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Entomopathogenic Fungi in the Soils of China and Their Bioactivity against Striped Flea Beetles *Phyllotreta striolata*

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Abstract: The present research aims to explore the occurrence and diversity of entomopathogenic fungi (EPF) in cultivated and uncultivated lands from different provinces of China and to search for EPF against *Phyllotreta striolata*. In this study, first, the EPF biodiversity from the soil of four provinces (Hunan, Hubei, Henan and Hebei) was surveyed. There were 302 fungal isolates obtained from 226 soil samples collected from croplands (114), arbor (79), grasslands (97) and fallow land (12); 188 EPF isolates were identified as 11 genera. The data indicate that Hubei Province has the greatest EPF diversity, with a Shannon Evenness Index (SHEI) value of 0.88. Here, the grassland, arbor and cropland had an EPF diversity with SHEI values of 0.81, 0.86 and 0.76, respectively, while the fallow land had the highest SHEI value of 1.00, which suggests that cultivation by humans affected the count and richness of soil fungi: the less human activity, the more kinds of fungi found. Finally, the pathogenicity of 47 fungal strains against the adult *P. striolata* was determined. *Isaria javanica* (IsjaHN3002) had the highest mortality. In conclusion, this study reports the EPF distribution and biodiversity in the soil from four provinces in China, showing that the amount and type of fungi in the soil varied by region and vegetation and that soil was one of the resources for acquiring EPF. The potential of *I. javanica* as a biocontrol must be studied further.

Keywords: *Isaria javanica*; pathogenicity

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1. Introduction

Entomopathogenic fungi (EPFs) are ubiquitous in nature. Biological plant protection with EPFs plays a key role in sustainable pest management programs [1]. In addition to absorbing nutrients for their own growth, some EPFs can control insect populations at low levels for long periods [2]. Fungi-based insecticides have great potential as a form of pest control [3]. Not only are EPFs are harmless to human beings, animals and crops, but they also have the advantages of long-term validity, non-resistance, no residue, no pollution, no damage to natural enemies, high epidemic potential and ease of production [4,5]. Therefore, using EPFs to control agricultural and forestry pests has become a new trend in pest control. EPFs are the largest group of insect-pathogenic microorganisms. According to incomplete statistics, about 100 genera and 1000 species of EPFs have been recorded around the world [6], and more than 40 genera and more than 400 species have been found in China [7], including *Beauveria*, *Metarhizium*, *Penicillium* and *Fusarium. Beauveria bassiana* and *Metarhizium anisopliae* have been extensively developed as mycoinsecticides [8]. These species are naturally present in agricultural soils, but the spore numbers in nature are often too low to result in the effective control of pest population outbreaks [9].

Through in-depth studies on the physiology, ecology and molecular biology of EPFs, the effect of applying EPFs to control insects has been significantly improved. Under the premise that pests generally develop resistance, more and more attention has been paid to sustainable development and pollution-free pest management, and researchers prefer the development and utilization of EPFs [10]. Some fungi have a unique method of infection (they can infect pests through the main body wall), which cannot be replicated by other microbial insecticides. The process of EPFs infecting insects mainly includes host recognition, mechanical destruction, toxin secretion and metabolism interference. The combined effect of various factors leads to the death of the host insects [8]. The host species of EPFs are highly specific, and the host spectrum and virulence of different strains are also quite different. Therefore, the isolation and identification of more strains will help us to enrich the resources of EPF and provide more materials for the development of biological control pesticides using EPF [11].

Phyllotreta striolata (Coleoptera: Chrysomelidae) is a prominent pest of *Brassicaceae*, *Solanaceae*, *Cucurbitaceae* and *Leguminosae* vegetables [12–15]. Brassicaceae are important crops in south China [16]. Their management is based on synthetic chemical pesticides, leading to insect resistance [17,18]. Few registered varieties of biopesticides can meet the needs of green prevention and control. EPFs represent the most promising candidates in the integrated pest management (IPM) program approach [19].

Popular EPFs, such as *Beauveria bassiana*, *Metarhizium anisopliae*, *Purpureocillium lilacinum* and *Isaria* (=*Cordyceps*) *javanica*, have been developed as mycopesticides to control agricultural, forest and disease vector pests such as locusts, grubs, aphids, whiteflies, moths, mosquitoes and phytopathogenic nematodes [20,21]. It was found that *B. bassiana* and *M anisopliae* can infect the larvae and adults of *P. striolata* [22,23], but this research is still at the laboratory stage. Because most EPFs are soil-dwelling microbes, investigating soil fungi will be beneficial for exploring new species of EPF resources [24–26].

The Hebei, Henan, Hubei and Hunan provinces have complex and diverse landforms, with a variety of plateaus, mountains, hills, basins and plains, as well as a large latitude span in the Yellow River and Yangtze River basins, which have sufficient water and diverse climate types and are suitable for farming. They are the main agricultural production areas in China and have rich agricultural ecological landscapes. However, the distributions of soil EPFs in these regions are not clear. Therefore, this research aims to investigate the distribution and abundance of EPFs in different soil habits of these Chinese provinces. Moreover, the impacts of human activities and changes in the environment on EPFs are analyzed and discussed. The study of EPFs in the soil of the four areas is beneficial for the exploration of new strains to enrich the diversity of EPFs and for mining highly pathogenic strains.

2. Materials and Methods

2.1. Soil Sample Collection

The soil samples were collected from different sites (cropland, fallow land, arbor and grassland). The longitude and latitude of each site were recorded by ICEGPS 100C (Shenzhen, China). From each site, approximately 200 g of soil (10~15 cm depth) from three points was collected, mixed and stored in a plastic bag at 4 °C until further use. In total, 226 samples were collected from these sites (Table A1, Appendix A).

2.2. Isolation of Fungi from the Soil Samples

The method from our previous work was used to isolate fungal strains from the soil samples [27]. Soil suspensions of 0.02 g/mL were prepared with 0.1% Tween-80 solution; then, 0.1 mL of the suspension was inoculated onto a selective medium (PDA, 0.2 g/L cycloheximide, 0.2 g/L chloramphenicol and 0.013 g/L Bengal red) and cultured at 25 ± 1 °C. When the fungi grew out, a single colony was transferred onto the PDA plate and cultured at 25 ± 1 °C, purified and cultured until a new colony was formed [28].

2.3. Identification of Fungal Species and Analysis of Genetic Homology

The identification of fungal isolates was based on the morphological characteristics and similarity of the rDNA-ITS sequences. DNA extraction kits (DP3112, Bio-Teke, Beijing) were used to extract the total DNA from fungal isolates. The primers ITS1 (5′-

TCCGTAGGTGAACCTGCGG-3′) and ITS4 (5′-TCCTCCGCTTATTGATATGC-3′) were used to amplify the ITS region on a T100^{TM} Thermal Cycler (BIO-RAD, Hercules, CA, USA) via a standard PCR cycling protocol (94 °C for 3 min, 94 °C for 30 s, 55 °C for 30 s and 72 °C for 1 min for 33 cycles, then 72 °C for 10 min). The obtained ITS rDNA sequences were submitted to GenBank and compared with similar sequences through the BLAST tool of NCBI. The phylogenetic trees of the fungi were constructed by MEGA X via the statistical method of maximum likelihood, a bootstrap test of 500 replications and the Jukes–Cantor model [29]. The fungal strains are listed in Table 1.

Table 1. The information of referred fungal strains.

Strain/Voucher	GenBank Accession Number	Geographic Origin	Reference
Acremonium exuviarum	NR_077167	Canada	[30]
Acrophialophora nainiana CBS 417.67	MK926894	China	Unpublished
Apiotrichum cacaoliposimilis ATCC 20505	NR_154671	USA	[31]
Arthrographis kalrae	AB506810	Japan	[32]
Arthropsis hispanica CBS 351.92T	HE965759	Spain	[33]
Aspergillus auricomus NRRL 391	NR_135388	USA	[34]
Aspergillus crustosus NRRL 4988	NR_135366	USA	[34]
Aspergillus fumigatus ATCC 1022	NR_121481	USA	[30]
Aspergillus granulosus NRRL 1932	NR_135348	USA	[30]
Aspergillus niger ATCC 16888	NR_111348	USA	[30]
Aspergillus nomius NRRL 13137	NR_121218	USA	[30]
Aspergillus pseudodeflectus NRRL 6135	NR_135372	USA	[34]
Aspergillus sclerotiorum NRRL 415	NR_131294	USA	[34]
Aspergillus sydowii CBS 593.65	NR_131259	Japan	Unpublished
Aspergillus tanneri ATCC MYA-4905	NR_111840	USA	[30]
Aspergillus terreus var. *subfloccosus* CBS 117.37	NR_149331	Netherlands	[35]
Aspergillus udagawae CBM FA-0702	NR_137442	Japan	Unpublished
Auxarthron alboluteum UAMH 2846	NR_111137	Canada	[30]
Beauveria bassiana ARSEF 1564	NR_111594	USA	[30]
Beauveria bassiana ARSEF 8187	HQ444271	Canada	[30]
Beauveria bassiana CBS 465.70	MH859798	Netherlands	[36]
Beauveria bassiana CBS 110.25	MH854802	Sri Lanka	[36]
Beauveria pseudobassiana ARSEF 3405	NR_111598	USA	[30]
Chloridium aseptatum MFLU 11-1051	NR_158365	China	[37]
Chrysosporium lobatum CBS 666.78	NR_111087	Spain	[30]
Clonostachys grammicospora CBS 209.93	NR_137650	Netherlands	[38]
Clonostachys rosea f. catenulata CBS 154.27	NR_145021	Netherlands	[38]
Coniochaeta fasciculata CBS 205.38	NR_154770	Spain	Unpublished
Cordyceps cateniannulata CBS 152.83	NR_111169	Thailand	[30]
Cunninghamella elegans CBS 160.28	NR_154747	China	[39]
Cutaneotrichosporon dermatis CBS 2043	NR_130667	USA	Unpublished
Fusarium falciforme CBS 475.67	NR_164424	Netherlands	[40]
Fusarium keratoplasticum FRC S-2477	NR_130690	USA	[41]
Fusarium solani CBS 140079	NR_163531	Slovenia	[42]
Gongronella butleri CBS 102.44	JN206284	Netherlands	[43]
Gongronella butleri CBS 157.25	JN206607	Netherlands	[43]
Hawksworthiomyces taylorii CMW 20741	NR_155176	South Africa	[44]
Isaria cateniannulata ARSEF 6242	GU734760	Brazil	[45]
Isaria farinosa ARSEF 4029	HQ880828	USA	[46]
Isaria farinosa CBS 262.58	AY624179	Thailand	[47]
Isaria fumosorosea ARSEF 887	EU553334	Brazil	[48]
Isaria fumosorosea CBS 244.31	AY624182	Thailand	[47]
Isaria fumosorosea CBS 337.52	EF411219	Thailand	Unpublished
Isaria javanica CBS 134.22	DQ403723	USA	[49]

Table 1. *Cont.*

Strain/Voucher	GenBank Accession Number	Geographic Origin	Reference
Isaria javanica CHE-CNRCB 303/2	KM234213	Mexico	[50]
Lecanicillium coprophilum CGMCC 3.18986	NR_163303	China	[51]
Lecanicillium saksenae IMI 179841	NR_111102	United Kingdom	[30]
Malbranchea aurantiaca CBS 127.77	AB040704	Japan	[52]
Melanoctona tectonae MFLUCC 12-0389	NR_154194	Thailand	Unpublished
Metarhizium anisopliae CBS 657.67	MH859066	Netherlands	[36]
Metarhizium flavoviride CBS 218.56	MH857590	Czech	[36]
Metarhizium marquandii CBS 282.53	MH857200	Netherlands	[36]
Metarhizium marquandii CBS 182.27	NR_131994	Thailand	[47]
Metarhizium carneum CBS 239.32	NR_131993	Thailand	[47]
Metapochonia bulbillosa 38G272	EU999952	USA	[53]
Metapochonia bulbillosa CBS 145.70	AJ292397	UK	[54]
Metapochonia bulbillosa FKI-4395	AB709836	Japan	[55]
Mucor ellipsoideus ATCC MYA-4767	NR_111683	USA	[55]
Nectria mauritiicola NHRC-FC048	AJ558115	Russia	Unpublished
Oidiodendron fuscum UAMH 8511	NR_111035	Canada	[30]
Paecilomyces formosus CBS 990.73B	NR_149329	Netherlands	[56]
Paecilomyces variotii CBS 338.51	FJ389930	Netherlands	[56]
Penicillium chrysogenum CBS 306.48	NR_077145	USA	[30]
Penicillium subrubescens CBS 132785	NR_111863	Netherlands	[30]
Penicillium rubens CBS 319.59	MH857874	Netherlands	[30]
Penicillium rubens CBS 129667	NR_111815	Netherlands	[30]
Penicillium guttulosum NRRL 907	NR_144820	USA	[57]
Penicillium citrinum NRRL 1841	NR_121224	USA	[30]
Penicillium mirabile CBS 624.72	JN899322	Netherlands	[58]
Phialophora livistonae CPC 19433	NR_111824	Netherlands	[30]
Purpureocillium lilacinum CBS 284.36	NR_111432	USA	[30]
Purpureocillium lavendulum FMR 10376	NR_111433	Spain	[30]
Simplicillium cylindrosporum JCM 18169	NR_111023	Japan	[30]
Simplicillium minatense JCM 18176	NR_111025	Japan	[30]
Talaromyces pinophilus CBS 631.66	NR_111691	Netherlands	[30]
Talaromyces purpureogenus CBS 286.36	NR_121529	Netherlands	[30]
Talaromyces trachyspermus CBS 373.48	NR_147425	Netherlands	[30]
Talaromyces variabilis CBS 385.48	NR_103670	Netherlands	[30]
Tolypocladium album CBS 869.73	NR_155018	Japan	Unpublished
Trichurus terrophilus CBS 368.53	LN850976	Spain	Unpublished

2.4. Evaluation of the Shannon Evenness Index

The biodiversity of fungi and EPFs in different soils was evaluated using the Shannon Evenness Index (SHEI). The SHEI was calculated via the formula SHEI = $-\sum_i^s (Pi)(\ln Pi)/\ln S$, where s is the total number of species in the sample, i is the total number of individuals in one species, Pi is the proportion of species in the sample, lnPi is the value of the natural logarithm of Pi and S is the total number of species.

