Chapter 18
Fungi as Biological Control Agents

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Abstract Nowadays, use of a fungal biocontrol agent (BCA) is considered to be a rapidly developing natural phenomenon in research area with implications for plant yield and food production. Fungal biocontrol agents (BCAs) do not cause any harm to the environment, and they generally do not develop resistance in various types of insects, pests, weeds, and pathogens due to their complex mode of action. They have been proved to be an alternative against the undesirable use of chemical pesticides. The advantage of fungi to be used as biological control agents is that they need not be ingested by the insect hosts, but they can invade directly through the insect's cuticle and control all insect pests including sucking insects, but in the case of viruses and bacteria, this is not possible. The present literature includes mechanisms of fungal biological control agents, advantages and limitations of BCAs, and list of commercially available BCAs against the insects, pests, weeds, nematodes, and plant pathogens.

18.1 Introduction

According to the most recent estimate by the UN, the population of the world is 7.3 billion, which may reach up to 9.7 billion by the end of 2050. This increase in population may result in food demand to increase anywhere between 59% and 98% by 2050 (Ray et al. 2013). Farmers worldwide will need to increase crop production. To fulfill the growing demand for food quality and quantity, we need to increase the crop production either by increasing the amount of agricultural land to grow crops or by enhancing productivity by controlling the crop losses caused by plant pathogens, pests, animals, and weeds (Strange and Scott 2005). Roughly 20–40% direct yield losses are caused by weeds, pathogens, and animals (Oerke et al. 1994; Teng and Krupa 1980; Teng 1987; Oerke 2006).

In the 1960s–1980s, synthetic insecticides, herbicides, and fungicides were introduced for the successful control of agricultural pests to increase the agricultural

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output. Ideally, the pesticides must be specific to their target, but actually, this is not the case. There is no doubt that the use of pesticides has increased the production of food and fibre, but they also have resulted in serious health implications to man and his environment because they are not specific to their target. Nowadays, enough evidences are available which prove that some of these chemicals are responsible for environmental damage and they have also adversely affected the human health (Forget 1993; Igbedioh 1991; Jeyaratnam 1985; Zeise et al. 2013; Eduati et al. 2015). Almost each and every segment of population has been exposed to pesticides, and the estimated number of worldwide deaths due to chronic diseases caused by pesticide poisoning is about 1 million per year (WHO 1990; Environews Forum 1999). Organochlorine (OC) compounds have polluted all life forms on the earth including air and water bodies such as lakes, rivers, and oceans (Hurley et al. 1998; Yusof et al. 2016). According to US National Academy of Sciences, the DDT metabolite DDE caused the decline in the population of bald eagle due to eggshell thinning (Liroff 2000). The pesticides, also known as endocrine disruptors, adversely affect the human health by antagonizing natural hormones in the body. The long-term and low-dose exposure of these chemical pesticides can cause immune suppression, reproductive abnormalities, hormone disruption, and cancer (Crisp et al. 1998; Hurley et al. 1998; Brouwer et al. 1999; Roghelia and Patel 2017).

Nowadays, strict regulations have been formulated against the use of chemical pesticide. Therefore, the alternative approaches are being developed by the pest management researchers to replace the use of synthetic chemicals for controlling the plant pathogens and the pests. Among few potent alternatives, the biological control agents are preferred eco-friendly approaches. It is considered to be a natural method for controlling the pests by using the living organisms. Those living organisms which are used to control the invasive species, and which are generally the natural enemies of the same are called as the “biological control agents.” Biocontrol means the use of living organisms to suppress the growth of the population of a pest. It is also called as “biological suppression”. Nowadays, fungi are considered as a new means of biological control against weeds and pathogens to improve the plant yield and food production. The present literature includes the past and current progress of fungal biocontrol agents and understanding about the mode of mechanism.

