microorganisms

MDPI

Review

Patents on Endophytic Fungi for Agriculture and Bio- and Phytoremediation Applications

Humberto E. Ortega [1,2], Daniel Torres-Mendoza [1,3] and Luis Cubilla-Rios [1,*]

1 Laboratory of Tropical Bioorganic Chemistry, Faculty of Natural, Exact Sciences and Technology, University of Panama, Panama 0824, Panama; humberto.ortegad@up.ac.pa (H.E.O.); dtorresm.507@gmail.com (D.T.-M.)
2 Department of Organic Chemistry, Faculty of Natural, Exact Sciences and Technology, University of Panama, Panama 0824, Panama
3 Vicerrectoría de Investigación y Postgrado, University of Panama, Panama 0824, Panama
* Correspondence: luis.cubilla@up.ac.pa; Tel.: +507-6676-5824

Received: 7 June 2020; Accepted: 7 July 2020; Published: 14 August 2020

check for updates

Abstract: Plant endophytic fungi spend all or part of their lives inside host tissues without causing disease symptoms. They can colonize the plant to protect against predators, pathogens and abiotic stresses generated by drought, salinity, high concentrations of heavy metals, UV radiation and temperature fluctuations. They can also promote plant growth through the biosynthesis of phytohormones and nutrient acquisition. In recent years, the study of endophytic fungi for biological control of plant diseases and pests has been intensified to try to reduce the ecological and public health impacts due the use of chemicals and the emergence of fungicide resistance. In this review, we examine 185 patents related to endophytic fungi (from January 1988 to December 2019) and discuss their applicability for abiotic stress tolerance and growth promotion of plants, as agents for biocontrol of herbivores and plant pathogens and bio- and phytoremediation applications.

Keywords: endophytic fungi; patent; abiotic stress tolerance; biocontrol; bioremediation; phytoremediation

1. Introduction

An endophytic fungus is any organism inhabiting plant organs that, at certain point in its lifetime, can colonize tissues without causing apparent harm [1]. Endophytic fungi have been a proven source of secondary metabolites with potential uses as anticancer, antibiotics, antivirals, anti-inflammatories, antioxidants, neuroprotective agents, insecticides and antifungals, and have multiple applications in biotechnological developments in pharmaceutical, agriculture, cosmetic, food industry and environmental processes [2]. In the last decades, studies of endophytic fungi have resulted in a number of patents linked to the production of biologically active secondary metabolites and in biotransformation processes [3].

Moreover, interaction between fungi and their hosts drives changes in the host metabolism, altering the response to environmental stress and predator attack. Additionally, this interaction leads to the production of secondary metabolites by both the fungi and the host, which further enhance the capability to respond to the environment [4–7].

The use of endophytic fungi for environmental applications such as growth promotion, relief of abiotic stress, biocontrol of pest and plant pathogens and bio/phytoremediation has gained important attention in recent years due to the concern about global climate change and contamination in soils and natural sources that increases stress in crops, limiting and reducing the production [8–11]. Furthermore, basic and applied research has been conducted to develop processes, methodologies and technologies that resulted in a considerable number of patents with new proposals to overcome some of these challenges. Therefore, in this review, we cover patents on endophytic fungi applications related to (a) abiotic stress tolerance and growth promotion of plants; (b) biocontrol of herbivores and plant pathogens; (c) bio- or phytoremediation.

The highlighted topics in each of the patents, cited here, could inspire other researchers to take their investigation to the next level and contribute to overcome, in a more efficient way, some of the principal challenges of humanity today.

2. Materials and Methods

The present review was conducted mainly through searches in the Scifinder® and Google Patents databases. The search was initially conducted in Scifinder® using the terms "endophytic fungi" and "patents" covering the period from 1988 to 2019. 12,315 references were found. After removing duplicates (those describing the same patent/endophyte), we selected those related to the aim of this review, resulting in 185 documents. The patents covered in this study are described in five tables below.

3. Results

The description and analysis of patents was divided, considering the main objective of each one, into four sections; those associated to: (Section 3.1) abiotic stress tolerance and growth promotion of plants; (Section 3.2) biocontrol of herbivores and plant pathogens, and (Section 3.3) bio- and phytoremediation applications; (Section 3.4) patents where the endophyte has multiple applications. The information in tables describe the fungi, the host plant where they were isolated, and the main application of the patent. All endophytes, listed in the tables, have beneficial effects on plants, even though some of them could be considered as pathogens in previous reports.

3.1. Abiotic Stress Tolerance and Growth Promotion of Plants

The principal abiotic stress factors in plants include drought, salinity, high heavy metal concentrations, UV radiation and temperature fluctuations [12]. Abiotic stress affects the cellular pathways of plants, resulting in negative changes to their physiology and morphology [12]. Endophytic fungi have been shown to help their host plant to overcome abiotic stress and promote plant growth through the biosynthesis of phytohormones (indole-3-acetic-acid, gibberellins, cytokinins, ethylene, acetoin, 2, 3-butanediol) and nutrient absorption and uptake [12–14].

Plant endophytic fungi have been patented based on their ability to improve the following in plants: (a) root and seed development; (b) nutrient uptake or absorption; (c) photosynthesis promotion; (d) growth of biomass; (e) increase chlorophyll content; and (f) abiotic stress resistance. Numerous genera have been used for such purposes, including *Acremonium*, *Alternaria*, *Aspergillus*, *Chaetomium*, *Fusarium*, *Penicillium*, and others (Tables 1 and 2). A specific area of application for which endophytic fungi have been widely used is in the growth promotion of medicinal plants; this includes such species as *Acanthopanax senticosus* [15], *Salvia miltiorrhiza* [16], *Rumex gmelinii* Turcz [17], *Acacia confusa* [18], *Coix lacryma-jobi* [19], *Cynanchum acuminata* [20], *Huperzia serrata* [21], *Anoectochilus roxburghii* [22], *Arnebia* sp. [23], *Saussurea* sp. [24], *Rhizoma bletillae* [25], *Salvia miltiorrhiza* [26,27], and *Eucalyptus* sp. [28–30]. Additionally, some endophytic fungi have been patented due to their capability to promote the growth of crop plants such as corn, tomato, soybean, rice, wheat, potato, and barley [31–37] as well as other useful plants such as *Casuarina equisetifolia* [38–41], fir [42–45], *Aleurites montana* [46–51], *Dendrobium* sp. [52–54], tobacco [55–58], *Schima superba* [59–61], *Bletilla striata* [62,63], and *Paphiopedilum* sp. [64].

Table 1. Endophytic fungi applied to enhance the abiotic stress tolerance of plants.

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN104762216A	*Arthrinium* sp.	*Salicornia bigelovii*	Plant anti-salt stress.	[65]
WO2004000017A2	*Curvularia* sp.	*Dichanthelium languinosum*	Conferring stress tolerance to inoculated plants (monocots and dicots).	[66]
WO2009012480A2	*Fusarium* sp.	*Leymus mollis*	Conferring stress tolerance to inoculated plants (monocots and dicots).	[67]
CN105296359A	*Lecanicillium* sp.	Tobacco	Reducing the absorption of heavy metals in tobacco.	[58]
CN101314760A	*Neotyphodium chisosum*	*Festuca arundinacea*	Improving the stress tolerance to drought and diseases.	[68]
CN104004665A	*Papulospora* sp.	Fir roots	Relieving phosphorus stress in fir.	[43]
CN105002099A	*Paraconiothyrium cyclothyrioides*	*Myricaria* root	Reducing heavy metal pollution in plants.	[69]
CN101974437A	*Penicillium* sp.	*Eucalyptus*	Relieving aluminum toxicity in *Eucalyptus*.	[30]
CN102002463A	*Penicillium* sp.	*Eucalyptus* roots, stems, and leaves	Improving the cold resistance of *Eucalyptus*.	[28]
CN103865806A	*Phialophora oryzae*	Not disclosed	Reducing the absorption of heavy metals in tobacco	[57]
CN107926549A	*Piriformospora indica*	Not disclosed	Improving the resistance of plants to the herbicide bensulfuron-methyl.	[70]
CN103834578A	*Pyrenochaeta* sp.	Tobacco	Promoting plant growth and reducing the heavy metal content in tobacco.	[55]
CN105316240A	*Rhizopycnis* sp.	Tobacco	Reducing the absorption of heavy metals in tobacco.	[56]
US20150366217A1	Group of several fungi [2]	Roots of *Triticum turgidum* L.	Improving seed vitality, biotic and abiotic stress resistance, and plant health and yield under both stressed and unstressed environmental conditions.	[71]

[1] Some patents just provided a common name for the host organism. [2] A list of the group of fungi is in Table S1.

Table 2. Endophytic fungi applied for the growth promotion of plants.

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN105907648A	*Acremonium* sp.	*Panax notoginseng*	Root and seed development of different plants including *Radix Ginseng*, *Oryza sativa* L., *Semen Maydis*, *Semen Tritici aestivi*, *Rhizoma Paridis*, Rhizoma *Solani tuberosi*, etc.	[34]
CN108513990A	*Alternaria alternata*	*Acanthopanax senticosus*	Seedling-stage growth of *A. senticosus*.	[15]
CN104911108A	*Alternaria* sp.	*Hippophae* sp.	Drought resistance on turf grass.	[72]
CN104818218A	*Alternaria* sp.	*Aleurites montana*	Phosphorus uptake in *A. montana*.	[47]
CN102086439A	*Alternaria tenuissima*	*Panax ginseng*	Growth of corn plant.	[31]
CN103173362A	*Aspergillus* sp.	*Casuarina* sp. rhizosphere	Photosynthesis in *C. equisetifolia*.	[38]
CN103173361A	*Aspergillus* sp.	*Casuarina* sp. rhizosphere	Nutrient element absorption in *Casuarina*.	[39]
CN103173364A	*Aspergillus* sp.	*Casuarina* sp. rhizosphere	*Casuarina* biomass growth.	[41]
CN110343619A	*Botryosphaeria* sp.	Root of *Schima superba*	*Schima superba* seedling height and ground diameter under a low-phosphorus environment.	[61]
CN109456902A	*Byssochlamys spectabilis*	*Rhizoma bletillae*	The growth of *R. bletillae*.	[25]
CN106929436A	*Cercosporella Sacc.*	*Rumex gmelini* Turcz	Growth in *R. gmelinii* Turcz.	[17]
CN106801014A	*Chaetomium globosum*	*Salvia miltiorrhiza*	Radix root biomass, plant height, crown diameter in *S. miltiorrhiza*.	[73]
CN109628322A	*Chaetomium nigricolor*	*Bletilla striata*	The growth of *B. striata*.	[62]
CN110438011A	*Cladosporium tenuissimum*	*Salvia miltiorrhiza*	Synthesis of effective components (tanshinone and salvianolic acid substances) in the root system of *Salvia miltiorrhiza*.	[26]
CN104630073A	*Claviceps* sp.	*Dendrobium officinale*	Growth and yield in *D. officinale*.	[74]
CN104004664A	*Colletotrichum* sp.	*Abies* sp. roots	Photosynthesis of cedar.	[45]
CN106085872A	*Colletotrichum* sp./*Fusarium* sp.	*Acacia* sp.	Nutrient absorption in *A. confusa*.	[18]
CN104805019A	*Coniothyrium* sp.	*Aleurites* sp.	Nutrient element absorption in wood oil tree.	[75]
CN104004666A	*Cylindrocarpon* sp.	fir plant	Growth of fir.	[42]
CN110250210A	*Darksidea* sp.	*Stipa capillata* root	Rooting and growth of maize.	[36]

Table 2. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN109504611A	*Diaporthe spectabilis*	*Bletilla striata*	Growth of *B. striata*.	[63]
CN103733829A	*Emericella foeniculicola*	*Salvia miltiorrhizae*	Growth of *S. miltiorrhizae*.	[76]
CN105624047A	*Epichloë bromicola*	*Coix lacryma-jobi*	Growth of *Coix lacryma-jobi*, *Arabidopsis thaliana* and other graminaceous plants.	[19]
CN105861334A	*Filobasidium* sp.	*Acacia* sp.	Taiwan *Acacia* biomass.	[77]
CN105861335A	*Filobasidium* sp.	*Acacia* sp.	Nutrient element absorption in Taiwan *Acacia* in a low-phosphorous environment.	[78]
CN106085873A	*Filobasidium* sp./*Penicillium* sp.	*Acacia* sp.	Phosphorous uptake in *A. confusa* under a low-phosphorus environment.	[79]
CN107432135A	*Fusarium redolens*	Not disclosed	Germination of *Cynanchum acuminata* seeds.	[20]
CN103173360A	*Fusarium* sp.	*Casuarina equisetifolia*	Chlorophyll content of *C. equisetifolia*.	[80]
CN110257259A	*Fusarium* sp.	*Schima superba stems*	Photosynthesis of *Schima superba*.	[59]
CN103114044A	*Heterodera oryzae*	rice	Plant growth regulation and/or plant pathogenicity.	[81]
CN103798293A	*Hypha* sp.	*Salvia miltiorrhiza*	The growth and improvement of *S. miltiorrhiza* hairy root tanshinone content.	[82]
CN1961631A	*Mycocentrospora* sp./*Leptodontidium* sp.	*Saussurea involucrata*	*Saussurea* sp. growth.	[24]
CN104593274A	*Nectria* sp.	*Dendrobium officinale*	Yield in *Dendrobium* artificial planting.	[83]
US20130104263A1	*Neotyphodium* sp.	perennial ryegrass	Beneficial properties (phenotype) for plant.	[84]
CN104004667A	*Paecilomyces* sp.	Not disclosed	Phosphorus absorption in fir.	[44]
CN106010984A	*Penicillium* sp.	*Acacia confusa*	Plant biomass growth of Taiwan *Acacia* plant under low-phosphorus environment.	[85]
CN101974438A	*Penicillium* sp.	*Eucalyptus*	Phosphorus absorption in *Eucalyptus*.	[29]
CN104818219A	*Penicillium* sp.	*Aleurites montana*	Root growth of *A. montana* in a low-phosphorous environment.	[51]