2.5. Bioassay of the Fungal Strains against P. striolata

The isolates of fungal species were subject to a bioassay against *P. striolata* based on the work of [27]. In summary, fungal conidia suspensions of 1.0×10^8 spores/mL were prepared with 0.02% Tween-80 solution. Spore suspension concentrations of 1.0×10^4, 1.0×10^5, 1.0×10^6, 1.0×10^7 and 1.0×10^8 spores/mL were prepared by culturing with a light cycle of 12:12 at 25 °C for 7 days. The population of *P. striolata* was fed with radish lumps, which changed every day. Adults were paralyzed with carbon dioxide and dipped into the conidial suspension for 20 s. The pest populations were surveyed every 24 h after treatment. The 0.02% Tween-80 solution was used as a control group. The experiment was replicated thrice, and 20 adults were used for each treatment.

2.6. Scanning Electron Microscopy

The samples were placed in a 2 mL centrifuge tube, fixed with 2.5% glutaraldehyde overnight, washed with physiological saline and dehydrated using a graded series of ethanol; isoamyl acetate was replaced overnight. They were vacuum-dried, fixed onto the platform and then coated with platinum with an ion coater before being observed using a scanning electron microscope.

2.7. Statistical Analysis

Analyses of the bioassay data were carried out using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA). The data were expressed as mean ± SD and were subjected to one-way ANOVA, followed by Duncan's multiple range test (DMRT). Significant differences were accepted at $p < 0.05$.

3. Results

3.1. EPF Species Diversity in the Soils of China

In total, 302 fungal isolates were purified. Among these, 188 EPF isolates were identified as belonging to 11 genera according to the morphological and molecular analyses. *Purpureocillium lavendulum*, with 69 isolates, was the dominant species, and the congeneric species *Purpureocillium lilacinum* had only 13 isolates (Figure 1, Table A1). The genus *Metarhizium* had three species—*M. anisopliae*, *M. marquandii* and *M.* sp.—for which 49, 33 and 17 isolates, respectively, were obtained (Figure 1, Table A1). *Penicillium* had six species—*Penicillium subrubescens*, *Penicillium guttulosum*, *Penicillium rubens*, *Penicillium chrysogenum*, *Penicillium citrinum* and *Penicillium mirabile*—with 12, 2, 3, 1, 11 and 6 isolates found, respectively (Figure 2, Table A1). *Aspergillus* had 12 species (Figure 2, Table A1). *Talaromyces* had four species (Figure 3, Table A1), and both *Beauveria* and *Isaria* had three species each (Figure 3, Table A1). Both *Lecanicillium* and *Simplicillium* had four species each (Figure 4, Table A1). *Fusarium*, *Coniochaeta* and *Clonostachys* each had six species (Figure 4, Table A1). Other species with one to four isolates were identified as *Tolypocladium album*, *Acremonium exuviarum*, *Acrophialophora nainiana*, *Nectria mauritiicola*, *Hawksworthiomyces taylorii*, *Chloridium aseptatum*, *Trichurus terrophilus*, *Chrysosporium lobatum*, *Arthropsis hispanica*, *Malbranchea aurantiaca*, *Auxarthron alboluteum*, *Arthrographis kalrae*, *Melanoctona tectonae*, *Phialophora livistonae*, *Xenopolyscytalum pinea*, *Oidiodendron fuscum*, *Cutaneotrichosporon dermatis*, *Apiotrichum cacaoliposimilis*, *Mucor ellipsoideus*, *Gongronella butleri* and *Cunninghamella elegans.* (Figure 5, Table A1). The other 73 isolates have not been classified yet. Obviously, *Purpureocillium lavendulum*, *M. anisopliae*, *M. marquandii*, *Purpureocillium lilacinum* and *B. bassiana* were the most abundant EPF species.

3.2. Distribution of Soil EPF in Different Regions

There were different numbers and isolating rates of EPFs in different regions. Compared with the average fungal isolating rates of 83.70% and 61.92% in all fungi and EPFs, Henan had the highest rate of >90% (Table 2). However, the Shannon Evenness Index indicated that Hubei and Hunan were districts with the highest EPF biodiversity, while Hunan and Hebei had the EPF biodiversity with SHEI values of 0.87 and 0.88, respectively (Table 2).

3.3. The Biodiversity of Soil EPF in Different Environments

There were different numbers and isolating rates of EPF in Central China. Compared with the average fungal isolating rates of 87.42% and 61.16% for all fungi and EPFs, cropland samples had higher rates of >69% (Table 3). However, the SHEI indicated that cropland had the lowest EPF biodiversity, while fallow land samples had the most abundant EPF biodiversity (Table 3).

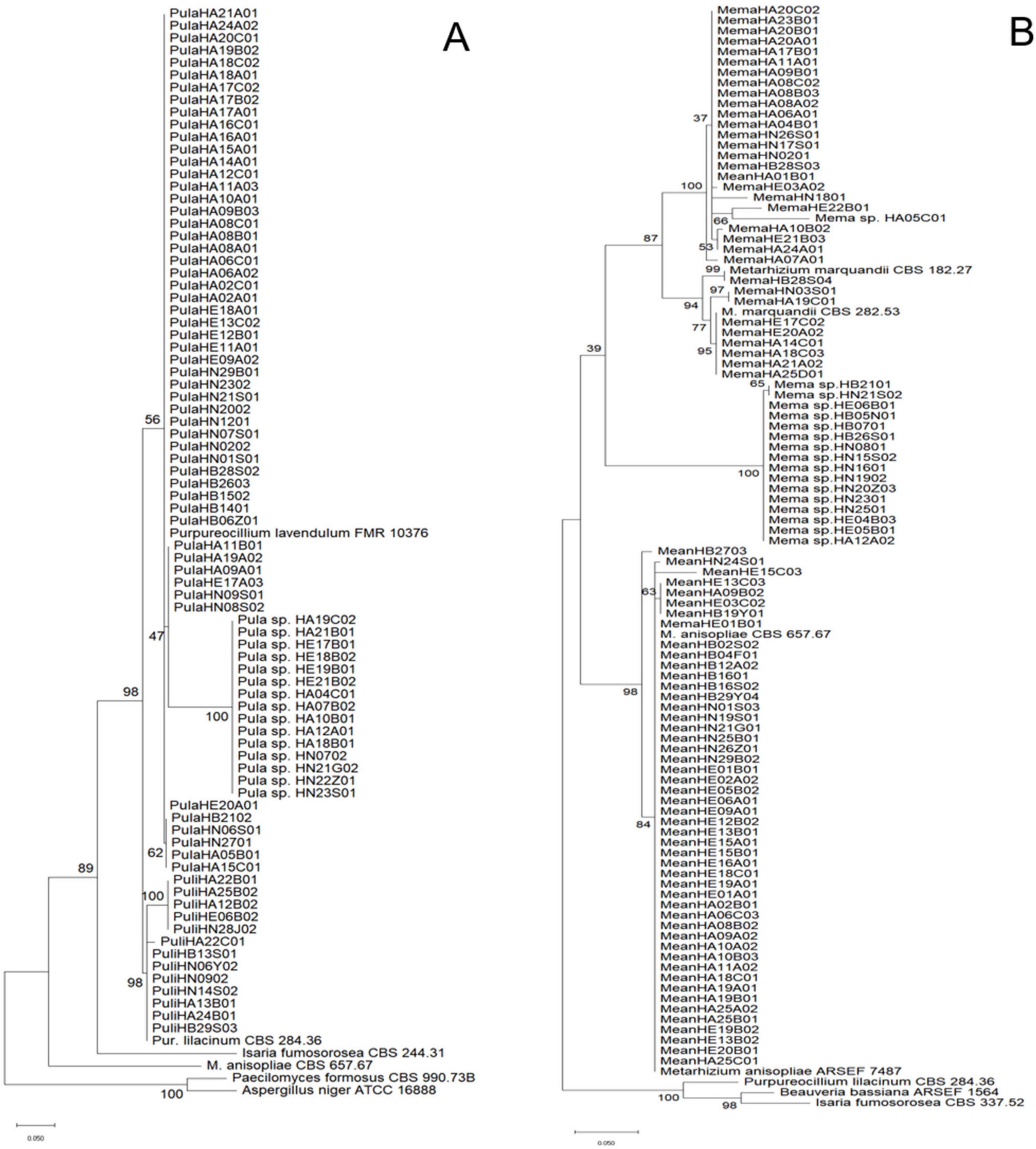

Figure 1. Phylogenetic tree of *Purpureocillium* spp. (**A**) and *Metarhizium* spp. (**B**) isolates.

3.4. The Pathogenicity of Fungal Isolates against *P. striolata*

Forty-seven isolates were subjected to a bioassay against *P. striolata*. The results indicate that *I. javanica* (IsjaHN3002) had the highest mortality, and *Aspergillus* spp., *Fusarium falciforme*, *Lecanicillium* spp., *Metarhizium* spp. and *Talaromyces* spp. all had obvious pathogenicity against *P. striolata* (Table 4).

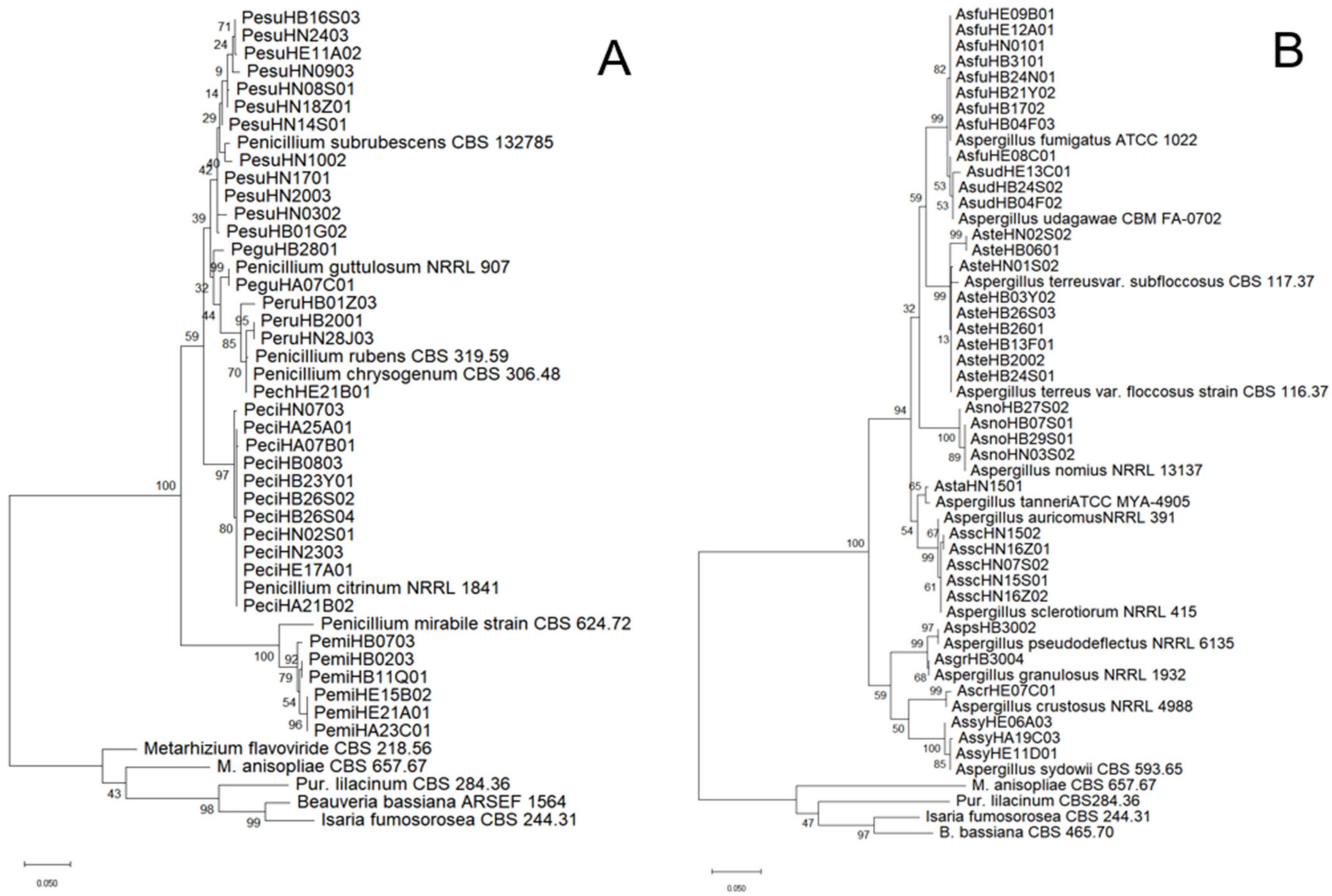

Figure 2. Phylogenetic tree of *Penicillium* spp. (**A**) and *Aspergillus* spp. (**B**) isolates.

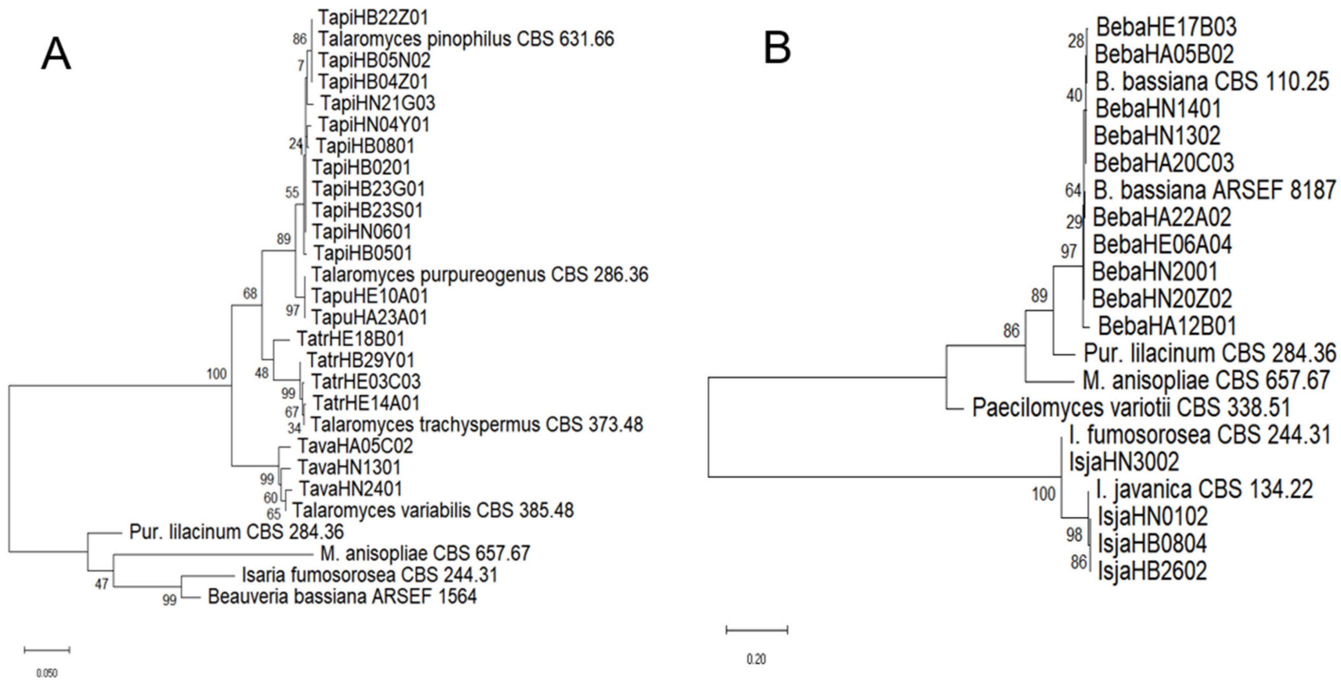

Figure 3. Phylogenetic tree of *Talaromyces* spp. (**A**) and *Beauveria/Isaria* (**B**) isolates.

