showed that the similarities between *P. cateniannulatus* and *P. farinosus* are only 26-38%, so the RAPD amplification pattern between them is very distinct.

In our laboratory, the results of preliminary experiments showed that some strains of this fungus have strong pathogenicity against an aphid and nematode.

Habitat: Some insects of Lepidoptera.

Distribution: Anhui (Huang *et al.*, 2002), Guizhou (Liang, 1981a).

Paecilomyces cateniobliquus Z.Q. Liang, Acta Microbiologica Sinica 21: 31 (1981). (Fig. 2)

Colonies on Czapek agar shrimp pink to deep rose to near shrimp pink - brazil red; synnemata awl-shaped and rosy; reverse orange-yellow to rose-purple. *Phialides* consisting of a cylindrical or globose inflated basal portion and tapering into a thin neck, $0.5 \mu\text{m}$ wide, $5-12 \times 1-2.5 \mu\text{m}$. *Conidia* ellipsoidal or somewhat irregularly cylindrical and arranged into imbricate chain.

All of the above-stated characters are different from any other species related in the genus *Paecilomyces* (Fig. 2).



Fig. 1. *P. cateniannulatus*. Bar = 10 μ m.



Fig. 2. *P. cateniobliquus*. Bar = 10 μ m.



Fig. 3. *P. atrovirens*. Bar = 5 μ m.



Fig. 4. *P. gunnii*. Bar = 5 μ m.

Habitat: A pupa of *Adoxophyes privatana* Walker.

Distribution: Anhui (Huang *et al.*, 2002), Guizhou (Liang, 1981a).

Paecilomyces cicadae (Miq.) Samson, *Studies in Mycology* 6: 52 (1974).

Colonies on natural substrates such as wheat, mycelium floccose to cottony, greyish to light yellow.

The fungus produces orange or vitelline synnemata after 20 days on solid media (Chen, 1991). Pharmacological assays revealed that artificial cultivation has evidence for anti-pain, sedation, analgesia and allaying fever (Chen *et al.*, 1993).

Habitat: Nymphs of *Cicada*.

Distribution: Anhui (Huang *et al.*, 2002), Guizhou (Liang *et al.*, 1993), Zhejiang (Chen, 1991).

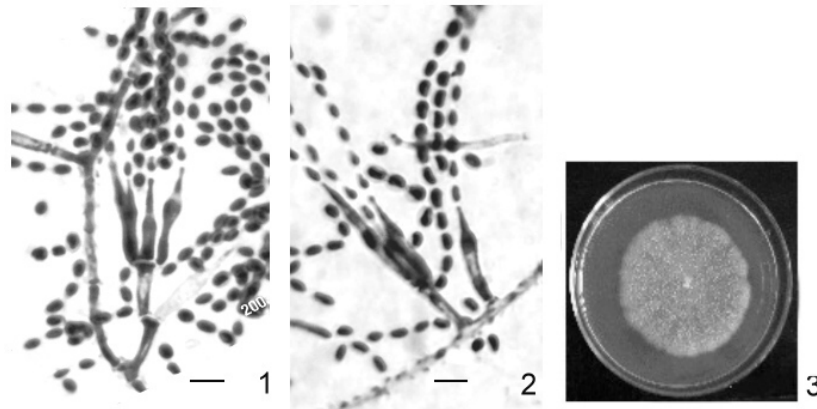


Fig. 5. Colonial feature and conidiogenous structure of *P. cylindricosporus*. **1, 2.** Phialides and conidia. **3.** A colony on Czapek agar. Bars = 5 µm.

***Paecilomyces cylindricosporus* Z.Q. Liang, Y.F. Han, *sp. nov.* (Fig. 5)**

Coloniae in agar Czapekii, ad 55-60 mm diam., 14 diebus 25°C, albae, planae, tenues, dispersione granulorum, radiatis sulculis et undulatis marginibus; *Mycelium ex hyphis* septatis, hyalinis, laevibus, 0.5-2.5 µm. crassis compostum. *Conidiophora* erecta, hyalina, laevia, simplicia, 14-47 × 0.5-2.5 µm, verticillis e 2-5 phialidibus. Phialides 7-15 × 1-5 µm, ad basem angustae cylindricae et ad centrum explanatae fusiformes vel cylindricae, angustatae collo longo minus quam 0.6 µm. *Conidia* monocellula, hyalina, vulgo cylindrica, aliquot ellipsoidea ad ovata, 1.3-3 × 0.5-1.3 µm, facientia divergentes, catenas exsiccatas.