18.2 Fungi as Biocontrol Agents

Nowadays, various biocontrol products are being produced commercially by using fungi to control the insect pests and plant diseases. The successful use of fungi as biocontrol agents is reported by Hasan (1972), Cullen et al. (1973), Hasan and Wapshere (1973), Emge et al. (1981), Shah and Pell (2003), Faria and Wraight (2007), and Lacey et al. (2015). Natural methods alone are not efficient to control the plant diseases, insect pests, and weeds because they are more labour-intensive than chemical pesticides. However, fungal biological control agents (BCAs) do offer several benefits which are as follows:

- Fungi are ubiquitous in distribution.
- They have high degree of host specificity.
- They are persistent, and they have dispersal efficiency, and they can cause destruction of the host.
- It is easy to culture and maintain the fungi in the laboratory.
- Fungi do not adversely affect the environment, and they are specific to their target, while the chemicals are not target specific.

18.3 Mechanism of Fungi-Mediated Biocontrol

Fungi use several mechanisms to prevent infection or to suppress the growth of insect pests and weeds, which include the following methods for effective biocontrol.

18.3.1 Direct Antagonism (Hyperparasitism)

Direct antagonism is a process in which a pathogen is killed by other microorganisms. It is also called as hyperparasitism (Baker and Cook 1974). If a fungus is parasitic on other fungi, then it is called as a mycoparasite. *Ampelomyces quisqualis* (deuteromycete hyper-parasite) reduces the growth of mildew colony through hyperparasitism and eventually kills them by producing pycnidia (fruiting bodies) within powdery mildew (Erysiphales) hyphae, conidiophore, and cleistothecia. *Trichoderma lignorum* (*T. viride*) control the damping off of citrus seedlings by parasitizing the hyphae of *Rhizoctonia solani* (Weindling 1932; Lo 1997; Harman et al. 2004; Asad et al. 2014; Abbas et al. 2017). *Trichoderma* species shows hyperparasitism against many economically important plant pathogens that makes *T. species* more suitable for the development of biocontrol strategies (Harman et al. 2004; Motlagh and Samimi 2013).

18.3.2 Antibiosis

When two or more organisms interact with each other and that interaction is harmful to at least one of them, this type of association is known as antibiosis. It can also be an association between an organism and the metabolic substances produced by another. Antagonistic fungi secrete antimicrobial compounds to suppress the growth of pathogenic fungi in the close proximity of its growth area. The loss of activity in nonproducing mutants of the antagonist provides the ultimate proof for the role of these compounds in biocontrol; for example, gliotoxin-minus mutants of *Gliocladium virens* loses its 50% antagonistic effect against the disease-causing pathogen as compared to the wild type (Wilhite et al. 1994; Vargas et al. 2014; Vinale et al. 2014). Most fungi are capable of secreting one or more compounds and secondary metabolites with the antibiotic activity. The most common species that produce the antibiotics are *Trichoderma* and *Gliocladium* spp.; *Trichoderma virens* (syn. *Gliocladium virens*) produces two major antifungal antibiotics, gliotoxin and gliovirin (Howell et al. 1993, Mendoza et al. 2015). *Trichoderma pseudokoningii* and *T. viride* inhibit *Botrytis cinerea* on strawberry fruits by producing some secondary metabolites (Tronsmo and Dennis 1977). Bae et al. (2001) evaluated the antibiosis of the culture filtrate of *Trichoderma* spp. against *Phytophthora capsici* and their phytotoxic activities against pepper. In this study, the strain DIS 320c (*T. caribbaeum* var. *aequatoriale*) showed 100% antibiosis against *P. capsici*. Nelson and Powelson (1988) reported that *Trichoderma hamatum* reduced the growth of *Botrytis cinerea* which causes grey mould of snap bean pods and blossom by 77–97% by producing inhibitory volatile compounds. Menendez and Godeas (1998) reported the inhibitory effect of *Trichoderma harzianum* in biocontrol of *Sclerotinia sclerotiorum* which is a soilborne plant pathogen which affects the yield of many economically important crops, such as soybean. Calistru et al. (1997) reported that the hyphae of *Trichoderma* spp. and *Fusarium moniliforme/Aspergillus flavus* on co-culturing show antibiosis without hyphal penetration, suggesting that mycoparasitism was not the sole cause for the observed inhibitory effects. Therefore, metabolites such as volatiles, extracellular enzymes, and antibiotics produced by *Trichoderma* spp. were probably responsible for antibiosis. Mendoza et al. (2015) evaluated in vitro antagonistic activity *of* 14 strains of *Trichoderma* spp. against *Macrophomina phaseolina*. Eleven out of 14 isolates showed antagonism by competition and stopped the growth of *M. phaseolina*. Szekeres et al. (2005) reported that *Trichoderma* spp. produce antagonistic secondary metabolites, namely, peptaibols and peptaibiotics. These metabolites are linear, amphipathic polypeptides that have strong antimicrobial activity against gram-positive bacteria and fungi (Wiest et al. 2002; Szekeres et al. 2005).