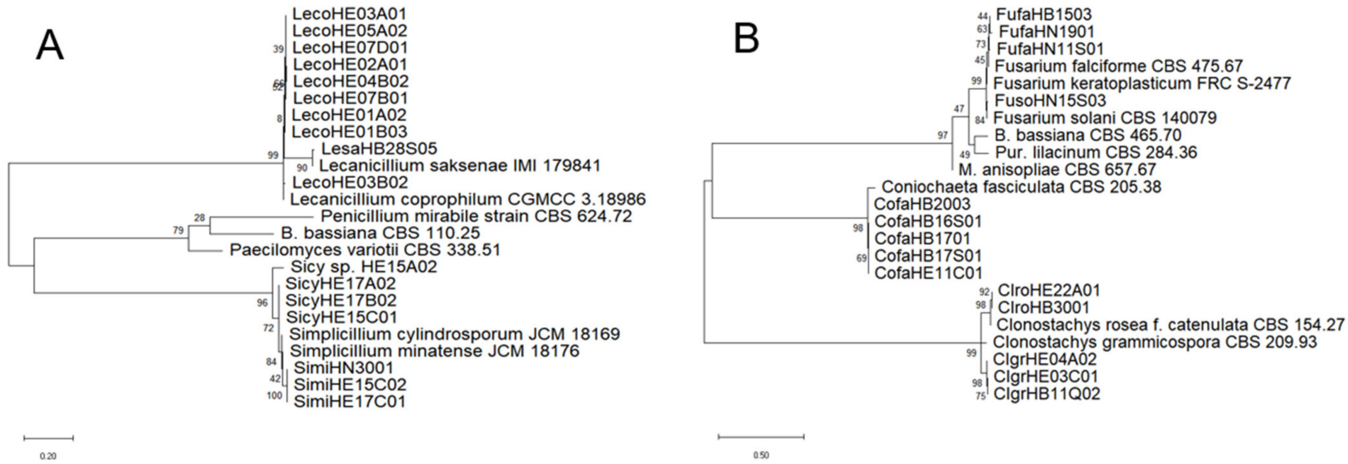

Figure 4. Phylogenetic tree of *Lecanicillium*/*Simplicillium* spp. (**A**) and *Fusarium*/*Coniochaeta*/*Clonostachys* (**B**) isolates.

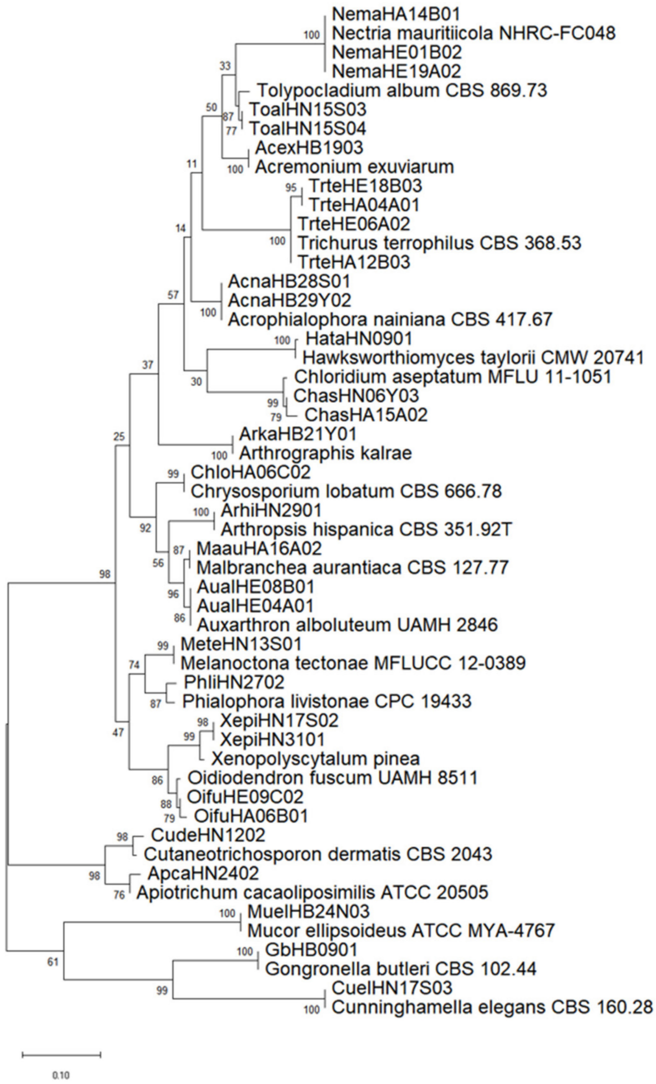

Figure 5. Phylogenetic tree of other isolates.

Table 2. The fungi isolation and biodiversity of different regions.

Region	Soil Sample Numbers	Isolate Number		Isolation Rate (%)		EPF Species	SHEI
		Fungi	EPF	Fungi	EPF		
Hunan	54	97	39	85.19	62.96	9	0.87
Hubei	50	58	24	80.00	40.00	8	0.88
Henan	63	73	83	98.41	90.48	7	0.84
Hebei	59	74	42	71.19	54.24	8	0.78
Total	226	302	188	83.70 *	61.92 *	11	–

* The mean isolation rate (%) of all regions. EPF: Entomopathogenic fungi; SHEI: Shannon evenness index.

Table 3. The fungi isolation and biodiversity of different samples.

Region	Soil Sample Numbers	Isolate Number		Isolation Rate (%)		EPF Species	SHEI
		Fungi	EPF	Fungi	EPF		
Arbor	64	79	45	79.69	59.38	9	0.86
Crop	85	114	83	84.71	69.41	9	0.76
Fallow land	9	12	6	100.00	55.56	6	1.00
Grass	68	97	54	85.29	60.29	9	0.81
Total	226	302	188	87.42 *	61.16 *	11	–

* The mean isolation rate (%) of all vegetation types sampled. EPF: Entomopathogenic fungi, SHEI: Shannon evenness index. Arbor: lands covered with arbor forests; cropland: farming lands planted with crops; fallow land: farming lands with no crops; grass: lands covered with grass.

Table 4. The pathogenicity of fungal isolates against adults of *P. striolata*.

Isolated Strain	Species	Adjusted Mortality (%)
ApcaHN2402	*Apiotrichum cacaoliposimilis*	12.96 ± 0.56
AsgrHB3004	*Aspergillus granulosus*	26.19 ± 0.24
AsnoHB27S02	*Aspergillus nomius*	21.05 ± 0.72
AsnoHN03S02	*Aspergillus nomius*	12.96 ± 0.57
AspsHB3002	*Aspergillus pseudodeflectus*	21.88 ± 0.85
AsscHN1502	*Aspergillus sclerotiorum*	7.55 ± 0.35
AssyHE06A03	*Aspergillus sydowii*	19.30 ± 0.38
AstaHN1501	*Aspergillus tanneri*	45.24 ± 0.39
AsteHN01S02	*Aspergillus terreus*	15.71 ± 0.73
AsudHE13C01	*Aspergillus udagawae*	16.00 ± 0.44
BebaHA22A02	*Beauveria bassiana*	10.70 ± 0.19
ChasHA15A02	*Chloridium aseptatum*	1.28 ± 0.51
CudeHN1202	*Cutaneotrichosporon dermatis*	2.83 ± 0.10
FufaHN1901	*Fusarium falciforme*	28.07 ± 0.68
IsjaHB2602	*Isaria javanica*	9.52 ± 0.30
IsjaHN3002	*Isaria javanica*	67.86 ± 0.61
LecoHE07B01	*Lecanicillium coprophilum*	18.18 ± 0.33
LesaHB28S05	*Lecanicillium saksenae*	26.32 ± 0.45
MeanHE15B01	*Metarhizium anisopliae*	23.56 ± 0.37
MeanHE20B01	*Metarhizium anisopliae*	19.62 ± 0.45
MemaHA24A01	*Metarhizium marquandii*	4.55 ± 0.42
MemaHN26S01	*Metarhizium marquandii*	22.81 ± 0.91
Mema sp. HN2501	*Metarhizium marquandii*	5.63 ± 0.41
MeteHN13S01	*Melanoctona tectonae*	15.00 ± 1.12
MuelHB24N03	*Mucor ellipsoideus*	15.00 ± 0.60
NemaHA14B01	*Nectria mauritiicola*	16.33 ± 0.30
OifuHA06B01	*Oidiodendron fuscum*	1.85 ± 0.19
PeciHA25A01	*Penicillium citrinum*	9.74 ± 0.29
PesuHN1002	*Penicillium subrubescens*	6.67 ± 0.27
PhliHN2702	*Phialophora livistonae*	16.33 ± 0.57

Table 4. *Cont.*

Isolated Strain	Species	Adjusted Mortality (%)
PulaHA08C01	*Purpureocillium lavendulum*	3.92 ± 0.30
SicyHE17A02	*Simplicillium cylindrosporum*	15.00 ± 0.27
SimiHE17C01	*Simplicillium minatense*	8.16 ± 0.23
TapiHB23G01	*Talaromyces pinophilus*	7.02 ± 0.16
TapiHB23S01	*Talaromyces pinophilus*	31.58 ± 0.32
TatrHE03C03	*Talaromyces trachyspermus*	11.11 ± 0.20
TatrHE14A01	*Talaromyces trachyspermus*	6.56 ± 0.44
TatrHE18B01	*Talaromyces trachyspermus*	8.33 ± 0.21
ToalHN15S03	*Tolypocladium album*	11.67 ± 0.65
HA13B02	–	2.27 ± 0.31
HA17C01	–	11.43 ± 0.18
HB3003	–	23.81 ± 0.34
HB3102	–	8.87 ± 0.69
HE07A01	–	14.81 ± 0.32
HN06Y05	–	14.81 ± 0.41
HN20Z01	–	7.41 ± 0.23
HN28J01	–	1.96 ± 0.22
Control	–	3.33 ± 0.45

Data in the table are mean values ± standard error. For each test, 20 *P. striolata* samples were used in each treatment, and the concentration of the fungal spore suspension was 1.0×10^8 spores/mL. The experiment was repeated three times.

3.5. The Pathogenicity of *I. javanica* against *P. striolata*

According to the results shown in Table 5, the number of muscardine cadavers increased with the spore concentration. The lethal rate of 1.0×10^8 spores/mL spore suspension treatment group was as high as 80%. When the spore concentration was lower than 1.0×10^6 spores/mL, no hyphae were observed on the body wall of *P. striolata* in the first 3 days. There was no significant difference in the rate of zombies in the groups treated with spore suspensions at concentrations of 1.0×10^4 and 1.0×10^5, 1.0×10^6 spores/mL in the first 3 days, but there was a significant difference in the rate of zombies in the group treated with spore suspensions with concentrations of 1.0×10^7 and 1.0×10^8 spores/mL in the first 3 days. After the seventh day, the differences among the treatment groups were revealed. Compared with other treatment groups, there was a significant difference in the lethal rate of the spore suspension with a concentration of 1.0×10^8 spores/mL.

Table 5. Pathogenicity of *I. javanica* in different concentrations against *P. striolata*.

Concentration (Spores/mL)	Accumulated Mortality (%)			Muscardine Cadaver Rate (%)		
	1 d	3 d	7 d	1 d	3 d	7 d
CK	3.33 ± 2.36 c	6.67 ± 2.36 c	10.00 ± 4.08 d	0	0	0
1.0×10^4	10.00 ± 4.08 bc	18.33 ± 2.36 b	40.00 ± 4.08 c	0	0	6.67 ± 4.71 c
1.0×10^5	15.00 ± 0 ab	23.33 ± 2.36 b	41.67 ± 2.36 c	0	0	11.67 ± 4.71 c
1.0×10^6	13.33 ± 6.23 abc	20.00 ± 4.08 b	53.33 ± 4.71 b	0	1.67 ± 2.36 b	21.67 ± 6.23 b
1.0×10^7	21.67 ± 8.5 a	33.33 ± 6.23 a	61.67 ± 4.71 b	0	3.33 ± 2.36 b	26.67 ± 2.36 b
1.0×10^8	23.33 ± 2.36 a	36.67 ± 4.71 a	80.00 ± 4.08 a	0	8.33 ± 2.36 a	41.67 ± 2.36 a

Muscardine cadavers were dead insects that grew mycelium. Accumulated mortality includes all dead insects. The data are the mean ± SE on different days after treatment. Different letters indicate a significant difference ($p < 0.05$) determined by DMRT.

3.6. Scanning Electron Microscopy Observations of Infection Process of *I. javanica*

The results showed that the attachment of conidia of *I. javanica* to different parts of the body surface was very different. After 2 h, the attachment of conidia was observed. No attachment of conidia was found on the head, abdomen, shard or other smooth surfaces. The conidia were mainly attached to the bristly areas and internodes such as the antennae, foot joints, chest and chest feet. The most densely attached site was the intersegmental membrane of the chest feet, followed by the foot joints (Figure 6).

