Plant Pathology Journal

ISSN 1812-5387

science alert

ANSInet
an open access publisher
http://ansinet.com

Plant Pathology Journal 9 (3): 92-102, 2010
ISSN 1812-5387

Why *Trichoderma* is Considered Super Hero (Super Fungus) Against the Evil Parasites?

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INTRODUCTION

Plant disease continues to threaten crop production in modern agriculture and plays a direct role in the destruction of natural resources in agriculture. In particular, soil borne plant pathogens especially fungi cause important losses and are most aggressive. Some of the important soil borne plant pathogens such as *Pythium*, *Phytopthora*, *Botrytis*, *Rhizoctonia, Fusarium* and *Meloidogyne* has spread very fast and have detrimental effects on crops of economic importance. With the advent of chemical compounds it was thought that a permanent and reliable solution of soil borne plant pathogens have been achieved but it was realized that pesticide application is not safe to the environment as the toxicants cause environmental pollution and has harmful effects on human beings. Unfortunately to control a target soil borne plant pathogen with a pesticide, over 100 species of non target organisms are adversely affected (Alabouvette and Couteadier, 1992). Despite realization of adverse effects of chemical pesticides on plants, animals and environment they are being applied indiscriminately to control soil borne plant pathogens. Moreover, some efficacious pesticides have been banned for use in agriculture (Table 1, 2). Hence, to reduce the use or dose of chemicals, one possibility is to utilize the disease suppressing activity of certain microorganisms which should be highly antagonistic against the targeted soil borne plant pathogens. Such microorganisms are commonly referred to as biological control (biocontrol) agents and their commercial formulations as biopesticides.

Table 1: List of pesticides banned in India

S. No.	Name of pesticides	S. No.	Name of pesticides
1.	Aldrin	16.	Pentachloro nitrobenzene (PCNB)
2.	Benzene hexachloride (BHC)	17.	Pentachlorophenol (PCP)
3.	Calcium cyanide	18.	Phenyl mercury acetate (PMA)
4.	Chlordane	19.	Sodium Methane arsonate (MSMA)
5.	Copper acetoarsenite	20.	Tetradifon
6.	Dibromochloropropane (DBCP)	21.	Toxaphene
7.	Endrin	22.	Phosphamidon 85% SL
8.	Ethyl mercury chloride	23.	Methomyl 12.5 % L
9.	Ethyl parathion	24.	Aldicarb
10.	Heptachlor	25.	Chlorbenzilate
11.	Manzona	26.	Dieldrin
12.	Methomyl 24% formulation	27.	Ethylene dibromide (EDB)
13.	Nicotine sulphate	28.	Maleic hydrazide
14.	Nitrofen	29.	Trichloro Acetic acid (TCA)
15.	Paraquat dimethyl sulphate		

Source: G:\ NESAC-Integrated Plant Protection Banned Pesticides.htm

Table 2: Pesticides refused registration

S. No.	Name of pesticides	S. No.	Name of pesticides
1.	Ammonium sulphamate	10.	Fentin Acetate
2.	Azinophos ethyl	11.	Fentin hydroxide.
3.	Azinophos methyl	12.	Lead arsenate
4.	Binapacryl	13.	Leptophos (phosve1)
5.	Calcium arsenate	14.	Mephosfolan
6.	Carbophenthion	15.	Mevinphos (phosdrin)
7.	Chinomethionate (morestan)	16.	2, 4, 5-T
8.	Dicrotophos	17.	Thiodemeton/disulfoton
9.	E P N	18.	Vamidothion

Source: G:\NESAC-Integrated Plant Protection Banned Pesticides.htm

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Recent researches on biological control have been conducted with greater systemic approach and practical utility. Various microorganisms viz., fungi, bacteria, mycorrhizae etc. have been tested for their ability to suppress plant pathogens. As most of the soil borne plant pathogens are fungi, biocontrol by fungi has been attempted extensively (Henis *et al*., 1979; Baker, 1987; Suarez *et al*., 2004).