Holotypus GZDX-IFR-105 isolatus ex solo ShenLongJia, Hubei Provincia, Sina, II, 2003, Guo Xuhui.

Colonies on Czapek agar at 25°C, 14 days, 55-60 mm in diam., white, flat, thin, with white disperse granules, with radiating furrow and wavy margins; reverse white. *Vegetative hyphae* septate, hyaline, smooth-walled, 0.5-2.5 µm wide. *Conidiophores* erect, hyaline, smooth-walled, simple, 14-47 × 0.5-2.5 µm, rarely branching, with whorls of 2 to 5 phialides. *Phialides* 7-15 × 1-5 µm, consisting of a narrowly cylindrical basal portion and flat fusiform or cylindrical at the centre, tapering into a thin neck, less than 0.6 µm wide. *Conidia* one-celled, hyaline, smooth-walled, most sub-cylindrical, with rounded ends, few ellipsoidal to ovate, 1.3-3 × 0.5-1.3 µm, forming divergent, dry chains.

Colonies on PDA at 25°C within 14 days, usually growing more rapidly than on Czapek agar, 65 mm, consisting of a felty grey mycelium, with dense white granules. Reverse brown in centre, with margin irregular, orange.

Colonies on Sabouraud agar, growing more rapidly than on Czapek agar, about 70 mm diam., consisting of a felt grey mycelium, with dense white granules, sometimes yellow in centre, with margin regular; reverse yellow to orange.

Holotype here designated: China, Hubei Province, ShenLongJia Mountains, isolated from soil, February 2003, collected by Guo Xuhui, GZDX-IFR-105.

Table 1. A comparison between *P. cylindricosporus* and its related species.

Species	Colony	Phialides	Conidia
<i>P. cylindricosporus</i>	White	Fusiform	Cylindric-ellipsoidal 1.3-3 × 0.5-1.3 μm
<i>P. ampullaris</i>	White	Fusiform	Subglobose-ellipsoidal 2.2-3.4 × 2-2.6 μm
<i>P. fimetarius</i>	Rose	Fusiform	Ellipsoidal 6.5-10 × 5-6 μm

Matsushima (1971, 1975) have reported five new species in *Paecilomyces* which have simple conidiophores and phialides which directly arise from the mycelium. Among these, the phialides in *P. ampullaris* Matsush. is most similar to this new species, but in *P. ampullaris* the subglobose-ellipsoidal conidia are distinct (Table 1). In addition, phialides of *P. fimetarius* (Moesz) Brown & Smith are also similar to this species, but *P. fimetarius* has large ellipsoidal conidia (6.5-10 × 5-6 μm) (Brown and Smith, 1957).

Paecilomyces cylindricosporus can be distinguished from the other species in the genus as: (1) colonies on Czapek agar are flat and very thin, (2) phialides consist of a narrowly cylindrical basal portion are fusiform or cylindrical in the middle, (3) most conidia are subcylindrical.

Paecilomyces farinosus (Holmsk.) Brown & Smith, Trans. Br. Mycol. Soc. 40: 50 (1957).

The nuclear staining showed that both conidia and mycelia are multinucleate. The heterokaryosis in the fungus is also stable in its life cycle (Liu and Wu, 1992).

Habitat: Larvae of Lepidoptera.

Distribution: Guizhou (Liang, 1981b), Taiwan (Tzean *et al.*, 1997), Anhui (Huang *et al.*, 2002), Shanxi (Li *et al.*, 2003a).

Paecilomyces fumosoroseus (Wize) Brown & Smith, Trans. Br. Mycol. Soc. 40: 67 (1957).

Zeng *et al.* (1965) reported *P. fumosoroseus* for the first time in Liaoning Province, China. The fungus can infect the pupae of *Crossocosmia tibialis* in nature and the infection rate was 3.4%-20.3%. Subsequently, this fungus has been discovered elsewhere in China.

Habitat: Some insects and soil.

Distribution: Jilin, Guizhou, Henan, Anhui, Shanxi and Taiwan (Tai, 1979; Liang, 1981b; Tzean *et al.*, 1997; Huang *et al.*, 2002; Li *et al.*, 2003a).

Paecilomyces fumosoroseus* var. *beijing Q.X. Fang & Q.T. Chen, Acta Mycologica Sinica 2: 168 (1983).

