First Report of Green Mold Disease Caused by *Trichoderma hengshanicum* on *Ganoderma lingzhi*

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**ABSTRACT**

*Ganoderma lingzhi* is a well-known source of natural fungal medicines which has been given for the treatment of several diseases. China is one of the major commercial producers of Ganoderma mushroom worldwide. However, with the expansion of the commercial cultivation, the occurrence of the fungal diseases on *G. lingzhi* has also been increased. The green mold disease symptoms were observed in the cultivation base of *G. lingzhi* in Zuojia Town, Jilin City, Jilin Province, China, causing the basidiomes to be rotten and withered, and the green mycelium layer generated gradually. The pathogenicity test showed the same symptoms as appeared naturally in Zuojia mushroom base. Morphology characters revealed conidial green, ellipsoid, globose, 2.56–4.83 × 2.09–4.22 μm, length-width ratio was 1.1–1.2 (n = 10). Conidiophores trichoderma-like, often asymmetry, branches solitary, paired or in whorls of 3 phialides formed solitary, paired in whorls, variable in shape, lageniform, sometimes ampulliform or subulate. While using molecular methodology, comparing with the sequences of *Trichoderma hengshanicum* from GenBank, the analyzed sequence showed 97.32% homology with the RPB2 sequences, 100% with the TEF1-α sequences. A fungus isolated from the diseased tissues was identified based on morphology and molecular studies as *T. hengshanicum*. This is the first report of *T. hengshanicum* causing the green mold disease of *G. lingzhi* in China.

**PLATES AND FIGURES**

1. A. Conidiophores trichoderma-like, often asymmetry, branches solitary, paired or in whorls of 3 phialides formed solitary, paired in whorls, variable in shape, lageniform, sometimes ampulliform or subulate. 2. A. Conidia starting after 2 days, formed on aerial mycelium loose, aerial hyphae numerous, more numerous in the center of the colony. Conidia green, ellipsoid, globose, 2.56–4.83 × 2.09–4.22 μm, length-width ratio was 1.1–1.2 (n = 10). Conidiophores trichoderma-like, often asymmetry, branches solitary, paired in whorls of 3 phialides formed solitary, paired in whorls, variable in shape, lageniform, sometimes ampulliform or subulate.

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shape, lageniform, sometimes ampulliform or subulate. No chlamydospores observed (Figure 2(B–D)). Distinct odor none, diffusing pigment absent. Morphological and cultural characteristics were accorded with *T. hengshanicum* [6].

Genomic DNA of the pathogen were extracted from the samples using the Biospin Fungus Genomic DNA Extraction Kit (Bioer Technology Co., Hangzhou, China). Sequence translation elongation factor 1-alpha (TEF1-α) was amplified using primers EF1160R and EF595F [7]. The second largest subunit of RNA polymerase II (RPB2) was amplified using primers fRPB2–5F and bRPB2–7R2 [8]. The Polymerase chain reaction (PCR) mixture contained 10 μL of templat DNA, 25 μL of 2 × Es Taq MasterMix (Dye), 1 μL of each primer, and 13 μL of ddH₂O, in a total volume of 50 μL. PCR parameters for the RPB2 and TEF1-α regions consisted of an initial 3–5 min denaturation at 94°C, 33 cycles at 94°C 30 s, 53°C–56°C for 30 s–40 s, 72°C for 30 s–50 s and a final extension at 72°C for 5 min, followed by immersion at 4°C. Finally, gel electrophoresis was used to detect the product and sequences were completed by BGI Co., Ltd, Beijing, China. The TEF1-α and RPB2 sequences generated in this study were deposited in GenBank and compared with other sequences on GenBank using BLAST. According to the results, the closely matched sequences and related sequences described in Table 1 were downloaded for phylogenetic analyses. The sequences were aligned with closely related strains by Clustal X 2.1 [9]. The phylogenetic tree was constructed using the Maximum Likelihood (ML) method with 1000 bootstrap replicates by MEGA 7 (https://www.megasoftware.net/archived_version_active_download) [10]. Comparing with the sequences of *T. hengshanicum* of GenBank, the analyzed sequence showed 97.32% homology with the RPB2 sequences (GenBank accession KY687992 and KY687991),

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Green mold of *G. lingzhi*. (A) Deseased Basidiome of *G. lingzhi* covered with green mycelium layer found naturally; (B) About 14 days later, the whole peilus of *G. lingzhi* was covered with green mycelium; (C) Deseased basidiome of *G. lingzhi* under high temperature and humidity conditions.

![Figure 2](https://example.com/figure2.png)

**Figure 2.** (A) The colony characteristics of *T. hengshanicum*, cultured on 2% PDA 5d; (B–D) Microscopic feature of *T. hengshanicum* Conidiophore, Phialides and Conidia.
100% with the TEF1-α sequences (KY688055.1 and KY688054.1). TEF1-α and RPB2 sequences of 1009 and other 33 related taxa were used to perform ML analysis. The phylogenetic tree indicated that strain 1009 was related to *T. hengshanicum* (Figure 3). Combining with morphological characteristics identification, strain 1009 was identified as *T. hengshanicum*.

