Advent of *Trichoderma* as a bio-control agent- A review

Anita Puyam

Department of Plant Pathology, Punjab Agricultural University, Ludhiana-141004 (Punjab), INDIA

E-mail: anitapau6243@gmail.com

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Abstract: *Trichoderma* spp are free living filamentous fungi. They are cosmopolitan and versatile in nature. They have the potential to produce several enzymes that can degrade the cell wall materials. Also, they release a number of fungal toxic substances that can inhibit the growth of the fungal pathogens. Many mechanisms have been described on how *Trichoderma* exert beneficial effects on plants as a bio-control agent. But due to its versatile nature, its potential cannot be explored to its full extent. And it is a developing science in the field of bio-control with its new discoveries adding to the usefulness of the fungi as a bio-control agent. Its development as a bio-control agent passes through many phases and each phase adding novel ideas that will help in the development of an efficient bio-agent which in turn will help in the crop improvement and disease management. The *in vitro* antagonistic activity of *Trichoderma viride* against phytopathogens (*Sclerotium rolfsii*, *Fusarium oxysporum* f.s.p. *ciceri*, *Fusarium oxysporum* f.s.p. *udum*) was studied and it was found to be potentially effective against *F. oxysporum* f.s.p. *ciceri* followed by *F. oxysporum* f.s.p. *udum* and *Sclerotium rolfsii*.

Keywords: Antibiosis, Bio-control agent, Mycoparasitism

INTRODUCTION

*Trichoderma* are free living fungi that are highly interactive in root, soil and foliar environment can parasitize other fungi (Harman et al., 2004). They are asexual filamentous fungi who share its anamorph with the genus *Hypocreae*. They are facultative anaerobes. They are versatile, highly rhizosphere competent, profuse root colonizers and cosmopolitan in nature. They are also opportunistic avirulent plant symbionts. They are known for prolific production of extracellular proteins and fungitoxic substances. They have been utilized extensively as model microorganisms to analyze and improve the understanding of the role that these antagonistic fungi have been playing in biological interactions, for instance with crop plants and phytopathogens (Marra et al., 2006). They have been gaining momentum as an important biocontrol agent (BCA) in control of plant diseases in recent times due to its eco-friendly nature, minimizing the use of chemicals, giving more cheaper and efficient disease control method. Intensive researches have been going on the complex mechanisms, among which, the most important being induction of host defense besides producing large amount of heterologous proteins, effecting plant metabolism and physiology. Because of the certain beneficial effects, *Trichoderma* has been gaining popularity as one of the most important bio-control agent. Their journey towards bio-control passes through many phases with new discoveries adding to the usefulness of this fungus (Lorito et al., 2010).

**Discovery of bio-control activity mediated by mycoparasitism:*** Trichoderma spp. is known for their ability to attack and control the plant pathogenic fungi. Mycoparasitism is one of the most important mechanisms that impart bio-control activity. The direct attack of one fungus on another or direct antagonism is known as mycoparasitism (Dix and Webster, 1995). This concept dates back to the work of Weindling (1932) who demonstrated the parasitism of *Rhizoctonia solani* hyphae by the hyphae of *Trichoderma virens* in controlling citrus seedling disease. Other researchers also showed the mycoparasitism of *Trichoderma* spp towards *Pythium ultimum* and *Sclerotium rolfsii* (Papavizas, 1985). Mycoparasitism is a sequential and complex process, involving three steps: chemotrophic growth and recognition; coiling and interaction of hyphae and secretion of specific lytic enzymes (Dix and Webster, 1995).

**Chemotrophic growth and recognition:** The chemical stimuli released by the target fungus are first sense by *Trichoderma* through their specific signaling mechanism. This mediates the growth of *Trichoderma* towards the target fungi. Apparently, *Trichoderma* releases low levels of extracellular exochitinase induced by the cell-wall oligomers of the target fungi and endochitinase gene is activated when interact with the target fungus. Ultimately, all these action induces the released of fungitoxic cell wall degrading enzymes.
Coiling and interaction of hyphae: As Trichoderma established contact, it starts coiling around and form appressoria for attachment mediated by carbohydrate (from the cell-wall of Trichoderma) and lectin (from the target fungus) complex (Howell, 2003).