Colonies on malt extract agar grey, 14 days, at 25°C, attaining a diam. of 15 mm. *Conidiophores* single, with verticillate branches, 40-60 × 2-3 μm.

Phialides ampullaceous, $5-6 \times 2-3 \mu\text{m}$. *Conidia* cylindrical to spindly, $3-4 \times 1-2 \mu\text{m}$, forming long chains.

Paecilomyces fumosoroseus var. *beijingensis* was isolated from *Trialeurodes vaporariorum* from a green house in Beijing. The main differences from the original species are that the growth is slower; the colony is grey and no synnemata are produced. In appropriate conditions, *P. fumosoroseus* var. *beijingensis* was shown to infect nymphae of *T. vaporariorum* in a green house with a death rate of 80-90% (Fang *et al.*, 1983).

Habitat: Adults of *Trialeurodes vaporariorum*.

Distribution: Beijing (Fang *et al.*, 1983).

Paecilomyces griseiviridis M.X. Dai, *Mycosystema* 17: 209 (1998).

Colonies on Czapek agar and PDA are greyish-green, reverse brown and conidia spindle-shaped ($1.2-1.8 \times 2.8-4.4 \mu\text{m}$).

Dai (1998) isolated this fungus from dead *Aphis gossypii*. This fungus can be distinguished from related species by greyish-green colonies on Czapek agar, phialides with a ellipsoid or cylindric inflated basal portion and spindle-shaped or fusiform conidia. Assays showed that death of aphids can attain 70% after 8 days if the concentration of spores is $1.5 \times 10^8/\text{ml}$, at 22°C , with relative humidity of 90%. The fermentation extract of the fungus also has insecticide activity (Dai, 1998).

Habitat: A dead *Aphis gossypii* Glover.

Distribution: Shandong (Dai, 1998).

Paecilomyces gunnii Z.Q. Liang, *Acta Mycologica Sinica* 4: 163 (1985) (Fig. 4)
= *Paecilomyces hawkesii* Z.M. Xiao, T.B. Li & Q.T. Chen, *Acta Mycol. Sin.* 3: 109 (1984).

Colonies on Czapek agar growing slowly, attaining a diam. of 25-28 mm, 14 days, at 25°C , vegetative hyphae $1.5-2.5 \mu\text{m}$ wide, submerged hyphae $2-4 \mu\text{m}$. *Conidiophores* mainly arising from aerial hyphae, short, about $60 \mu\text{m}$. *Phialides* $7-19 \times 2-3 \mu\text{m}$, consisting of a swollen basal portion, tapering into a long thin neck, sometimes slightly bending away from the main axis, some phialides proliferous, forming 1-2 lateral necks. *Conidia* ellipsoidal oval or fusiform, $1.6-4.8 \times 1.2-3.5 \mu\text{m}$, spinuose, in divergent chains.

In the genus *Paecilomyces*, rare species have echinulate conidia. *Paecilomyces gunnii* can be distinguished from other species in having a grey colony on Czapek agar and echinulate conidia (Fig. 4).

Some experimental results using mycelial fermentation showed that the LD_{50} of powder given orally to rats was more than 6g/kg and the LD_{50} of liquids given orally, hypodermatically and intraperitoneally were more than 30g/kg. In the subchronic toxicity experiment, rats were fed a diet containing up to 3g/kg/day of mycelia of *P. gunnii* for 3 months. The blood findings,

livers and kidney functions and pathological sections of viscera were all normal. The cultured mycelia showed no embryo toxic and teratogenic effects on mice at dose levels up to 6g/kg/day for 18 days. The results of Ames, micronucleus and sister chromosome exchange tests showed that *P. gunnii* had no mutagenicity affects. Fermentation mycelia had efficacies of sedation, analgesia, enhancing memory, protecting brain from oxygen deficiency, reducing the oxygen consumption of heart muscle in the case of oxygen deficiency and improving the phagocytic effect of peritoneal macrophages in mice. Mycelia were also rich in various amino acids, VC, VE and nicotinic acid (Liang *et al.*, 1991).

Paecilomyces hawkesii is similar to *Paecilomyces gunnii* in some aspects such as cultivation character and micro-characters. In recent years molecular analysis have shown that they are the same species (Liu *et al.*, 2002).

Habitat: Larvae of a species of *Hepialidae*.

Distribution: Guizhou (Liang, 1985), Hunan (Chen *et al.*, 1984b).

Paecilomyces gunnii* var. *minor Z.Z. Li, C.R. Li, B. Huang, M.Z. Fan & M.W. Lee, Korean Journal of Mycology 27: 232 (1999).