Table 2. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN104789481A	*Penicillium* sp.	*Aleurites montana*	Growth and photosynthesis enhancement of *A. montana* in a low-phosphorus environment.	[48]
CN104762219A	*Penicillium* sp.	*Aleurites montana*	Biomass growth of *A. montana* in a low-phosphorus environment.	[49]
CN110257258A	*Penicillium* sp.	*Schima superba* leaves	Phosphorus absorption of *Schima superba*.	[60]
WO2016210238A1	*Penicillium* sp.	Not disclosed	Cultivation of agricultural plants, such as soybean and maize.	[33]
CN104818217A	*Pestalotia* sp.	Not disclosed	Biomass growth of *A. montana*.	[50]
CN105886405A	*Pestalotiopsis* sp.	*Dendrobium officinale*	Growth of *D. officinale* and change in metabolic components.	[54]
CN107988087A	*Pezicula ericae*	wild blueberry root	Growth effects.	[86]
CN109706084A	*Phoma herbarum*	*Salvia miltiorrhiza*	Growth of *Salvia miltiorrhiza* and synthesis of tanshinone compounds.	[27]
CN104593273A	*Phyllachora* sp.	*Dendrobium officinale*	*Dendrobium* yield.	[87]
CN103173363A	*Phyllosticta* sp.	*Casuarina* sp.	Photosynthesis of *C. equisetifolia*.	[40]
ES2500790A1	*Pochonia chlamydosporia*	Not disclosed	Flowering and fruiting and increased yield in crops such as tomatoes.	[32]
WO2016038234A1	*Pochonia chlamydosporia*	*Meloidogyne* spp.	Culture yield and reduction in flowering and fructification times.	[88]
CN105039172A	*Pythium* sp.	*Huperzia serrata*	Improved transplant survival rate of *H. serrate*.	[21]
CN108041078A	*Rhizopycnis* sp.	tobacco	Rice growth.	[89]
WO2019113255A1	*Serendipita vermifera* ssp. *bescii*	Australian orchid	Enhancement of plant performance in combination with phosphite as a phosphorous source.	[90]
CN105420119A	*Schizophyllum commune*	*Ginseng*	Host tissue culture hairy root biomass and ingredients of ginseng saponins.	[91]
CN104774771A	*Thermomyces* sp.	Not disclosed	Photosynthesis of *A. montana* under a low-phosphorus environment.	[46]
CN107046965A	*Trichoderma* sp.	*Anoectochilus formosanus*	Seedling adaptation cultivation.	[92]

Table 2. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN104745482A	*Trichoderma* sp.	*Arnebia euchroma*	Growth of *Arnebia* hairy roots and improved shikonin component content in hairy roots.	[23]
CN105969672A	*Trichoderma* sp. *Fusarium* sp.	*Acacia* sp.	Increase in the height and ground diameter of *A. confusa* seedlings.	[93]
CN110408551A	*Tulasnella calospora*	Roots of *Paphiopedilum*	Growth of aseptic seedlings of *Paphiopedilum*.	[64]
CN102876584A	*Xylaria striata*	*Oryza meyeriana*	Plant growth.	[94]
CN107460133A	*Zasmidium* sp.	mangrove	Growth and development of *D. officinale*.	[95]
WO2016179047A1	*Group of fungi*	Not disclosed	Agronomic traits in plants.	[96]
CZ306950B6	*Group of fungi*	*Miscanthus* sp.	Growth, especially of graminaceous and *Miscanthus* plants.	[97]
WO2017134664A1	*Acremonium sclerotigenum/ Sarocladium implicatum*	Set of grass relatives of wheat	Nutrient uptake.	[98]
US20150373993A1	Group of several [2] fungi	A diverse type of wild relatives or ancestral landraces of maize, wheat, rice, and other seeds	Agronomic traits.	[99]
WO2018102733A1	Group of several [2] fungi	Agricultural plants	Modulation of the nutritional quality traits in seeds	[100]

[1] Some patents just provided a common name for the host organism. [2] A list of the group of fungi is in Table S1.

3.2. Biocontrol of Herbivores and Plant Pathogens

Crop plant diseases represent a major threat in agriculture [101]. The number of chemicals that can be effectively used to control pathogens has been reduced due to the emergence of fungicide resistance along with an increased awareness of the negative associated ecological and public health impacts [101]. Due to these problems, study of the biological control of plant diseases with endophytes has intensified in recent years [101]. Endophytes have been shown to protect their hosts against diseases, reducing infection levels and inhibiting the growth of pathogens [102,103]. The proposed mechanisms used by endophytes are the production of antimicrobial and structural compounds, niche competition, and the induction of plant immunity [104].

Several patents describe the biocontrol of herbivores and plant pathogens using endophytic fungi (Table 3). Species of the genus *Acremonium* have been described to control *Verticillium* wilt [105]; Argentine stem weevil (*Listronotus bonariensis*) [106]; plant diseases caused by banana root nematode and different pathogenic microbes such as *Bipolaris oryzae*, *Colletotrichum falcatum*, *Colletotrichum gloeosporioides*, *Corynespora cassiicola*, *Corynespora* sp., *Drechslera* sp., *Fusarium oxysporum*, *Gloeosporium musarum*, and *Magnaporthe grisea* [107]; and to prevent fescue toxicosis [108]. Species of *Alternaria* can control the growth of different pathogens such as *Rhizoctonia solani*, *Fusarium oxysporum*, *Botrytis cinerea*, *Phytophthora capsici*, *Pseudomonas aeruginosa*, *Proteus hauseri*, and *Plasmopara viticola* [109–115]. Members of the genus *Aspergillus* have been applied to limit the growth of nematodes in soil [116]; the plant pathogenic fungi *Sclerotinia sclerotiorum*, *Rhizoctonia solani,* and *Thanatephorus cucumeris* [52,117,118]; as well as grass fungi [119]. Several strains of the genus *Chaetomium* have been reported to enhance plant disease resistance in *Anoectochilus roxburghii* cultivation [16], to control different plant pathogenic fungi [120–122], to inhibit *Erwinia* causing soft rot and *Ralstonia solanacearum* causing bacterial wilt [123], to inhibit anthracnose apple pathogens [124], in the preparation of an anti-plant pathogen fermentation liquid broth [125], and in the production of chaetoglobosin A with antagonistic activity against *Exserohilum turcicum*, *Coniothyrium diplodiella,* and *Rhizopus stolonifer* [126]. Species of *Fusarium* can prevent and treat black spot and fungal diseases in *Panax notoginseng* [127,128], control five plant pathogenic fungi (*Fusarium oxysporum*, *Cytospora mandshurica*, *Colletotrichum gloeosporioides*, *Venturia pyrina*, and *Fusarium graminearum*) [129], and control rice blast disease [130,131] and bacterial wilt of ginger [132]. Species of *Neotyphodium* can decrease the mildewing rate of *Elymus sibiricus* seeds at the germination stage [133] and improve fungicide and pest resistance in plants [134,135]. Species of *Penicillium* can restrain the effects of *Panax notoginseng* anthracnose, root rot [136–138], and *Alternaria panax* [139]; control different harmful pathogenic fungi [140,141] and litchi downy blight [142]; and prevent plant diseases such as *Sclerotinia* rot of colza and tobacco blackleg [53]. Species of *Rhexocercosporidium* can control the fungal pathogens *Colletotrichum gloeosporioides*, *Fusarium solani*, and *Alternaria panax* Whetzel on *Panax notoginseng* [143–145].

Endophytic fungi of different genera such as *Beauveria*, *Cladosporium*, *Metarhizium*, *Muscodor*, *Trichoderma,* and others have also been described in patents to control pests or different plant diseases (Table 3).

Table 3. Endophytic fungi applied as biocontrol agents of herbivores and plant pathogens.

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN103897992A	*Acremonium alternatum*	cotton	*Verticillium* wilt.	[105]
US93951A0	*Acremonium coenophialum*	Not disclosed	Fescue toxicosis.	[108]
AU639084B2	*Acremonium lolii*	French perennial ryegrass ecotype	Argentine stem weevil (*Listronotus bonariensis*) by production of compound peramine.	[106]
CN101235355A	*Acremonium strictum*	*Brachiaria brizantha*	Banana root-knot nematode and different pathogenic microbes.	[107]
WO2012174585A1	*Acremonium* sp.	*Brachiaria/Urochloa*	Fungal plant diseases.	[146]
CN108192832A	*Acrocalymma* sp.	*Sinomenium acutum*	Plant diseases caused by pathogenic bacteria.	[147]
CN108085259A	*Arcopilus aureus*	*Dendrobium sp.*	The plant pathogenic fungus *Botrytis cinerea.*	[148]
CN102204570A	*Alternaria alternata*	*Cinnamomum camphora*	*Rhizoctonia solani*, *Fusarium oxysporum*, and *Botrytis cinerea.*	[111]
CN102191184A	*Alternaria alternata*	*Cinnamomum camphora*	Plant pathogenic fungi such as *Rhizoctonia solani*, *Fusarium oxysporum*, and *Botrytis cinerea.*	[110]
CN110373331A	*Alternaria alternata*	*Huperzia serrata*	Gray mold of crops.	[115]
ES2696982A1	*Alternaria alternata* and *Fusarium acuminatum*	*Artemisia thuscula* and *Austrian Artemisia*	Plant pathogenic fungi with the production of antifungal compounds.	[114]
CN103232942A	*Alternaria* sp.	*Spiraea* sp.	The plant pathogenic fungus *Phytophthora capsici.*	[112]
CN106520572A	*Alternaria mali*	*Toona sinensis*	The pathogens *Pseudomonas aeruginosa* or *Proteus hauseri.*	[113]
WO2008007251A2	*Alternaria alternata*	Not disclosed	*Plasmopara viticola.*	[109]
CN108441426A	*Aspergillus niger*	Aquatic plant	Plant parasitic nematodes in soil.	[116]
CN104560735A	*Aspergillus oryzae*	*Tephrosia purpurea*	Plant pathogenic fungi such as *Sclerotinia* rot of colza and tobacco black shank disease.	[52]
CN102191185A	*Aspergillus restrictus*	*Allium sativum*	Plant pathogenic fungi such as *Rhizoctonia solani* and *Thanatephorus cucumeris.*	[117]
CN109504610A	*Aspergillus* sp.	Epiphyte	The pathogenic fungus *rhizoctonia solani.*	[118]
CN108342328A	*Aspergillus versicolor*	seaweed	Grass fungi.	[119]

Table 3. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
US8709399B2	*Beauveria bassiana*	maize stem borer *Busseola fusca*	Herbivorous insects and/or plant pathogens.	[149]
CN105462892A	*Burkholderia* sp.	*Sophora tonkinensis*	*Panax notoginseng* black spot.	[150]
CN105838613A	*Chaetomium globosum*	*Cajanus cajan*	Fungal plant diseases with the production of flavipin.	[151]
CN107475123A	*Chaetomium globosum*	*Anoectochilus roxburghii*	Plant disease in *Anoectochilus roxburghii* cultivation.	[16]
CN102742605A	*Chaetomium globosum*	*Ginkgo biloba*	Plant pathogenic fungi.	[122]
CN102690759A	*Chaetomium globosum*	*Solidago canadensis*	Plant pathogenic fungi propagation	[121]
CN101280320A	*Chaetomium globosum*	Not disclosed	Plant fungal diseases with the production of antibiotic substances	[120]
CN106754396A	*Chaetomium globosum*	*Toona sinensis*	*Erwinia* and *Ralstonia solanacearum*	[123]
CN104877919A	*Chaetomium globosum*	*Phellopterus littoralis*	Anthracnose pathogens of apples and certain inhibitory actions against other plant pathogens	[124]
CN103255065A	*Chaetomium globosum*	*Camptotheca acuminata*	Plant pathogens with broth culture of the endophytic fungi	[125]
CN102754652A	*Chaetomium globosum*	*Ginkgo biloba*	*Exserohilum turcicum*, *Coniothyrium diplodiella*, and *Rhizopus stolonifer*	[126]
CN105368720A	*Chaetomium* sp.	Healthy cotton plant	Cotton *Verticillium* wilt.	[152]
CN109749938A	*Cladosporium tenuissimum*	Healthy *Panax notoginseng*	*Panax notoginseng* rot.	[153]
CN110172408A	*Clonostachys rosea*	*Podophyllum hexandrum*	Diseases and pests of *Podophyllum hexandrum*.	[154]
CN110272829A	*Colletotrichum boninense*	*Huperzia serrata*	*Sclerotinia sclerotiorum* of crops.	[155]
WO2014136070A1	*Epichloë*	*Elymus mutabilis*	Pests on *Secale* spp. plants.	[156]
CN105483022A	*Fusarium solani*	*Sophora tonkinensis*	*Panax notoginseng* black spot.	[127]
CN105483021A	*Fusarium solani*	*Sophora tonkinensis*	*Panax notoginseng* fungal diseases.	[128]
CN103194490A	*Fusarium solani*	*Ginkgo biloba*	Five plant pathogenic fungi.	[129]
CN105087386A	*Fusarium* sp.	Yinchuan *Phragmites communis*	Rice blast disease.	[130]
CN108624527A	*Fusarium* sp.	*Ginkgo sp.*	Bacterial wilt in ginger.	[132]