Trichoderma species are among the most frequently isolated soil fungi and present in plant root ecosystems (Harman *et al*., 2004). The fungi are opportunistic, avirulent plant symbionts and function as parasites and antagonists of many phytopathogenic fungi, thus protecting plants from diseases. So far *Trichoderma* sp. are among the most studied fungal biocontrol agents and commercially marketed as a potent biopesticides, biofertilizer and also used in soil amendments (Harman, 2000; Harman *et al*., 2004). Depending upon the strain the use of Trichoderma in agriculture can provide numerous advantages:

(1) Colonization of the rhizosphere (rhizosphere competence) allowing rapid establishment within the stable microbial communities in the rhizosphere, (2) control of pathogenic and competitive/deleterious microflora by using a variety of mechanism, (3)iImproving of the plant health and (4) stimulation of root growth (Harman *et al*., 2004).

Systematics of *Trichoderma*: *Trichoderma* is classified as under:

Division	Ascomycota
Sub division	Pezizomycotina
Class	Sordariomycetes
Order	Hypocreales
Family	Hypocreaceae
Genus	Trichoderma

History of *Trichoderma*: The genus *Trichoderma* was described in 1791 in Germany and four species were originally described. In 1927 Gilman and Abbott recognized four species. These species were distinguished on the basis of color and shape of their conidia and on the colony appearance. Most species were identified as *T. lignorum* (= *T. viride*) because of its globose conidia or as *T. koningii* because of its oblong conidia. The potential for use of *Trichoderma* sp. as biocontrol agents was suggested more than 75 years ago by Weindling (1932) who was the first to demonstrate the parasitic activity of members of this genus to pathogens such as *R. solani*. *Trichoderma* is perhaps the best known mycoparasite suggested as a biocontrol agent against many soil borne plant pathogens (Table 3).

Factors influencing biocontrol agent: Rhizosphere competence: Rhizosphere competence is the ability to colonize and grow in association with plant roots. This is possibly the most important factor in considering the potential of any given isolate for biological control because it is a measure of the ability of an isolate to survive in the soil.

Temperature: It is important to understand the cycle of the pathogen in order to determine the best time for application of a biocontrol agent. Potential biocontrol strains need to cover the thermal spectrum of the target organism, e.g., *Botrytis* has a very wide spectrum. *Crinipellis* seems to grow at a higher optimum temperature than *T. stromaticum* thus limiting the ability of the *Trichoderma* to control the plant parasite.

Moisture: Moisture can limit the ability of a biocontrol agent to colonize the habitat. Lack of moisture can limit the ability of the biocontrol spores to germinate. Moisture controls availability of nutrients essential to growth of the biocontrol agent. Applications can be timed to periods when there will be enough moisture to stimulate spore germination.

Nutrients: *Trichoderma* conidia are very small. They must take up water and swell before germination. That process requires the presence of nutrients (carbon, nitrogen). Hyphae and chlamydospores are less sensitive to soil fungistasis.

Mechanism of disease suppression: The activities of biocontrol agents mainly depends on different physicochemical environmental conditions to which they are subjected. Understanding both the genetic diversity of strains within *Trichoderma* species and their mechanisms of biocontrol will lead to improved application of the different strains as biocontrol agents. These mechanisms are complex and what has been defined as biocontrol is the final result of different mechanisms acting synergistically to achieve disease control (Howell, 2003). Biocontrol results either from competition for nutrients and space or as a result of the ability of *Trichoderma* biocontrol agents to produce and/or resist metabolites that either impede spore germination (fungistatis), kill the cells (antibiosis) or modify the rhizosphere, e.g., by acidifying the soil, so that pathogens cannot grow. Biocontrol may also result from a direct interaction between the pathogen itself and the biocontrol agent, as in mycoparasitism, which involves physical contact and synthesis of hydrolytic enzymes, toxic compounds and/or antibiotics that act synergistically with the enzymes. *Trichoderma* sp. can