Colonies on Czapek agar white or yellowish-white, attaining a diam. of 29 mm, 14 days at 25°C. *Conidiophores* erect, cylindrical, hyaline, 11-95 × 1.3-2.2 µm. *Phialides* ampullaceous 12.6-39.6 × 1.4-2.7 µm, consisting of a cylindrical and somewhat inflated base, tapering into a thin long neck. *Conidia* subglobose or fusiform, spinose, 2.2-11 × 1.8-3.3 µm.

This fungus is very similar to the *P. gunnii*. It differs from the later mainly by the colony colour and conidial size. The colour of colony reverse of *P. gunnii* var. *minor* is olive-yellow to olive-green on Czapek medium and the conidia are subglobose or fusiform (Li *et al.*, 1999).

Habitat: Larvae of *Phassus excrescens* Bulter (Lepidoptera: Hepialidae).

Distribution: Anhui (Li *et al.*, 1999).

Paecilomyces huaxiensis Z.Q. Liang & Y.F. Han, Mycotaxon 91: 362 (2005).

Colonies on Czapek agar usually growing rapidly, attaining a diam. of 45-49 mm within 14 days at 25°C; dense felty, flat, giving a powdery appearance, sometimes with tiny dewdrops; yellow in middle, then saffron yellow, white at margin; after long culture becoming red; reverse scarlet, saffron yellow to yellow from centre to margin; vegetative hyphae septate, hyaline, smooth-walled, 1.2-3 µm wide. *Conidiophores* short, hyaline, smooth-walled, 27-45 µm, with whorls of 2 to 4 phialides. *Phialides* 7-18 × 0.6-1.8 µm, consisting of a narrowly cylindrical basal portion, tapering to a thin neck, less than 0.5 µm wide. *Conidia* one-celled, hyaline, smooth-walled, mostly ellipsoidal to ovate, 1.2-2.4 × 0.9-2 µm, forming divergent, dry chains.

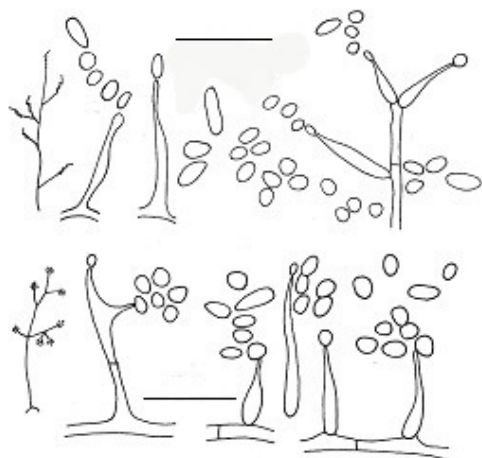


Fig. 6. *P. militaris*. Bar = 10 μ m.



Fig. 7. *P. loushanensis*. Bar = 10 μ m.

Paecilomyces huaxiensis differs from other species by (1) colony saffron-yellow on Czapek agar, (2) phialides consisting of more or less cylindrical bases that taper abruptly to a long thin neck in compact whorls, and (3) small, ellipsoidal conidia.

Habitat: Soil surrounding a corn root system.

Distribution: Huaxi, Guiyang, Guizhou Province (Han *et al.*, 2005b).

Paecilomyces javanicus (Friedrichs & Bally) Brown & Smith, *Trans. Br. Mycol. Soc.* 40: 65 (1957).

Formation of fruiting body by artificial culture has shown that *P. javanicus* may be the anamorph of *Cordyceps scarabaeicola* (Liang *et al.*, 1993).

Habitat: Larvae of Lepidoptera.

Distribution: Guizhou (Liang *et al.*, 1993), Taiwan (Tai, 1979; Tzean *et al.*, 1997).

Paecilomyces lilacinus (Thom) Samson, *Stud. Mycol.* 6: 58 (1974).

Yunnan University, Xiamen University and Nanjing Agricultural University have experimented with using this fungus as a bioinsecticide. At the same time the fungus has been found to produce many kinds of metabolites, which can stimulate plant growth (Lin *et al.*, 1999).

Habitat: Soil.

Distribution: Anhui (Huang *et al.*, 2002), Shanxi (Li *et al.*, 2003a).