Table 3. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN110558337A	*Fusarium oxysporum*	*Ginkgo biloba*	Rice blast disease.	[131]
CN102174416A	*Fusella* sp.	*Angelica sinensis*	Plant pathogenic bacteria.	[157]
WO2016034751A1	*Guignardia mangiferae*	*Persea indica*	Phytopathogens and plant pests.	[158]
WO2013081448A2	*Hendersonia* sp.	Not disclosed	Basal stem rot disease and *Ganoderma* disease in oil palms.	[159]
CN109536390A	*Hypoxylon* sp. nov	Midvein of citrus leaves	Citrus black spot disease.	[160]
CN103642704A	*Leptosphaeria* sp.	cotton	Cotton *Verticillium* wilt.	[161]
CN103289906A	*Metarhizium* sp.	*Gentiana manshurica*	*G. manshurica* leaf blight.	[162]
CN110229758A	*Mortierella elongata*	*Atractylodes macrocephala*	*Atractylodes macrocephala* root rot.	[163]
CN101691541A	*Muscodor sp.*	Not disclosed	Pathogenic fungi.	[164]
US20040141955A1	*Muscodor albus and Muscodor roseus*	Not disclosed	Organisms such as microbes, insects, and nematodes with volatile compounds.	[165]
WO2002082898A1	*Muscodor albus and Muscodor roseus*	Not disclosed	Plant pathogens, bacteria, nematodes, and insects with volatile antibiotics.	[166]
WO2010115156A2	*Muscodor strobelii*	Not disclosed	Pests and pathogenic microbes, including *Ganoderma boninense.*	[167]
WO2004034785A2	*Muscodor vitigenus*	*Paullinia paullinioides*	Insects with the production of repellents by a novel endophytic fungus.	[168]
CN106893678A	*Myrothecium verrucaria*	grapes	Grape gray mold.	[169]
CN104774768A	*Nectria haematococca*	*Fritillaria wabuensis*	Bacteria such as *S. aureus* and *P. aeruginosa* and pathogenic fungi.	[170]
CN106538108A	*Neotyphodium sp.*	gramineous plants	Mildewing rate of *Elymus sibiricus* seeds in the germination stage.	[133]
WO2007021200A1	*Neotyphodium* sp.	Not disclosed	Plant pathogenic fungi.	[134]
CA2319847C	*Neotyphodium* sp.	*Festuca arundinacea*	Pests and reduce ergopeptine alkaloid levels.	[135]
CN102191186A	*Nigrospora oryzae*	*Allium sativum*	Plant pathogenic fungi such as *Rhizoctonia solani*, *Colletotrichum lindemuthianum*, and *Botrytis cinerea.*	[171]
CN104789482A	*Nigrospora sp.*	*Magnolia officinalis*	Wheat disease.	[172]

Table 3. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN110178857A	*Paecilomyces variotii*	*Hippophae rhamnoides*	Plant virus. Induces plant endogenous salicylic acid accumulation and enhances the plant RNA silencing efficiency.	[173]
CN105462854A	*Penicillium citrinum*	*Sophora tonkinensis*	*Panax notoginseng* anthracnose.	[136]
CN105462850A	*Penicillium citrinum*	*Sophora tonkinensis*	*Panax notoginseng* root rot.	[137]
CN105462855A	*Penicillium citrinum*	*Sophora tonkinensis* Gagnep	*Alternaria panax*.	[139]
CN104531543A	*Penicillium griseofulvum*	*Tephrosia purpurea*	Plant diseases such as *Sclerotinia* rot of colza, tobacco blackleg, and others with a fermentation product.	[53]
CN105255742A	*Penicillium* sp.	*Malus hupehensis*	Harmful pathogens such as *Fusarium solani*, *F. proliferatum*, *F. moniliforme*, and *F. oxysporum*.	[140]
CN108546651A	*Penicillium* sp.	*Kandelia candel*	Plant pathogenic fungi such as *Fusarium graminearum*, *Phytophthora sojae*, and *Colletotrichum musae* with a fermentation product.	[141]
CN109112069A	*Penicillium* sp.	*Panax notoginseng* root	*Panax notoginseng* root rot.	[138]
CN103773699A	*Penicillium purpurogenum*	Litchi	Litchi downy blight.	[142]
CN103627643A	*Penicillium simplicissimum*	Healthy cotton plant	Cotton *Verticillium* wilt.	[174]
CN104161049A	*Pestalotiopsis uvicola*	*Artemisia japonica*	Kiwifruit *Sclerotinia sclerotiorum*, *Phytophthora capsici*, and other plant pathogenic fungi with a fermentation product.	[175]
CN110511878A	*Pezicula neosporulosa*	Fir	The pathogenic fungus *Fusarium oxysporum*.	[176]
CN109769535A	*Phialophora oryzae*	Wild rice root	Bacterial blight of rice.	[177]
CN102154116A	*Phomopsis wenchengensis*	Not disclosed	Plant pathogenic fungi by antifungal compounds.	[178]
CN105462853A	*Rhexocercosporidium* sp.	*Sophora tonkinensis*	*Colletotrichum gloeosporioides* on *Panax notoginseng*.	[143]
CN105462851A	*Rhexocercosporidium* sp.	*Sophora tonkinensis*	*Fusarium solani* on *Panax notoginseng*.	[144]
CN105462848A	*Rhexocercosporidium* sp.	*Sophora tonkinensis*	*Alternaria panax* Whetzel on *Panax notoginseng*.	[145]
CN102234618A	*Rhizopus* and *Trichoderma*	Not disclosed	Soft rot disease of the orchid family *Dendrobium* plants.	[179]
CN110452290A	*Sarocladium brachiariae*	*Brachiaria brizantha*	Plant disease and pests.	[180]

Table 3. *Cont.*

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN110468057A	*Seimatosporium* sp.	*Rosa multiflora*	Tobacco powdery mildew caused by *Erysiphe cichoracearum.*	[181]
CN106167767A	*Schizothecium* sp.	Not disclosed	Banana wilt.	[182]
CN110558336A	*Spirillum roseum*	Not disclosed	Lettuce *sclerotinia* rot.	[183]
CN103834580A	*Talaromyces flavus*	Not disclosed	Cotton *Verticillium* wilt	[184]
CN106119134A	*Talaromyces flavus*	Not disclosed	Fruit rot	[185]
CN109593658A	*Talaromyces* sp.	*Fructus corni*	Fungal diseases of wheat	[186]
CN105211105A	*Trichothecium roseum*	strawberries	Powdery mildew of wheat	[187]
US20120108425A1	*Trichoderma atroviride*	healthy tea leaves	Foliar disease in tea plantations caused by *Cercospora theae*	[188]
CN108179115A	*Zopfiella* sp.	*Chrysanthemum morifolium*	Plant pathogens such as *Fusarium moniliforme*, *F. oxysporum*, *Curvularia lunata*, and *Pythium*	[189]
WO2018119419A1	Group of several [2] fungi	cotton	Nematodes, aphids, flea hopper, lygus bug, stink bug, soy looper, cabbage looper, or fungi	[190]
US9469836B2	Not disclosed	*Pinus strobus*	Pests in *Pinus strobus*	[191]

[1] Some patents just provided a common name for the host organism. [2] A list of the group of fungi is in Table S1.

3.3. Bio- and Phytoremediation

Bioremediation is a process that uses microorganisms, plants or enzymes to detoxify contamination in natural sources. In phytoremediation, plants and their own metabolic system can extract toxic chemicals from water, soil and air. This chemicals or contaminants include metals and metalloid pollutants, carcinogenic agents, industrial organic waste material, inorganic pesticides and herbicides, chlorinated products, excess nutrients and radionuclides [10,11,192].

Endophytic fungi have the capability to degrade small and large organic compounds by enzymatic reactions, decompose environmental contaminants, and improve the soil microenvironment [193]. They can also increase the ability of host plants to remove contaminants from soil, water, sediment, and air [194], and to modulate morphological and physiological functions in the host plant improving its resistance to metals and providing different detoxification routes such as extracellular scavenging and complexation, compartmentalization and volatilization [14,195]. Figure 1 shows different bioremediation techniques involving endophytic fungi.

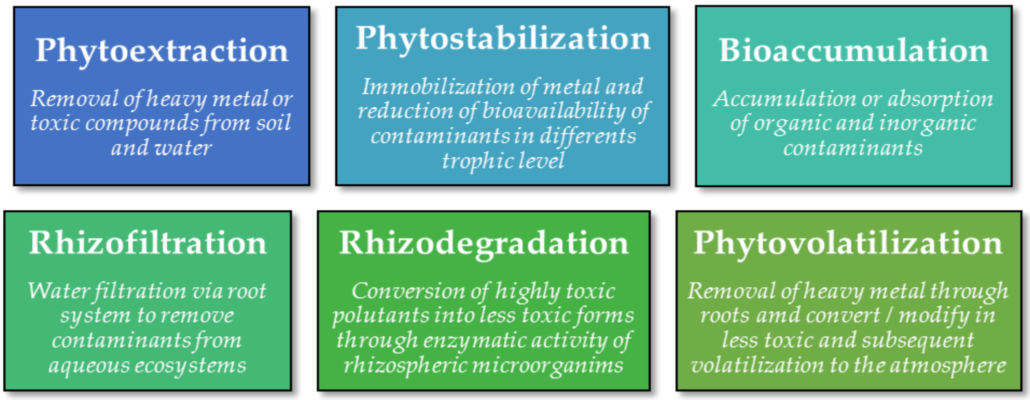

Figure 1. Bio- and phytoremediation approaches involving endophytic fungi.

Some patents describe the use of endophytic fungi for bioremediation and phytoremediation (Table 4). Strains of the genus *Fusarium* have been reported to induce phytoremediation in heavy metal-contaminated soil [196], repair uranium-polluted water bodies [197], and decontaminate and decompose human and animal waste [198]. Additionally, the endophytic fungi Y2R14 and RWDL4-1 can be used to treat wastewater polluted by cadmium [199]. Heavy metals such as mercury, cadmium, arsenic, chromium, and lead are toxic at low concentrations. They can be accumulated in the ecosystem inside living organisms and are capable of entering the food chain [200]. The functions of several organs of the human body can be affected by heavy metals, and some of these substances can cause cancer by long-term exposure [200]. Uranium is a radioactive substance and is also harmful for the environment and human beings [197]. The use of microorganisms to repair large areas of farmland pollution can reduce costs, the use of large amounts of chemicals, and secondary pollution [196].

Species of *Phomopsis* and *Xylaria* have been reported to degrade the herbicide MCPA (2-methyl-4-chlorophenoxyacetic acid) in water and soil [201,202]. Additionally, several genera of fungi can be used to produce high-laccase content for soil bioremediation [203].

3.4. Patents that Claim Multiple Applications

A small number of patents comprised more than one possible application (Table 5); this is the case of the applications for *Neotyphodium uncinatum* to induce insect resistant and drought tolerance in plants [204]; *Phoma* sp. can improve salt stress resistance, promote the growth and increase biomass in crop plants such as wheat and rice [205]; *Clonostachys rosea* promotes plant growth, stress resistance and reduces dependency on chemical pesticides [206,207]; *Fusarium* sp. stimulates plant growth and reduces heavy metal absorption in tobacco [208], and *Rhizoctonia* sp. fosters plant growth and stress resistance in *Anoectochilus roxburghii* [22].

Table 4. Endophytic fungi applied in bioremediation and phytoremediation.