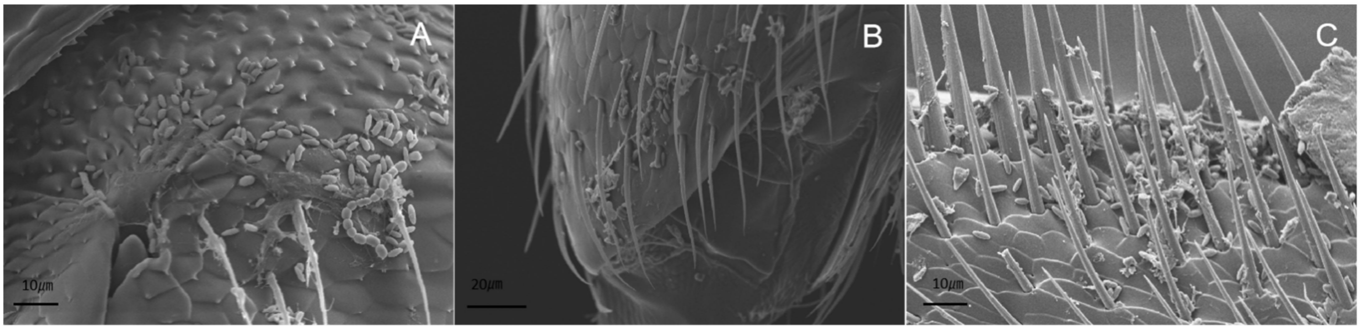

Figure 6. The attachment of conidia of *I. javanica* on the body surface after inoculation for 2 h. (**A**) Chest internode; (**B**) hind foot internode; (**C**) foot end.

After 12 h of inoculation, some conidia began to germinate, forming short germ tubes at the top. Twenty-four hours after infection, the top of the germ tube expanded to form an appressorium and continued in the direction of the intersegmental membrane, forming tendrils (Figure 7A–C) and looking for a suitable invasion site. The germ tube could also directly invade the body wall (Figure 7D). At 48 h, hyphae began to grow between the foot internode, and new conidiophores and conidia sprouted (Figure 8A). Next, 48–72 h after inoculation, the surface of the insect body was gradually covered by mycelia until it was completely covered (Figure 8B–D). Through stereoscopic observation, the mycelia were observed to grow from the body surface on the third day, and then the mycelium coverage increased day by day (Figure 9), while the control group never experienced mycelial growth.

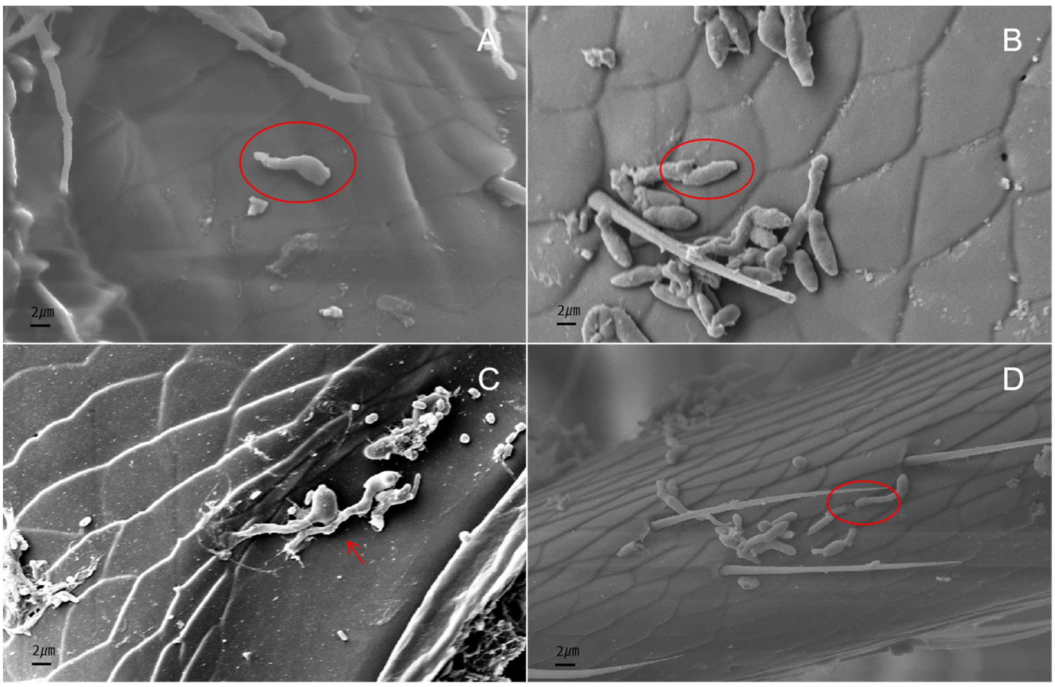

Figure 7. SEM observations of the inoculation of *I. javanica* for 12–24 h. (**A**) Spores germinate to form a short dental canal; (**B**) apical expansion to form an adherent cell; (**C**) adnexal extension; (**D**) bud tube invades the body wall.

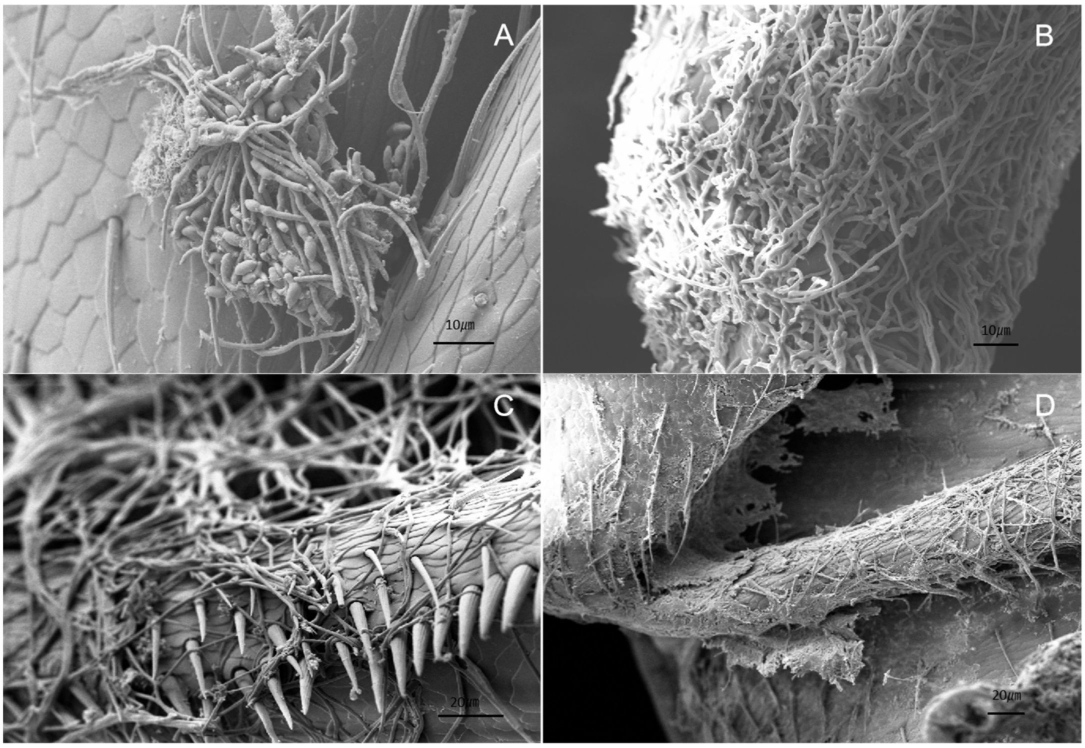

Figure 8. SEM observations of the inoculation of *I. javanica* for 48–72 h. (**A**) At 48 h, hyphae grew between the foot nodes, and new conidiophores and new conidia were formed. (**B**) At 60 h, conidia germination in vitro produced new hyphae covering the hindfoot. (**C**) At 72 h, the end of the foot was covered with mycelia. (**D**) At 72 h, the hind foot was covered with mycelia.

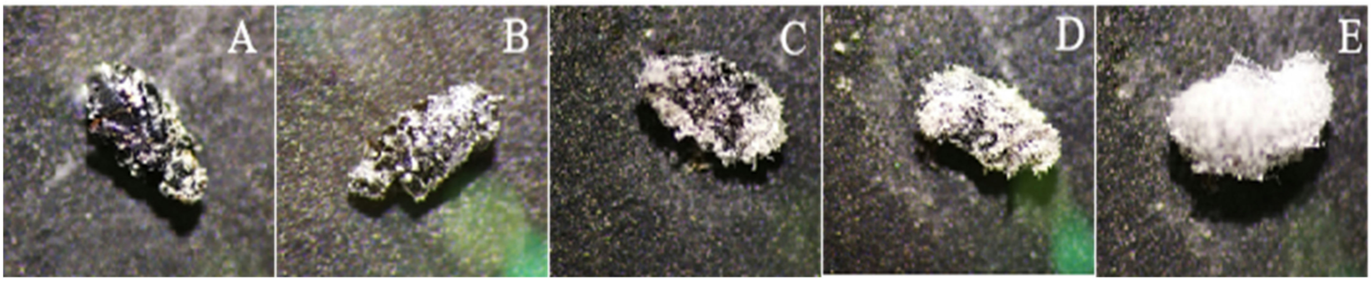

Figure 9. Mycelial growth of *Phyllotreta striolata* infected by *I. javanica.* (**A**) 3 d; (**B**) 4 d; (**C**) 5 d; (**D**) 6 d; (**E**) 7 d.

4. Discussion

This study surveyed the EPF distribution at a broad scale in China. ITS sequences are small and easy to analyze and have been widely used in the phylogenetic analysis of different fungal species, but their accuracy is controversial. Therefore, the identification of the fungal species in this study has some defects. Undoubtedly, our results initially provide a large amount of information about the soil fungi in these areas. Moreover, the results indicate that the soil environment strongly impacts the distribution of EPFs. Compared to arbor and non-cultivated land, the cropland samples had fewer EPFs. The isolation rate of EPFs was not high, which showed that soil fungi were not abundant in these areas and that the sampling and isolation methods also affected the isolation of fungi. The EPF diversity may be affected by the use of fungicides in croplands. China is a heavy consumer of pesticides, and a large number of broad-spectrum fungicides such as carbendazim, chlorothalonil and azoxystrobin, etc., are sprayed on croplands and probably inhibit fungi [59,60].

EPFs can parasitize insects and cause insect diseases, including some obligate parasitism that may not cause insect death but that can reduce the vitality of the host insects and weaken them [61] or affect insect spawning [62]; as such, when using EPFs, we can observe changes in the behavior of host insects [63,64]. Some studies have suggested that insects can actively identify fungi, with the target location being the cell wall of the fungi, while the fungi will take a series of measures to evade the host's defenses in the face of insect recognition [65]. Therefore, the invasion of host insects by EPF is a process of mutual influence and interaction [66]. As a result, the body surface of *P. striolata* may be able to recognize *I. javanica*, and the resistance and defense of *I. javanica* may also take measures to promote the germination of conidia in advance. In view of this fact, we can further explore what receptor binds the cell wall of conidia of *I. javanica* to produce signal molecules and promote spore germination, determining the factors promoting spore germination and improving pathogenicity.

Through scanning electron microscope observation, 12 h after infection with *I. javanica*, some conidia began to germinate, as shown in Figure 7. After 24 h of infection, only some scattered spores germinated. Because of the hard shell and dense structure on the body surface, the structure of the body wall varies greatly in different parts, and the outer skin has hydrophobic components. However, in tests of the bioactivity of different concentrations of spore suspensions against *P. striolata*, it was found that the spore suspension concentration of *I. javanica* had a stimulative effect on the production of zombies. This may be the QS phenomenon observed in *I. javanica*, which refers to a change in the physiological and biochemical characteristics of the microbial population in the process of its growth due to an increase in the population density, showing the characteristics of a small number of bacteria or a single bacterium. Cells use the QS mechanism to carry out cell-to-cell communication so that they can coordinate in a complex environment, and their "team combat ability" better ensures that the whole population survives. At present, the study of QSM is mainly focused on bacteria, and QSM has also been reported in related fungi [67]. In recent years, more reports have confirmed that fungi have QSM [68,69] and have QSM pheromones that are similar to the bacterial regulation of the physiological behavior of fungi [70–72]. However, in-depth studies of fungal QSM have not been carried out. Therefore, in the production of fungicidal insecticides using *I. javanica*, we can choose the appropriate formulation or use new production technology to help *I. javanica* survive in the form of sporangia, and it can also attach to the body surface after application to invade the body faster and improve its pathogenicity.

Several species have not been reported as EPF, namely *Aspergillus*, *Lecanicillium*, *Monascus*, *Talaromyces* and *Fusarium*. Their pathogenicity against *P. striolata* was discovered, and their potential for pest control deserves further research. Our experiment will provide new insight into the distribution characteristics of EPF and the conservation of their biodiversity.

5. Conclusions

In conclusion, 188 EPF isolates were identified from 226 soil samples, and the amount and types of fungi in the soil varied by region and vegetation type. *Metarhizium*, with 89 isolates, was recognized as the dominant EPF species, whereas *Purpureocillium* and *Beauveria* (respectively with 81 and 11 isolates) were the richer genera. Finally, it was first reported that *I. javanica* had pathogenicity against *P. striolata*, and we described its infection process.

Author Contributions: K.Z. and X.Z. completed most of the experiments, including the collection of the soil samples, the isolation and identification of the fungi strains and the bioassay and data analysis. Q.H. designed the experiments and collected partial soil samples. K.Z. and Q.W. wrote the article. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found here: https://www.ncbi.nlm.nih.gov/nuccore/?term=OM372687:OM373035[accn], submission ID SUB9030162; accessed on 25 January 2022.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The information of the soil samples collected and fungal isolates.