Paecilomyces loushanensis Z.Q. Liang & A.Y. Liu, *Mycosystema* 16: 62 (1997). (Fig. 7)

Paecilomyces loushanensis is the anamorph of *Cordyceps loushanensis* (Liang *et al.*, 1997). Its cylindrical conidia always aggregate into imbricate chains (Fig. 7).

Synnemata claviform, arising from the cocoon of a species of Lepidoptera, simple, 3-10 fasciculate, white, 35 × 1 mm. *Colonies* on Czapek agar white or yellowish, attaining a diam. of 45 mm, 14 days at 25°C. *Conidiophore* erect, ramose. *Phialides* consisting of a cylindrical, pyriform or subglobose inflated base, tapering into a thin long neck. *Conidia* elongate cylindrical, 5.4-13 × 2-3.6 μm, always aggregating into a decussate long chain, occasionally bi-celled, 12 × 2.5 μm.

Habitat: A larva of Lepidoptera.

Distribution: Guizhou (Liang *et al.*, 1997).

Paecilomyces marquandii (Mass.) Hughes, Mycol. Pap. 45: 30 (1951).

Studies have shown that *P. marquandii* has a high vitamin A and E content (Han *et al.*, 2003).

Habitat: Soil.

Distribution: Hebei, Jiangsu (Tai, 1979), Fujian (Han *et al.*, 2003), Hong Kong (Ho *et al.*, 2002).

Paecilomyces militaris Z.Q. Liang, *Acta Edulis fungi* 8: 29 (2001). (Fig. 6)

Colonies on Czapek agar white to yellowish, attaining a diam. of 50 mm within 14 days at 25°C, reverse bright yellow. *Phialides* solitarily or fasciculate arising from aerial hyphae or conidiophore, usually with cylindrical swelling at the basal portion, 0.5-1.5 × 6-20 μm, tapering into a thin long neck, sometimes awl-shaped, 1-1.5 × 12-20 μm. *Conidia* one-celled, hyaline, smooth-walled, subglobose, 1.5-2 μm in diam., or ovate, 1-2 × 1.5-3 μm. The conidia at the tip of chains, elongate cylindrical, 0.8-1.5 × 3-8 μm, conidia always aggregating into long imbricate chains or in loose heads.

Kobayasi (1941) first considered *Cephalosporium militare* as the anamorph of *Cordyceps militaris* in his monograph of *Cordyceps*, but he did not formally describe *C. militare* (no Latin description). Brown and colleagues put forward different opinions for the classified status of the anamorph of *C. militaris* (Brown and Smith, 1957; Gams, 1971; Balazy, 1973), but they were based on Kobayasi's informal specific names. Liang (1990, 2001) and Liang and Fox (1998) used *P. militaris* as the anamorph of *C. militaris* and formally described and published it in Latin based on the studied results of morphology and biology (Fig. 6), where the mature sexual fruit body of *C. militaris* had been artificially cultivated from *P. militaris*. Results showed that an optimum medium could upgrade the content of cordycepin up to 1.21%, which is 8 times more than CK in Czapek liquid (Li *et al.*, 2003b).

Habitat: Various insects of Lepidoptera.

Distribution: Widespread in China (Tai, 1979).

Paecilomyces odonatae Z.Y. Liu, Z.Q. Liang & A.Y. Liu *Mycosystema* 8, 9: 84 (1996).

Colonies on PDA spreading broadly, 5-6.2 cm in diam. at 25°C for 14 days, fire-rock-brown, fluffy and pale yellow in reverse. Two types of *conidiogenous structure*, (1) *Paecilomyces*-type of conidiogenous structure: smooth-walled, hyaline, consisting of single or verticillate branches with whorls of 2-4 phialides; phialides $1.8-2.4 \times 4.8-17 \mu\text{m}$, with a swollen basal portion tapering into a distinct neck. *Conidia* ellipsoidal to fusiform, $1.8-2 \times 2.4-2.8 \mu\text{m}$, in chains; (2) *Acremonium*-type of conidiogenous structure: phialides awl-shaped or sometimes in a little basal portion-swollen, $1.8-2 \times 4.8-17 \mu\text{m}$. *Conidia* cylindrical, $2.4-4.2 \times 1.7-2.2 \mu\text{m}$, sliming together in head. Two types of conidiogenous structures sometimes were found on one hypha or conidiophore.

This fungus was isolated from a cadaver of dragonfly infected by *Cordyceps odonatae*. The typical character distinguished it from the other species of *Paecilomyces* was the two types of conidiogenous structures, which are the *Paecilomyces*-type with ellipsoidal conidia in chains and the *Acremonium*-type with cylindrical conidia in a slime head (Liu *et al.*, 1996).

