Pak. J. Bot., 46(4): 1489-1493, 2014.

TRICHODERMA SPP.: A BIOCONTROL AGENT FOR SUSTAINABLE MANAGEMENT OF PLANT DISEASES

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Abstract

Trichoderma spp. are mainly asexual fungi that are present in all types of agricultural soils and also in decaying wood. The antagonistic activity of *Trichoderma* species showed that it is parasitic on many soil-borne and foliage pathogens. The fungus is also a decomposer of cellulosic waste materials. Recent discoveries show that the fungi not only act as biocontrol agents, but also stimulate plant resistance, and plant growth and development resulting in an increase in crop production. The biocontrol activity involving mycoparasitism, antibiotics and competition for nutrients, also induces defence responses or systemic resistance responses in plants. These responses are an important part of *Trichoderma* in biocontrol program. Currently, *Trichoderma* spp., is being used to control plant diseases in sustainable diseases management systems. This paper reviews the published information on *Trichoderma* spp., and its biocontrol activity in sustainable disease management programs.

Introduction

Plant disease management as well as improvement of yields using traditional methods such as chemical pesticides, herbicides, or fertilizer are not an ecofriendly approach, as they consist of various aromatic groups or methylated and ethylated substances which to a large extent have extreme effects on the environment. Long term using of chemical pesticides contaminate water, cause atmosphere pollution, and some-times leave harmful residues which can lead to development of certain resistant organisms. To overcome these problems researchers look for alternative options such as the use of bicontrol agents (BCA) for disease control either alone or in an integrated approach with other chemicals for ecofriendly and sustainable methods of disease control. Currently, several biocontrol agents have been recognized and are available as bacterial agents for example *Pseudomas, Bacillus*, and *Agrobacterinum*, and as fungal agents such as *Aspergillus*, *Gliocladium*, *Trichoderma*, *Ampelomyces*, *Candida*, and *Coniothyrium* (Papavizas, 1985; Koumoutsi *et al.,* 2004; Mavrodi *et al.,* 2002; Atehnkeng *et al.,* 2008; Gilardi *et al.,* 2008). Among these biocontrol agents *Trichoderma* spp. is one of the most versatile biocontrol agents which has long been used for managing plant pathogenic fungi. A previous study found that the disease of seed rot, damping off, root rot of sunflower and mugbean caused by *Sclerotium rolfsii* was prevented as well as the plant growth was enhanced when plants were treated with the conidial suspensions of *Trichoderma* spp. (Yaqub & shahzad, 2008). The pathogenic fungal growth of *Ganoderma* was inhibited by *T. harzianum* and *T. virens* (Naher *et al.,* 2012).

Trichoderma spp., are typical anaerobic, facultative and cosmopolitan fungi that can be found in large numbers in agricultural soils and in other substrates such as decaying wood (Samuels, 1996; Irina & Christian, 2004). They belong to the subdivision Deuteromycetes, members of which do not have or do not exhibit a determinate sexual state as most strains are adapted to an asexual life cycle (Harman, 2004a). The role of *Trichoderma* spp. is not only to control growth of pathogenic microbes, but there are various other uses for *Trichoderma* such as, i) stimulate colonization of rhizosphores, (ii) stimulates plant growth, root growth, and (iii) enhance plant defence responses (Vinale *et al.,* 2008; Harman, 2004a).

In the early 1930s *Trichoderma* was introduced as possessing biocontrol ability (Weindling, 1934). *Trichoderma* is an opportunistic, avirulent plant symbiont fungus which acts as an antagonistic and parasitic fungus against many plant pathogenic fungi and offers protection from phytopathogenic plant diseases. It has been proven in numerous studies that *Trichoderma* spp. are effective biocontrol agents for managing plant disease, and currently commercial products of *Trichoderma* are available as biopesticides or soil amendments or as enhancers for plant growth (Papavizas, 1985; Chet 1987; Harman, 2004a; Vinale *et al.,* 2008). Weindling (1932) demonstrated the biocontrol activity of *Trichoderma lingnorum* (*viride*) on soil-borne fungal pathogen of *Rhizoctonia solani.* Later the mycoparsitic action of the same species of *Trichoderm*a on *Phytophthora, Pythium, Rhizopus and Sclerotium rolfsii* was observed (Well, 1988). Today fungal biocontrol observation and foundation are based on *Trichoderma* spp. and thus, this fungus has drawn much attention as a biocontrol model (Chet, 1993).