Secretion of specific lytic enzymes: Several fungi-toxic CWDEs and peptaidol antibiotics are produced by the Trichoderma induced by the cell wall materials of the target fungus. This induces a cascade of physiological changes within the fungus. Due to action of these CWDEs holes are produced in the hyphae of target fungus near the site of appressoria. The antagonistic hyphae grow along the host hyphae and secrete different lytic enzymes such as glucanase, chitinase and pectinase that are involved in mycoparasitism. This ultimately leads to the degeneration of the target fungus (Howell, 2003).

Discovery of bio-control activity mediated by antibiosis: Weindling (1934) proposed “lethal principle”. This gave a shift to the concept of mycoparasitism. According to which, besides showing mycoparasitic activity, Trichoderma do produced certain lethal factors in the soil that inhibits the growth and the development of the pathogenic fungi. Later, in 1941, he showed that the factor behind the lethal principle is Gliotoxin secreted by Trichoderma virens. This led to the development of another mechanism behind the bio-control potential i.e. antibiosis. Trichoderma produces low molecular weight diffusible compounds or antibiotics possessing antifungal and antibacterial properties. These substances can penetrate the host cell, inhibit cell wall synthesis of the target fungus (Lorito et al., 1996). They also inhibit the growth, uptake of nutrients, sporulation, production of metabolites of the target fungus (Wilcox et al., 1992; Howell, 1998). Antibiosis is species specific i.e., different strains exhibit different antifungal activity (Howell et al., 1993). Howell and Stipanovic (1983) isolated gliovirin from T. virens that inhibited Pythium ultimum and Pythophthora.

However, Howell (1987) showed that mycoparasitism and antibiosis was not the major mechanisms behind the bio-control activity through his studies on cotton seedling disease incited by Rhizoctonia solani. He showed that the mutants deficient in mycoparasitism and antibiosis do showed their potential to control the disease. This again points to the involvement of other mechanisms that drives the bio-control activity.

Discovery of competition as a basis of bio-control: Trichoderma are good rhizosphere competent and efficient soil colonizers. This makes them an efficient competitor against other soil microflora. Competition as the basis of bio-control was first reported from the controlled of Chondrostereum purpureum, the silver leaf pathogen of plum trees due to competition exerted by the Trichoderma colonization (Corke and Hunter, 1979). They can proliferate in the soil and out beat the growth of other soil micro-flora. They can compete for nutrients, space, water or oxygen against other soil micro-flora. They have the capacity to mobilise and take up soil nutrients compare to other organisms. Also, they are resistant to a variety of toxins produced by other micro-organisms and other anti-microbial substances produced by the plants due to the presence of ATP-binding cassetts (ABC) transporters that reduce the toxic effects. This enhances the competitive ability against other micro-organisms. 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). Tijamos et al. (1992) demonstrated that T. harzianum T-35 controls Fusarium oxysporum by competing for both rhizosphere colonization and nutrients. Some Trichoderma spp produce highly efficient low molecular weight ferric iron specific chelators termed as siderophores to mobilize or chelate environmental iron and stop the growth of other fungi (Chet and Inbar, 1994). Chet et al. (1997) reported that starvation of pathogen due to limiting nutrients results in its death. But, cruciality in viewing competition as primary role in bio-control is that T. koningii, which is an excellent root colonizer when treated against R. solani, there is little or no bio-control (Howell, 2003). These findings again gave an enigma to the Trichoderma researchers on how Trichoderma interact with the plant, the target pathogen and its environment.