Habitat: A dead dragonfly.

Distribution: Guizhou (Liu *et al.*, 1996).

Paecilomyces persicinus Nicot., Bull. Trimest. Soc. Mycol. Fr. 74: 227 (1958).

= ***Acremonium persicinum*** (Nicot) W. Gams, *Cephalosporium-artige Schimmelpilze* (Stuttgart): 75 (1971).

This taxon had been transferred to the genus *Acremonium*, some strains in the species have echinulate conidia (Gams, 1971).

In China *P. persicinus* was isolated from a rice leaf with lesion of bacterial blight in Wuhan, Hubei. Studies showed that this fungus can produce a new peptide antibiotic, which exhibits anti-microbial activity against several Gram-positive and Gram-negative bacteria. The minimal inhibitory concentration against *Xanthomonas oryzae* pv. *oryzae* was 0.2 $\mu\text{g/ml}$ (Zhen *et al.*, 1993).

Habitat: An insect.

Distribution: Hubei (Zhen *et al.*, 1993), Sichuan (Tai, 1979).

Paecilomyces puntonii (Vuill.) Nannizzi, Tratt. Micopatol. Umana 4: 245 (1934).

Colonies reverse white on Czapek medium. *Conidiophores* short, simple. *Conidia* fusiform, small, $1.3-3 \times 1-2 \mu\text{m}$ (Han *et al.*, 2003).

Habitat: Soil.

Distribution: Guizhou (Han *et al.*, 2003).

Paecilomyces rariramus Z.Q. Liang & B. Wang, Fungal Diversity 12: 129 (2003).

Pupae of host insect covered with yellowish mycelia. *Synnemata* white to pale yellow, capitate, several; ramified at upper part, ellipsoidal, compact farinose, 3-7 × 2-3 mm. *Stipe* 10 mm long and 1-2 mm thick. *Hyphae* of conidiogenous structure 1.5-3 µm thick, with few ramifications. *Phialides* 4.5-5 × 2-2.5 µm, globose or subglobose at basal portion, inflated, tapering up into a thin neck, 1.5-1.8 µm long and 0.4 µm wide. *Conidia* subglobose, hyaline, smooth-walled, 1-1.5 × 1.2-1.8 µm.

Paecilomyces rariramus has fewer ramifications in the conidiogenous structure than the others members in the genus (Liang *et al.*, 2003c). Moreover, the synnemata have a compact farinose head and subglobose conidia.

Habitat: Pupa of a species of Lepidoptera.

Distribution: Sichuan (Liang *et al.*, 2003c).

Paecilomyces sinensis Q.T. Chen, S.R. Xiao & Z.Y. Shi, Acta Mycol. Sin. 3: 25 (1984).

Colonies on PDA white, attaining 20mm in 14 days at 25°C. *Synnemata* simple, white, solitarily or fasciculate, 10-50 mm long. *Phialides* flask-shaped, somewhat swollen at the basal portion, 9-56.3 × 2-3.8 µm. *Conidia* hyaline, smooth-walled, spindle, oblong ovate or lanceolate, 4.5-7.5 × 1.2-3.8 µm, aggregating into long chains or pseudo heads.

Chen *et al.* (1984a) isolated this fungus from a fresh specimen of *C. sinensis* collected from Kangding County, Sichuan Province, China. The morphological characters of this fungus are quite similar to the *P. militaris* except for the shape and size of conidia as well as size of phialides.

Habitat: Larvae of a species of Hepialidae.

Distribution: Sichuan (Chen *et al.*, 1984a).

Paecilomyces stipitatus Z.Q. Liang & Y.F. Han, Mycotaxon 92: 312 (2005).

Colonies on Czapek agar, attaining a diam. of 50 to 60 mm within 14 days at 25°C, flat, white, felt, regular in the margin; reverse yellowish. *Vegetative hyphae* hyaline, smooth-walled, 1.1-3.5 µm wide. *Conidiophores* ramose, directly bearing conidiogenous cell or consisting of verticillate branches with whorls of 2 to 5 phialides. *Phialides* 9.7-24.2 × 1.4-2.5 µm, consisting of a swollen, cylindrical or ellipsoidal basal portion, usually having a long and septate stalk under the swollen basal portion, tapering into a thin neck, less than 0.5 µm wide. *Conidia* one-celled, hyaline, smooth-walled, subglobose or ellipsoidal or fusiform, 1.7-5.9 × 1.3-3.3 µm.