This review paper highlights information on the mechanisms of *Trichoderma* biocontrol activity and its role as a plant health enhancer, its commercial production and applications.

Biocontrol mechanisms of *Trichoderma* spp.: *Trichoderma* spp. are biocontrol agents effective against fungal phytopathogens. They can act indirectly, by competing for nutrients and space, modifying environmental conditions, or promoting plant growth and plant defensive mechanisms and antibiosis, or directly, by mechanisms such as mycoparasitism (Papavizas, 1985; Howell, 2003; Vinale *et al.,* 2008). The mechanisms can be described as:

i. Biocontrol by competition for nutrients and living space: *Trichoderma* spp., are rapidly growing fungi that have persistent conidia and a broad spectrum of substrate utilization. They are very efficient competitors for nutrition and living space (Hjeljord *et al.,* 2000). In addition, *Trichoderma* spp., are naturally resistant to many toxic compounds, including herbicides, fungicides, and phenolic compounds. Therefore, they can grow rapidly and impact pathogens by producing metabolic compounds that impede spore germination (fungistasis), kill the cells (antibiosis), or modify the rhizosphere, (e.g. by acidifying the soil so that the pathogens cannot grow) (Benitez *et al*., 2004). Starvation is the most common cause of death for microorganisms, so competition for limited nutrients is especially important in the biocontrol of phytopathogens. Iron uptake is essential for filamentous fungi and under iron starvation; fungi excrete low-molecular weight ferric-iron-specific chelators, termed siderophores. *Trichoderma* spp. produce highly efficient siderophores that chelate iron and stop the growth of other fungi (Benitez *et al*., 2004). Therefore, soil characteristics influence *Trichoderma* as a biocontrol agent.

ii. Biocontrol by mycoparasitism: The direct interaction between *Trichoderma* and pathogen is called mycoparasitism. As mentioned earlier, Weindling (1932) was the first to recognize that *Trichoderma* spp., is a biocontrol agent and at the same time he also noticed mycoparasitism of *T. lignorum* (*viride*) hypae coiling and killing *R. solani* (Wells, 1988). Mycoparasitism is a complex mechanism that generally involves the production of a cell wall lytic enzyme. Chet *et al.,* (1998) described that the mycoparasitism process involves four sequential steps: chemotropism and recognition; attachment and coiling; cell wall penetration; and digestion of host cell. *Trichoderma* strains detect other fungi, grow straight towards them, and sequentially produce hydrolytic cell-wall degrading enzymes. *Trichoderma* attach to the host, and coil hyphae around the host, form appressoria on the host surface, penetrate the host cell, and collapse the host hyphae (Steyaert *et al*., 2003).

The molecular level induction of mycoparasitism was first reported in 1994 (Carsolio *et al.,* 1999), based on the study of regulation of an endochitinase-encoding gene (ech42). Ech42 was expressed during the mycoparasitic interaction between *T. harzianum* and *Rhizoctonia solani*. Another study showed that in the P1 mutant strain of *T. atroviride*, the expression of exochitinase *nagI* or endochitinase *ech42* gene was needed to induce mycoparasitism in treatments containing purified colloidal chitin from the fungal cell walls (Vinale *et al.,* 2008). Production and regulation of lytic enzymes such as chitinases, glucanases, and proteases by *Trichoderma* spp. also play key roles in the mycoparasitism/biocontrol process (Mukherjee *et al.,* 2008).

Plant growth enhancement by *Trichoderma* spp.: *Trichoderma* spp. are not only control pathogens, they also enhance plant growth and root development (biofertilizer) and stimulate plant defence mechanisms (Harman, 2004a). Some *Trichoderma* strains have been shown to penetrate the epidermis and establish robust and long-lasting colonization of root surfaces (Harman, 2004a). *Trichoderma* spp. have been shown to improve growth of lettuce, tomato and pepper plants (Vinale *et al*., 2006). In a study of maize plants, several months after treatment with *Trichoderma harzianum* strain T-22, the plant roots were about twice as long when compared to untreated plants (Harman, 2004a). Cutler (1986, 1989) showed that the secondary metabolites produced by *Trichoderma koningii* (koniningin A) and *Trichoderma harzianum* (6-pentyl-alpha pryone) act as plant growth regulators. *Trichoderma* spp. also produced gluconic and citric acids, decreased the soil pH, and enhanced the solubilization of phosphates, micronutrients, and mineral components such as iron, magnesium, and manganese (Benitez *et al.,* 2004; Harman *et al.,* 2004b; Vinale *et al.,* 2008).