18.3.3 Competition

Competition is a process in which two organisms compete with each other for nutrients such as macronutrients and micronutrients. Some species of filamentous fungi and yeasts can inhibit fungal pathogens by competition, which reduces the concentration of nutrients that become responsible for the reduced rate of spore germination and in slower growth of germ tube (Blakeman and Fokkema 1982; Blakeman 1993; Elad 1995; Funck Jensen and Lumsden 1999). Competition for limiting nutrients leads to starvation which is the most common cause of death of microorganisms, which results in biological control of fungal phytopathogens (Chet et al. 1993). *Trichoderma* spp. produce a number of secondary metabolites with pharmaceutical and biotechnological importance that include nonribosomal peptides, peptaibols, polyketides, pyrones, volatile and non-volatile terpenes, and siderophores, (Vinale et al. 2008, 2012; Velázquez-Robledo et al. 2011; Müller et al. 2013). The association of *Trichoderma* with the root system of the plant leads to better nutrient and water uptake and provides protection from pathogenic organisms (Harman 2000; Benítez et al. 2004; Harman 2006; Contreras-Cornejo et al. 2013, 2015). Blakeman (1978) reported that iron, which is extremely limited in the rhizosphere, works as a basic tool for biocontrol based on competition. Iron occurs in ferric form in highly oxidized and aerated soils at very low concentration and at pH 7.4 (Lindsay 1979). Under iron starvation, filamentous fungi secrete iron-binding ligands called siderophores, which facilitate the mobilization of environmental iron (Eisendle et al. 2004). Siderophore biosynthesis is negatively controlled by carbon source in *Aspergillus fumigatus* and *Aspergillus nidulans* (Eisendle et al. 2004). These siderophores increase the rhizosphere competence in *Trichoderma harzianum* which can be used as biocontrol agents against other fungi (Chet and Inbar 1994). For example, *Trichoderma* effectively controls the growth of *Pythium* and *Fusarium oxysporum* in soil depending upon the availability of iron (Tjamos et al. 1992).

18.3.4 Induced Resistance

Induced resistance (IR) is considered as one of the important modes of biocontrol in the plants against soilborne pathogens and foliar pathogens (Sequeira 1983; Kuc 1987; Kloepper et al. 1992). Induced resistance limits the growth and spread of pathogen by secreting defence-related enzymes such as chitinases, proteases, and peroxidases (Hammerschmidt et al. 1982; Metraux and Boller 1986). Induced resistance has been demonstrated in vitro against wilt diseases with avirulent strain of fungi, but under field conditions, induced resistance by nonpathogenic strain of *F. oxysporum* is not so effective in sweet potato against *Fusarium oxysporum* f. sp. *batatas* (Ogawa and Komada 1986).

Salicylic acid produced by T39 of *Trichoderma harzianum* induced resistance against *Botrytis cinerea* in bean (De Meyer et al. 1998). When the leaves and roots of cucumber seedlings were inoculated with *Trichoderma harzianum,* it resulted in increased activity of peroxidase and chitinase (Yedidia et al. 1999). If a biocontrol agent is applied directly on a separated part of the infected plant, it demonstrates induced systemic resistance (ISR), while the use of dead cells of inducer (BCA) to suppress the disease may demonstrate the local induced resistance (IR). For example, the use of dead cells of T39 can inhibit the infection of powdery mildew on cucumber and the infection of *Botrytis cinerea* on tobacco, pepper, and beans.