Habitat: Soils.

Distribution: Hubei and Heilongjiang Province (Han *et al.*, 2005a).

Paecilomyces suffultus (Petch) Samson, Stud. Mycol. 6: 55 (1974).

The conidiogenous structure, especially conidial size and shape of *Paecilomyces suffultus* are similar to *P. cicadae*. The former differs from the later by having larger ($5.4-12 \times 2.4-5.5 \mu\text{m}$) and straight conidia (Liang *et al.*, 1993).

Habitat: A larva of Lepidoptera.

Distribution: Guizhou (Liang *et al.*, 1993).

Paecilomyces taitungiacus K.Y. Chen & Z.C. Chen, Mycotaxon 60: 226 (1996).

Colonies on YpSs growing over plate at 40°C within 6 days, aerial and prostrate hyphae abundant, white to yellow. *Conidiophores* erect, hyaline, septate, smooth-walled, consisting of an irregularly arranged branch system, and with the apex of each branch bearing 1-3 phialides. *Phialides* $2.8-5.6 \times 18-32 \mu\text{m}$, cylindrical or slightly flask-shaped, with a thin neck, up to 8 μm long. *Conidia* smooth-walled, cylindrical, $2.2-3.4 \times 4-7 \mu\text{m}$ or ellipsoidal, $3-5.5 \times 5-8 \mu\text{m}$ to subglobose, 2.5-6 μm in diam. (Chen and Chen, 1996).

This fungus is a thermophilic. The optimum temperature for mycelial growth was between 30°C and 40°C. The most abundant production of conidia was observed at 40°C (Chen and Chen, 1996).

Habitat: Weed soils.

Distribution: Taiwan (Chen and Chen, 1996).

Paecilomyces tenuipes (Peck) Samson, Stud. Mycol. 6: 49 (1974).

Some pharmacological functions of *P. tenuipes* have been tested. The LD₅₀ of extracts of this fungus to mice was about 17.62g/kg by abdominal injection and LD₅₀>70g/kg per oral administration. The endurance of anoxia in normal pressure, function of sedation and analgesia to mice were distinctly different from the control (Chen and Xu, 1989).

Artificial cultures compared with natural *C. sinensis* showed that their IR spectrum and the thin-layer chromatography all are similar (Chen and Chen, 1990).

The teleomorphic stage of this fungus, *Cordyceps takaomontana*, was recently recorded for the first time in Guizhou Province, China (Liang *et al.*, 2003b).

Habitat: Some insects.

Distribution: Anhui (Huang *et al.*, 2002), Guizhou (Liang, 1981b), Zhejiang (Chen and Xu, 1989), Taiwan (Tzean *et al.*, 1997).

Paecilomyces variotii Bainier, Bull. Soc. mycol. Fr. 23: 27 (1907).

Paecilomyces variotii is a common fungus. We have isolated this fungus from air in our laboratory recently. Its colony colour is tan on Czapek agar.

The size of larger conidia are $6-12 \times 1.5-3 \mu\text{m}$ and the smaller ones only $3-6 \times 1.5-2.5 \mu\text{m}$.

Habitat: Soil.

Distribution: Hebei, Hubei, Sichuan (Tai, 1979), zhejiang, Hunan (Pu and Li, 1996), Guizhou.

Paecilomyces vinaceus Y.F. Han & Z.Q. Liang, Mycotaxon 92: (2005).

Colonies on Czapek agar, attaining a diam. of 35 to 40mm within 14 days at 25°C, white, floccose, sometimes having dewdrops on the surface; reverse yellow to vinaceous from the centre to margin, appearing radial furrow and soluble pigment. *Vegetative hyphae* hyaline, smooth-walled, $1.3-3.7 \mu\text{m}$ wide. *Conidiophores* simple, rare, always consisting of verticillate branches with whorl of 2 to 3 phialides. *Phialides* $7-15.5 \times 1.4 - 2.8 \mu\text{m}$, consisting of a swollen, clavate basal portion, tapering into a thin neck, less than $0.5 \mu\text{m}$ wide. *Conidia* one-celled, hyaline, smooth-walled, subglobose to ellipsoidal, $2.6-3.6 \times 1.3 - 2.6 \mu\text{m}$.

Habitat: Soil.

Distribution: Shandong Province (Han *et al.*, 2005a).