**Table 1.** Closely matched and related sequences downloaded and used for phylogenetic analyses in this study.

| Species                  | Isolate/strain | GenBank accession number |
|--------------------------|----------------|-------------------------|
| *Trichoderma liberatum*  | HMAS 248832    | KY687970.1 (96.62)     |
| *Trichoderma liberatum*  | HMAS 248831    | KY687969.1 (96.62)     |
| *Trichoderma solum*      | HMAS 248847    | KY687986.1 (96.52)     |
| *Trichoderma solum*      | HMAS 248848    | KY687987.1 (96.52)     |
| *Trichoderma solum*      | HMAS 248849    | KY687988.1 (96.52)     |
| *Trichoderma pseudodensum*| HMAS:248829   | KY687968.1 (96.62)     |
| *Trichoderma pseudodensum*| HMAS:248828   | KY687967.1 (96.62)     |
| *Trichoderma solum*      | HMAS 248827    | KY687966.1 (97.22)     |
| *Trichoderma solum*      | HMAS 248826    | KY687965.1 (97.22)     |
| *Trichoderma solum*      | HMAS 248824    | KY687964.1 (97.22)     |
| *Trichoderma hengshanicum*| HMAS:248853    | KY687992.1 (97.32)     |
| *Trichoderma hengshanicum*| HMAS:248852    | KY687991.1 (97.32)     |
| *Trichoderma concentration*| HMAS:248858   | KY687977.1 (96.52)     |
| *Trichoderma concentration*| HMAS:248833   | KY687971.1 (96.52)     |
| *Trichoderma brevicrassum*| HMAS:248872    | KY688009.1 (100)       |
| *Trichoderma brevicrassum*| HMAS:248871    | KY688008.1 (100)       |
| *Trichoderma aureoviride*| HMAS 266607    | KF923306.1 (97.18)     |
| *Trichoderma alpinum*    | HMAS 248825    | KY687960.1 (96.33)     |
| *Trichoderma alpinum*    | HMAS 248823    | KY687959.1 (96.43)     |
| *Hypocrea strictipila*   | HMAS 252545    | KF923312.1 (96.43)     |

**Figure 3.** The phylogenetic tree based on combined of TEF1-α and RPB2 sequences using Maximum Likelihood method with 1000 bootstrap replicates.
To check the pathogenicity of representative strain 1009, the experiments were carried out in duplicate. *G. lingzhi* HMJU10001 used to inoculate pathogen was stored at the microbiology laboratory of Jilin Agriculture Science and Technology College. The artificial inoculation was performed when the pilus of *G. lingzhi* grew to a large area with yellowish brown color and size 3–4 cm. All treatments were maintained at 25 °C to 30 °C and humidity 80% to 90% under controlled cultivation conditions. The pathogen block was inoculated with a spore suspension (1 × 10⁷ conidia/mL). Different parts of the basidiome (peilus, mycelium tube, stipe) were used to inoculate with the help of syringe needles. The control block was inoculated with the suspension prepared from PDA alone and four repetitions per treatment were maintained while pathogenicity experiment was repeated twice. Changes in disease symptoms were observed and recorded every day for 14 days. Pathogens were reisolated from infected basidiomes at different disease stages (after every 2 days until 14 days of inoculation).

All of the inoculated basidiomes of *G. lingzhi* showed first symptoms after 24 h in which surface of the peilus, mycelium tube and stipe appeared taupe lesions. After 3 days, the peilus and stipe were mantled with white to green colonies and color became light, white villous mycelia grew from the inoculation site of mycelium tubes and aqua spores were produced around the site gradually. There were no obvious changes from macroscopic observation and never produced white villous mycelia also on the surface of peilus and stipe after 5 days, while brown rot was occurred on the diseased part of mycelium tubes and diseased range was diffused to 3.8–5.4 cm. With green colonies and abundant mycelia, the rotten range was greater than 1/2 of the whole *G. lingzhi’s* basidiome. Colonies of the diseased part of mycelium tubes were dark green and covered with a new layer of white spores again after the ninth day. After 14 days, the whole mycelium tubes of *G. lingzhi* were covered with green mycelia, while the basidiomes were rotten and withered (Figure 1(B,C)), however, the mushrooms grew up normally under the control block.

The pathogenicity experiments showed that the symptom of fruiting bodies inoculated with spore suspensions from the isolate was similar to that of the original symptomatic samples, Hence Koch’s postulates were proved. Based on the morphological and molecular characteristics and Koch’s postulates, we confirmed that the myco-pathogenic fungus *T. hengshanicum* was the causal agent of the disease on *G. lingzhi*. To our knowledge, this is the first report of Green Mold Disease caused by Trichoderma hengshanicum on *Ganoderma lingzhi*.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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