Induction of plant defence by *Trichoderma* spp.: It is well documented that *Trichoderma* spp. induce gene expression of proteins in plants such as chitinase, glucanase, and peroxidase against antagonistic microbes (Yedidia *et al.,* 2003; Hanson *et al.,* 2004; Harman, 2004b). It has also been shown that pre-treatment of plants with *Trichoderma* spp. increased plant resistance to pathogen attack (Harman, 2004a). *Trichoderma* spp. are opportunistic invaders, fast growers and large spore producers. They contain cell wall degrading enzymes (e.g., celluloses, chitinases, and glucanases) and produce antibiotics (Vinale *et al.,* 2008). Moreover, the presence of *Trichoderma* spp. stimulates the induction of the hypersensitive response, systemic acquired resistance (SAR), and induced systemic resistance (ISR) in plants (Benitez *et al*., 2004; Vinale *et al*., 2008). For example, tomato plants colonized by *T. hamatum* actively induced systemic changes in plant physiology and disease resistance (Alfano *et al*., 2007). In a study of cucumber plants, *T. asperellum* induced a systemic response of two defence genes encoding phenylalanine and hydroperoxidase lyase and systemic accumulation of phytoalexins against *Pseudomonas syringae* pv. *lachrymans* (Yedidia *et al*., 2003). In oil palm plants the defence gene of chitinase expression was increased in *T. harzianum* and *Ganoderma boninense* treated plants compared to *G. boninense* alone treated plants (Naher *et al*., 2011). Several studies also showed that *Trichoderma* spp. may indirectly contribute to systemic resistance (Ahmed *et al.,* 2000; Lo *et al.,* 2000). Harman *et al.,* (2004a) reported that the induction of localized or systemic resistance is an important component for plant disease control by *Trichoderma* spp. Thus, disease control by root-colonizing *Trichoderma* spp. involves a complex interaction between the host plant, the pathogen, the biocontrol agent and several environmental factors (Harman, 2004a; Hoitink, *et al.,* 2006; Alfano *et al.,* 2007).

Plant root colonization by *Trichoderma* spp.: Studies of the early invading fungi *Trichoderma* spp. showed that root colonization stimulated plant defence responses such as induction of peroxidases, chitinases, β-1, 3 glucanase, phenylalanine, and hydroperoxidase lyase; activated signaling of biosynthetic pathways; and caused accumulation of low-molecular weight phytoalexins (Howell *et al*., 2000; Yedidia *et al*., 2003; Harman *et al*., 2004a;). Yedidia *et al.,* (1999) observed the physical interaction between *T. harzianum* T-203 and a cucumber plant under the electron microscope and found that the fungus penetrated the root and grew in the epidermis and outer cortex, which stimulated increases of peroxidase and chitinase. Therefore, the interaction appears to be a symbiotic relationship in which *Trichoderma* lives in the nutritional niche provided by the plant, and the plant was protected from disease.