Redman et al. (1999) reported that mutualistic symbiotic association between the host and the nonpathogenic isolate of fungi confers the disease resistance against other pathogenic fungi; for example, a pathogenic isolate of *Colletotrichum magna* (a common pathogen of cucurbits) was converted to a nonpathogenic isolate by UV radiation and gene disruption. This converted nonpathogenic endophytic mutualist enables the symbiont to confer disease resistance against *Phytophthora, Colletotrichum, and Fusarium.* This phenomenon was defined as "endophyteassociated resistance” (EAR) (Redman et al. 1999). Mycorrhizal fungi prevent soilborne diseases in plants by inducing EAR. However, mycorrhizal plants may be more susceptible to foliar pathogens because pathogenesis-related (PR) proteins take long time to accumulate in the foliage (St. Arnaud et al. 1994; Shaul et al. 1999).

18.4 Limitations of Biocontrol Agents

- An isolate (BCA) may control the growth of a certain pathogen on one crop, but on another crop, it may not be effective to control the disease. This is because of plant host effect. The host on which BCA is effective certainly provides some soluble and volatile exudates secreted by the root, leaf, flower, and seed, which can support introduced BCAs. While on another host on which BCA is not effective, it does not provide such nutrients. For example, PGPR (BCA) is differently effective on different cultivars of wheat (Chanway et al. 1988).
- Microclimate, abiotic factors largely affect the suppression of diseases by BCAs (Shtienberg and Elad 1997). Various factors such as fluctuating temperature, VPD, surface wetness, gases, and air movement affect the indigenous microflora and BCAs directly (Burrage 1971). For example, *Trichoderma harzianum* T39 is more capable to control grey mould in cucumber (fruit and stem) under dry conditions at temperatures above 20 °C in comparison with wet conditions and temperatures below 20 °C (Elad et al. 1993).
- Plant surface produces some chemical exudates that contain macro- and micro-elements, amino acids, organic acids, sugars, sugar alcohols, and pectic substances. Environmental factors along with the age of plant affect the nature and amount of the exudates released from the plants. These changes may modify the leaf characteristics like morphology, chemistry of the surface, and the metabolic state, which directly or indirectly affect plant surface microflora (Cutter 1976). The community in the rhizosphere changes with colonization by bacteria, yeasts, and filamentous fungi that result in the fluctuation in the concentration of nutrients due to competition among microflora (Blakeman 1985). Similarly, rhizosphere is affected by other abiotic factors like rain events, daytime drought, and weathering processes that result in fluctuation in salt concentration and soil particle structure. These changes in the rhizosphere interfere with the establishment and efficacy of the introduced biocontrol agents (BCAs).

18.5 Fungi-Mediated Biocontrol of Insects

Entomophthorales (*Zygomycota*) is the order consisting of a large number of fungal species which are related to biocontrol of insects. Extensive research has been carried out on the use of *Bauvaria* to control chinch bugs in Kansas (Feng and Poprwaski 1994; Lacey et al. 2001). The common fungi which have been used as the mycoinsecticides include *Cordyceps* species*, Beauvaria,* and *Paecilomyces* which infect the larvae of beetles, moths, and other insects; *Hirsutella* infects the larva of a citrus mite; *Aschersonia* infects citrus white flies, and *Noumorea* infects soybean looper. *Metarhizium* species has a special character to mention, that is, it infects a number of insects by forming long chains of spores. This feature enables its use in novel roach traps, which is superior to use of chemicals because chemicals will kill only the insects that enter the chamber, whereas insects that become infected with *Metarhizium* will carry the fungus to their hiding places and infect their neighbours. *Coelomomyces* species are able to infect the mosquitoes which are the major concern to people because their bites are painful and they transmit some of the most important diseases like malaria, dengue, and chikungunya. Some commercially available products (BCAs) manufactured by using fungi as control agents against insect pests are listed in Table 18.1. The different modes of treatments which can be used for the biological control of insects are as follows.

18.5.1 Permanent Introduction

This method involves the introduction and establishment of native fungi at the site of host population. This is one of the cheapest methods but labour-intensive, involving the periodic release of fungal spores to maintain a high density of the biocontrol fungus. The resting spores of *Entomophaga maimaiga* were released in 1991 and 1992 at 50 sites, over 4 states, to control the larvae of gypsy moths. After a year of release of the fungal spores, gypsy moth populations were found to be declined not only in the areas of spore release, but cadavers of larvae could be found in areas where release of spores did not occur.