Discovery of the ability to improve plant resistance to diseases: Strains of Trichoderma added to the rhizosphere protect plants against pathogens 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). The concept of improving plant resistance by Trichoderma is the most accepted phenomena by the researchers. The first demonstration of induced resistance by Trichoderma was shown by Bigirimana et al. (1997) through his studies on the foliage disease of beans caused by Colletotrichum lindemuthianum and Botrytis cinerea. Yedidia et al. (1999) supported the concept of induce resistance through their studies on cucumber seedling disease by T. harzianum. A model system for Trichoderma induced resistance may be attributed to the potential functioning of MAMP triggered immunity in the host plant. Trichoderma strains produce a variety of (MAMPs) such as hydrophobins, expaslin-like protein, secondary metabolites and enzymes. They elicit the production of defense metabolites and enzymes such as the enzymes Phenyl Alanine ammonia Lyase (PAL) and Chalcon Synthase (CHS), involved in the biosynthesis of phytoalexins.
(HR response), chitinases and glucanases, which are important pathogenesis related proteins (SAR response) and enzymes involved in the response to oxidative stress (Mohiddin et al., 2010). Trichoderma produces a number of metabolites that may act as elicitors of plant resistance 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 (Elad et al., 2001) and also to hostile abiotic conditions (Harman et al., 2004).

Under abiotic stressful conditions Trichoderma can improve plant growth by lowering deleterious elevated ethylene levels accompanied by an elevated antioxidative capacity (Viterbo et al., 2001) and also by reducing over expression of stress genes (Harman, 2000). Improve plant tolerance against salinity has been reported in Trichoderma treated seed. Reduced ascorbic acid has been reported in Trichoderma treated plants and this has been attributed to the expression of catalase (cat) and Mn/Cu-dependent superoxide dismutate (SOD) genes (Viterbo et al., 2001).

**Discovery of the ability to promote plant growth:**

Trichoderma are reported to increase the fertility of soils and significantly improved the plant growth beyond disease control (Harman, 2000). This plant growth promotion may be due to production of plant hormones or increased uptake of nutrients by the plant (Chet et al., 1993). They promote root growth, nutrient availability and uptake for the plant, and released plant growth regulators (Benitez et al., 2004). All these are energy requiring processes and thus, stimulate plant respiration and enhance photosynthesis and photosynthetic efficiency. Root colonization by Trichoderma strains frequently enhances root growth, root area, cumulative root length, significant increases in dry weight, shoot length and leaf area (Yedidia et al., 2003) and also promote development, crop productivity, resistance to abiotic stresses and the uptake and use of nutrients (Arora et al., 1992). They stimulate plant growth directly by making available these nutrients to the plants and indirectly by inducing a competitive environment for nutrients against other micro-floras. Trichoderma colonization in the roots and soil helps in solubilization of minerals such as rock phosphate, Fe, Mn, Cu and Zn. Trichoderma also enhances N-used efficiency (Harman, 2000). Seed treatment with Trichoderma spores have shown significant increase in yield (Chet et al., 1997).

**Trichoderma as a bio-control agent- No more a myth**

**Disease control:** Trichoderma is a promising biocontrol agent and extensively used against the soil borne diseases. It has been used against pathogenic fungi such as *Rhizoctonia, Fusarium* and *Colletotrichum* etc. A number of diseases are reported to be controlled by Trichoderma species (Table 1). It is effective against both foliar and soil borne pathogens (Ha, 2010). The *in vitro* antagonistic activity of *Trichoderma viride* against phytopathogens (*Sclerotium rolfsii, Fusarium oxysporum* f.sp. *ciceri, Fusarium oxysporum* f.sp. *udum*) was studied and it was found to be maximum against *F. oxysporum* f.sp. *ciceri* (62.85% mycelial growth inhibition) followed by *F. oxysporum* f.sp. *udum* (59.37% mycelial growth inhibition) and *S. rolfsii* (58.03% mycelial growth inhibition) (Puyam et al., 2013). Induced systemic resistance by *Trichoderma* is also one of the important mechanisms of resistance against the pathogens. This has been reported for cucumber, strawberry, bean and tomato against *Botrytis cinerea* and powdery mildew in cucumber (Levy et al., 2015). At present, the induced systemic resistance mechanism by Trichoderma has been gaining importance, but still it is a budding science. In depth study is required to construct efficient biocontrol Trichoderma strains, and produce good effect agent of Trichoderma. It is significant for controlling plant diseases.