Table 3: Various soil borne plant pathogens controlled by *Trichoderma* species

Crop	Disease	Pathogen	References
Rice	Sheath Blight	*Rhizoctonia solani*	Chakravarthy and Nagamani (2007)
Apple	Ring rot	*Botryosphaeria beregeriana* f. sp. *piricola*	Kexiang *et al.* (2002)
Chilli	Dry root rot	*Rhizoctonia solani*	Bunker and Mathur, 2001
Pea	Collar rot		Kumar and Dubey (2001)
Groundnut		*Aspergillus flavus*	Srilakshmi *et al.* (2001)
Tomato	Fusarium wilt	*Fusarium oxysporum* f. sp. *lycopersici*	Singh (2007), Khan and Akram (2000)
Tomato	Damping off	*Pythium aphanidermatum*	Kumar and Hooda (2007), Hazarika *et al.* (2000), Manoranjitham *et al.* (2001)
Potato	Late Blight	*Phytophthora infestans*	Gogoi *et al.* (2007), Gupta *et al.* (2004), Basu *et al.* (2001)
Potato	Black scurf	*Rhizoctonia solani*	Gogoi *et al.* 2007; Singh *et al.* (2001), Tsror *et al.* (2001)
Potato	Bacterial brown rot	*Fusarium* and *Phoma* sp.	Gogoi *et al.* (2007)
Potato	Leaf roll virus		Gogoi *et al.* 2007
Green gram	Seedling blight	*Rhizoctonia solani*	Jash and Pan (2004)
Chilli	Fusarial wilt	*Fusarium oxysporum* and *Fusarium solani*	Singh (2007)
Black gram	Root rot	*Macrophomina phaseolina*	Sundravadana and Alice (2006)
Tomato	Septoria leaf spot, Alternaria rot and Black eye rot	*Alternaria solani, Septoria lycopersici, Alternaria alternata, Phytophthora nicotianae* var. *parasitica*	Rathee *et al.* (2006)
Chickpea	Root rot	*Rhizoctonia solani*	Khan and Rehman (1997)
Egg plant	Root rot	*Macrophomina phaseolina R. solani*	Khan and Gupta (1998)
Gladiolus	Corm rot	*Fusarium oxysporum* f. sp. *gladioli*	Khan and Mustafa (2005)
Pigeonpea	Wilt	*Fusarium udum*	Chaudhary and Prajapati (2004)
Wheat	Spot blotch	*Chaetomium globosum*	Selvakumar *et al.* (2001)
Chilli	Damping off		Marnoranjitham *et al.* (2000)
Sunflower	Head rot	*Sclerotinia sclerotiorum*	Singh *et al.* (2004)
Egg plant	Wilt	*Fusarium oxysporum*	Wani (2005)
Apple	White root rot	*Dematophora necatrix*	Tapwal *et al.* (2005)
Chickpea	Wilt, Wilt complex	*Fusarium, Sclerotium, Rhizoctonia*	Gupta *et al.* (2005)
Chickpea	Root rot	*Rhizoctonia solani*	Gaur *et al.* 2005
Horticulture and field crops	Damping off, root rot and wilt	*Fusarium oxysporum* and *Rhizoctonia*	Pandey *et al.* (2005)
Groundnut	Root rot	*Sclerotium rolfsii*	Roy and Pan (2005)
Chickpea	Dry root rot	*Rhizoctonia bataticola*	Gaur *et al.* (2005)
Sugarcane	Pine apple disease	*Ceratocystis paradoxa*	Achuta *et al.* (2004)
Sesame	Wilt	*Fusarium oxysporum* f. sp. *sesame*	Sangle and Bambawale (2004)
Safflower	Wilt	*Fusarium oxysporum* f. sp. *carthami*	Prameela *et al.* (2005)
Guava	Die back	*Lasiodiplodia theobromae*	Yadav and Majumdar (2005)
Wheat	Leaf blight	*Alternaria triticina*	Parveen and Kumar (2004)
Wheat	Leaf blight	*Alternaria triticina*	Kumar and Parveen (2002)
Groundnut	Stem and pod rot	*Sclerotium rolfsii*	Parakhia and Akbari (2004)
Potato	Wilt	*Sclerotium rolfsii*	Rao *et al.* (2004)
Cumin	Wilt	*Fusarium oxysporum* f. sp. *cumini*	Ghasolia and Jain (2004)
Black gram	Dry root rot	*Macrophomina phaseolina*	Sajeena *et al.* (2004)
Sunflower	Charcoal rot	*Macrophomina phaseolina*	Suriachardraselvan *et al.* (2004)
Lime	Dry root rot	*F. solani*	Kavitha *et al.* (2004)
Wheat	Loose smut	*Ustilago segetum*	Singh (2004a)
Soybean	Root rot	*R. solani, S. rolfsii, M. phaseolina, Sclerotinia sclerotiorum*	Bohra and Mathur (2004)
Brinjal	Damping off	*P. aphanidermatum*	Ramesh (2004)
Green gram	Seedling blight	*R. solani*	Jash and Pan (2004)
Urd bean		*R. solani, Colletotrichum truncatum*	Shailbala and Tripathi (2004)
Cucumber	Powdery mildew	*Sphaerotheca fuliginea*	Singh (2004b)
Bell pepper	Blight	*Phytophthora capsici*	Srivastava and Prasad (2005)