Production of antibiotics and secondary compounds by *Trichoderma* spp.: Secondary compounds and antibiotics produced by *Trichoderma* spp. play a vital role in antagonistic biocontrol activity (Vinale *et al.,* 2008; Ajitha & Lakshmidevi, 2010). Sivasithamparam and Ghisalberti (1998) reported that *Trichoderma* spp. produced several secondary compounds, including antibacterial and antifungal antibiotics such as polyketides, pyrones, and terpenes. Secondary metabolites, including antibiotics, that are not directly involved in natural growth, development, or reproduction and are chemically different from natural compounds may play important roles in the defence response, symbiosis, metal transport, differentiation, and stimulating or inhibiting spore formation and germination (Demain & Fang, 2000; Vinale *et al.,* 2008). Antibiotics are often associated with biocontrol activity. For example, the production of a pyrone-like antibiotic from *T. harzianum* exhibited biocontrol activity against *Ganumannomyces graminis* (Ghisalberti *et al.,* 1990). The peptide antibiotic paracelsin was the first secondary metabolite characterized in *Trichoderma* spp. (Bruckner & Graf, 1983; Bruckner *et al.,* 1984). Sivasithamparam & Ghisalberti (1991) suggested that secondary metabolites produced by *Trichoderma* spp., can be grouped into three categories: (i) volatile compounds (e.g., 6-pentyl-alpha-pyrone), (ii) water-soluble compounds (e.g., heptelidic acid), and (iii) peptaibol compounds, which are linear oligopeptides composed of 12-22 amino acids that are rich in alpha-aminoisobutyrate, N-acetylated at the N-terminus and have an amino alcohol group at the C-terminus.

Other uses of *Trichoderma* spp.: The discovery of cellulase production by *Trichoderma reesei*, which was isolated by Reese (1976), led to it becoming a very important cellulase or enzyme producer. The cellulase produced by *Trichoderma* spp. is used mainly for malting, baking, and grain alcohol production (Galante *et al.,* 1998b). The filamentous cellulolytic *Trichoderma* spp., produce a broad range of cellulases and hemicellulases. The main application of lignocellulosic biomass is the production of biofuels such as ethanol (Lin & Tanaka, 2006; Gimbert *et al.,* 2008), although it is also used in the pulp, paper and textile industries (Galante *et al.,* 1998a). *Trichoderma* spp. are also used for safe industrial enzyme production (Nevalaines *et al.,* 1994). Macerating enzymes are used to improve the brewing process for fruit juice production and as a feed additive for livestock and pet food (Schaster & Schmoll, 2010). *Trichoderma* also used for seed germination for example, a study showed that sunflower seeds germination significantly increased in *T. viride* or *T. resei* treated plants compared to control plants (Anis *et al*., 2012). The commercial use of several *Trichoderma* species for the protection and growth enhancement of a number of crops is ongoing (Lumsden *et al.,* 1993; Samuels, 1996). Currently, the commercially available formulations are RootShield^{TM}, BioTrek 22^{TM}, T-22G^{TM}, and T-22HB^{TM} (Bio-works, USA); Suprevisit^{TM} (Borregaard BioPlant, Denmark); Binab^{TM} (Bio-Innovation Sweden); Trichopel^{TM}, Trichojet^{TM}, Trichodowels^{TM}, and Trichoseal^{TM} (Agimm, New Zealand); Trieco^{TM} (Ecosense Labs, India), and Tricho-green (Mycology Lab, Malaysia). Not all of these products are registered as biocontrol agent, but they are marketed as plant growth promoters, plant strengtheners, or soil conditioners.

Conclusion

In 1930, Weindling first discovered the genus *Trichoderm* spp. as a biocontrol agent and since then numerous studies have demonstrated that *Trichoderma* is an effective bicontrol agent for phytopathogenic microorganisms (Harman, 1996). A biocontrol program is only established when the bicontrol agent can successfully manage the interaction between the host plant and pathogen. The ability of *Trichoderma* to successfully manage this interaction has been well established. The fungi have also been demonstrated to enhance the defence responses in plants. Thus, as an effective biocontrol agent the use of *Trichoderma* will certainly ensure sustainable disease management.

References

Ahmed, A.S., C.P. Sanchez and M.E. Candela. 2000. Evaluation of induction of systemic resistance in pepper plants (*Capsicum annum*) to *Phytopthora capsici* using *Trichoderma harzianum* and its relation with capsidiol accumulation. *Eur. J. Plant Pathol*., 106: 817-829.

Ajitha, P.S. and N. Lakshmedevi. 2010. Effect of volatile and von-volatile compounds from *Trichoderma* spp. against *Colletotrichum capsici* incitant of anthracnose on Bell peppers. *Nature and Sci*., 8: 265-296.

Alfano, G., L.M. Lewis Ivey, C. Cakir, J.I.B. Bos, S.A. Miller, VL. Madden Kamoun and J.A.H. Hoitink. 2007. Systemic modulation of gene S. expression in tomato by *Trichoderma hamatum* 382. *Biolog Control*, 97: 429-437.