18.5.2 Inoculation Augmentation

This method involves the release of the pathogen in the field for seasonal control of disease, which occurs annually, and the inoculation of the fungus is not expected to carry on over the following years. This method is potentially a dangerous technique of dispersing the fungus; however, there is no report till yet of accidents involving this method. The fungi are applied as a spray or dust with the help of air or ground equipment. The inoculations are applied usually at 3-year intervals. The best suitable example for the inoculation augmentation is the use of *Beauveria bassiana* for the biological control of *Dendrolimus* (the pine moth), in the People's Republic of China.

Table 18.1 Products developed from fungi for the biological control of pests

Fungus	Product	Target	Producer
Verticillium lecanii	Mycotal	Whitefly and thrips	Koppert, the Netherlands
	Vertalac	Aphids	Koppert, the Netherlands
Metarhizium anisopliae	BIO 1020	Vine weevil	Licenced to Taensa, USA
	Biogreen	Scarab larvae on pasture	Bio-Care Technology, Australia
	Metaquino	Spittle bugs	Brazil
	Bio-path	Cockroaches	EcoScience, USA
	Bio-blast	Termites	EcoScience, USA
	Cobican	Sugarcane spittle bug	Probioagro, Venezuela
Metarhizium flavoviride	Green Muscle	Locusts, grasshoppers	CABI—BioScience, UK
Beauveria bassiana	Conidia	Coffee berry borer	Live Systems Technology, Colombia
	Ostrinil	Corn borer	Natural Plant Protection (NPP), France
	Corn guard	European corn borer	Mycotech, USA
	Mycotrol GH	Grasshoppers, locusts	Mycotech, USA
	Mycotrol WP and BotaniGard	Whitefly, aphids, thrips	Mycotech, USA
	Naturalis-L	Cotton pests including bollworms	Troy Biosciences, USA
	Proecol	Army worm	Probioagro, Venezuela
	Boverin	Colorado beetle	Former USSR
	Boverol	Colorado beetle	Czechoslovakia
	Boverosil	Colorado beetle	Czechoslovakia
Beauveria brongniartii	Engerlingspilz	Cockchafer	Andermatt, Switzerland
	Schweizer Beauveria	Cockchafer	Eric Schweizer, Switzerland
	Melocont	Cockchafer	Kwizda, Austria
Paecilomyces fumosoroseus	PFR-97	Whitefly	ECO-tek, USA
	Pae-Sin	Whitefly	Agrobionsa, Mexico
Lagenidium giganteum	Laginex	Mosquito larvae	AgraQuest, USA

18.5.3 Conservation or Environmental Manipulations

In this method, favourable conditions are provided for the growth of the fungus by modifying the environment of the host. For example, the favourable conditions can be provided for the fungal infection by spraying a mild chemical insecticide that would weaken the host, and another means is by maintaining high humidity and wet conditions in order to favour fungal growth. *Medicago sativa*, alfalfa, is infected by a number of common pathogens; among them is the alfalfa weevil, which can be biologically controlled by the introduction of various species of *Erynia*

(*Entomophthorales*). Highly moist and warm microclimatic conditions are maintained along with the light spray of chemical insecticide to encourage the growth and development of *Erynia* sp.

18.6 Fungi to Control the Plant Disease

Some commercially available mycofungicide products (BCAs) to control the plant diseases are listed in Table 18.2. *Trichoderma* is one of the important fungi which have been proved to be the best mycofungicide against many plant diseases such as root rot diseases of many crops, stem blight of peanuts (Ganesan et al. 2007), choanephora wet rot in okra (Siddiqui et al. 2008), and silverleaf of plums (Corke and Hunter 1979), followed by *Verticillium* to control cotton wilt (Hanson 2000), *Sphaerellopsis* to control rust diseases on a number of plants, and several others. Many commercial products as BCAs have been produced by using *Trichoderma* to control various plant pathogens such as *Pythium*, *Rhizoctonia, Fusarium, Sclerotina, Botrytis cinerea*, etc.