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
CN105733958A	*Fusarium oxysporum*	Not disclosed	Phytoremediation of heavy metal-contaminated soil	[196]
CN106340337A	*Fusarium* sp.	mangrove	Repair of uranium-polluted water body	[197]
WO2005116272A2	*Fusarium culmorum* and *Muscodor albus*	Not disclosed	Decontamination and decomposition of human and animal waste	[198]
CN106947697A	*Phomopsis* sp.	Not disclosed	Degradation of the herbicide MCPA (2-methyl-4-chlorophenoxyacetic acid) in water or soil	[201]
CN107177511A	*Xylaria* sp.	Not disclosed	Degradation of the herbicide MCPA in water and soil	[202]
CN107900098A	Group of several fungi [2]	Not disclosed	Production and application of a high-laccase content soil remediation agent	[203]
CN108751424A	Not disclosed	wild soybean	Treatment of wastewater polluted by the heavy metal cadmium	[199]

[1] Some patents just provided a common name for the host organism. [2] A list of the group of fungi is in Table S1.

Table 5. Patents that claim multiple applications.

Patent No.	Endophyte	Host [1]	Patent Application	Ref.
WO2000062600A1	*Neotyphodium uncinatum*	meadow fescue	Import desired traits: include no adverse effects on herbivore, insect resistance, drought tolerance and improved persistence in the plants.	[204]
CN104293681A	*Phoma* sp.	Not disclosed	Improving salt stress resistance in rice and wheat. Promotion of growth in rice seedling, delaying salt damage of wheat in saline and alkaline land. Increasing biomass accumulation in wheat.	[205]
US20160007613A1	*Clonostachys rosea*	Not disclosed	Promotion of plant vigor, health, growth, yield, and resistance to competitive stress.	[206]
WO2007107000A1	*Clonostachys rosea*	Not disclosed	Enhanced plant vigor, health, growth, yield, reducing environmental stress and reduction of dependency on chemical pesticides for pest control.	[207]
CN103849572A	*Fusarium* sp.	Not disclosed	Promoting plant growth and reduction of heavy metal absorption in tobacco.	[208]
CN101953261A	*Rhizoctonia* sp.	*Anoectochilus roxburghii*	Growth of *A. roxburghii*, improved the reproductive rate, survival rate and stress resistance.	[22]
WO2019115582A1	Group of several fungi [2]	*Hordeum murinum*	Increased yield and biomass in cereal crops, and promotes biotic and abiotic stress resistance in cereal crops	[37]
WO2016030535A1	*Group of several fungi* [2]	*Hordeum murinum subsp. murinum*	Improving dry shoot weight, mean dry grain weight and suppression of seed-borne infection in a cereal crop.	[35]

[1] Some patents just provided a common name for the host organism. [2] A list of the group of fungi is in Table S1.

We found two patents, whose applications implicated the use a plural number of fungi (genus/species); one of them claims the capability to increase biomass and promote biotic and abiotic stress resistance in cereal crops [37], the other claims to improve dry shoot weight, mean dry grain weight and suppression of seed-borne in cereal crops [35].

4. Discussion

In the present review, we highlight a wide number of endophytic fungi that have been patented for developing processes, methodologies, or new techniques in applications that include but are not restricted to (a) alternatives to overcome biotic and abiotic stress and to reduce the use of chemicals associated with environmental toxicity in agricultural practices, (b) the degradation of harmful compounds, and (c) improvement in the ability of plants to remove contaminants from soil, water, and air. Abiotic stress tolerance and growth promotion of plants, and biocontrol of herbivores and plant pathogens, were the most patentable applications of endophytic fungi with 88 and 90 patents, respectively; concerning bio- and phytoremediation, 7 patents were recorded for the period 1988–2019 (Figure 2). The most representative genera of these applications belong to *Alternaria*, *Aspergillus*, *Chaetomium*, *Fusarium*, *Penicillium* and *Muscodor*.

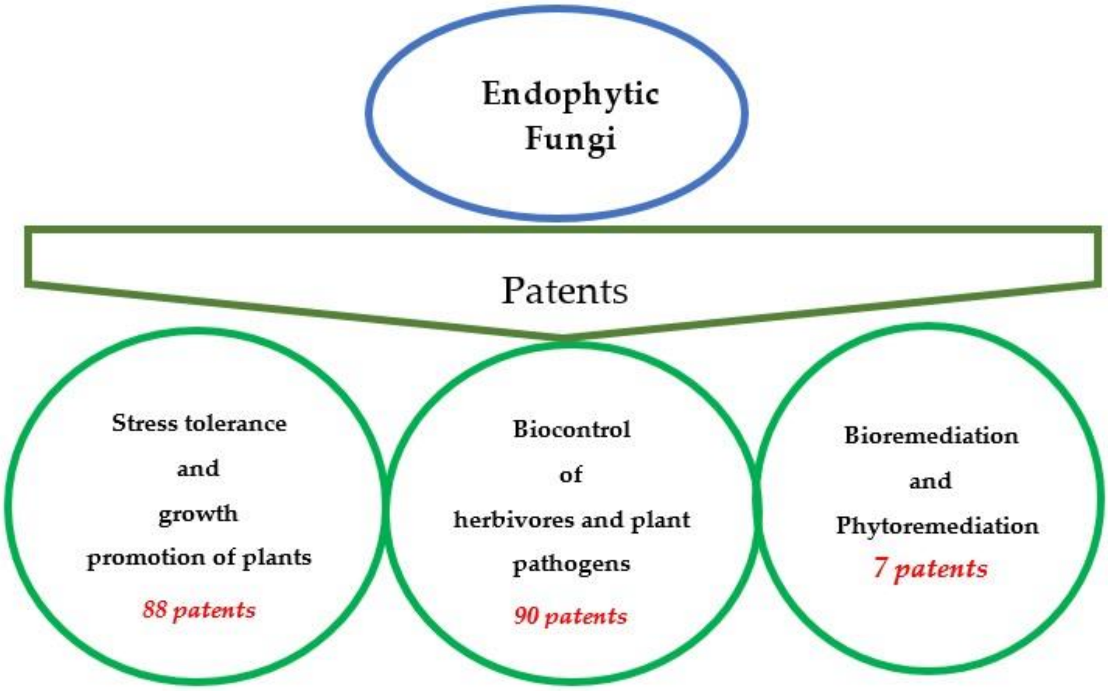

Figure 2. Total number of patents for area of application in the period 1988 to 2019.

Studies of endophytic fungi ecology have allowed the understanding of the multiple interactions they develop with their host, other endophytes, as well with herbivores and pathogens that put the host under abiotic stress. Nonetheless, it is evident that one individual or group of endophytes can be used for mitigation stresses from different origins. Due to the concerns about global climate change and its implications in food security, there are an increased interest to develop applications for the use of endophytic fungi in abiotic stress tolerance and growth promotion of important food crops [209], as well as the use for biocontrol of herbivores and plant pathogens. This increment can be noted since 2011 as shown in Figure 3. The loss of growing areas due to contamination and the recovery of spaces contaminated by heavy metals, organic and inorganic compounds will lead the focus of research on endophytic fungi for bio- and phytoremediation applications.

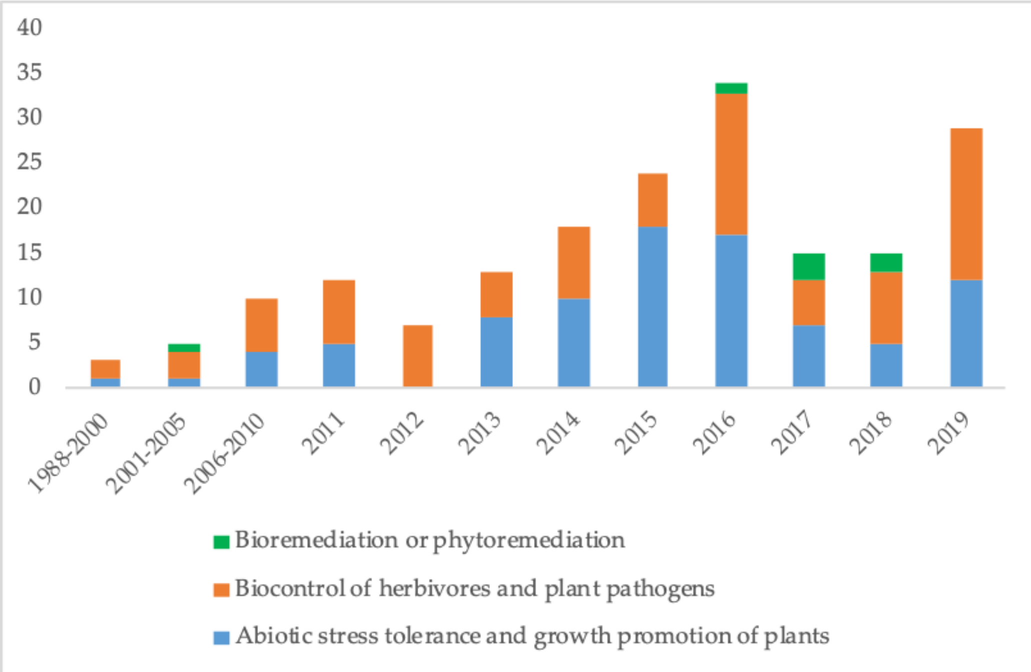

Figure 3. Patents of endophytic fungi for agricultural purposes and bio/phytoremediation registered from 1988 to 2019.

Considering the abundance of endophytic fungi under study, the development of patentable applications like those reviewed here, and other applications still unexplored like fungal pigments [210], has become a prominent research area for this class of microorganisms.

Future Perspectives

The use of endophytic fungi to improve the nutrients absorption in plants can change the optimum usage of organic and inorganic fertilizers [211]. The capability of endophytic fungi to increase biotic and abiotic stress tolerance in plant hosts is an unexplored area for agricultural purposes; the control of pests and diseases under climate change conditions [211]; studies in fungal species related to develop resistance to changes in their environment could lead their application in food production in limited resources areas and as an important alternative for crop production for human sustainability. Many endophytes are now often recognized as symbionts with unique and intimate interactions with the plant host [10]. The genetic engineering of fungi is an easier process than in plants. The genetic modification of endophytic fungi with useful genes could contribute, with new traits, to the inoculation of plants [212].

The use of endophytic fungi on remediation of contaminated ecosystems is an interesting prospect for further studies. Fungi that could increase the capacity of CO_2 absorption by plants, degradation and biotransformation of waste, enhance food production without altering its quality or those that provided drought resistance/nutrient absorption capability to plant species related to human or animal feeding could be areas of significance to develop new applications and patents. The investigations applied in these fields are forwarded by the advance in the techniques used for the characterization of endophytic fungi and also by the technological advances in analytical techniques for carrying out studies of chemical processes at the cellular level.

Supplementary Materials: The following are available online at http://www.mdpi.com/2076-2607/8/8/1237/s1, Table S1: List of patens grounded in the use of several endophytic fungi to develop applications.

Author Contributions: H.E.O. and D.T.-M. performed the data search and organized and analyzed the data, visualized and wrote the manuscript; L.C.-R. conceptualized, visualized, supervised, wrote and reviewed the manuscript. All authors read and approved the final manuscript.

Funding: This project was supported by the National System of Research (SNI) and the National Secretariat for Science and Technology of Panama (SENACYT).