even exert positive effects on plants with an increase in plant growth (mineralization) and the stimulation of plant defense mechanisms. Mechanism of disease suppression may be due to competition, antibiosis or mycoparasitism.

Competition

Fungistatis: The nature of competition is fungistatic (inhibitor). Good antagonists are usually able to overcome the fungistatic effect of soil that results from the presence of metabolites produced by other species including plants and to survive under very extreme competitive conditions. *Trichoderma* strains grow rapidly when inoculated in the soil because they are naturally resistant to many toxic compounds including herbicides, fungicides and pesticides such as DDT and phenolic compounds (Chet *et al.*, 1997). Resistance to toxic compounds may be due to the presence of ABC transport systems in *Trichoderma* strains (Harman *et al.*, 2004). *Trichoderma*

strains are very efficient in controlling several phytopathogens such as *R. solani*, *P. ultimum* and *S. rolfsii* when alternated with methyl bromide, benomyl, captan or other chemicals due to the presence of ABC transport system (Vyas and Vyas, 1995).

Competition for nutrients: Starvation is the most common cause of death for microorganisms, so that competition for limiting nutrients results in biological control of fungal phytopathogens (Chet *et al*., 1997). For instance, in most filamentous fungi iron uptake is essential for viability (Eisendle *et al*., 2004) and under iron starvation most fungi excrete low molecular weight ferric iron specific chelators termed as siderophores to mobilize environmental iron (Eisendle *et al*., 2004). For this reason, soil composition influences the biocontrol effectiveness of *Pythium* by *Trichoderma* according to iron availability. Some *Trichoderma* biological agents produce highly efficient siderophores that chelate iron and stop the growth of other fungi (Chet and Inbar, 1994). One of the most sensitive stages for nutrient competition in the life cycle of *Fusarium* is chlamydospore germination (Baker, 1986). In soil the chlamydospores of *F. oxysporum,* need nutrition to maintain a germination rate of 20-30%. The germination may decrease due to sharing of nutrients by other microorganisms. Root exudates are major source of nutrients in soil which are excreted from the root tips. Thus, colonization in the rhizosphere of root tip by an antagonist might reduce infection by *Fusarium*-like pathotypes (Cook and Baker, 1983). In addition, *T. harzianum* T35 controls *F. oxysporum* by competing for both rhizosphere colonization and nutrients with biocontrol becoming more effective as the nutrient concentration decreases (Alabouvette and Couteadier, 1992). Competition for carbon has also been involved in the determination of the antagonism expressed by different strains of *Trichoderma* sp. against several plant pathogens, especially *F. oxysporum* (Sivan and Chet, 1989). *T. viride* controlled *Chondrostereum purpureum,* the silver leaf pathogen of plum trees due to competition exerted by the former (Corke and Hunter, 1979). Competition has proved to be particularly important for the biocontrol of phytopathogens such as *Botrytis cinerea*, the main pathogenic agent during the pre and post-harvest in many countries (Latorre *et al*., 2001). The advantage of using *Trichoderma* to control *Botrytis cinerea* is the coordination of several mechanisms, the most important is nutrient competition, since *Botrytis cinerea* is particularly sensitive to the lack of nutrients.

Trichoderma has a superior capacity to mobilize and take up soil nutrients compared to other organisms. The efficient use of available nutrients is based on the ability of *Trichoderma* to obtain ATP from the metabolism of different sugars, such as those derived from polymers wide spread in fungal environments: cellulose, glucan and chitin among others, all of them rendering glucose (Chet *et al*., 1997). While, the role of the glucose transport systems remains to be discovered, its efficiency may be crucial in competition (Delgado-Jarana *et al*., 2003) as supported by the isolation of a high affinity glucose transporter, Gtt 1, in *T. harzianum* CECT 2413. This strain is present in environments very poor in nutrients and it relies on extracellular hydrolases for survival. The Gtt 1 is only expressed at very low glucose concentrations, i.e., when sugar transport is expected to be limiting in nutrient competition (Delgado-Jarana *et al*., 2003).