**Plant growth promoter:** The initiative to prove the researched findings and promotion of *Trichoderma* as

| Crop         | Disease                  | Pathogen                  | References                        |
|--------------|--------------------------|---------------------------|-----------------------------------|
| Rice         | Sheath blight            | *Rhizoctonia solani*      | Biswas and Datta (2013)           |
| Bakanae      | Fusarium moniliforme     |                           | Ng et al., 2015                   |
| Wheat        | Loose smut               | *Ustilago segetum*        | Parveen and Kumar (2004)          |
| Chickpea     | Wilt, wilt complex       | *Fusarium, Sclerotium, Rhizoctonia* | Gupta et al., 2005              |
|              | Root rot                 | *Rhizoctonia solani*      | Gupta et al., 2005                |
| Pigeon pea   | Wilt                     | *Fusarium udum*           | Chaudhary and Prajapati (2004)    |
| Apple        | Ring rot                 | *Botryosphaeria beregeriana f.sp. piricola* | Kexiang et al., 2002         |
| Guava        | White root rot           | *Dematophora necatrix*    | Tapwal et al., 2005               |
| Chilli       | Die back                 | *Lasiodiplodia theobromae* | Yadav and Majumdar (2005)         |
| Tomato       | Fusarium wilt            | *Fusarium oxysporum f.sp. lycopersici* | Komy et al., 2015              |
|              | Crown stem and root rot diseases | *Rhizoctonia solani, Sclerotinia spp. and Pythium* | Marzano et al., 2013          |
|              | Collar rot of tomato     | *Sclerotium rolfsii*      | Amin et al., 2010                 |
| Potato       | Black Scurf              | *Rhizoctonia solani*      | Gogoi et al., 2007                |
|              | Bacterial brown rot      | *Fusarium and Phoma spp.* | Gogoi et al., 2007                |
| Beans        | web blight of beans      | *Sclerotinia sclerotiorum* | Amin et al., 2010                 |

**Table 1.** Various diseases controlled by *Trichoderma* spp.
Table 2. Commercial formulation of Trichoderma used abroad.

| Commercial Product | Biocontrol Organism(s) | Formulation and Application | Pathogens controlled | Manufacturer Country |
|--------------------|------------------------|-----------------------------|----------------------|----------------------|
| Binab T            | *T. harzianum*, *T. polysporum* | Pellets, wettable powder or granules; spray, drench, mixed in soil | Wood rots causing internal decay, or originating from pruning wounds; *Didymella, Chondrostereum, Heterobasidion, Botrytis, Verticillium, Pythium, Fusarium, Phytophthora, Rhizoctonia* | BINAB Bio-Innovation AB, Sweden (http://www.algonet.se) |
| Plant Shield       | *T. harzianum*          | Granules, wettable powder; soil drench, foliar spray Powder | *Pythium, Fusarium, Rhizoctonia, Cylindrocladium, Thielaviopsis*; damping-off diseases | BioWorks, Inc., USA (http://www.bioworksbiocontrol.com) |
| Antagon            | *Trichoderma spp.*     |                             |                      | DeCeusterMeststoffenN.V. (DCM), Belgium (http://www.agroBiologicals.com) |
| Promot PlusWP      | *Trichoderma spp.*     |                             | Wilt, Root rot diseases | Tan Quy, Vietnam (Ha, 2010) |
| Promot PlusDD      | *Trichoderma koningii* |                             |                      |                      |
|                    | *Trichoderma harzianum* |                             |                      |                      |