Anis, M., M.J. Zaki and S. Dawar. 2012. Development of a Na-alginate based bioformulation and its use in the management of charcoal rot sunflower (*Helianthus annuus* L.). *Pak. J. Bot.,* 44: 1167-1170.

Atehnkeng, J., P.S. Ojiambo, T. Ikotum, R.A. Sikora, P.J. Cotty and R. Bandyopadhyay. 2008. Evaluation of atoxigenic isolates of *Aspergillus flavus* as potential biocontrol agents for aflatoxin in maize. *Food Additives & Contaminants: Part A*., 25: 1266-1273.

Benitez, T., A.M. Rincon, M.C. Limon and A.C. Codon. 2004. Biocontrol mechanism of *Trichoderma* strains. *International Microbiol*., 7: 249-260.

Bruckner, H. and H. Graf. 1983. Paracelsin, a peptide antibiotic containing alpha-aminoisobutyric acid, isolated from *Trichoderma reesei* Simmons Part A. *Experientia*., 139: 528-530.

Bruckner, H., H. Graf and M. Bokel. 1984. Paracelsin; characterization by NMR spectroscopy and circular dichroism, and hemolytic properties of a peptaibol antibiotic from the cellulolytically active mold Trichoderma reesei Part B. *Experientia*., 40: 1189-1197.

Carsolio, C., N. Benhamou, S. Haran, C. Cortes, A. Gutierrez, I. Chet and A. Herrera-Estrella. 1999. Role of the *Trichoderma harzianum* endochitinase gene, *ech42*, in mycoparasitism. *Appl. Environ. Microbioly*., 65: 929-935.

Chet, I. 1987. *Trichoderma*-application, mode of action, and potential as a biocontrol agent of soilborne plant pathogenic fungi. In: *Innovative approaches to plant disease control*. (Ed.) I. Chet, John Wiley and Sons, New York, pp.147-160.

Chet, I. 1993. Biological control of soil-borne plant pathogens with fungal antagonists in combination with soil treatments. In: *Biological control of soil borne plant pathogens*. (Ed.): D. Hornby. CABI publishers, UK, pp. 15.

Chet, I., G.E. Harman and R. Baker. 1981. *Trichoderma hamatum*: its hyphal interaction with *Rhizoctonia solani* and *Pythium* spp. *Microbial Biol*., 7: 29-38.

Chet, I., N. Benhamou and S. Harman. 1998. Mycoparasitism and lytic enzymes. In: *Trichoderma and Gliocladium* Vol. 2. (Eds.): G.E. Harman and C.P. Kubick. London, Taylor and Francis. pp. 153-172.

Cutler, H.G., D.S. Himmetsbach, R.F. Arrendale, P.D. Cole and R.H. Cox. 1989. Koninginin A: a novel plant regulator from *Trichoderma koningii*. *Agricul. Biolog. Chem*., 53: 2605-2611.

Cutler, H.G., R.H. Cox, F.G. Crumley and P.D. Cole. 1986. 6-Pentyl-apyrone from *Trichoderma harzianum*: Its plant growth inhibitory and antimicrobial properties. *Agricul Biolog Chem*., 50: 2943-2945.

Demain, A.L. and A. Fang. 2000. The natural functions of secondary metabolites. *Advances in Biochemi Engineer Biotechnol*., 69: 1-39.

Galante, Y.M., A. Conti and R. Monteverdi. 1998a. Application of *Trichoderma* enzymes in the textile industry. In: *Trichoderma and Gliocladium,* (Eds.): G.E. Harman and C.P. Kubicek. Vol. 2. Taylor and Francis, London, pp. 311-326.

Galante, Y.M., A. Conti and R. Monteverdi. 1998b. Application of *Trichoderma* enzymes in the food and food inductries. In: *Trichoderma and Gliocladium,* (Eds.): G.E. Harman and C.P. Kubicek. Vol. 2. Taylor and Francis, London, pp. 327-342.

Ghisalberti, E.L., M.J. Narbey, M.M. Dewan and K. Sivasithamparam. 1990. Variability among strains of *Trichoderma harzianum* in their ability to reduce take-all and to produce pyrones. *Plant and Soil*, 121: 287-291.