Acknowledgments: The authors want to thank University of Sao Paulo, Brazil, for granted access to "Portal de Periodicos CAPES/MEC" and to Phyllis D. Coley for critical review of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Petrini, O. Fungal Endophytes of Tree Leaves. In *Microbial Ecology of Leaves*; Andrews, J.H., Hirano, S.S., Eds.; Springer: New York, NY, USA, 1991; pp. 179–197. [CrossRef]
2. Tan, R.X.; Zou, W.X. Endophytes: A Rich Source of Functional Metabolites. *Nat. Prod. Rep.* **2001**, *18*, 448–459. [CrossRef] [PubMed]
3. Torres-Mendoza, D.; Ortega, H.E.; Cubilla-Rios, L. Patents on Endophytic Fungi Related to Secondary Metabolites and Biotransformation Applications. *J. Fungi* **2020**, *6*, 58. [CrossRef] [PubMed]
4. Carroll, G. Fungal Endophytes in Stems and Leaves: From Latent Pathogen to Mutualistic Symbiont. *Ecology* **1988**, *69*, 2–9. [CrossRef]
5. Hallmann, J.; Sikora, R.A. Toxicity of Fungal Endophyte Secondary Metabolites to Plant Parasitic Nematodes and Soil-Borne Plant Pathogenic Fungi. *Eur. J. Plant Pathol.* **1996**, *102*, 155–162. [CrossRef]
6. Sturz, A.; Nowak, J. Endophytic Communities of Rhizobacteria and the Strategies Required to Create Yield Enhancing Associations with Crops. *Appl. Soil Ecol.* **2000**, *15*, 183–190. [CrossRef]
7. Azevedo, J.L.; Araujo, W.L. Diversity and Applications of Endophytic Fungi Isolated from Tropical Plants. In *Fungi: Multifaceted Microbes*; Ganguli, B.N., Deshmukh, S.K., Eds.; CRC Press: New Delhi, India, 2007; pp. 189–207.
8. Bamisile, B.S.; Dash, C.K.; Akutse, K.S.; Keppanan, R.; Afolabi, O.G.; Hussain, M.; Qasim, M.; Wang, L. Prospects of Endophytic Fungal Entomopathogens as Biocontrol and Plant Growth Promoting Agents: An Insight on How Artificial Inoculation Methods Affect Endophytic Colonization of Host Plants. *Microbiol. Res.* **2018**, *217*, 34–50. [CrossRef]
9. Bilal, S.; Shahzad, R.; Imran, M.; Jan, R.; Kim, K.M.; Lee, I.J. Synergistic Association of Endophytic Fungi Enhances *Glycine max* L. Resilience to Combined Abiotic Stresses: Heavy Metals, High Temperature and Drought Stress. *Ind. Crops Prod.* **2020**, *143*, 111931. [CrossRef]
10. Deng, Z.; Cao, L. Fungal Endophytes and Their Interactions with Plants in Phytoremediation: A Review. *Chemosphere* **2017**, *168*, 1100–1106. [CrossRef]
11. Nandy, S.; Das, T.; Tudu, C.K.; Pandey, D.K.; Dey, A.; Ray, P. Fungal Endophytes: Futuristic Tool in Recent Research Area of Phytoremediation. *S. Afr. J. Bot.* **2020**. [CrossRef]
12. Yan, L.; Zhu, J.; Zhao, X.; Shi, J.; Jiang, C.; Shao, D. Beneficial Effects of Endophytic Fungi Colonization on Plants. *Appl. Microbiol. Biotechnol.* **2019**, *103*, 3327–3340. [CrossRef]
13. Ripa, F.A.; Cao, W.; Tong, S.; Sun, J. Assessment of Plant Growth Promoting and Abiotic Stress Tolerance Properties of Wheat Endophytic Fungi. *Biomed. Res. Int.* **2019**, *2019*, 1–12. [CrossRef] [PubMed]
14. He, W.; Megharaj, M.; Wu, C.Y.; Subashchandrabose, S.R.; Dai, C.C. Endophyte-Assisted Phytoremediation: Mechanisms and Current Application Strategies for Soil Mixed Pollutants. *Crit. Rev. Biotechnol.* **2020**, *40*, 31–45. [CrossRef]
15. Wang, Z.; Liu, Y.; Wang, Q.; Wang, C.; Shen, H. A Kind of Method for Promoting the Growth of Manyprickle *Acanthopanax* Root at Seedling Stage. CN 108513990 A, 11 September 2018.
16. Zheng, C.; Wu, J.; Wu, Y.; Qin, L.; Ye, B.; Zhai, X.; Han, T.; Xin, H. *Anoectochilus* Endophytic Fungi and Its Application. CN 107475123 A, 15 December 2017.
17. Ding, C.; Wang, Q.; Wang, Z.; Li, J.; Zhang, S. Can Promote Hair Pulse Acid Mold Growth of Endophytic Fungi and Its Application. CN 106929436 A, 7 July 2017.

18. Lin, H.; Fan, H.; Hong, T.; Zhou, Y.; Wu, C.; Chen, C. Mixed Endophyte Fungi Capable of Promoting Nutrient Absorption of *Acacia confusa*. CN 106085872 A, 9 November 2016.
19. Qin, L.; Jia, M.; Yang, Y.; Han, T.; Xin, H.; Zhang, Q.; Li, Y.; Kong, Z. *Coix lacryma-jobi* Seed Endophytic Fungi and Its Application. CN 105624047 A, 1 June 2016.
20. Cui, J.; Zhang, Y. By Fungi for Promoting Seed Germination Method for Cynomorii Herba. CN 107432135 A, 5 December 2017.
21. Guo, B.; He, M.; Chen, X.; He, W.; Wei, Y. One Kind of *Lycopodium serratum* Endophytic *Pythium* and Its Application. CN 105039172 A, 11 November 2015.
22. Fang, X.; Jiang, Q.; Zheng, G. Application of Endophytic Fungus *Rhizoctonia* in Raising Seedlings of *Anoectochilus roxburghii*. CN 101953261 A, 26 January 2011.
23. Han, T.; Qin, L.; Jia, X.; Zheng, C.; Jia, M. A *Lithospermum euchromum* Endophytic Fungus and Its Application. CN 104745482 A, 1 July 2015.
24. Guo, S.; Wu, L.; Chen, X.; Wang, C.; Meng, Z.; Xiao, P. Application of Dark Septate Endophyte in Culture of *Saussurea*. CN 1961631 A, 16 May 2007.
25. Li, L.; Chen, J.; Huang, R. A *Rhizoma bletillae* Endophytic Fungus 1-N2 and Application Thereof. CN 109456902 A, 12 March 2019.
26. Chen, H.; Liang, Z.; Ma, Y.; Zhang, H.; Zhang, X.; Yang, D.; Hu, X. *Cladosporium tenuissimum* and Application Thereof for Promoting Synthesis of Effective Components in Root System of *Salvia miltiorrhiza*. CN 110438011 A, 12 November 2019.
27. Chen, H.; Liang, Z.; Wu, H.; Yan, B.; Yu, H.; Zhang, H.; Hu, X.; Yang, D. A Kind of *Salvia miltiorrhiza* Endophytic Fungi and Its Application in Promoting Growth and/or Effective Ingredient and Application in Synthesis. CN 109706084 A, 3 May 2019.
28. Hong, W.; Wu, C.; Xie, A. Endophytic Fungus *Penicillium* sp. Strain 1 Capable of Improving Cold Resistance of *Eucalyptus* and Its Application. CN 102002463 A, 6 April 2011.
29. Hong, W.; Wu, C.; Xie, A. *Penicillium* sp. Strain 1 as Endophytic Fungus of Eucalyptus and Its Application in Increasing Low-Phosphorus Stress Tolerance and Promoting Phosphorus Absorption of *Eucalyptus*. CN 101974438 A, 16 February 2011.
30. Hong, W.; Wu, C.; Xie, A. *Penicillium* sp. Strain 2 as Endophytic Fungus of *Eucalyptus*, and Preparation Method of Its Microbial Solution and Its Application in Alleviating Aluminum Poisoning. CN 101974437 A, 16 February 2011.
31. Tao, C.; Yang, T.; Yang, Z.; Hu, W.; Ma, X.; Wang, N.; Xiao, J.; Wang, H.; Zhao, Y.; Chen, X.; et al. Endophytic Fungus of *Panax ginseng* for Promotion Growth of Corn. CN 102086439 A, 8 June 2011.
32. Lopez Llorca, L.V.; Zavala Gonzalez, E.A.; Ramirez Lepe, M. Use of *Pochonia chlamydosporia* to Promote Flowering and Fruiting in Cultivated Crops. ES 2500790 A1, 30 September 2014.
33. Djonovic, S.; McKenzie, E.A.; Toledo, G.V.; Sadowski, C.; Von Maltzahn, G.; Ambrose, K.V.; Zhang, X.; Johnston, D.M.; Gulick, T.A. *Penicillium* Endophyte Compositions and Methods for Improved Agronomic Traits in Plants. WO 2016210238 A1, 29 December 2016.
34. Du, Y. Preparation Method and Application of *Panax pseudoginseng* and/or *Panax notoginseng* Endophytic Fungus *Acremonium strictum*. CN 105907648 A, 31 August 2016.
35. Murphy, B.; Hodkinson, T.; Doohan, F. Fungal Endophytes for Improving the Mean Dry Shoot Weight, Mean Dry Grain Weight, and Suppressing Seed-Borne Infection in Barley. WO 2016030535 A1, 3 March 2016.
36. Bi, Y.; Xue, Z.; Quan, W. Optimal Dse Strain for Promoting Corn Seed Soaking Rooting. CN 110250210 A, 20 September 2019.
37. Murphy, B.; Doohan, F.; Hodkinson, T. Endophytes from Wild Populations of Barley Increase Crop Yield. WO 2019115582 A1, 20 June 2019.
38. Hong, W.; Wu, C.; Xie, A.; Lin, Y.; Li, J. An Endophytic Fungus Capable of Promoting the Photosynthesis of *Casuarina equisetifolia*. CN 103173362 A, 26 June 2013.
39. Hong, W.; Wu, C.; Xie, A.; Lin, Y.; Lin, H. Endophytic Fungus Capable of Promoting Nutrient Element Absorption of *Casuarina*. CN 103173361 A, 26 June 2013.
40. Wu, C.; Hong, W.; Xie, A.; Lin, Y.; Lin, Y. *Phyllosticta* sp. for Promoting Photosynthesis of *Casuarina equisetifolia*. CN 103173363 A, 26 June 2013.
41. Xie, A.; Hong, W.; Wu, C.; Lin, Y.; Hong, T. One Strain of Endophytic Fungus Which Can Promote *Casuarina* Biomass. CN 103173364 A, 26 June 2013.

42. Lin, H.; Xu, C.; Hong, W.; Wu, C.; Xie, A.; Li, J. Endophytic Fungus Capable of Promoting Growth of Fir. CN 104004666 A, 27 August 2014.
43. Wu, C.; Xie, A.; Xu, C.; Hong, W.; Lin, Y. Endophytic Fungus for Reliving Phosphorus Stress in Fir. CN 104004665 A, 27 August 2014.
44. Xie, A.; Hong, W.; Wu, C.; Xu, C.; Fan, H. Endophytic Fungus Capable of Promoting Phosphorus Absorption of Fir. CN 104004667 A, 27 August 2014.
45. Xu, C.; Wu, C.; Xie, A.; Hong, W.; Hong, T. Endophytic Fungus Capable of Promoting Photosynthesis of Fir. CN 104004664 A, 27 August 2014.
46. Hong, T.; Liu, J.; Wu, C.; Lin, H.; Xie, A.; Hong, C. A Strain of Endophyte Fungi for Promoting Millennium Tong Photosynthesis under Low Phosphorus Environment. CN 104774771 A, 15 July 2015.
47. Hong, C.; Gong, H.; Lin, H.; Zhang, G.; Hong, T.; Wu, C. An Endophytic Fungi for Promoting Phosphorus Uptake of *Aleurites montana*. CN 104818218 A, 5 August 2015.
48. Hong, C.; Lin, H.; Xie, A.; Hong, T.; Wu, C.; Hong, W. Endophyte Fungi That Promotes *Aleurites montana* Growth and Photosynthesis at Low Phosphorus Environment. CN 104789481 A, 22 July 2015.
49. Lin, H.; Chen, J.; Hong, T.; Hong, C.; Xie, A.; Wu, C. An Endophytic Fungus Strain for Promoting *Aleurites montana* Biomass Growth in Low-p Environment. CN 104762219 A, 8 July 2015.
50. Lin, H.; Hong, C.; Hong, T.; Su, S.; Wu, C.; Xie, A. Endophyte That Can Promote the Growth of Biomass in Millennium Tong. CN 104818217 A, 5 August 2015.
51. Xie, A.; Hong, T.; Hong, C.; Lin, H.; Li, J.; Wu, C. An Endophytic Fungus for Promoting the Growth of *Aleurites montana* Root System under Low Phosphorus Environment. CN 104818219 A, 5 August 2015.
52. Li, Y.; Luo, Z.; Ding, W. *Tephrosia purpurea* Endophytic Fungi Tpl35 and Its Application in Preventing and Controlling Plant Diseases. CN 104560735 A, 29 April 2015.
53. Li, Y.; Luo, Z.; Ding, W.; Zou, K. Herba *Tephrosiae purpureae* Endophytic Fungi Tpl25 and Its Application in Preventing and Controlling Plant Diseases. CN 104531543 A, 22 April 2015.
54. Wu, L.; Si, J.; Dong, H.; Han, T.; Zhu, B. A *Dendrobium officinale* Endophytic Fungi and Its Application. CN 105886405 A, 24 August 2016.
55. Xia, C.; Xu, Q.; Zhou, G.; Jin, H.; Zhang, Y.; Wu, J.; Li, Y.; Zhang, C.; Lin, F.; Liu, H.; et al. Endophytic Fungi Strain Ycef193 and Its Use. CN 103834578 A, 4 June 2014.
56. Xia, C.; Xu, Q.; Cheng, C.; Jin, H.; Liu, H.; Zhang, Y.; Li, Y.; Zhang, L.; Li, X.; Zhang, C.; et al. An Endogenous Fungal Strain Nyn8g01 and Its Applications. CN 105316240 A, 10 February 2016.
57. Zhang, C.; Lin, F.; Liu, H.; Feng, X. Endophytic Fungal Strain R5-6-1 Application. CN 103865806 A, 18 June 2014.
58. Jin, H.; Li, X.; Zhang, C.; Feng, X.; Liu, H.; Lin, F.; Xu, Q.; Cheng, C.; Xiang, B.; Li, D.; et al. An Endogenous Fungal Strain Nyn771c06 and Its Applications. CN 105296359 A, 3 February 2016.
59. Li, J.; Xu, H.; Wu, C.; Lin, Y.; Hong, T.; Lin, H. Endophytic Fungus Capable of Improving Photosynthesis of *Schima superba*. CN 110257259 A, 20 September 2019.
60. Li, J.; Xu, H.; Wu, C.; Lin, Y.; Hong, T.; Lin, H. Endophytic Fungus Capable of Promoting Phosphorus Absorption of *Schima superba*. CN 110257258 A, 20 September 2019.
61. Li, J.; Xu, H.; Wu, C.; Lin, Y.; Lin, H.; Hong, T. Endophytic Fungus Capable of Promoting Growth of *Schima superba* Seedling Height and Ground Diameter under Low-Phosphorus Environment. CN 110343619 A, 18 October 2019.
62. Huang, R.; Tian, P.; Li, L. Bletilla Striata Endophytic Fungus 3-G2 and Application Thereof. CN 109628322 A, 16 April 2019.
63. Li, L.; Tian, P.; Huang, R. A Bletilla Striata Endophytic Fungi Strain 1-G1 and Application Thereof. CN 109504611 A, 22 March 2019.
64. Huang, J.; Zhang, S.; Zhu, X.; Qin, J.; Hu, H. Tulasnella Calospora Qs104, Application Thereof and Method for Promoting Growth of Aseptic Seedling of *Paphiopedilum*. CN 110408551 A, 5 November 2019.
65. Zhou, F.; Huo, G.; Gu, Z.; Hua, C. One Kind of Anti-Salt Stress Fungal Strain and Breeding Methods and Their Application. CN 104762216 A, 8 July 2015.
66. Henson, J.M.; Sheehan, K.B.; Rodriguez, R.J.; Redman, R.S. The Use of Endophytic Fungi to Treat Plants. WO 2004000017 A2, 31 December 2003.
67. Redman, R.S.; Rodriguez, R.J. Fungal Isolates and Their Use to Confer Salinity and Drought Tolerance in Plants. WO 2009012480 A2, 22 January 2009.