Antibiosis: Antibiosis is required as one of the most important attribute in deciding the competitive saprophytic ability of *Trichoderma* sp. Our first knowledge of toxic metabolite production by species of *Trichoderma* was largely due to Weindling (1934, 1937) who showed the production of an antifungal metabolite by *T. lignorum*, later stated to be *G. frimbiatum*. The metabolite was named as gliotoxin. Antibiosis occurs during interactions involving low molecular weight diffusible compounds or antibiotics produced by *Trichoderma* strains that inhibit the growth of other microorganisms. Most *Trichoderma* strains produce volatile and non volatile metabolites (Table 4) that impede colonization by antagonized microorganisms; among these metabolites, the production of harzianic acid, alamethicins, tricholin, peptaibols, antibiotics, 6-penthyl-a-pyrone, massoilactone, viridin, gliovirin, glisoprenins, heptelidic acid and others have been described (Vey *et al*., 2001). In some cases, antibiotic production correlates with biocontrol ability and purified antibiotics mimic the effect of the whole agent. Volatile substances from *Trichoderma* sp. inhibited the mycelial growth of *Macrophomina phaseolina* by 22-51% (Angappan, 1992). The volatile antibiotics of *T. harzianum* and *T. atroviride* significantly decreased the growth of canker pathogen fungi of poplar, *Cytospora chrysosperma* and *Dothiorella gregaria* (Gao *et al.,* 2001). Non-volatile metabolites in the culture filtrate of *Trichoderma* sp. inhibited the linear growth of pathogens (Deshmukh and Pant, 1992). Dwivedi (1992) reported that culture filtrate of *T. harzianum* inhibited the growth of *F. solani* and *F. longipus* by 60 and 64%, respectively.

Mycoparasitism: Mycoparasitism, the direct attack of one fungus on another, is a very complex process that involves sequential events including recognition, attack and subsequent penetration and killing of the host.

Table 4: Antibiotics or antibiotics-like effectors produced by *Trichoderma* species

Antibiotics or antibiotics-like effectors	References
Trichodermin Gotfredson and Vangedal (1965)	
Trichoviridin	Yamano *et al.* (1970)
Trichosetin	Marfori *et al.* (2002)
Gliotoxin, Trichodermin, Viridin	Haggag and Mohamed (2002)
Chitinase	Elad *et al.* (1982)
Protease	Elad *et al.* (2000)
Chitobiase	Ulhao and Peberdy (1993)
Sesquiterpene heptalic acid	Itoh *et al.* (1980)
a-gluxosidase protein	Shanmugam *et al.* (2001)
Dermadin	Pyke and Dietz (1966)
b-1,3-glucanase	Perez *et al.* (2001)
Alamethicine, Paracelsin, Trichotoxin	Lumsden *et al.* (1991)
Heptelidic acid	Howell *et al.* (1993)
Chitin-1-4-b-chitobiosidase n-acetyl, b-D glucosaminase, Endochitinase	Harman *et al.* (1993)
6-n-pentenyl-2H-pyran-2 one, 6-n-pentenyl-2H-pyran-2-one,	Claydon *et al.* (1987)
Harzianolide [3-(2-hydroxyl-propyl) -4(hexa-2"-dienyl-2(5H) furanone	Claydon *et al.* (1991)
Trichorzianines, Trichorviridin, Propionic acid, 3-(3-isocyanocyclopent-2-enzylidene), Acrylic acid, 3-(3-isocyano-6-oxabicyclo (3, 10) hex-2-eh-5-yl	Baldwin *et al.* (1981)