Gilardi, G, D.C. Manker, A. Garibaddi and M.L. Gullino. 2008. Efficacy of the biocontrol agents *Bacillus subtilis* and *Ampebmyces quisqualis* applied in combination with fungicides against powdery mildew of Zucchini. *J. Plant Diseases Protect*., 115: 208-213.

Gimbert, H.S., A. Margeor, A. Dolla, G. Jan, D. Molle, S. Lignon, H. Mathis, C.J. Sigoillot, F. Monot and M. Asther. 2008. Comparative secretoma analyses of two *Trichoderma reesei* RUT-C30 and CL847 hypersecretory strains. *Biotechnol for Biofuels*., 1: 18.

Hanson, L.E. and C.R. Howell. 2004. Elicitors of plant defence responses from biocontrol strains of *Trichoderma virens*. *Phytopathol*., 94: 171-176.

Harmam, G.E., R. Petzoldt, A. Comis and J. Chen. 2004b. Interactions between *Trichoderma harzianum* strain T22 and maize inbred line M017 and effects of these interactions on diseases by *Pythium ultimum* and *Collectotrichum graminicola*. *Phytopathol*., 94: 147-153.

Harman, G.E. 1996. Trichoderma for biocontrol of plant pathogens: From basic research to commercialization products. *www. entomology. cornell. edu. shelton/cornell*. Accession on October 2013.

Harman, G.E., C.R. Howell, A. Viterbo, I. Chet and M. Lorito. 2004a. *Trichoderma s*pecies-opportunistic, avirulent plant symbionts. *Nature Rev. Microbiol*., 2: 43-56.

Hjeljord, L.G., A. Stensvand and A. Tronsmo. 2000. Effect of temperature and nutrient stress on the capacity of commercial *Trichoderma* products to control *Botrytis cinerea* and *Mucor piriformis* in greenhouse strawberries. *Biolog Control*, 19: 149-160.

Hoitink, H.A.J., L.V. Madden and A.E. Dorrance. 2006. Systemic resistance induced by *Trichoderma* spp.: Interactions between the host, the pathogen, the biocontrol agent, and soil organic matter quality. *Phytopathol*., 96: 186-189.

Howell, C.R. 2003. Mechanisms employed by *Trichoderma* species in the biological control of plant diseases: the history and evolution of current concepts. *Plant Disease*, 87: 4-10.

Howell, C.R., L.E. Hanson, R.D. Stipanovic and L.S. Puckhaber. 2000. Induction of terpenoid synthesis in cotton roots and control of *Rhizoctonia solani* by seed treatment with *Trichoderma virens*. *Phytopathol.,* 90: 248-252.

Irina, D. and P.K. Christian. 2004. Species and biodiversity in *Trichoderma* and *Hypocera*: from aggregate species to species clusters. *J. of Zhejiang Uni. Sci*., 6: 100-112.

Koumoutsi, A., X.H. Chen, A. Henne, H. Liesegang, G. Hitzeroth, P. Franhe, J. Vater and R. Borris. 2004. Structural and functional characterization of gene clusters directing nonribosomal syntheis of bioactive cyclie lipopepetides in Bacillus amyloli quefaciens strain FZB42. *J. Bactriol*., 186: 1084-1096.

Lin, Y. and S. Tanaka. 2006. Ethanol fermentation from biomass resources: current state and prospect. *Appl. Microbiol. Biotechnol*., 69: 627-624.

Lo, C.T., T.F. Liao and T.C. Deng. 2000. Induction of systemic resistance of cucumber to cucumber green mosaic virus by the root-colonizing *Trichoderma* spp. *Phytopathol*., 90: S47.

Lumsden, R.D., J.A. Lewis and J.C. Lock. 1993. Managing soilborne plant pathogens with fungal antagonists. *In*: *In pest management: Biology based technologies*. (Eds.): R.D. Lumsden and J.L. Vaughn. American Chemical Society Publishers, Washington, pp. 196-203.

Mavrodi, D.V., O.V. Mavrodi, B.B. McSpaddenss-Gardener, B.B. Landa, D.M. Weller and L.S. Thomashow. 2002. Identification of differences in genome content among phID-positive Pseudomonas fluorescens strains by using PCR based substractive hybridization. *Appl Environ Microbiol*., 68: 5170-5776.