Penicillium chrysogenum is responsible for the post-harvest rot of citrus fruits. It can be controlled biologically by applying the yeast *Pichia guilliermondii* to the fruit after harvest but before storage or shipping. *Pythium ultimum* which causes damping off of cotton and *Rhizoctonia solani* can be controlled by the treatment of soil with the fungus *Gliocladium virens*. *Heterobasidion annosum* is a common cause of root rot of conifers. The disease may be controlled by the treatment of the surface of cut pine stumps with a spore suspension of *Phlebia gigantean*, which colonizes the stump surfaces and prevents subsequent colonization by *H. annosum*.

18.7 Biocontrol of Nematodes

Nematodes are small, needle-shaped worms that can infect plants and animals. A large number of crop plants are being infected by plant pathogenic nematodes, and they are costly to control. Thousands of dollars are invested annually to control these diseases. The chemical nematocides are helpful to control nematodes, but they are detrimental to our environment. Nematophagous fungi are the natural enemies of gastrointestinal helminth parasites, and they have been proved to be effective as biocontrol agents against the nematodes (Kerry 2000; Yang et al. 2011; Ward et al. 2012; Araujo et al. 2013). Ovicidal fungi are a group of fungi that colonize and consume the contents of eggs and larvae of nematodes (Frassy et al. 2010; Mello et al. 2013). Important ovicidal fungi which are being used for biocontrol of nematodes include *Pochonia chlamydosporia* (syn. *Verticillium chlamydosporium* Goddard), *Paecilomyces lilacinus,* and *Dactyella ovoparasitica* (Lysek and Sterba 1991). *Dactyella* and *Arthrobotrys* have peculiar nets, constricting rings, and knobs that can trap the nematodes, and that is the reason they are known as nematode-

Table 18.2 Fungal products developed for the biological control of plant diseases

Fungus	Product	Target	Producer
Trichoderma harzianum	Trichoderma 2000	*Rhizoctonia solani*, *Sclerotium rolfsii*, *Pythium*	Mycontrol (EfA1) Ltd, Israel
	Trichopel	Wide range of fungal diseases	Agrimm Technologies Ltd, New Zealand
	T-22 and T-22HB Bio-Trek, RootShield	*Pythium*, *Rhizoctonia*, *Fusarium*, *Sclerotina*	BioWorks (=TGT Inc) Geneva, USA
	Trichodex	Fungal diseases, e.g. *Botrytis cinerea*	Makhteshim-Agan, several European companies, e.g. DeCeuster, Belgium
Trichoderma harzianum and T. viride	Trichodowels, Trichoject, Trichoseal, and others	*Chondrostereum purpureum* and other soil and foliar pathogens	Agrimm Technologies Ltd, New Zealand
Trichoderma harzianum and T. polysporum	Binab T	Fungi causing wilt, wood decay	Bio-Innovation, Sweden
Pythium oligandrum	Polygandron, Polyversum	*Pythium ultimum*	Plant Protection Institute, Slovak Republic
Fusarium oxysporum	Fusaclean	*Fusarium oxysporum*	Natural Plant Protection, France
	Biofox C	*Fusarium oxysporum*, *F. moniliforme*	SIAPA, Italy
Candida oleophila	Aspire	*Botrytis* spp., *Penicillium* spp.	Ecogen Inc., USA
Cryptococcus albidus	YIELDPLUS	*Botrytis* spp., *Penicillium* spp.	Anchor Yeast, S. Africa
Ampelomyces quisqualis	AQ10 Biofungicide	Powdery mildews	Ecogen Inc., USA
Coniothyrium minitans	Cotans WG	*Sclerotinia* species	Prophyta, Germany. KONI, Germany
Gliocladium virens	SoilGard (=GlioGard)	Several plant diseases Damping off and root pathogens	ThermoTrilogy, USA
Gliocladium catenulatum	Primastop	Several plant diseases	Kemira, Agro Oy, Finland
Rotstop	*Phlebiopsis* (=*Peniophora*) *gigantea*	*Heterobasidion annosum*	Kemira Agro Oy, Finland

trapping fungi. As the nematode is trapped by the fungal hyphae, the fungus will invade the body cavity of the nematode, resulting in death. *Lagenidium* (aquatic oomycete) attacks on susceptible aquatic nematodes.