Site				Isolate	GenBank Access No.	Species
NO.	**Address**	**Latitude and Longitude**	**Sample Environment**			
HB01	Xianning, Hubei	29.267 N, 113.746 E	Fallow land	HB01Z01	–	
				HB01Z02	–	
				PeruHB01Z03	OM372687	*Penicillium rubens*
				HB01Z04	–	
			Crop	HB01G01	–	
				PesuHB01G02	OM372688	*Penicillium subrubescens*
HB02	Xianning, Hubei	29.568 N, 114.193 E	Crop	–	–	
			Arbor	HB02S01	–	
				MeanHB02S02	OM372689	*Metarhizium anisopliae*
			Grass	TapiHB0201	OM372690	*Talaromyces pinophilus*
				HB0202	–	
				PemiHB0203	OM372691	*Penicillium mirabile*
HB03	Daye, Hubei	29.973 N, 114.667 E	Crop	HB03Y01	–	
				AsteHB03Y02	OM372692	*Aspergillus terreus*
				HB03Y03	–	
			Grass	HB0301	–	
HB04	Huanggang, Hubei	30.372 N, 115.161 E	Fallow land	TapiHB04Z01	OM372693	*Talaromyces pinophilus*
			Crop	MeanHB04F01	OM372694	*Metarhizium anisopliae*
				AsudHB04F02	OM372695	*Aspergillus udagawae*
				AsfuHB04F03	OM372696	*Aspergillus fumigatus*
HB05	Xinzhou, Hubei	30.863 N, 114.881 E	Crop	Mema sp. HB05N01	OM372697	*Metarhizium marquandii*
				TapiHB05N02	OM372698	*Talaromyces pinophilus*
			Grass	TapiHB0501	OM372699	*Talaromyces pinophilus*
HB06	Huanggang, Hubei	31.257 N, 115.056 E	Arbor	HB06S01	–	
			Fallow land	PulaHB06Z01	OM372700	*Purpureocillium lavendulum*
			Grass	AsteHB0601	OM372701	*Aspergillus terreus*
HB07	Wuhan, Hubei	30.887 N, 114.462 E	Grass	Mema sp. HB0701	OM372702	*Metarhizium marquandii*
				HB0702	–	
				PemiHB0703	OM372703	*Penicillium mirabile*
			Arbor	AsnoHB07S01	OM372704	*Aspergillus nomius*
HB08	Xiaogan, Hubei	31.030 N, 113.938 E	Crop	–	–	
			Grass	TapiHB0801	OM372705	*Talaromyces pinophilus*
				HB0802	–	
				PeciHB803	OM372706	*Penicillium citrinum*
				IsjaHB0804	OM372707	*Isaria javanica*
HB09	Xiaogan, Hubei	31.325 N, 113.580 E	Fallow land	GobuHB0901	OM372708	*Gongronella butleri*
				HB0902	–	
	Suizhou, Hubei	31.665 N, 113.269 E	Arbor	–	–	
			Grass	–	–	
HB11	Xiangyang, Hubei	31.948 N, 112.929 E	Crop	HB11Y01	–	
				PemiHB11Q01	OM372709	*Penicillium mirabile*
				ClgrHB11Q02	OM372710	*Clonostachys grammicospora*
HB12	Xiangyang, Hubei	32.178 N, 112.211 E	Grass	HB12A01	–	
				MeanHB12A02	OM372711	*Metarhizium anisopliae*
			Arbor	–	–	
HB13	Xiangyang, Hubei	32.307 N, 111.614 E	Crop	AsteHB13F01	OM372712	*Aspergillus terreus*
				HB13F02	–	
			Arbor	PuliHB13S01	OM372713	*Purpureocillium lilacinum*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	Address	Latitude and Longitude	Sample Environment			
HB14	Shiyan, Hubei	32.502 N, E111.100 E	Grass	PulaHB1401	OM372714	*Purpureocillium lavendulum*
			Arbor	HB14S01	–	
HB15	Shiyan, Hubei	32.020 N, 110.679 E	Fallow land	–		
			Grass	HB1501	–	
				PulaHB1502	OM372715	*Purpureocillium lavendulum*
				FufaHB1503	OM372716	*Fusarium falciforme*
HB16	Shennongjia, Hubei	31.823 N, 110.508 E	Grass	MeanHB1601	OM372717	*Metarhizium anisopliae*
			Arbor	CofaHB16S01	OM372718	*Coniochaeta fasciculata*
				MeanHB16S02	OM372719	*Metarhizium anisopliae*
				PesuHB16S03	OM372720	*Penicillium subrubescens*
HB17	Shennongjia, Hubei	31.514 N, 110.338 E	Grass	CofaHB1701	OM372721	*Coniochaeta fasciculata*
				AsfuHB1702	OM372722	*Aspergillus fumigatus*
			Arbor	CofaHB17S01	OM372723	*Coniochaeta fasciculata*
HB18	Yichang, Hubei	31.266 N, 110.686 E	Grass	HB1801	–	
HB19	Enshi, Hubei	30.007 N, 110.377 E	Grass	HB1901	–	
				HB1902	–	
				AcexAB1903	OM372724	*Acremonium exuviarum*
			Crop	MeanHB20Y01	OM372725	*Metarhizium anisopliae*
HB20	Enshi, Hubei	30.556 N, 109.889 E	Grass	PeruHB2001	OM372726	*Penicillium rubens*
				AsteHB2002	OM372727	*Aspergillus terreus*
				CofaHB2003	OM372728	*Coniochaeta fasciculata*
			Arbor	HB20S01	–	
				HB20S02	–	
HB21	Yichang, Hubei	30.615 N, 110.513 E	Grass	Mema sp. HB2101	OM372729	*Metarhizium marquandii*
				PulaHB2102	OM372730	*Purpureocillium lavendulum*
			Crop	ArkaHB21Y01	OM372731	*Arthrographis kalrae*
				AsfuHB21Y02	OM372732	*Aspergillus fumigatus*
HB22	Yichang, Hubei	30.582 N, 111.028 E	Fallow land	TapiHB22Z01	OM372733	*Talaromyces pinophilus*
			Crop	HB22Y01	–	
				HB22Y02	–	
HB23	Yichang, Hubei	30.688 N, 111.517 E	Crop	PeciHB23Y01	OM372734	*Penicillium citrinum*
			Orchard	TapiHB23G01	OM372735	*Talaromyces pinophilus*
			Arbor	TapiHB23S01	OM372736	*Talaromyces pinophilus*
HB24	Jingmen, Hubei	30.904 N, 112.185 E	Arbor	AsteHB24S01	OM372737	*Aspergillus terreus*
				AsudHB24S02	OM372738	*Aspergillus udagawae*
			Crop	AsfuHB24N01	OM372739	*Aspergillus fumigatus*
				HB24N02	–	
				MuelHB24N03	OM372740	*Mucor ellipsoideus*
				HB24N04	–	
HB25	Jingmen, Hubei	30.991 N, 112.854 E	Arbor	HB25S01	–	
			Grass	–		
HB26	Xiaogan, Hubei	30.868 N, 113.576 E	Arbor	Mema sp.HB26S01	OM372741	*Metarhizium marquandii*
				PeciHB26S02	OM372742	*Penicillium citrinum*
				AsteHB26S03	OM372743	*Aspergillus terreus*
				PeciHB26S04	OM372744	*Penicillium citrinum*
			Grass	AsteHB2601	OM372745	*Aspergillus terreus*
				IsjaHB2602	OM372746	*Isaria javanica*
				PulaHB2603	OM372747	*Purpureocillium lavendulum*
HB27	Wuhan, Hubei	30.478 N, 113.874 E	Arbor	HB27S01	–	
				AsnoHB27S02	OM372748	*Aspergillus nomius*
			Grass	HB2701	–	
				HB2702	–	
				MeanHB2703	OM372749	*Metarhizium anisopliae*
HB28	Xiantao, Hubei	30.350 N, 113.424 E	Grass	PeguHB2801	OM372750	*Penicillium guttulosum*
			Arbor	AcnaHB28S01	OM372751	*Acrophialophora nainiana*
				PulaHB28S02	OM372752	*Purpureocillium lavendulum*
				MemaHB28S03	OM372753	*Metarhizium marquandii*
				MemaHB28S04	OM372754	*Metarhizium marquandii*
				LesaHB28S05	OM372755	*Lecanicillium saksenae*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	**Address**	**Latitude and Longitude**	**Sample Environment**			
HB29	Qianjiang, Hubei	30.373 N, 112.889 E	Crop	TatrHB29Y01	OM372756	*Talaromyces trachyspermus*
				AcnaHB29Y02	OM372757	*Acrophialophora nainiana*
				HB29Y03	–	
				MeanHB29Y04	OM372758	*Metarhizium anisopliae*
			Arbor	AsnoHB29S01	OM372759	*Aspergillus nomius*
				HB29S02	–	
				PuliHB29S03	OM372760	*Purpureocillium lilacinum*
				HB29S04	–	
HB30	Jingzhou, Hubei	30.352 N, 112.338 E	Grass	ClroHB3001	OM372761	*Clonostachys rosea*
				AspsHB3002	OM372762	*Aspergillus pseudodeflectus*
				HB3003	–	
				AsgrHB3004	OM372763	*Aspergillus granulosus*
			Crop	–		
HB31	Jingzhou, Hubei	30.043 N, 112.158 E	Grass	AsfuHB3101	OM372764	*Aspergillus fumigatus*
				HB3102	–	
			Crop	–		
HN01	Changsha, Hunan	28.203 N, 113.303 E	Crop	PulaHN01S01	OM372765	*Purpureocillium lavendulum*
				AsteHN01S02	OM372766	*Aspergillus terreus*
				MeanHN01S03	OM372767	*Metarhizium anisopliae*
			Crop	AsfuHN0101	OM372768	*Aspergillus fumigatus*
				IsjaHN0102	OM372769	*Isaria javanica*
HN02	Changde, Hunan	29.634 N, 111.840 E	Grass	MemaHN0201	OM372770	*Metarhizium marquandii*
				PulaHN0202	OM372771	*Purpureocillium lavendulum*
			Arbor	PeciHN02S01	OM372772	*Penicillium citrinum*
				AsteHN02S02	OM372773	*Aspergillus terreus*
HN03	Changde, Hunan	29.131 N, 111.706 E	Grass	HN0301	–	
				PesuHN0302	OM372774	*Penicillium subrubescens*
			Arbor	MemaHN03S01	OM372775	*Metarhizium marquandii*
				AsnoHN03S02	OM372776	*Aspergillus nomius*
HN04	Zhangjiajie, Hunan	29.424 N, 111.163 E	Orchard	TapiHN04Y01	OM372777	Talaromyces pinophilus
			Grass	–	–	
HN05	Zhangjiajie, Hunan	29.348 N, 110.568 E	Arbor	HN05S01	–	
			Grass	–	–	
HN06	Xiangxi, Hunan	29.034 N, 110.228 E	Arbor	PulaHN06S01	OM372778	*Purpureocillium lavendulum*
			Grass	TapiHN0601	OM372779	Talaromyces pinophilus
			Crop	HN06Y01	–	
				PuliHN06Y02	OM372780	*Purpureocillium lilacinum*
				ChasHN06Y03	OM372781	*Chloridium aseptatum*
				HN06Y04	–	
				HN06Y05	–	
HN07	Xiangxi, Hunan	28.623 N, 109.547 E	Grass	HN0701	–	
				Pula sp. HN0702	OM372782	*Purpureocillium lavendulum*
				PeciHN0703	OM372783	*Penicillium citrinum*
			Arbor	PulaHN07S01	OM372784	*Purpureocillium lavendulum*
				AsscHN07S02	OM372785	*Aspergillus sclerotiorum*
HN08	Huaihua, Hunan	26.963 N, 109.747 E	Grass	Mema sp. HN0801	OM372786	*Metarhizium marquandii*
			Arbor	PesuHN08S01	OM372787	*Penicillium subrubescens*
				PulaHN08S02	OM372788	*Purpureocillium lavendulum*
HN09	Huaihua, Hunan	26.614 N, 109.671 E	Grass	HataHN0901	OM372789	*Hawksworthiomyces taylorii*
				PuliHN0902	OM372790	*Purpureocillium lilacinum*
				PesuHN0903	OM372791	*Penicillium subrubescens*
			Arbor	PulaHN09S01	OM372792	*Purpureocillium lavendulum*
				HN09S02	–	
HN10	Yongzhou, Hunan	26.662 N, 111.493 E	Grass	HN1001	–	
				PesuHN1002	OM372793	*Penicillium subrubescens*
				HN1003	–	
			Arbor	HN10S01	–	
HN11	Yongzhou, Hunan	26.063 N, 111.831 E	Arbor	FufaHN11S01	OM372794	*Fusarium falciforme*
			Fallow land	–	–	
HN12	Yongzhou, Hunan	25.528 N, 112.111 E	Grass	PulaHN1201	OM372795	*Purpureocillium lavendulum*
				CudeHN1202	OM372796	*Cutaneotrichosporon dermatis*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	Address	Latitude and Longitude	Sample Environment			
HN13	Chenzhou, Hunan	25.659 N, 112.729 E	Grass	TavaHN1301	OM372797	*Talaromyces variabilis*
				BebaHN1302	OM372798	*Beauveria bassiana*
				HN1303	–	
			Arbor	MeteHN13S01	OM372799	*Melanoctona tectonae*
HN14	Chenzhou, Hunan	25.965 N, 113.042 E	Grass	BebaHN1401	OM372800	*Beauveria bassiana*
			Arbor	PesuHN14S01	OM372801	*Penicillium subrubescens*
				PuliHN14S02	OM372802	*Purpureocillium lilacinum*
HN15	Hengyang, Hunan	26.426 N, 112.889 E	Grass	AstaHN1501	OM372803	*Aspergillus tanneri*
				AsscHN1502	OM372804	*Aspergillus sclerotiorum*
			Arbor	AsscHN15S01	OM372805	*Aspergillus sclerotiorum*
				Mema sp. HN15S02	OM372806	*Metarhizium marquandii*
				ToalHN15S03	OM372807	*Tolypocladium album*
				ToalHN15S04	OM372808	*Tolypocladium album*
				FusoHN15S05	OM372809	*Fusarium solani*
HN16	Hengyang, Hunan	26.974 N, 112.425 E	Grass	Mema sp. HN1601	OM372810	*Metarhizium marquandii*
			Orchard	AsscHN16Z01	OM372811	*Aspergillus sclerotiorum*
				AsscHN16Z02	OM372812	*Aspergillus sclerotiorum*
HN17	Loudi, Hunan	27.440 N, 112.132 E	Grass	PesuHN1701	OM372813	*Penicillium subrubescens*
			Arbor	MemaHN17S01	OM372814	*Metarhizium marquandii*
				XepiHN17S02	OM372815	*Xenopolyscytalum pinea*
				CuelHN17S03	OM372816	*Cunninghamella elegans*
HN18	Loudi, Hunan	27.821 N, 111.763 E	Grass	MemaHN1801	OM372817	*Metarhizium marquandii*
				HN1802		
			Fallow land	PesuHN18Z01	OM372818	*Penicillium subrubescens*
HN19	Yiyang, Hunan	28.264 N, 111.712 E	Arbor	MeanHN19S01	OM372819	*Metarhizium anisopliae*
				HN19S02		
				HN19S03		
			Grass	FufaHN1901	OM372820	*Fusarium falciforme*
				Mema sp. HN1902	OM372821	*Metarhizium marquandii*
HN20	Yiyang, Hunan	28.525 N, 112.045 E	Grass	BebaHN2001	OM372822	*Beauveria bassiana*
				PulaHN2002	OM372823	*Purpureocillium lavendulum*
				PesuHN2003	OM372824	*Penicillium subrubescens*
			Fallow land	HN20Z01	–	
				BebaHN20Z02	OM372825	*Beauveria bassiana*
				Mema sp. HN20Z03	OM372826	*Metarhizium marquandii*
HN21	Changsha, Hunan	28.222 N, 112.567 E	Crop	MeanHN21G01	OM372829	*Metarhizium anisopliae*
				Pula sp. HN21G02	OM372830	*Purpureocillium lavendulum*
				TapiHN21G03	OM372831	*Talaromyces pinophilus*
			Arbor	PulaHN21S01	OM372827	*Purpureocillium lavendulum*
				Mema sp. HN21S02	OM372828	*Metarhizium marquandii*
HN22	Xiangtan, Hunan	27.806 N, 112.511 E	Fallow land	Pula sp. HN22Z01	OM372832	*Purpureocillium lavendulum*
			Arbor	–	–	
HN23	Xiangtan, Hunan	27.846 N, 113.017 E	Grass	Mema sp. HN2301	OM372833	*Metarhizium marquandii*
				PulaHN2302	OM372834	*Purpureocillium lavendulum*
				PeciHN2303	OM372835	*Penicillium citrinum*
			Arbor	Pula sp. HN23S01	OM372836	*Purpureocillium lavendulum*
HN24	Hengyang, Hunan	27.229 N, 112.897 E	Grass	TavaHN2401	OM372837	*Talaromyces variabilis*
				ApcaHN2402	OM372838	*Apiotrichum cacaoliposimilis*
				PesuHN2403	OM372839	*Penicillium subrubescens*
			Arbor	MeanHN24S01	OM372840	*Metarhizium anisopliae*
				HN24S02	–	
HN25	Zhuzhou, Hunan	26.893 N, 113.374 E	Grass	Mema sp. HN2501	OM372841	*Metarhizium marquandii*
			Orchard	MeanHN25B01	OM372842	*Metarhizium anisopliae*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	Address	Latitude and Longitude	Sample Environment			
HN26	Zhuzhou, Hunan	27.496 N, 113.486 E	Arbor	MemaHN26S01	OM372843	*Metarhizium marquandii*
				HN26S02	–	
			Fallow land	MeanHN26Z01	OM372844	*Metarhizium anisopliae*
HN27	Xiangxi, Hunan	27.914 N, 109.385 E	Grass	PulaHN2701	OM372845	*Purpureocillium lavendulum*
				PhliHN2702	OM372846	*Phialophora livistonae*
HN28	Huaihua, Hunan	27.896 N, 109.702 E	Orchard	HN28J01	–	
				PuliHN28J02	OM372847	*Purpureocillium lilacinum*
				PeruHN28J03	OM372848	*Penicillium rubens*
HN29	Huaihua, Hunan	27.367 N, 109.935 E	Fallow land	PulaHN29B01	OM372849	*Purpureocillium lavendulum*
				MeanHN29B02	OM372850	*Metarhizium anisopliae*
			Grass	ArhiHN2901	OM372851	*Arthropsis hispanica*
HN30	Huaihua, Hunan	27.216 N, 110.420 E	Arbor	SimiHN3001	OM372852	*Simplicillium minatense*
				IsjaHN3002	OM372853	*Isaria javanica*
HN31	Shaoyang, Hunan	26.941 N, 110.638 E	Arbor	XepiHN3101	OM372854	*Xenopolyscytalum pinea*
HN32	Shaoyang, Hunan	26.322 N, 110.837 E	Grass	–	–	
HE01	Xingtai, Hebei	36.905 N, 114.559 E	Crop	MeanHE01A01	OM372855	*Metarhizium anisopliae*
				LecoHE01A02	OM372856	*Lecanicillium coprophilum*
			Grass	MeanHE01B01	OM372857	*Metarhizium anisopliae*
				NemaHE01B02	OM372858	*Nectria mauritiicola*
				LecoHE01B03	OM372859	*Lecanicillium coprophilum*
HE02	Shijiazhuang, Hebei	35.994 N, 113.758 E	Arbor	LecoHE02A01	OM372860	*Lecanicillium coprophilum*
				MeanHE02A02	OM372861	*Metarhizium anisopliae*
				HE02A03	–	
HE03	Baoding, Hebei	39.138 N, 115.536 E	Crop	LecoHE03A01	OM372862	*Lecanicillium coprophilum*
				MemaHE03A02	OM372863	*Metarhizium marquandii*
			Grass	HE03B01	–	
				LecoHE03B02	OM372864	*Lecanicillium coprophilum*
			Poplar	ClgrHE03C01	OM372865	*Clonostachys grammicospora*
				MeanHE03C02	OM372866	*Metarhizium anisopliae*
				TatrHE03C03	OM372867	*Talaromyces trachyspermus*
HE04	Zhangjiakou, Hebei	39.273 N, 115.455 E	Poplar	AualHE04A01	OM372868	*Auxarthron alboluteum*
				ClgrHE04A02	OM372869	*Clonostachys grammicospora*
			Crop	HE04B01	–	
				LecoHE04B02	OM372870	*Lecanicillium coprophilum*
				Mema sp. HE04B03	OM372871	*Metarhizium marquandii*
HE05	Zhangjiakou, Hebei	39.375 N, 114.866 E	Poplar	HE05A01	–	
				LecoHE05A02	OM372872	*Lecanicillium coprophilum*
			Crop	Mema sp. HE05B01	OM372873	*Metarhizium marquandii*
				MeanHE05B02	OM372874	*Metarhizium anisopliae*
HE06	Zhangjiakou, Hebei	40.488 N, 114.838 E	Orchard	MeanHE06A01	OM372875	*Metarhizium anisopliae*
				TrteHE06A02	OM372876	*Trichurus terrophilus*
				AssyHE06A03	OM372877	*Aspergillus sydowii*
				BebaHE06A04	OM372878	*Beauveria bassiana*
			Crop	Mema sp. HE06B01	OM372879	*Metarhizium marquandii*
				PuliHE06B02	OM372880	*Purpureocillium lilacinum*
HE07	Zhangjiakou, Hebei	41.267 N, 114.785 E	Crop	HE07A01	–	
				AscrHE07C01	OM372882	*Aspergillus crustosus*
			Grass	LecoHE07B01	OM372881	*Lecanicillium coprophilum*
			Poplar	LecoHE07D01	OM372883	*Lecanicillium coprophilum*
HE08	Zhangjiakou, Hebei	41.073 N, 115.389 E	Grass	HE08A01	–	
				HE08A02	–	
			Crop	AualHE08B01	OM372884	*Auxarthron alboluteum*
				AsfuHE08C01	OM372885	*Aspergillus fumigatus*
HE09	Chengde, Hebei	41.581 N, 116.023 E	Grass	MeanHE09A01	OM372886	*Metarhizium anisopliae*
				PulaHE09A02	OM372887	*Purpureocillium lavendulum*
			Elm	AsfuHE09B01	OM372888	*Aspergillus fumigatus*
			Crop	HE09C01	–	
				OifuHE09C02	OM372889	*Oidiodendron fuscum*
HE10	Chengde, Hebei	42.001 N, 116.975 E	Grass	TapuHE10A01	OM372890	*Talaromyces purpureogenus*
			Crop	–	–	