68. Ren, A.; Gao, Y.; Chen, L.; Zhao, N.; Wang, Y.; Xie, F. Method for Transferring Fungal Endophyte of Wild Grasses to Turf Grasses for Improving Stress Tolerances to Drought and Diseases. CN 101314760 A, 3 December 2008.
69. An, H.; Luo, X.; Dong, J. Heavy Metal-Resistant Endophytic Fungi *Paraconiothyrium cyclothyrioides* Mr2-1 and Application Thereof. CN 105002099 A, 28 October 2015.
70. Lv, M.; Zhou, W.; Wang, J.; Li, L.; Xu, L.; Bai, Q.; Song, W.; Zhu, J. Method for Improving Crop Resistance to Herbicide Bensulfuron-Methyl Using *Piriformospora indica*. CN 107926549 A, 20 April 2018.
71. Vujanovic, V.; Germida, J.J. Endophytic Microbial Symbionts in Plant Prenatal Care. US 20150366217 A1, 24 December 2015.
72. Zhao, Y.; Xiao, J.; Ma, X.; Wang, H.; Chen, X.; Yang, T.; Yang, Z.; Wang, Y.; Ren, Z. Seabuckthorn Endogenous Fungi and Their Extracts for Use to Promote Drought Resistance of Lawn Grass. CN 104911108 A, 16 September 2015.
73. Zheng, C.; Qin, L.; Zhai, X.; Li, X.; Han, T.; Zhang, Q.; Jiang, Y.; Jia, M. Improving *Salviae miltiorrhizae radix* Yield and Effective Ingredient Content of Endophytic Fungi and Its Application. CN 106801014 A, 6 June 2017.
74. Li, W.; Wang, L.; Ma, Z.; Tang, C.; Zhang, C.; Hu, Z.; Wang, Z. *Dendrobium officinale* Endophytic Fungi Strains Nt66g01 and Its Applications. CN 104630073 A, 20 May 2015.
75. Wu, C.; Hong, C.; Hong, T.; Xiao, Y.; Lin, H.; Chen, C. An Endophytic Fungi for Promoting Nutrient Absorption of Millennium Tung. CN 104805019 A, 29 July 2015.
76. Wei, X.; Wang, F.; Ma, C.; Wan, S.; Jing, M.; Liu, Y.; Wang, Z. Method for Artificially Planting *Salvia miltiorrhiza*. CN 103733829 A, 23 April 2014.
77. Li, J.; Lin, H.; Zhou, Y.; Chen, C.; Xie, A.; Fan, H. Can Promote the Growth of Taiwan *Acacia* Biomass Endophytic Fungi. CN 105861334 A, 17 August 2016.
78. Hong, T.; Lin, Y.; Lin, H.; Zhou, Y.; Xie, A.; Chen, C. A under Low Phosphorus Environment Promoting Taiwan *Acacia* Nutrient Absorption of Endophytic Fungi. CN 105861335 A, 17 August 2016.
79. Wu, C.; Lin, H.; Zhou, Y.; Chen, C.; Xie, A.; Li, J. Mixed Endophytic Fungi for Promoting *Acacia confusa* Phosphorus Uptake under Low Phosphorus Environment. CN 106085873 A, 9 November 2016.
80. Wu, C.; Hong, W.; Xie, A.; Lin, Y.; Fan, H. One Endophytic Fungus Capable of Increaing the Chlorophyll Content of *Casuarina*. CN 103173360 A, 26 June 2013.
81. Zhang, C.; Feng, X.; Su, Z.; Lin, F. Endophytic Fungi Strain RR21 and Its Application in Plant Growth Regulation and/or Plant Pathogenicity. CN 103114044 A, 22 May 2013.
82. Ming, Q.; Qin, L.; Han, T.; Zhang, Q.; Zheng, C.; Zhang, H.; Jia, M. Preparation and Application of Water-Soluble Extract of Endophytic Fungus Hypha in *Salvia miltiorrhiza* and Part of the Extract. CN 103798293 A, 21 May 2014.
83. Li, W.; Wang, L.; Ma, Z.; Tang, C.; Zhang, C.; Hu, Z.; Wang, Z. *Dendrobium officinale* Endophytic Fungi Strain Nt04y01 and Its Application. CN 104593274 A, 6 May 2015.
84. Spangenberg, G.C.; Guthridge, K.M.; Forster, J.W.; Sawbridge, T.I.; Ludlow, E.J.I.; Kaur, J.; Rochfort, S.J.; Rabinovich, M.A.; Ekanayake, P. *Neotyphodium* Endophytes of Perrenial Ryegrass and Tall Fescue with Beneficial Properties for Plant Growth. US 20130104263 A1, 25 April 2013.
85. Xie, A.; Chen, C.; Lin, H.; Wu, C.; Hong, T.; Zhou, Y. A under Low Phosphorus Environment for Promoting Growth of Taiwan *Acacia* Biomass Endophytic Fungi. CN 106010984 A, 12 October 2016.
86. Yao, Q.; Chen, M.; Zhou, Y.; Zhu, H. Blueberry Endogenetic Fungus Strain with Growth-Promoting Function and Application Thereof. CN 107988087 A, 4 May 2018.
87. Li, W.; Wang, L.; Ma, Z.; Tang, C.; Zhang, C.; Hu, Z.; Wang, Z. *Dendrobium officinale* Endophytic Fungi Strain Nt43j06 and Its Application. CN 104593273 A, 6 May 2015.
88. Lopez Llorca, L.V.; Zavala Gonzalez, E.; Ramirez Lepe, M. Use of *Pochonia chlamydosporia* to Promote Flowering and Fruiting in Cultivated Crops. WO 2016038234 A1, 17 March 2016.
89. Mao, L.; Zhang, C.; Lin, F.; Feng, X. Application of Endophytic Fungus Strain NYN8G01 in Promoting Rice Growth. CN 108041078 A, 18 May 2018.
90. Craven, K.; Ray, P. A Symbiont *Serendipita vermifera bescii* for Enhancement of Plant Performance. WO 2019113255 A1, 13 June 2019.
91. Han, T.; Chen, L.; Qin, L.; Xin, H.; Zheng, C.; Jia, M.; Zhai, X.; Shen, H.; Yang, Y. *Radix ginseng* Endophytic Fungi and Its Application. CN 105420119 A, 23 March 2016.
92. Zhang, L. *Anoectochilus formosanus* Seedling Adaptation Cultivation Method. CN 107046965 A, 18 August 2017.

93. Zhou, Y.; Lin, H.; Chen, C.; Lin, Y.; Hong, T.; Wu, C. Mixed Endophytic Fungi for Promoting Growth of Height and Ground Diameter of *Acacia confusa* Seedling. CN 105969672 A, 28 September 2016.
94. Zhang, C.; Lin, F.; Feng, X.; Li, Y. *Xylaria striata* for Promoting Plant Growth and Increasing Plant Biomass. CN 102876584 A, 16 January 2013.
95. Lan, T.; Xie, L.; Zhang, Y.; Chen, Y.; Zhang, W.; Su, Q.; Qin, L.; Huang, C.; Lu, J. Dark with Spacer Endophytic Fungi Hs40 Thereof in Herba Dendrobii Herba Production Application. CN 107460133 A, 12 December 2017.
96. Ambrose, K.V.; Boghigian, B.A.; Djonovic, S.; Gray, P.A.; Toledo, G.V.; Marquez, L.M.; Pelaez, J.N.; Von Maltzahn, G. Designed Complex Endophyte Compositions and Methods for Improved Plant Traits. WO 2016179047 A1, 10 November 2016.
97. Mrnka, L.; Schmidt, C.S.; Frantik, T.; Vosatka, M.; Jandejsek, Z.; Fulin, T.; Kastanek, P.; Kronusova, O.; Lovecka, P.; Demnerova, K. A Mixture of Endophytic Fungi for Increasing the Production of Biomass, the Method of Its Preparation and Its Use. CZ 306950 B6, 4 October 2017.
98. Sharon, A.; Gur, Y.; Ofek-Lalzar, M.; Llorens, E.; Sharon, O. Fungal Endophyte Species for Agrochemical Uses. WO 2017134664 A1, 10 August 2017.
99. Von Maltzahn, G.; Flavell, R.B.; Toledo, G.V.; Leff, J.W.; Samayoa, P.; Marquez, L.M.; Johnston, D.M.; Djonovic, S.; Millet, Y.A.; Sadowski, C.; et al. Endophytes, Associated Compositions, and Methods of Use Thereof. US 20150373993 A1, 31 December 2015.
100. Riley, R.; Djonovic, S.; Vosnidou, N.; Bitas, V. Novel Endophytic Microbes for Modulation of the Nutritional Quality Traits in Seeds. WO 2018102733 A1, 7 June 2018.
101. Latz, M.A.C.; Jensen, B.; Collinge, D.B.; Jørgensen, H.J.L. Endophytic Fungi as Biocontrol Agents: Elucidating Mechanisms in Disease Suppression. *Plant Ecol. Divers.* **2018**, *11*, 555–567. [CrossRef]
102. Calvo-Polanco, M.; Sánchez-Romero, B.; Aroca, R. Arbuscular mycorrhizal fungi and the tolerance of plants to drought and salinity. In *Symbiotic Endophytes*; Aroca, R., Ed.; Springer: Berlin/Heidelberg, Germany, 2013; pp. 271–288.
103. Bacon, C.W.; White, J.F. Functions, Mechanisms and Regulation of Endophytic and Epiphytic Microbial Communities of Plants. *Symbiosis* **2016**, *68*, 87–98. [CrossRef]
104. Pandey, P.K.; Samanta, R.; Yadav, R.N.S. Inside the Plant: Addressing Bacterial Endophytes in Biotic Stress Alleviation. *Arch. Microbiol.* **2019**, *201*, 415–429. [CrossRef] [PubMed]
105. Feng, Z.; Zhu, H.; Li, Z.; Huang, D.; Wang, L.; Shi, Y.; Zhao, L. A Kind of Endophytic Fungi Cef-193 of Cotton and Application Thereof. CN 103897992 A, 2 July 2014.
106. Latch, G.C.M.; Fletcher, L.R.; Rolston, M.P.; Easton, H.S.; Popay, A.J.; Tapper, B.A.; Rowan, D.D.; Christensen, M.J. Endophytic Fungi: *Acremonium lolii*. AU 639084 B2, 15 July 1993.
107. Huang, G.; Guo, Z.; Cai, J.; Shi, T.; Liu, X. *Acremonium strictum* HND5 Isolated from Leaf of *Brachiaria* sp. and Its Application in Biocontrol of Plant Diseases. CN 101235355 A, 6 August 2008.
108. Lipham, L.B.; Stuedemann, J.A.; Thompson, F.N., Jr. Method and Compositions for Prevention and Treatment of Fescue Toxicosis Using Dopamine Antagonists Specific for D2 Receptors. US 93951 A0, 1 March 1988.
109. Musetti, R.; Borselli, S.; D'Ambrosio, M. Antifungal Compositions Containing the Endophyte Fungus *Alternaria alternata* and/or Its Metabolites Belonging to the Family of Diketopiperazines, as Antagonist Agents of *Plasmopara viticola*. WO 2008007251 A2, 17 January 2008.
110. Shentu, X.; Yu, X.; Dong, S.; Hao, P.; Bian, Y.; Ma, Z. Strain of *Alternaria alternata* 31 as Biocontrol Fungus. CN 102191184 A, 21 September 2011.
111. Yu, X.; Shentu, X.; Dong, S.; Hao, P.; Bian, Y.; Ma, Z. Application of Metabolites of *Alternaria alternata* 31 in Preventing and Treating *Rhizoctonia solani*, *Fusarium oxysporium*, and *Botrytis cinerea*. CN 102204570 A, 5 October 2011.
112. Hua, R.; Xu, Q.; Bai, Y.; Zeng, X.; Cao, H.; Wu, X. Endophytic Fungus of Spiraea for Biocontrol of Plant Pathogens. CN 103232942 A, 7 August 2013.
113. Wang, Z.; Wang, X.; Zhao, H.; Shi, G.; Zhao, S.; Yang, H.; Zhang, Y. *Toona sinensis* Endophytic Fungus 56-50 (*Alternaria mali*), Its Secondary Metabolite, Preparation Method and Application in Degrading *Pseudomonas aeruginosa* or *Proteus*. CN 106520572 A, 22 March 2017.
114. Cosoveanu, A.; Cabrera Perez, R. Extracts Obtained from Endophytic Fungi HTF58 *Alternaria alternata* and HRO8 *Fusarium acuminatum* of Artemisa thuscula and *Austrian artemis* as Antifungals for Agricultural Use. ES 2696982 A1, 21 January 2019.