Mukherjee, K.P, C.S. Nautiyal and A.N. Mukhopadhyay. 2008. *Molecular mechanisms of plant and microbe coexistence*. Springer, Heidelberg.

Naher, L., U.K.Yusuf, S. Siddiquee, J. Ferdous and M.A. Rahman. 2012. Effect of media on growth and antagonistic activity of selected *Trichoderma* strains against *Ganoderma*. *Afr. J. Microbiol. Res.,* 6: 7449-7453.

Naher. L., C.L. Ho, S.G. Tan, U.K. Yusuf and F. Abdullah. 2011. Cloning transcripts encoding chitinases from *Elaeis guineensis* Jacq. and their expression profiles in response to fungal infections. *Physiol. Mol. Plant Pathol.,* 76: 96-103.

Nevalaines, H., P. Suominen and K. Taimisto. 1994. On the safety of *Trichoderma reesei*. *J. Biotech*., 37: 193-200.

Papavizas, G.C. 1985. *Trichodema* and *Gliocladium*: Biology, ecology and potential for biocontrol. *Ann. Rev. Phytopathol*., 22: 23-54.

Reese, E.T. 1976. History of the cellulose program at the U.S. Army Natick development center. *Biotechnol. Bioeng Sympos.,* 6: 9-20.

Samuels, G.J. 1996. *Trichoderma*: A review of biology and systematics of the genus. *Mycol. Res*., 100: 923-935.

Schaster, A. and M. Schmoll. 2010. Biology and Biotechnology of *Trichoderma*. *Appl. Microbiol. Biotechnol*., 87: 787-799.

Sivasithamparam, K. and E.L. Ghisalberti. 1998. Secondary metabolism in *Trichoderma* and *Gliocladium*. In: *Trichoderma and Gliocladium.* (Eds.): G.E. Harman and C.P. Kubicek. Taylor and Francis, London, pp. 139-192.

Steyaert, J.M, H.J. Ridgway, Y. Elad and A. Stewart. 2003. Genetic basis of mycoparasitism: A mechanism of biological control by species of *Trichoderma*. ***J. Crop. Horticul. Sci***., 31: 281-291.

Vinale, F., K. Sivasithamparam, L.E. Ghisalberti, R. Marra, L.S. Woo and M. Lorito. 2008. *Trichoderma*-plant-pathogen interactions. ***Soil. Biol. Biochem***., 40: 1-10.

Vinale, F., R. Marra, F. Scale, E.L. Ghisalberti, M. Lorito and K. Sivasithamparam. 2006. Major secondary metabolites produced by two commercial *Trichoderma* strains active different phytopathogens. *Letter in Applied Microbiol*., 43: 143-148.

Weindling, R. 1934. Studies on lethal principle effective in the parasitic action of *Trichoderma lignorum* on *Rhizoctinia solani* and other soil fungi. *Phytopathol*., 24: 1153-1179.

Wells, D.H. 1988. *Trichoderma* as a biocontrol agent. In: *Biocontrol and plant diseases*. (Eds.): K.G. Mukerji and K.L. Garg. CRC press, Florida, pp. 73.

Yaqub, F and S. Shahzad. 2008. Effect of seed pelleting with *Trichoderma* spp., and *Gliocladium virens* on growth and colonization of roots of sunflower and mugbean by *Sclerotium rolfsii*. ***Pak. J. Bot.,*** 40: 947-963.

Yedidia, I., M. Shoresh, Z. Kerem, N. Benhamou, Y. Kapulnik and I. Chet. 2003. Concomitant induction of systemic resistance to *Pseudomonas syringae* pv. lachrymans in cucumber by *Trichoderma asperellum* (T-203) and accumulation of phytoalexins. *Appl. Environ. Microbiol*., 69: 7343-7353.

Yedidia, I., N. Benhamou and I. Chet. 1999. Induction of defence responses in cucumber plants (*Cucumis sativus* L.) by the biocontrol agent *Trichoderma harzianum*. *Appl. Environ. Microbiol*., 65: 10061-1070.

(Received for publication 30 January 2013)