Key to species of *Paecilomyces* in China

- | | | |
|----|--|------------------------------------|
| 1. | Conidia echinulate | 2 |
| 1. | Conidia non-echinulate | 4 |
| 2. | Colony pink on Czapek agar | <i>P. carneus</i> |
| 2. | Colony white on Czapek agar | 3 |
| 3. | Conidia ellipsoidal oval or fusiform | <i>P. gunnii</i> |
| 3. | Conidia subglobose or fusiform | <i>P. gunnii</i> var. <i>minor</i> |
| 4. | Phialides with a septate thin stalk | <i>P. stipitatus</i> |
| 4. | Phialides without a septate thin stalk | 5 |
| 5. | Conidia aggregating into an imbricate chain | 6 |
| 5. | Conidia aggregating into a straight chain | 10 |
| 6. | Colony white to yellowish, conidia sometimes aggregating into a head | <i>P. militaris</i> |
| 6. | Colony dark or bright coloured | 7 |
| 7. | Colony dark green, phialides with a basal portion in lecythiform | <i>P. atrovirens</i> |
| 7. | Colony bright coloured | 8 |
| 8. | Colony pale red, phialides with a cylindrical basal portion | <i>P. cateniobliquus</i> |
| 8. | Colony white | 9 |
| 9. | Conidia ellipsoidal, 2-3.5 μm long | <i>P. cateniannulatus</i> |
| 9. | Conidia cylindrical, 5.4-13 μm long | <i>P. loushanensis</i> |

10. Colony rose, saffron yellow or purple	11
10. Colony white or other	14
11. Colony rose.....	<i>P. amoeneroseus</i>
11. Colony saffron yellow or purple	12
12. Colony saffron yellow	<i>P. huaxiensis</i>
12. Colony purple	13
13. Colony reverse pale red to purple	<i>P. lilacinus</i>
13. Colony reverse yellow	<i>P. marquandii</i>
14. Colony pink, grey or greyish green.....	15
14. Colony other colours.....	17
15. Colony pink, conidia 3-4 × 1-2 μm	<i>P. fumosoroseus</i>
15. Colony grey or greyish green.....	16
16. Colony grey, conidia cylindrical to spindly, 3-4 × 1-2 μm.....	<i>P. fumosoroseus</i> var. <i>beijing</i>
16. Colony greyish green, conidia fusiform, 2.8-4.4 × 1.2-1.8 μm.....	<i>P. griseiviridis</i>
17. Colony yellowish or olive, conidia 3-12 × 1.5-3 μm.....	<i>P. variotii</i>
17. Colony white to yellowish	18
18. Colony white, reverse yellow to vinaceous, with whorl of 2 to 3 phialides	<i>P. vinaceus</i>
18. Not with combination of above characters	19
19. Conidia less than 3.5 μm long	20
19. Conidia more than 3.5 μm long	23
20. Conidia subglobose, 1.2-1.8 × 1-1.5 μm.....	<i>P. rariramus</i>
20. Conidia ovoid, cylindrical, ellipsoidal or fusiform	21
21. Conidia fusiform or ovoid, 2-3 × 1-2 μm	<i>P. farinosus</i>
21. Conidia ellipsoidal or cylindrical	22
22. Conidia ovoid to ellipsoidal, 2.3-3.2 × 1.6-2.1 μm.....	<i>P. breviramusus</i>
22. Conidia cylindrical, small, 1.3-3 × 0.5-1.3 μm.....	<i>P. cylindricosporus</i>
23. Conidia cylindrical to sausage-shaped, 3-10 × 1.6-2.8 μm.....	<i>P. tenuipes</i>
23. Conidia not sausage-shaped	24
24. Conidia fusiform to ovoid	<i>P. sinensis</i>
24. Conidia cylindrical or ellipsoidal	25
25. Conidia chains, imbricate and straight.....	<i>P. odonatae</i>
25. Conidia chains, only straight	26

26. The optimum temperature more than 30°C..... *P. taitungiacus*
 26. The optimum temperature less than 30°C.....27
27. Conidia cylindrical, somewhat curved.....*P. cicadae*
 27. Conidia cylindrical to ellipsoidal, straight.....28
28. Conidia more than 5 µm long29
 28. Conidia, 3.5-4 × 1.7-2µm, ellipsoidal or cylindrical*P. puntonii*
29. Conidia 5.4-12 × 2.5-5.4 µm*P. suffultus*
 29. Conidia 3-12 × 1-3 µm*P. javanicus*

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