115. Shu, S.; Cui, L.; Yan, L. An Endophytic Fungus of *Huperzia serrata* Resistant to Gray Mold and Application Thereof. CN 110373331 A, 25 October 2019.
116. Yu, Z.; Qiao, M. A Kind of Endophytic Bacterial for Preventing and Treating Plant Nematodes. CN 108441426 A, 24 August 2018.
117. Shentu, X.; Yu, X.; Dong, S.; Hao, P.; Bian, Y.; Ma, Z. Strain of *Aspergillus restrictus* 28 as Biocontrol Fungus. CN 102191185 A, 21 September 2011.
118. Wang, J.; Zhang, P.; Wu, P.; Wang, G.; Wang, C. Plant Endophytic Fungus *Aspergillus* sp. Mbl1612 Extract and Application Thereof. CN 109504610 A, 22 March 2019.
119. Han, X.; Ji, J.; Zhao, J.; Zhao, D.; Liu, M.; Zhang, C.; Peng, Y.; Li, Y.; Liu, J.; Zhang, Z.; et al. Herbicidal Fungus Screened from Seaweed and Its Extracts and Application in Weed Control of Farmland. CN 108342328 A, 31 July 2018.
120. Gao, K.; Liu, X.; He, B.; Li, C. Method for Producing Antibiotic Substance from Plant Endophytic Fungus *Chaetomium globosum* ND35. CN 101280320 A, 8 October 2008.
121. Guo, Z.; Hua, R.; Bai, Y.; Cao, H.; Wu, X.; Li, X.; Tang, J. Separating and Purifying Endogenous Endophytic Fungus of *Solidago canadensis* for Control of Phytopathogenic Fungi. CN 102690759 A, 26 September 2012.
122. Liu, J.; Zhang, G.; Pan, H.; Qin, J.; Qu, X.; Mo, H.; Zhang, J.; Zhang, Y. Application of *Chaetomium globosum* NO.04 for Preventing and Treating Plant Pathogenic Fungi. CN 102742605 A, 24 October 2012.
123. Wang, Z.; Wang, X.; Zhang, Y.; Shi, G.; Zhao, S.; Zhao, H.; Yang, H. *Toona sinensis* Endophytic Fungus TS8 and Its Secondary Metabolites, Preparation Method and Application Thereof. CN 106754396 A, 31 May 2017.
124. Zhang, P.; Mao, Z.; Cheng, S. *Chaetomium globosum* and Its Application. CN 104877919 A, 2 September 2015.
125. Hua, R.; Zeng, X.; Bai, Y.; Xu, Q.; Cao, H.; Wu, X. Endophytic Fungus of *Camptotheca acuminata* for Biocontrol of Phytopathogenic Fungi. CN 103255065 A, 21 August 2013.
126. Qin, J.; Zhang, G.; Pan, H.; Li, X.; Zhang, Y.; Mo, H.; Tian, Y.; Cheng, H. Application of Chaetoglobosin A in Preparing Microbial Pesticide for Control of Northern Leaf Blight of Corn, Grape White Rot and Tomato *Rhizopus* Fruit Rot. CN 102754652 A, 31 October 2012.
127. Zhang, P.; Li, L.; Huang, R.; Yao, Y. Sophora Tonkinensis Gagnep. Endogenetic Fungus TRXY-34-1 and Preparation Method of Metabolite Thereof for Preventing and Treating Black Spot of *Radix notoginseng*. CN 105483022 A, 13 April 2016.
128. Huang, R.; Lan, F.; Yao, Y.; Li, L. *Sophora tonkinensis gagnep*. Endogenetic Fungus TRXY-34-1 and Preparation Method of Metabolite Thereof for Preventing and Treating Anthracnose of *Radix notoginseng*. CN 105483021 A, 13 April 2016.
129. Hua, R.; Bai, Y.; Cao, H.; Wu, X.; Xu, Q.; Zeng, X. Method for Preparing *Ginkgo biloba* Endophytic Fungi Fermentation Broth as Fungicide against Plant Pathogen. CN 103194490 A, 10 July 2013.
130. Xiao, J.; Chen, X.; Wang, H.; Zhao, Y.; Gong, N.; Yang, T.; Yang, Z.; Li, H. Endophytic Fungus of *Phragmites communis*, Preparation of Its Extract for Control of Rice Disease. CN 105087386 A, 25 November 2015.
131. He, F.; Yuan, Z.; Zhang, B.; Liu, X.; Zhang, Z. Biocontrol Preparation for Preventing and Controlling Rice Blast and Preparation Method Thereof. CN 110558337 A, 13 December 2019.
132. Yuan, Z.; He, F.; Zhang, B.; Liu, X.; Zhang, Z.; Zhao, Z.; Pu, X. Preventing Ginger Bacterial Wilt of *Ginkgo* Source Growth-Promoting Preparation. CN 108624527 A, 9 October 2018.
133. Li, X.; Li, C.; Wei, X.; Liu, J. A Method for Reducing the Old of e.Sibiricus Seed Germination Period Rate Method for Mildew. CN 106538108 A, 29 March 2017.
134. Rolston, M.P.; Simpson, W.R. Grass Endophyte with Enhanced Fungicide Resistance. WO 2007021200 A1, 22 February 2007.
135. Latch, G.C.M.; Christensen, M.J.; Tapper, B.A.; Easton, H.S.; Hume, D.E.; Fletcher, L.R. Tall Fescue Endophytes Which Enhance Pest Resistance and Reduce Ergopeptine Alkaloid Levels. CA 2319847 C, 10 April 2012.
136. Huang, R.; Yao, Y.; Lan, F.; Li, L. Application of *Sophora tonkinensis* Endophytic Fungi SDTE-P in Preventing and Controlling Anthracnose of *Panax notoginseng*. CN 105462854 A, 6 April 2016.
137. Huang, R.; Yao, Y.; Lan, F.; Li, L. Application of Sophora tonkinensis Endophytic Fungus SDTE-P in Controlling *Pseudo-Ginseng* Root Rot. CN 105462850 A, 6 April 2016.
138. Zhang, Y.; Zhang, M.; Zhang, T.; Xie, J.; Hou, S. A Biocontrol Endophytic Fungus and Application Thereof. CN 109112069 A, 1 January 2019.
139. Li, L.; Yao, Y.; Huang, R.; Lu, X. Application of *Sophora tonkinensis gagnep*. Endophytic Fungi SDTE-P in *Alternaria panax* Control. CN 105462855 A, 6 April 2016.

140. Yin, C.; Xiang, L.; Mao, Z.; Zhang, X.; Wang, G.; Chen, X. An Endophytic Fungus Resisting Four Kind of *Fusarium* Fungus and the Application Thereof. CN 105255742 A, 20 January 2016.
141. Ye, Y.; Dong, G.; Huang, H.; Fang, Y. Kandelia Candel Endophytic Fungus *Penicillium* sp. 2cpe-1, Fermentation Broth and Application Thereof. CN 108546651 A, 18 September 2018.
142. Xi, P.; Jiang, L.; Xu, D.; Jiang, Z.; Xu, Z.; Chen, J.; Li, M.; Huang, L.; Zhong, J. *Penicillium purpurogenum* Strain and Its Biological Preparation and Application in Controlling Litchi Downy Blight. CN 103773699 A, 7 May 2014.
143. Li, L.; Yao, Y.; Huang, R.; Lu, X. Application of *Rhexocercosporidium* sp. TRXY-59-2 as *Sophora tonkinensis* Endophytic Fungi in Preventing and Controlling *Panax notoginseng* Anthracnose. CN 105462853 A, 6 April 2016.
144. Wei, J.; Yao, Y.; Huang, R.; Li, L. Application of *Sophora tonkinensis* Endophytic Fungi TRXY-59-2 in Preventing and Treating Root Rot of *Panax notoginseng*. CN 105462851 A, 6 April 2016.
145. Yao, Y.; Huang, R.; Wu, X.; Li, L. Application of *Sophora tonkinensis gagnep* Endophytic Fungus TRXY-59-2 to Prevent and Control *Alternaria panax whetz*. CN 105462848 A, 6 April 2016.
146. Spangenberg, G.C.; Guthridge, K.M. Novel Fungal Endophytes from *Brachiaria* and *Urochloa* for Use in Resistance to Fungal Plant Diseases. WO 2012174585 A1, 27 December 2012.
147. Zu, L.; Xiao, J. A New Strain of Endophytic Fungi Qty from *Caulis sinomenii* and Application in Biological Control Thereof. CN 108192832 A, 22 June 2018.
148. Zhang, C.; Zhang, J.; Dai, D.; Liu, Y. Biocontrol Plant Endophytic Fungi and Application Thereof in Preventing Gray Mold of Cash Crop. CN 108085259 A, 29 May 2018.
149. Vidal, S.; Tefera, T. Bio-Pesticide and Method for Pest Control. US 8709399 B2, 29 April 2014.
150. Li, L.; Yao, Y.; Lu, X.; Huang, R. Application of *Sophora tonkinensis* Endophytic Fungus B21 in Preventing and Treating *Panax notoginseng* Black Spot. CN 105462892 A, 6 April 2016.
151. Fu, Y.; Yao, M.; Gao, C.; Sun, J.; Wang, W.; Zhao, C.; Gu, C. A Pigeonpea Endophytic Fungi for High Yielding of Flavipin and Its Application. CN 105838613 A, 10 August 2016.
152. Zhu, H.; Zhang, Y.; Feng, Z.; Feng, H.; Li, Z.; Shi, Y.; Zhao, L. The Cotton Endophytic Fungi Cef-082 and Its Application in the Cotton *Verticillium* Wilt. CN 105368720 A, 2 March 2016.
153. Zhang, Y.; Zhang, T.; Zhang, M. Endophytic Fungus for Reducing the Incidence of *Panax notoginseng* Rot and Microbial Inoculum Thereof. CN 109749938 A, 14 May 2019.
154. Yang, T.; Wang, Z.; Wei, Y.; Li, S.; Li, X.; Fang, Y. Endophytic Fungus of *Podophyllum hexandrum* and Application Thereof. CN 110172408 A, 17 August 2019.
155. Shu, S.; Cui, L.; Yan, L. *Sclerotinia sclerotiorum* Resistant *Huperzia serrata* Endophytic Fungus and Application Thereof. CN 110272829 A, 24 September 2019.
156. Hume, D.E.; Johnson, R.D.; Simpson, W.R.; Card, S.D. Improved Fungal Endophytes for Improved Pest Protection of *Secale* spp. Host Plant. WO 2014136070 A1, 12 September 2014.
157. Jiang, S.; Duan, J.; Qian, D.; Tao, J. Fusella DG09 Having Activity in Resisting Plant Pathogens, and Its Fermentation Broth and Application. CN 102174416 A, 7 September 2011.
158. Gonzalez Coloma, A.; Diaz Hernandez, C.E.; Andres Yeves, M.; Fraga Gonzalez, B.M.; Bolanos Gonzalez, P.; Cabrera Perez, R.; Gimenez Marino, C. Fungal Biocidal Products and Their Use for Control of Phytopathogens and Plant Pests. WO 2016034751 A1, 10 March 2016.
159. Seman, I.A.; Kushairi Din, A.; Moslim, R.; Ramli, N.R.; Ahmad Zairun, M.; Sebran, N.H. Compositions for Controlling Ganoderma Disease in Plants and Method Thereof by Using Endophytic Fungus, *Hendersonia gano* EF1. WO 2013081448 A2, 6 June 2013.
160. Zhang, L.A. *Citrus* Endophytic Fungi and Application Thereof. CN 109536390 A, 29 March 2019.
161. Zhu, H.; Feng, Z.; Li, Z.; Wang, L.; Zhao, L.; Shi, Y.; Zheng, H. Cotton Endophytic Fungi Cef-714 and Its Application in Control of Cotton *Verticillium* Wilt. CN 103642704 A, 19 March 2014.
162. Du, X.; Zhou, Y.; Shang, X.; Liu, D. An Endophytic Fungus Strain of *Gentiana manshurica* and Application Thereof. CN 103289906 A, 11 September 2013.
163. Zhu, B.; Qin, L.; Zhang, Q.; Yang, K.; Zhang, W.; Wu, W.; Lu, J.; Dong, S. *Atractylodes macrocephala* Endophytic Fungus and Application Thereof in Preventing and Treating Root Rot of *Atractylodes macrocephala*. CN 110229758 A, 13 September 2019.
164. Lin, F.; Wang, G.; Zhang, C.; Mao, L.; Zhou, Z. Plant Endophytic Fungus *Muscodor* sp. ZJLQ024, Application Thereof, and Antimicrobial Agent. CN 101691541 A, 7 April 2010.
165. Strobel, G.A.; Manker, D.C.; Mercier, J.; Jimenez, J.; Lin, J.; Thurston, J.; Kersting, B. Biopesticidal *Muscodor albus* Formulations. US 20040141955 A1, 22 July 2004.