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	**Address**	**Latitude and Longitude**	**Sample Environment**			
HE11	Chengde, Hebei	42.253 N, 117.143 E	Grass	PulaHE11A01	OM372891	*Purpureocillium lavendulum*
				PesuHE11A02	OM372892	*Penicillium subrubescens*
			Pine	CofaHE11C01	OM372893	*Coniochaeta fasciculata*
			Crop	AssyHE11D01	OM372894	*Aspergillus sydowii*
HE12	Chengde, Hebei	41.997 N, 117.655 E	Orchard	AsfuHE12A01	OM372895	*Aspergillus fumigatus*
			Grass	PulaHE12B01	OM372896	*Purpureocillium lavendulum*
				MeanHE12B02	OM372897	*Metarhizium anisopliae*
HE13	Chengde, Hebei	41.302 N, 118.038 E	Crop	HE13A01	–	
				MeanHE13B01	OM372898	*Metarhizium anisopliae*
				MeanHE13B02	OM372899	*Metarhizium anisopliae*
			Poplar	AsudHE13C01	OM372900	*Aspergillus udagawae*
				PulaHE13C02	OM372901	*Purpureocillium lavendulum*
				MeanHE13C03	OM372902	*Metarhizium anisopliae*
HE14	Chengde, Hebei	40.578 N, 117.704 E	Crop	TatrHE14A01	OM372903	*Talaromyces trachyspermus*
			Grass	–	–	
HE15	Tangshan, Hebei	40.108 N, 117.985 E	Crop	MeanHE15A01	OM372904	*Metarhizium anisopliae*
				Sicy sp. HE15A02	OM372905	*Simplicillium cylindrosporum*
			Arbor	MeanHE15B01	OM372906	*Metarhizium anisopliae*
				PemiHB15B02	OM372907	*Penicillium mirabile*
			Grass	SicyHE15C01	OM372908	*Simplicillium cylindrosporum*
				SimiHE15C02	OM372909	*Simplicillium minatense*
				MeanHE15C03	OM372910	*Metarhizium anisopliae*
HE16	Tangshan, Hebei	39.584 N, 118.264 E	Grass	MeanHE16A01	OM372911	*Metarhizium anisopliae*
HE17	Tangshan, Hebei	39.490 N, 118.682 E	Grass	PeciHE17A01	OM372912	*Penicillium citrinum*
				SicyHE17A02	OM372913	*Simplicillium cylindrosporum*
				PulaHE17A03	OM372914	*Purpureocillium lavendulum*
			Orchard	Pula sp. HE17B01	OM372915	*Purpureocillium lavendulum*
				SicyHE17B02	OM372916	*Simplicillium cylindrosporum*
				BebaHE17B03	OM372917	*Beauveria bassiana*
			Poplar	SimiHE17C01	OM372918	*Simplicillium minatense*
				MemaHE17C02	OM372919	*Metarhizium marquandii*
HE18	Tangshan, Hebei	39.408 N, 117.954 E	Crop	PulaHE18A01	OM372920	*Purpureocillium lavendulum*
				TatrHE18B01	OM372921	*Talaromyces trachyspermus*
				Pula sp. HE18B02	OM372922	*Purpureocillium lavendulum*
				TrteHE18B03	OM372923	*Trichurus terrophilus*
			Poplar	MeanHE18C01	OM372924	*Metarhizium anisopliae*
HE19	Tianjin, Hebei	38.768 N, 117.184 E	Crop	MeanHE19A01	OM372925	*Metarhizium anisopliae*
				NemaHE19A02	OM372926	*Nectria mauritiicola*
			Orchard	Pula sp. HE19B01	OM372927	*Purpureocillium lavendulum*
				MeanHE19B02	OM372928	*Metarhizium anisopliae*
HE20	Cangzhou, Hebei	38.151 N, 115.740 E	Crop	PulaHE20A01	OM372929	*Purpureocillium lavendulum*
				MemaHE20A02	OM372930	*Metarhizium marquandii*
			Grass	MeanHE20B01	OM372931	*Metarhizium anisopliae*
HE21	Hengshui, Hebei	37.719 N, 115.193 E	Crop	PemiHB21A01	OM372932	*Penicillium mirabile*
			Grass	PechHE21B01	OM372933	*Penicillium chrysogenum*
				Pula sp. HE21B02	OM372934	*Purpureocillium lavendulum*
				MemaHE21B03	OM372935	*Metarhizium marquandii*
HE22	Handan, Hebei	36.804 N, 115.193 E	Crop	ClroHE22A01	OM372936	*Clonostachys rosea*
				MemaHe22B01	OM372937	*Metarhizium marquandii*
HA01	Xinxiang, Henan	35.268 N, 113.974 E	Orchard	HA01A01	–	
			Crop	MemaHA01B01	OM372938	*Metarhizium marquandii*
			Grass	–	–	
HA02	Linzhou, Henan	35.994 N, 113.758 N	Crop	PulaHA02A01	OM372939	*Purpureocillium lavendulum*
				MeanHA02B01	OM372940	*Metarhizium anisopliae*
			Arbor	PulaHA02C01	OM372941	*Purpureocillium lavendulum*
HA03	Linzhou, Henan	35.928 N, 113.655 E	Crop	–	–	
HA04	Puyang, Henan	36.090 N, 115.124 E	Crop	TrteHA04A01	OM372942	*Trichurus terrophilus*
				MemaHA04B01	OM372943	*Metarhizium marquandii*
				HA04B02	–	
			Grass	Pula sp. HA04C01	OM372944	*Purpureocillium lavendulum*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	Address	Latitude and Longitude	Sample Environment			
HA05	Kaifeng, Henan	34.790 N, 114.485 E	Crop	–	–	
			Grass	PulaHA05B01	OM372945	*Purpureocillium lavendulum*
				BebaHA05B02	OM372946	*Beauveria bassiana*
			Crop	Mema sp. HA05C01	OM372947	*Metarhizium marquandii*
				TavaHA05C02	OM372948	*Talaromyces variabilis*
HA06	Kaifeng, Henan	34.895 N, 114.328 E	Crop	MemaHA06A01	OM372949	*Metarhizium marquandii*
				PulaHA06A02	OM372950	*Purpureocillium lavendulum*
				HA06A03	–	
			Poplar	OifuHA06B01	OM372951	*Oidiodendron fuscum*
				HA06B02	–	
			Grass	PulaHA06C01	OM372952	*Purpureocillium lavendulum*
				ChloHA06C02	OM372953	*Chrysosporium lobatum*
				MeanHA06C03	OM372954	*Metarhizium anisopliae*
HA07	Zhengzhou, Henan	34.481 N, 113.030 E	Arbor	MemaHA07A01	OM372955	*Metarhizium marquandii*
			Orchard	PeciHA07B01	OM372956	*Penicillium citrinum*
				Pula sp. HA07B02	OM372957	*Purpureocillium lavendulum*
			Crop	PeguHA07C01	OM372958	*Penicillium guttulosum*
HA08	Luoyang, Henan	34.555 N, 112.873 E	Crop	PulaHA08A01	OM372959	*Purpureocillium lavendulum*
				MemaHA08A02	OM372960	*Metarhizium marquandii*
				PulaHA08B01	OM372961	*Purpureocillium lavendulum*
				MeanHA08B02	OM372962	*Metarhizium anisopliae*
				MemaHA08B03	OM372963	*Metarhizium marquandii*
				PulaHA08C01	OM372964	*Purpureocillium lavendulum*
				MemaHA08C02	OM372965	*Metarhizium marquandii*
HA09	Luoyang, Henan	34.768 N, 112.093 E	Crop	PulaHA09A01	OM372966	*Purpureocillium lavendulum*
				MeanHA09A02	OM372967	*Metarhizium anisopliae*
			Poplar	MemaHA09B01	OM372968	*Metarhizium marquandii*
				MeanHA09B02	OM372969	*Metarhizium anisopliae*
				PulaHA09B03	OM372970	*Purpureocillium lavendulum*
HA10	Sanmenxia, Henan	34.797 N, 111.243 E	Crop	PulaHA10A01	OM372971	*Purpureocillium lavendulum*
				MeanHA10A02	OM372972	*Metarhizium anisopliae*
				Pula sp. HA10B01	OM372973	*Purpureocillium lavendulum*
				MemaHA10B02	OM372974	*Metarhizium marquandii*
				MeanHA10B03	OM372975	*Metarhizium anisopliae*
HA11	Sanmenxia, Henan	34.626 N, 110.914 E	Crop	MemaHA11A01	OM372976	*Metarhizium marquandii*
				MeanHA11A02	OM372977	*Metarhizium anisopliae*
				PulaHA11A03	OM372978	*Purpureocillium lavendulum*
				PulaHA11B01	OM372979	*Purpureocillium lavendulum*
			Grass	–	–	
HA12	Nanyang, Henan	33.566 N, 111.185 E	Crop	Pula sp. HA12A01	OM372980	*Purpureocillium lavendulum*
				Mema sp. HA12A02	OM372981	*Metarhizium marquandii*
				BebaHA12B01	OM372982	*Beauveria bassiana*
				PuliHA12B02	OM372983	*Purpureocillium lilacinum*
				TrteHA12B03	OM372984	*Trichurus terrophilus*
			Grass	PulaHA12C01	OM372985	*Purpureocillium lavendulum*
HA13	Nanyang, Henan	33.072 N, 111.792 E	Crop	–	–	–
				PuliHA13B01	OM372986	*Purpureocillium lilacinum*
				HA13B02	–	–
HA14	Nanyang, Henan	32.780 N, 112.707 E	Crop	PulaHA14A01	OM372987	*Purpureocillium lavendulum*
				NemaHA14B01	OM372988	*Nectria mauritiicola*
			Grass	MemaHA14C01	OM372989	*Metarhizium marquandii*
HA15	Xinyang, Henan	32.401 N, 113.931 E	Crop	PulaHA15A01	OM372990	*Purpureocillium lavendulum*
				ChasHA15A02	OM372991	*Chloridium aseptatum*
			Grass	PulaHA15C01	OM372992	*Purpureocillium lavendulum*
HA16	Xinyang, Henan	32.338 N, 114.128 E	Crop	PulaHA16A01	OM372993	*Purpureocillium lavendulum*
				MaauHA16A02	OM372994	*Malbranchea aurantiaca*
			Grass	PulaHA16C01	OM372995	*Purpureocillium lavendulum*
HA17	Zhumadian, Henan	32.707 N, 114.109 E	Crop	PulaHA17A01	OM372996	*Purpureocillium lavendulum*
				MemaHA17B01	OM372997	*Metarhizium marquandii*
				PulaHA17B02	OM372998	*Purpureocillium lavendulum*
			Grass	HA17C01	–	–
				PulaHA17C02	OM372999	*Purpureocillium lavendulum*