Trichoderma sp. may exert direct biocontrol by parasitizing a range of fungi detecting other fungi and growing towards them. The remote sensing is partially due to the sequential expression of cell wall degrading enzymes, mostly chitinases, glucanases and proteases (Harman *et al.*, 2004). *Trichoderma* attaches to the pathogen with cell wall carbohydrates that bind to pathogen lectins. Once *Trichoderma* is attached, it coils around the pathogen and forms the appresoria. The following step consists of the production of cell wall degrading enzymes and peptaibols (Howell, 2003) which facilitate both the entry of *Trichoderma* hypha into the lumen of the parasitized fungus and the assimilation of the cell wall content. *Trichoderma* sp. react violently with hyphae of the *Fusarium* species. The hyphae of *Trichoderma* sp. when near to pathogen induce morphological deformalities in the host hyphae. Many a time bursting of hyphae and vacoulation has been observed (Komatsu, 1968; Gao *et al.*, 2001). In addition, granulation, coagulation, disintegration and finally lysis of the pathogen occurs (Lim and The, 1990; Elad *et al.*, 1983; Nigam *et al.*, 1997; Gao *et al.*, 2001). *In vitro* studies have revealed that purified endochitinase, chitobiosidase, n-acetyl-b-glucosidase and glucan 1,3-β-glucosidase and combinations thereof, greatly suppressed the spore germination and germ tube elongation in nine different fungal species (Lorito *et al.*, 1993, 1994a, b; Di Pietro *et al.,* 1993). *T. harzianum* TM transformants overexpressing chit36 chitinase inhibited *F. oxysporum* and *S. rolfsii* more strongly than the wild type. Moreover, culture filtrates inhibited the germination of *B. cinerea* almost completely (Viterbo *et al.*, 2001).

Stimulation of host defence response: The ability of *Trichoderma* strains to protect plants against root pathogens has long been attributed to an antagonistic effect against the invasive pathogen (Chet *et al.*, 1997). However, these root fungus associations also stimulate plant defensive mechanisms (Howell *et al.,* 2000; Hanson and Howell, 2004). Strains of *Trichoderma* added to the rhizosphere protect plants against numerous classes of pathogens, e.g., those that produce aerial infections, including viral, bacterial and fungal pathogens, which point to the induction of resistance mechanisms similar to the Hypersensitive Response (HR), Systemic Acquired Resistance (SAR) and Induced Systemic Resistance (ISR) in plants (Harman *et al.*, 2004). At a molecular level, resistance results in an increase in the concentration of metabolites and enzymes related to defensive mechanisms such as the enzymes Phenyl Alanine ammonia Lyase (PAL) and Chalcone Synthase (CHS), involved in the biosynthesis of phytoalexins (HR response), chitinases and glucanases. These comprise pathogenesis related proteins (SAR response) and enzymes involved in the response to oxidative stress. The addition to *Trichoderma* metabolites that may act as elicitors of plant resistance or the expression in transgenic plants of genes whose products act as elicitors, also results in the synthesis of phytoalexins, PR proteins and other compounds and in an increase in resistance against several plant pathogens, including fungi and bacteria (De Las Mercedes *et al.*, 2001; Elad *et al.*, 2000) as well as resistance to hostile abiotic conditions (Harman *et al.*, 2004). Barley expressing *Trichoderma atroviride* endochitinase Ech 42 showed increased resistance towards *Fusarium* infection.

Cotton seedlings treated with efficient strain of *T. virens* had higher levels of defense related compounds such as terpenoids and peroxidase activity in the root (Howell *et al.,* 2000). An ethylene-inducing xylanase produced by *T. viride* (Dean and Anderson, 1991) elicited the production of phytoalexin reversatrol in grapevine cells (Calderon *et al.*, 1993). Hanson and Howell (2004) reported that culture filtrates from a strain of *T. virens* stimulated synthesis of terpenoid in cotton and the elicitors were presumably proteins or glycoproteins.

Plant growth promotion by *Trichoderma* species: Root colonization by *Trichoderma* strains frequently enhances root growth and development, crop productivity, resistance to abiotic stresses and the uptake and use of nutrients (Arora *et al.*, 1992) (Table 5). Crop productivity in fields can increase upto 300% after the addition of *T. hamatum* or *T. koningii.* The experiments carried out in green houses with seed treatment with *Trichoderma* spores have shown significant greater yield (Chet *et al.*, 1997). Equal degree of yield enhancement was observed when plant seeds were separated from *Trichoderma* by a cellophane membrane. This indicates that *Trichoderma* produces growth factors that enhanced the rate of seed germination, plant growth and yield (Benitez *et al.*, 1998). Zimand *et al.* (1996) reported that *T. harzianum* T39 besides having inhibitory effect on the conidial germination and germ tube elongation of *Botrytis cinerea,* also reduced the production and activity of pathogen secreted pectolytic enzymes three days after inoculation. Reduced activities of pectolytic enzymes may increase the accumulation of pectic enzyme products, i.e., oligogalacturonides. These sugars can elicit the host plant (bean) defence mechanisms, thus checking the disease development. Activity of biocontrol agents could also reduce the concentration of substances in soil that are inhibitory to plant growth (Windham *et al.,* 1986). Thus, the plant growth promotion may be due to production of plant hormones or increased uptake of nutrients by the plant (Chet *et al.*, 1993); control of one or more sub potential pathogens (Baker, 1986) and/or