166. Strobel, G.A.; Manker, D.C. Endophytic Fungi of the Genus *Muscodor* and Their Volatiles as Pesticides. WO 2002082898 A1, 24 October 2002.
167. Green, W.A.; Herrgard, M.J.; Kerovuo, J.S.; Lomelin, D.; Mathur, E.J.; Richarson, T.H.; Schwartz, A.S.; Strobel, G.A. Endophytic Fungus *Muscodor strobelii* and Its Nucleic Acid and Polypeptide Sequences and Uses for Killing or Inhibiting Plant Pests or Pathogens. WO 2010115156 A2, 7 October 2010.
168. Strobel, G.A.; Daisy, B. Naphthalene Insect Repellent from *Muscodor vitigenus*. WO 2004034785 A2, 29 April 2004.
169. Li, Z.; Wang, X. A Kind of Grape Endophytic Fungi and Its Application for Preventing and Treating Grape Gray Mold. CN 106893678 A, 27 June 2017.
170. Wu, W.; Su, X.; Pan, F.; Chen, A.; Tang, X. A *Fritillaria wabuensis* Endophytic Fungi Wbs003 and Its Application. CN 104774768 A, 15 July 2015.
171. Yu, X.; Shentu, X.; Dong, S.; Hao, P.; Bian, Y.; Ma, Z. Strain of *Nigrospora oryzae* 46 as Biocontrol Fungus. CN 102191186 A, 21 September 2011.
172. Jiang, H. Cortex *Magnolia officinalis* Endophytic Fungi Hpfj3 and Its Application in Preventing Wheat Take-All Disease. CN 104789482 A, 22 July 2015.
173. Zhu, C.; Peng, C.; Wang, Q.; Wang, H.; Geng, Q.; Kong, B.; Zhang, A. *Hippophae fructus* Endophytic Fungi Strain Sj1 Fermentation Extract for Use. CN 110178857 A, 30 August 2019.
174. Zhu, H.; Li, Z.; Feng, Z.; Wang, L.; Zheng, H.; Shi, Y.; Zhao, L. Cotton Endophytic Fungi Cef-818 and the Application in Cotton *Verticillium* Wilt Control Thereof. CN 103627643 A, 12 March 2014.
175. Qian, Y.; Kang, J.; Geng, K. Application of *Pestalotiopsis uvicola* Metabolite in Prevention and Treatment of Kiwi *Monilinia fructicola*. CN 104161049 A, 26 November 2014.
176. Yang, Y.; Yuan, Z.; Wang, X. *Pezicula neosporulosa* with Bacteriostasis and Lignocellulose Degradation Activity and Application Thereof. CN 110511878 A, 29 November 2019.
177. Su, Z.; Zhang, C.; Lin, F.; Feng, X. Endophytic Fungi Strain R5-6-1 in Prevention and Treatment of Rice Bacterial Blight Application Of. CN 109769535 A, 21 May 2019.
178. Wang, G.; Zhang, C.; Lin, F.; Xia, J.; Zhou, Z. Endophytic Fungus *Phomopsis wenchengensis* ZJWCF252 for Manufacture of Agricultural Fungicide 2,3-Dihydro-2-Hydroxy-2,4-Dimethyl-5-Trans-Propenylfuran-3-One. CN 102154116 A, 17 August 2011.
179. Guo, S.; Li, X.; Chen, X.; Wang, H. Endophytic Fungi *Rhizopus* Dhs96 and *Trichoderma* Df188 Capable of Preventing *Dendrobium* Soft Rot. CN 102234618 A, 9 November 2011.
180. Yang, Y.; Cai, J.; Chen, Y.; Wang, B.; Xu, C.; Li, B.; Huang, G. Application of Elicitor Protein Derived from *Sarocladium brachiariae* and Its Coding Gene in Vegetable Biocontrol. CN 110452290 A, 15 November 2019.
181. Li, H.; Zhao, Y.; Zhu, Z.; Tang, W.; Li, S. Plant Endophytic *Seimatosporium* Fungus M7sb41 and Application Thereof. CN 110468057 A, 19 November 2019.
182. Xie, L.; Nong, Q.; Zhang, W.; Su, Q.; Chen, Y.; Lan, T.; Zhang, Y.; Qin, L. Controlling Banana Blight Disease of Endophytic Fungi l—14 and Application Thereof. CN 106167767 A, 30 November 2016.
183. Yuan, Z.; Zhang, B.; Liu, X.; He, F.; Zhang, Z. Biocontrol Preparation for Preventing and Treating Lettuce *Sclerotinia* and Preparation and Use Method Thereof. CN 110558336 A, 13 December 2019.
184. Li, Z.; Zhu, H.; Feng, Z.; Zhao, L.; Shi, Y. Cotton Endophytic Fungus Cef-642 and Its Application. CN 103834580 A, 4 June 2014.
185. Liu, P.; Zhou, S.; Tang, X.; Zhu, L.; Ye, Z.; Jia, B.; Heng, W.; Liu, L. Yellow Compacted Shaped Molded Y28 Thereof in Prevention and Treatment of Fruit Rot Application of. CN 106119134 A, 16 November 2016.
186. Zhao, X.; Hu, Z.; Lv, S.; Hou, D.; Song, P. A Kind of Endophytic Fungi Zxl-Szy-r-9 with Antibiosis and Its Application. CN 109593658 A, 9 April 2019.
187. Yu, D.; Gong, S.; Xiang, L.; Yang, L. Pink Trichothecenes and Its Fermented Products Used in the Control of Wheat Powdery Mildew. CN 105211105 A, 6 January 2016.
188. Gnanamangai, B.M., Jr.; Ponnusamy, P.P., Sr. Biosynthesis of Gold and Silver Nanoparticles for Stability and Extended Shelf-Life of Antagonistic Activities. US 20120108425 A1, 3 May 2012.
189. Tang, J.; Wang, G.; Lu, J.; Tang, J.; Zhu, Y.; Li, Q. An Endophytic Fungus of *Chrysanthemum morifolium* and Its Application. CN 108179115 A, 19 June 2018.
190. Sword, G.A. Fungal Endophytes for Improved Crop Yields and Protection from Pests. WO 2018119419 A1, 28 June 2018.
191. Miller, J.D.; Adams, G.W.; Sumarah, M. Antifungal Metabolites from Fungal Endophytes of *Pinus strobus*. US 9469836 B2, 28 July 2012.

192. Pietro-Souza, W.; de Campos Pereira, F.; Mello, I.S.; Stachack, F.F.F.; Terezo, A.J.; da Cunha, C.N.; White, J.F.; Li, H.; Soares, M.A. Mercury Resistance and Bioremediation Mediated by Endophytic Fungi. *Chemosphere* **2020**, *240*, 124874. [CrossRef]
193. Krishnamurthy, Y.L.; Naik, B.S. Endophytic Fungi Bioremediation. In *Endophytes: Crop Productivity and Protection*; Maheshwari, D.K., Annapurna, K., Eds.; Springer: Cham, Switzerland, 2017; Volume 2, pp. 47–60. [CrossRef]
194. Li, H.-Y.; Wei, D.-Q.; Shen, M.; Zhou, Z.-P. Endophytes and Their Role in Phytoremediation. *Fungal Divers.* **2012**, *54*, 11–18. [CrossRef]
195. Fomina, M.A.; Alexander, I.J.; Colpaert, J.V.; Gadd, G.M. Solubilization of Toxic Metal Minerals and Metal Tolerance of Mycorrhizal Fungi. *Soil Biol. Biochem.* **2005**, *37*, 851–866. [CrossRef]
196. Peng, K.; Wen, T.; Xiong, R.; Tian, S.; Chen, C.; Zhong, Z.; Jiang, P.; Peng, Y.; Wan, Y. *Fusarium Oxysporum* and Its Application in Phytoremediation of Heavy Metal Contaminated Soil. CN 105733958 A, 6 July 2016.
197. Tan, N.; Hou, D.; Liao, S.; Yang, X.; Gao, Y.; Wang, J.; Nie, C.; Yan, X.; Wu, Y.; Jiang, M.; et al. A Method for Repairing Uranium-Polluted Water Body with Imprinted Material Prepared by Facultative Marine Fungi as Basal Body and Phytic Acid as Functional Monomer. CN 106340337 A, 18 January 2017.
198. Strobel, G.A.; Dirkse, E.; Ezra, D.; Castillo, U.; Phillips, B. A Method of Using Endophytic Fungi to Decontaminate and Decompose Human and Animal Wastes. WO 2005116272 A2, 8 December 2005.
199. Xiao, J.; Zhang, Q.; Yin, J.; Sun, J.; Zhang, L.; Zhang, Y.; Yang, H.; Kong, Q. A Method for by Use of Wild Soybean Endophytic Fungi Adsorption Water Body in Heavy Metal Cadmium Pollution. CN 108751424 A, 6 November 2018.
200. Verma, S.; Kuila, A. Bioremediation of Heavy Metals by Microbial Process. *Environ. Technol. Innov.* **2019**, *14*, 100369. [CrossRef]
201. Wang, Y.; Zeng, D.; Feng, G.; Tang, W.; Li, H. One Kind of Stem Point Enzyme E41 Metal Fungal Strain and Application Thereof. CN 106947697 A, 14 July 2017.
202. Wang, Y.; Feng, G.; Li, H.; Zeng, D.; Tang, W. One Kind of Carbon Angle Bacterial Genus E68 Fungal Strain and Application Thereof. CN 107177511 A, 19 September 2017.
203. Dai, C.; Zhou, J.; Jia, Y. Laccase-Containing Soil Remediation Agent, and Its Production Method and Application. CN 107900098 A, 13 April 2018.
204. Hignight, K.W.; Rush, D.L. Enhancing Endophyte in Grass. WO 2000062600 A1, 26 October 2000.
205. Wang, H.; Chen, Y.; Lin, F. Phoma Endophytic Fungi and Its Application. CN 104293681 A, 21 January 2015.
206. Brown, W.G. *Clonostachys rosea* Inoculated Plant Materials with Fungicides and Adjuvants. US 20160007613 A1, 14 January 2016.
207. Stewart, J.F.; Brown, W.G. The Production and Use of Endophytes as Novel Inoculants for Promoting Enhanced Plant Vigor, Health, Growth, Yield Reducing Environmental Stress and for Reducing Dependency on Chemical Pesticides for Pest Control. WO 2007107000 A1, 27 September 2007.
208. Xu, Q.; Xia, C.; Cheng, C.; Jin, H.; Xie, Y.; Liu, H.; Liao, F.; Zhang, C.; Lin, F.; Liu, H.; et al. Endophytic Fungal Strain Ycef005 and Its Use. CN 103849572 A, 11 June 2014.
209. Chakraborty, S.; Newton, A.C. Climate Change, Plant Diseases and Food Security: An Overview. *Plant. Pathol.* **2011**, *60*, 2–14. [CrossRef]
210. Venil, C.K.; Velmurugan, P.; Dufossé, L.; Devi, P.R.; Ravi, A.V. Fungal Pigments: Potential Coloring Compounds for Wide Ranging Applications in Textile Dyeing. *J. Fungi* **2020**, *6*, 68. [CrossRef] [PubMed]
211. Bamisile, B.S.; Dash, C.K.; Akutse, K.S.; Keppanan, R.; Wang, L. Fungal Endophytes: Beyond Herbivore Management. *Front. Microbiol.* **2018**, *9*, 544. [CrossRef] [PubMed]
212. Mei, C.; Flinn, B. The Use of Beneficial Microbial Endophytes for Plant Biomass and Stress Tolerance Improvement. *Recent Pat. Biotechnol.* **2010**, *4*, 81–95. [CrossRef] [PubMed]