18.8 Biocontrol of Weeds and Noxious Plants

There are about 30,000 species of plants which are considered as weeds, and about 1600 of these can cause serious crop losses. In order to control weeds, agriculturists have started using herbicides or weedicides. The chemical herbicides are detrimental to our environment, and they have contaminated our water bodies including underground aquifers. There are several reports which state that the chemical herbicides can pose serious health implications to human health. Biological control of weeds can solve this problem by using mycoherbicides (bioherbicides) which have advantages over chemical herbicides. Recently, the successful use of a cocktail of three pathogens has been demonstrated in the field to control several weeds (Chandramohan 1999; Chandramohan et al. 2000). Charudattan (2001) reported that broad-spectrum bioherbicides do not have very high levels of host specificity; therefore, they could be used against more than one weed species (e.g. *Dactylaria higginsii* for *Cyperus* spp., *Phomopsis amaranthicola* for *Amaranthus* spp., etc.). Many facultative parasites, such as *Alternaria cassiae, Chondrostereum purpureum, Colletotrichum gloeosporioides, Cylindrobasidium levae, Dactylaria higginsii, Phomopsis amaranthicola, Pseudomonas syringae* pv. *tagetis,* and *Sclerotinia sclerotiorum,* are either registered or being developed as bioherbicides (Charudattan 2001). Table 18.3 shows the list of commercially available mycoherbicides to control the weeds and noxious plants. Mycoherbicides are more host-specific, and their preparation cost is cheaper, and also they are nonhazardous to human health. A number of mycoherbicides have been marketed by Mycogen Co. in San Diego, CA. *Puccinia* species can control the growth of skeleton weed and thistle under greenhouse conditions. Milkweed or strangler vine, a major problem on citrus in south Florida, can be controlled by using the mycoherbicide "Divine" composed of *Phytophthora palmivora.* Jointvetch "Collego" produced a mycoherbicide by using *Colletotrichum gloeosporoides* to control jointvetch, which lowers the market value of rice during harvesting. Sicklepod can be biologically controlled by *Alternaria cassia*. Water hyacinth can be controlled biologically by applying an inoculum of *Cercospora rodmanii*, renamed *C. piaropi*. Some fungi have been discovered to infect *Hydrilla* which causes the most problems to fishermen.

18.9 Conclusion

The use of fungi as biological control agents has achieved a significant progress over the last two decades. Some commercially available BCA products are already being sold in the market. Future use of fungi as biocontrol agents will expand if scientists can successfully develop resting spores and competent mycelia. Biocontrol agents alone are not sufficient to control all kinds of plant diseases under diverse conditions. Nowadays, mechanisms of action of some BCAs are becoming clearer. However, more research and development need to be done in the field of fungal biocontrol

Table 18.3 Fungi developed or commercially available for the biological control of weeds

Fungus	Target	Commercial name	Supplier or country where registered
Alternaria cassiae	Sicklepod (*Cassia obtusifolia*) and coffee senna (*C. occidentalis)* in soybeans and peanuts	Casst	USA
Cercospora rodmanii	Water hyacinth *(Eichhornia crassipes)*	'ABG 5003'	Abbott Labs, USA
Colletotrichum coccodes	Velvetleaf (*Abutilon theophrasti*) in corn and soybeans	Velgo	USA and Canada
Colletotrichum gloeosporioides f. sp. *cuscutae*	*Cuscuta chinensis, C. australis* in soybeans	Luboa 2	PR China
Colletotrichum gloeosporioides f. sp. *malvae*	Mallow (*Malva pusilla*) in wheat and lentils	Biomal	Canada
Colletotrichum gloeosporioides f. sp. *aeschynomene*	Northern Jointvetch (*Aeschynomene virginica*) USA in rice	Collego	Encore Technologies, USA
Chondrostereum purpureum	Black cherry (*Prunus serotina*) in forestry in The Netherlands	BioChon	Koppert, The Netherlands
Phytophthora palmivora	Milkweed vine (*Morrenia odorata*) in Florida citrus	Devine	Sumitomo, Valent, USA

agents for better understanding of their behaviour as BCAs. Genetic transformation of fungi can improve the performance of fungal BCAs under variable environmental conditions. However, the potential risk associated with release of these organisms into the environment should be further studied to enable acceptable guidelines for their implementation.

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