Table 5: Percent yield increase of various crops by the application of *Trichoderma* sp.

Crop	Yield (%)	References
Potato	62	Gogoi *et al.* (2007)
Cotton	300	Chet *et al.* (1997)
Chickpea	124	Prasad *et al.* (2002)
Groundnut	123	Thakur *et al.* (2003)
Urd	13	Dubey (2003)
Mungbean	35	Dubey (2003)
Strawberry	85	Porras *et al.* (2007)
Maize	79	Sankar and Sharma (2001)
Black pepper	170	Rajan *et al.* (2002)
French bean	58	Dubey (2002)
Tomato	166	Das and Dutta (2002)
Rice	78	Kharakrang *et al.* (2002)
Castor	165	Chattopadhyay and Varaprasad (2001)

Table 6: Commercial formulations of *Trichoderma* species available in India

Antagonist	Antagonist	Target pathogen	Crop	Source
Antagon Tv	*T. viride*	*Macrophomina, Pythium, Phytopthora*	Oil seeds, Pulses, Vegetables	Green Tech, Agroproducts, Rajaji Road Coimbatore
Trichostar	*T. harzianum*	*Fusarium, Rhizoctonia, Sclerotium, Pythium*	Pulses and Vegetables	GBPUAT, Pantnagar
Gliostar	*T. virens*	-do-	-do-	-do-
Trichoderma	*Trichoderma* sp.	-do-	-do-	Innovative Pest Control Lab, Bangalore
Monitor	*Trichoderma* sp.	-do-	-do-	Agricultural and Biotech Pvt, Ltd. Gujarat
Phule Trichokill	*Trichoderma* sp.	-do-	-do-	Department of Plant Pathology, MPKV, Rahuri
Monitor WP	*Trichoderma* sp.	-do-	Pulses, Oilseeds, Vegetables, Sugarcane, Potato, Cotton, Spices, Fruits	Agriland Biotech Pvt. Ltd., 36, Prince Industrial State Mota-Metipi Baroda (Guj.)
Funginil	*T. viride*	do	do	Crop Health Products Ltd. Industrial Area, Meerut Road Ghaziabad.
Pant Biocontrol Agent 1	*T. harzianum*			GBPUAT, Pantnagar
Biowilt-X	*T. harzianum*			Deptt. of Plant Protection, AMU, Aligarh
	T. harzianum			Deptt. of Plant Protection, AMU, Aligarh
Bioderma	*T. viride/T. harzianum*			Biotech International Ltd., India
Ecofit		*T. viride*		Hoechst Schering Afgro Evo Ltd., India
Ecoderma	*T. viride + T. harzianum*			Margo Biocontrol Pvt. Ltd. Banglore
Defence		*T. viride*		Wockhardt Life Science Ltd. Mumbai
Trichoguard	*T. viride*			Anu Biotech Int. Ltd. Faridabad

strengthening plant's own defense mechanism (Zimand *et al.,* 1996).

Commercial formulations: For field application of a bioagent, an inert immobilizing substrate is essentially required which could carry maximum number of propagules of the biocontrol agent with minimum volume and necessarily maintain integrity of the organism. Various carriers viz., peat, seeds, meals, kernels, husks, brans, bagasse, FYM, cowdung, cake, compost, oilcakes, wood bark, vermiculite, sand, clay etc. have been tested to prepare commercial formulations of *Trichoderma* (Table 6).

ACKNOWLEDGMENTS

The author wish to dedicate this paper to the beloved Boba who breathed her last on 30 June, 2006. She was a great source of inspiration and strength for me. May her soul rest in the best place in heaven! Aameen.

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