Table A1. *Cont.*

Site				Isolate	GenBank Access No.	Species
NO.	Address	Latitude and Longitude	Sample Environment			
HA18	Luohe, Henan	33.510 N, 113.980 E	Crop	PulaHA18A01	OM373000	*Purpureocillium lavendulum*
				Pula sp. HA18B01	OM373001	*Purpureocillium lavendulum*
				HA18B02	–	
			Grass	MeanHA18C01	OM373002	*Metarhizium anisopliae*
				PulaHA18C02	OM373003	*Purpureocillium lavendulum*
				MemaHA18C03	OM373004	*Metarhizium marquandii*
HA19	Pingdingshan, Henan	33.652 N, 113.370 E	Crop	MeanHA19A01	OM373005	*Metarhizium anisopliae*
				PulaHA19A02	OM373006	*Purpureocillium lavendulum*
				MeanHA19B01	OM373007	*Metarhizium anisopliae*
				PulaHA19B02	OM373008	*Purpureocillium lavendulum*
			Grass	MemaHA19C01	OM373009	*Metarhizium marquandii*
				Pula sp. HA19C02	OM373010	*Purpureocillium lavendulum*
				AssyHA19C03	OM373011	*Aspergillus sydowii*
HA20	Xuchang, Henan	34.052 N, 113.709 E	Crop	MemaHA20A01	OM373012	*Metarhizium marquandii*
				MemaHA20B01	OM373013	*Metarhizium marquandii*
			Grass	PulaHA20C01	OM373014	*Purpureocillium lavendulum*
				MemaHA20C02	OM373015	*Metarhizium marquandii*
				BebaHA20C03	OM373016	*Beauveria bassiana*
HA21	Zhoukou, Henan	33.978 N, 114.867 E	Crop	PulaHA21A01	OM373017	*Purpureocillium lavendulum*
				MemaHA2102	OM373018	*Metarhizium marquandii*
			Grass	Pula sp. HA21B01	OM373019	*Purpureocillium lavendulum*
				PeciHA21B02	OM373020	*Penicillium citrinum*
HA22	Shangqiu, Henan	34.350 N, 115.572 E	Crop	HA22A01	–	
				BebaHA22A02	OM373021	*Beauveria bassiana*
				PuliHA22B01	OM373022	*Purpureocillium lilacinum*
			Grass	PuliHA22C01	OM373023	*Purpureocillium lilacinum*
HA23	Shangqiu, Henan	34.596 N, 115.109 E	Crop	TapuHA23A01	OM373024	*Talaromyces purpureogenus*
				MemaHA23B01	OM373025	*Metarhizium marquandii*
				HA23B02	–	
			Orchard	PemiHA23C01	OM373026	*Penicillium mirabile*
HA24	Kaifeng, Henan	34.771 N, 114.806 E	Crop	MemaHA24A01	OM373027	*Metarhizium marquandii*
				PulaHA24A02	OM373028	*Purpureocillium lavendulum*
				PuliHA24B01	OM373029	*Purpureocillium lilacinum*
HA25	Zhengzhou, Henan	34.838 N, 114.036 E	Crop	PeciHA25A01	OM373030	*Penicillium citrinum*
				MeanHA25A02	OM373031	*Metarhizium anisopliae*
			Grass	MeanHA25B01	OM373032	*Metarhizium anisopliae*
				PuliHA25B02	OM373033	*Purpureocillium lilacinum*
			Crop	MeanHA25C01	OM373034	*Metarhizium anisopliae*
			Poplar	MemaHA25D01	OM373035	*Metarhizium marquandii*
				HA25D02	–	

References

1. Assadi, B.H.; Chouikhi, S.; Ettaib, R.; M'Hamdi, N.B.; Belkadhi, M.S. Effect of the native strain of the predator *Nesidiocoris tenuis* Reuter and the entomopathogenic fungi *Beauveria bassiana* and *Lecanicillium muscarium* against *Bemisia tabaci* (Genn.) under greenhouse conditions in *Tunisia*. *Egypt. J. Biol. Pest Control* **2021**, *31*, 47. [CrossRef]
2. Ni, C.C. Current situation and prospect of using entomopathogenic microorganisms to control pests. *World Pestic.* **2005**, *27*, 35–37.
3. Peng, Y.; Li, S.J.; Yan, J.; Tang, Y.; Cheng, J.P.; Gao, A.J.; Yao, X.; Ruan, J.J.; Xu, B.L. Research Progress on Phytopathogenic Fungi and Their Role as Biocontrol Agents. *Front. Microbiol.* **2021**, *12*, 670135. [CrossRef] [PubMed]
4. Chen, Z.Q.; Liang, W.L.; Huang, L.P.; Shen, B.B. Identification of 29 strains of entomogenous fungi and their toxicity to *Bemisia tabaci*. *J. South China Agric. Univ.* **2020**, *41*, 57–67. [CrossRef]
5. Lian, T.; Qin, C.S.; Jie, Y.Z.; Xu, J.Z.; Zhao, D.Y.; Qiu, H.L.; Yang, H.; Lai, G.D. Biological characteristics of six strains of entomophytic fungi and theirpathogenicity against *Curculio chinensis* (Coleoptera: Curculionidae). *J. Environ. Entomol.* **2019**, *41*, 642–649. [CrossRef]
6. Wang, J.X.; Ma, J.L. Application of entomogenous fungi in biological control of agriculture and forestry pests. *J. Zhejiang For. Colg.* **2009**, *26*, 286–291. [CrossRef]
7. Song, X.B.; Peng, A.T.; Cheng, B.P.; Ling, J.F.; Chen, X.; Zhang, L.H. Isolation of identification of a *Beauveria bassiana* strain infecting *Diaphorina citri*. *Plant Prot.* **2017**, *43*, 139–144. [CrossRef]
8. Mascarin, G.M.; Lopes, R.B.; Delalibera, I., Jr.; Fernandes, E.; Luz, C.; Faria, M. Current status and perspectives of fungal entomopathogens used for microbial control of arthropod pests in Brazil. *J. Invertebr. Pathol.* **2019**, *165*, 46–53. [CrossRef]

9. Zec-Vojinovic, M.; Hokkanen, H.M.T.; Büchs, W.; Klukowski, Z.; Luik, A.; Nilsson, C.; Ulber, B.; Williams, I.H. Natural occurrence of pathogens of oilseed rape pests in agricultural fields in Europe. In Proceedings of the International Symposium of Integrated Pest Management in Oilseed Rape, Gottingen, Germany, 3–5 April 2006.
10. Li, Z.Z. Application status of entomogenous fungi in pest control. *J. Anhui Agric. Colg.* **1987**, *14*, 59–66.
11. Wu, Y.Y.; Tang, Y.L.; Gu, N.C.; Li, T.T.; Bao, J.L.; Li, T.; Li, C.F.; Wei, J.H.; Pan, G.Q.; Zhou, Z.Y. Isolation and identification of three Beauveria bassiana isolates in Chongqing area. *J. Southwest Univ.* **2019**, *41*, 14–19. [CrossRef]
12. Soroka, J.; Grenkow, L.; Otani, J.; Gavloski, J.; Olfert, O. *Flea beetle* (Coleoptera: Chrysomelidae) species in canola (Brassicaceae) on the northern Great Plains of North America. *Can. Èntomol.* **2018**, *150*, 100–115. [CrossRef]
13. Cao, C.X.; Huang, D.Y.; Yao, J.W.; Zhu, Z.G.; Zheng, J.L.; Zhou, R.H.; Wang, K. Field application techniques for control of Phyllotreta striolata with microbial insecticides on radish. *Chin. J. Biol. Control.* **2020**, *36*, 987–991. [CrossRef]
14. Noosidum, A.; Mangtab, S.; Lewis, E.E. Biological control potential of entomopathogenic nematodes against the striped flea beetle, *Phyllotreta sinuata* Stephens (Coleoptera: Chrysomelidae). *Crop Prot.* **2020**, *141*, 105448. [CrossRef]
15. Gao, X.J.; Zhang, M.M.; Wang, H.L.; Zu, J.H.; Yang, W.J.; Qiao, Y.S. The combined effect and safety of bifenthrin-acetamiprid on *Phyllotreta striolata*. *Agrochem* **2022**, *61*, 57–60. [CrossRef]
16. Yan, X.; Han, R.; Moens, M.; Chen, S.; De Clercq, P. Field evaluation of entomopathogenic nematodes for biological control of striped flea beetle, *Phyllotreta striolata* (Coleoptera: Chrysomelidae). *BioControl* **2012**, *58*, 247–256. [CrossRef]
17. Andersen, C.L.; Hazzard, R.; Vandriesche, R.; Mangan, F.X. Alternative Management Tactics for Control of *Phyllotreta cruciferae* and *Phyllotreta striolata* (Coleoptera: Chrysomelidae) on *Brassica rapa* in Massachusetts. *J. Econ. Èntomol.* **2006**, *99*, 803–810. [CrossRef]
18. Mason, J.; Alford, A.M.; Kuhar, T.P. Flea *Beetle* (Coleoptera: Chrysomelidae) Populations, Effects of Feeding Injury, and Efficacy of Insecticide Treatments on Eggplant and Cabbage in Southwest Virginia. *J. Econ. Èntomol.* **2019**, *113*, 887–895. [CrossRef]
19. Hoarau, C.; Campbell, H.; Prince, G.; Chandler, D.; Pope, T. Biological control agents against the cabbage stem flea beetle in oilseed rape crops. *Biol. Control* **2022**, *167*, 104844. [CrossRef]
20. Mascarin, G.M.; Pereira-Junior, R.A.; Fernandes, E.; Quintela, E.D.; Dunlap, C.A.; Arthurs, S.P. Phenotype responses to abiotic stresses, asexual reproduction and virulence among isolates of the entomopathogenic fungus *Cordyceps javanica* (Hypocreales: Cordycipitaceae). *Microbiol. Res.* **2018**, *216*, 12–22. [CrossRef]
21. Fang, W.; Lu, H.-L.; King, G.; Leger, R.J.S. Construction of a Hypervirulent and Specific Mycoinsecticide for Locust Control. *Sci. Rep.* **2014**, *4*, 7345. [CrossRef]
22. Kuang, Z.B.; Lv, L.H.; Feng, X.; Chen, H.Y.; Wu, Y.J.; He, Y.R. Pathogenicity of Beauveria bassiana isolate to cruciferous vegetable insect pests. *Chin. Bull. Entomol.* **2005**, *42*, 673–676. [CrossRef]
23. He, Y.C.; Chen, J.; Shi, M.Z.; Li, J.Y.; Wang, T.; Fu, J.W.; Wu, M.X. Screening and culture of a strain of Metarhizium highly pathogenic to *Phyllotreta striolata*, Fujian. *J. Agric. Sci.* **2017**, *32*, 189–194. [CrossRef]
24. Meyling, N.V.; Eilenberg, J. Occurrence and distribution of soil borne entomopathogenic fungi within a single organic agroecosystem. *Agric. Ecosyst. Environ.* **2006**, *113*, 336–341. [CrossRef]
25. Masoudi, A.; Koprowski, J.L.; Bhattarai, U.R.; Wang, D. Elevational distribution and morphological attributes of the entomopathogenic fungi from forests of the Qinling Mountains in China. *Appl. Microbiol. Biotechnol.* **2017**, *102*, 1483–1499. [CrossRef]
26. Niu, X.; Xie, W.; Zhang, J.; Hu, Q. Biodiversity of Entomopathogenic Fungi in the Soils of South China. *Microorganisms* **2019**, *7*, 311. [CrossRef]
27. Dong, T.; Zhang, B.; Jiang, Y.; Hu, Q. Isolation and Classification of Fungal Whitefly Entomopathogens from Soils of Qinghai-Tibet Plateau and Gansu Corridor in China. *PLoS ONE* **2016**, *11*, e0156087. [CrossRef]
28. Hu, Q.-B.; Ren, S.-X.; Wu, J.-H.; Chang, J.-M.; Musa, P.D. Investigation of destruxin A and B from 80 Metarhizium strains in China, and the optimization of cultural conditions for the strain MaQ10. *Toxicon* **2006**, *48*, 491–498. [CrossRef]
29. Kumar, S.; Stecher, G.; Li, M.; Knyaz, C.; Tamura, K. MEGA X: Molecular Evolutionary Genetics Analysis across Computing Platforms. *Mol. Biol. Evol.* **2018**, *35*, 1547–1549. [CrossRef]
30. Schoch, C.L.; Robbertse, B.; Robert, V.; Vu, D.; Cardinali, G.; Irinyi, L.; Meyer, W.; Nilsson, R.H.; Hughes, K.; Miller, A.N.; et al. Finding needles in haystacks: Linking scientific names, reference specimens and molecular data for Fungi. *Database* **2014**, *2014*, bau061. [CrossRef]
31. Gujjari, P.; Suh, S.-O.; Coumes, K.; Zhou, J.J. Characterization of oleaginous yeasts revealed two novel species: *Trichosporon cacaoliposimilis* sp. nov. and *Trichosporon oleaginosus* sp. nov. *Mycologia* **2011**, *103*, 1110–1118. [CrossRef]
32. Sugiura, Y.; Hironaga, M. Arthrographis kalrae, a rare causal agent of onychomycosis, and its occurrence in natural and commercially available soils. *Med. Mycol.* **2010**, *48*, 384–389. [CrossRef] [PubMed]
33. Giraldo, A.; Sutton, D.A.; Gené, J.; Fothergill, A.W.; Cano-Lira, J.F.; Guarro, J. Rare Arthroconidial Fungi in Clinical Samples: Scytalidium cuboideum and *Arthropsis hispanica*. *Mycopathologia* **2012**, *175*, 115–121. [CrossRef] [PubMed]
34. Peterson, S.W. Phylogenetic analysis of *Aspergillus* species using DNA sequences from four loci. *Mycologia* **2008**, *100*, 205–226. [CrossRef] [PubMed]
35. Samson, R.; Peterson, S.; Frisvad, J.; Varga, J. New species in Aspergillus section Terrei. *Stud. Mycol.* **2011**, *69*, 39–55. [CrossRef] [PubMed]

36. Vu, D.; Groenewald, M.; De Vries, M.; Gehrmann, T.; Stielow, B.; Eberhardt, U.; Al-Hatmi, A.; Groenewald, J.Z.; Cardinali, G.; Houbraken, J.; et al. Large-scale generation and analysis of filamentous fungal DNA barcodes boosts coverage for kingdom fungi and reveals thresholds for fungal species and higher taxon delimitation. *Stud. Mycol.* **2019**, *92*, 135–154. [CrossRef] [PubMed]
37. Wei, M.-J.; Zhang, H.; Dong, W.; Boonmee, S.; Zhang, D. Introducing *Dictyochaeta aquatica* sp. nov. and two new species of *Chloridium* (Chaetosphaeriaceae, Sordariomycetes) from aquatic habitats. *Phytotaxa* **2018**, *362*, 187–199. [CrossRef]
38. Schroers, H.J. A monograph of *Bionectria* (Ascomycota, Hypocreales, Bionectriaceae) and its *Clonostachys* anamorphs. *Stud. Mycol.* **2001**, *17*, 1–214. [CrossRef]
39. Liu, X.Y.; Huang, H.; Zheng, R.Y. Relationships within *Cunninghamella* based on sequence analysis of ITS rDNA. *Mycotaxon* **2001**, *80*, 77–95.
40. Sandoval-Denis, M.; Crous, P. Removing chaos from confusion: Assigning names to common human and animal pathogens in *Neocosmospora*. *Pers. Mol. Phylogeny Evol. Fungi* **2018**, *41*, 109–129. [CrossRef]
41. Short, D.P.G.; O'Donnell, K.; Zhang, N.; Juba, J.H.; Geiser, D.M. Widespread Occurrence of Diverse Human Pathogenic Types of the Fungus Fusarium Detected in Plumbing Drains. *J. Clin. Microbiol.* **2011**, *49*, 4264–4272. [CrossRef]
42. Schroers, H.-J.; Samuels, G.J.; Zhang, N.; Short, D.P.; Juba, J.; Geiser, D.M. Epitypification of *Fusisporium* (*Fusarium*) *solani* and its assignment to a common phylogenetic species in the *Fusarium solani* species complex. *Mycologia* **2016**, *108*, 806–819. [CrossRef]
43. Walther, G.; Pawłowska, J.; Alastruey-Izquierdo, A.; Wrzosek, M.; Rodriguez-Tudela, J.; Dolatabadi, S.; Chakrabarti, A.; de Hoog, G. DNA barcoding in Mucorales: An inventory of biodiversity. *Pers. Mol. Phylogeny Evol. Fungi* **2013**, *30*, 11–47. [CrossRef]
44. De Beer, Z.W.; Marincowitz, S.; Duong, T.A.; Kim, J.-J.; Rodrigues, A.; Wingfield, M.J. *Hawksworthiomyces* gen. nov. (Ophiostomatales), illustrates the urgency for a decision on how to name novel taxa known only from environmental nucleic acid sequences (ENAS). *Fungal Biol.* **2016**, *120*, 1323–1340. [CrossRef]
45. Humber, R.A.; Rocha, L.F.; Inglis, P.W.; Kipnis, A.; Luz, C. Morphology and molecular taxonomy of Evlachovaea-like fungi, and the status of this unusual conidial genus. *Fungal Biol.* **2013**, *117*, 1–12. [CrossRef]
46. Rehner, S.A.; Minnis, A.M.; Sung, G.-H.; Luangsa-Ard, J.J.; Devotto, L.; Humber, R.A. Phylogeny and systematics of the anamorphic, entomopathogenic genus *Beauveria*. *Mycologia* **2011**, *103*, 1055–1073. [CrossRef]
47. Luangsa-Ard, J.J.; Hywel-Jones, N.L.; Manoch, L.; Samson, R.A. On the relationships of *Paecilomyces* sect. *Isarioidea* species. *Mycol. Res.* **2005**, *109*, 581–589. [CrossRef]
48. Inglis, P.W.; Tigano, M.S. Identification and taxonomy of some entomopathogenic *Paecilomyces* spp. (Ascomycota) isolates using rDNA-ITS Sequences. *Genet. Mol. Biol.* **2006**, *29*, 132–136. [CrossRef]
49. Cabanillas, H.E.; de León, J.H.; Humber, R.A.; Murray, K.D.; Jones, W.A. *Isaria poprawskii* sp. nov. (Hypocreales: Cordycipitaceae), a new entomopathogenic fungus from Texas affecting sweet potato whitefly. *Mycoscience* **2013**, *54*, 158–169. [CrossRef]
50. Ayala-Zermeño, M.; Gallou, A.; Berlanga-Padilla, A.; Serna-Domínguez, M.; Arredondo-Bernal, H.; Montesinos-Matías, R. Characterisation of entomopathogenic fungi used in the biological control programme of *Diaphorina citri* in Mexico. *Biocontrol Sci. Technol.* **2015**, *25*, 1192–1207. [CrossRef]
51. Su, L.; Zhu, H.; Guo, Y.; Du, X.; Guo, J.; Zhang, L.; Qin, C. *Lecanicillium coprophilum* (Cordycipitaceae, Hypocreales), a new species of fungus from the feces of *Marmota monax* in China. *Phytotaxa* **2019**, *387*, 55–62. [CrossRef]
52. Sugiyama, M.; Mikawa, T. Phylogenetic analysis of the non-pathogenic genus *Spiromastix* (Onygenaceae) and related onygenalean taxa based on large subunit ribosomal DNA sequences. *Mycoscience* **2001**, *42*, 413–421. [CrossRef]
53. Koehn, F.E.; Kirsch, D.R.; Feng, X.; Janso, J.; Young, M. A Cell Wall-Active Lipopeptide from the Fungus *Pochonia bulbillosa*. *J. Nat. Prod.* **2008**, *71*, 2045–2048. [CrossRef]
54. Oxelman, B.; Lidén, M.; Rabeler, R.K.; Popp, M. A revised generic classification of the tribe *Sileneae* (Caryophyllaceae). *Nord. J. Bot.* **2000**, *20*, 743–748. [CrossRef]
55. Nonaka, K.; Ōmura, S.; Masuma, R.; Kaifuchi, S. Three new *Pochonia* taxa (Clavicipitaceae) from soils in Japan. *Mycologia* **2013**, *105*, 1202–1218. [CrossRef]
56. Samson, R.; Houbraken, J.; Varga, J.; Frisvad, J. Polyphasic taxonomy of the heat resistant ascomycete genus *Byssochlamys* and its *Paecilomyces* anamorphs. *Pers. Mol. Phylogeny Evol. Fungi* **2009**, *22*, 14–27. [CrossRef]
57. Peterson, S.W.; Orchard, S.S.; Menon, S. *Penicillium menonorum*, a new species related to *P. pimiteouiense*. *IMA Fungus* **2011**, *2*, 121–125. [CrossRef]
58. Samson, R.; Yilmaz, N.; Houbraken, J.; Spierenburg, H.; Seifert, K.; Peterson, S.; Varga, J.; Frisvad, J. Phylogeny and nomenclature of the genus *Talaromyces* and taxa accommodated in *Penicillium* subgenus *Biverticillium*. *Stud. Mycol.* **2011**, *70*, 159–183. [CrossRef]
59. Pan, X.; Richardson, M.D.; Deng, S.; Kremer, R.J.; English, J.T.; Mihail, J.D.; Sams, C.E.; Scharf, P.C.; Veum, K.S.; Xiong, X. Effect of Organic Amendment and Cultural Practice on Large Patch Occurrence and Soil Microbial Community. *Crop Sci.* **2017**, *57*, 2263–2272. [CrossRef]
60. Dung, J.K.; Kaur, N.; Walenta, D.L.; Alderman, S.C.; Frost, K.E.; Hamm, P.B. Reducing *Claviceps purpurea* sclerotia germination with soil-applied fungicides. *Crop Prot.* **2018**, *106*, 146–149. [CrossRef]
61. Dash, C.K.; Bamisile, B.S.; Keppanan, R.; Qasim, M.; Lin, Y.; Islam, S.U.; Hussain, M.; Wang, L. Endophytic entomopathogenic fungi enhance the growth of *Phaseolus vulgaris* L. (Fabaceae) and negatively affect the development and reproduction of Tetranychus urticae Koch (Acari: Tetranychidae). *Microb. Pathog.* **2018**, *125*, 385–392. [CrossRef]

62. De Azevedo, A.G.C.; Stuart, R.M.; Sigsgaard, L. Presence of a generalist entomopathogenic fungus influences the oviposition behaviour of an aphid-specific predator. *BioControl* **2018**, *63*, 655–664. [CrossRef]
63. Sangbaramou, R.; Camara, I.; Huang, X.-Z.; Shen, J.; Tan, S.-Q.; Shi, W.-P. Behavioral thermoregulation in *Locusta migratoria* manilensis (Orthoptera: Acrididae) in response to the entomopathogenic fungus, *Beauveria bassiana*. *PLoS ONE* **2018**, *13*, e0206816. [CrossRef] [PubMed]
64. Canassa, F.; Tall, S.; Moral, R.A.; de Lara, I.A.; Delalibera, I.; Meyling, N.V. Effects of bean seed treatment by the entomopathogenic fungi *Metarhizium robertsii* and *Beauveria bassiana* on plant growth, spider mite populations and behavior of predatory mites. *Biol. Control* **2019**, *132*, 199–208. [CrossRef]
65. Hou, C.X.; Qin, G.X.; Liu, T.; Guo, X.J. Advances in defense mechanism of insects against pathogenic fungi. *J. Anhui Agric. Sci.* **2012**, *40*, 11649–11652. [CrossRef]
66. Horikawa, M.; Shimazu, M.; Aibe, M.; Kaku, H.; Inai, M.; Tsunoda, T. A role of uroleuconaphins, polyketide red pigments in aphid, as a chemopreventor in the host defense system against infection with entomopathogenic fungi. *J. Antibiot.* **2018**, *71*, 992–999. [CrossRef]
67. Hornby, J.M.; Jensen, E.C.; Lisec, A.D.; Tasto, J.J.; Jahnke, B.; Shoemaker, R.; Dussault, P.; Nickerson, K.W. Quorum sensing in the dimorphic fungus Candida albicans is mediated by farnesol. *Appl. Environ. Microbiol.* **2001**, *7*, 2982–2992. [CrossRef]
68. Alem, M.A.S.; Oteef, M.D.Y.; Flowers, T.H.; Douglas, L.J. Production of Tyrosol by *Candida albicans* Biofilms and Its Role in Quorum Sensing and Biofilm Development. *Eukaryot. Cell* **2006**, *5*, 1770–1779. [CrossRef]
69. Baert, K.; Devlieghere, F.; Bo, L.; Debevere, J.; De Meulenaer, B. The effect of inoculum size on the growth of Penicillium expansum in apples. *Food Microbiol.* **2008**, *25*, 212–217. [CrossRef]
70. Li, C.Y.; Liang, Z.H.; Huang, K.L. Research progress on quorum sensing of Aspergilus flavus. *J. Food Saf. Qual.* **2015**, *6*, 3205–3210. [CrossRef]
71. Ke, H.; Niu, Y.; Gu, D.; Wu, J.; Chen, Q. Quorum sensing molecule, farnesol and its action mechanism in fungi. *J. Food Saf. Qual.* **2017**, *8*, 862–868. [CrossRef]
72. Chen, H.; Fujita, M.; Feng, Q.; Clardy, J.; Fink, G.R. Tyrosol is a quorum-sensing molecule in *Candida albicans*. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 5048–5052. [CrossRef]