A commercial product was done by The Cornell University and BioWorks, Inc., Geneva, NY. They have conducted thousands of assays on crops ranging from ferns to beans to corns and to ornamental flowering plants mainly based on the particular *Trichoderma harzianum* strain-22 (Harman, 2000). And from the experiment, they have found many fascinating results. It was observed that the species colonized all parts of root systems and can displace other micro-flora thereby changing the root micro-floral composition. Also enhances fertilizer used efficiency by the plants and provides long-term protection against diseases from single application at the beginning of the season and increases biomass production. The application of *Trichoderma* enhances root development in field crops induced by *Trichoderma harzianum* strain T-22 in an experiment performed on sweet corn and soybean and enhanced deep rooting in field corn. Their ability to cause the production of more robust and deep roots is likely to be quite profound. These deep roots cause crops, such as corn and ornamental plants, such as pointsettia, to become more resistant to drought. In one of the report, the treatment of corn whose roots are colonized by *Trichoderma* strain T-22 require about 40% less nitrogen fertilizer than in the absence of the organism in the corn root. Another in field report by the Management Collaborative Research Support Program (IPM CRSP), managed by Virginia Tech, *Trichoderma* has been used to combat a range of fungal diseases that affect crops from India to Honduras (www.oired.vt.edu/ipmcrsp/). World wide it has been used to manage a number of diseases. Their survey showed that in Bangladesh and Indonesia it is used against soil-borne diseases of vegetable crops, citrus, oil palm, langsat, durian, vanilla and cacao. In India and Philippines, it is used as sprayed on seedlings as a treatment for vegetable crops. In Indonesia, it is used against clubroot of broccoli. In India, it is used against pythium rot and fusarium wilt and on diseases of horticultural crops. And in the Philippines, it is used to combat anthracnose bulb rot, damping off, and pink rot diseases of onion. And in Honduras, it is being tested on watermelon for the control of fusarium wilt. *Trichoderma*, being a growth promoting agent also helps in increasing yield of crops which has been demonstrated by application of *T. harzianum* (Th3) in irrigated and dry areas of Kota and Jaipur districts of Rajasthan, India (Sharma et al., 2012). Under the project entitled “On Farm Demonstration and Commercial Production of *Trichoderma* as biopesticide and Growth Promoter”, they evaluated the rhizospheric competence Index along with its growth promotion effect on tillers rootlets, weight of grains and grain yield by using it at three stages of crop viz., seed, flowering and pre-harvesting. They reported a significant increase in yield of wheat from 36.25 to 46.73Q/ha (29% in Jaipur) and from 36.88 to 50.12Q/ha (36% in Kota) after continuous application for three years (2008-2011).The total income and the benefit cost ratio of farmers increased both at Jaipur (Rs 56242/ha, 1:1.8) and Kota (Rs 60332/ha, 1:1.9). Besides, food crops, four *T. atroviride* isolates have been used as bio-control for soil-borne pathogens of pasture species and also for growth promotion (Kandula et al., 2015).

From all these available facts and data, we can now conclude that adoption of *Trichoderma* as a bio-control agent is no longer a myth but a reality that needs to be promoted for the real world success (Harman, 2000).

Drought tolerance: *Trichoderma* has a symbiotic relationship with the host plant. The proteome and transcriptome of plants change as a consequence of the interaction of *Trichoderma* metabolites or plant coloni-
The three mechanisms employed by the fungi in enhancing plant growth under drought stress are secretion of phytohormonal analogues, alleviation of damage by reactive oxygen species (ROS) and water-use efficiency. Globally, studies clearly reveal that, the use of Trichoderma spp. under drought stress can effectively augment plant growth (Chepsergon et al., 2014).

**Mass production:** The development of a successful biological control agent depends on the mass culturing and delivery system of the bio-control agent. The most commonly used solid substrate for mass culturing of *Trichoderma* spp are sorghum grain (Upadhyay and Mukhopadhyay, 1986), wheat bran-saw dust (Jogani et al., 2013) and other agro-based waste products. Wastage of potato peel, brinjal, banana, papaya, guava, spinach, sugarcane, used tea leaves and pea husk medium of solid and liquid was reported to be a substrate for the multiplication of *Trichoderma harzianum* and *Trichoderma viride* isolates. The growth media used for production of *Trichoderma* in liquid state fermentation includes molasses and brewer’s yeast (Sankar and Jeyarajan, 1996) and Jaggery-soy medium (Prasad and John, 2014). However, sporulation of *Trichoderma* is comparatively high on solid substrates to that of the liquid media.

**Formulation:** It protects the a.i. (conidia, spores, mycelial germlings) against the adverse environmental conditions like extreme pH, high/low humidity etc. So, standard formulation is needed if one expects the strain to come up to their expectations. A final formulation must have a minimum shelf-life of two years at room temperature, must be easy to handle and stable over a range of 5 to 35°C. Characteristics of an ideal formulation are as follows:

- **Control of plant diseases.**
- **Should dissolve well in water.**
- **Carriers must be cheap and readily available**
- **Formulation development.**
- **Should be compatible with other agrochemicals** (Kumar et al., 2014).

Developing a safe, cost effective and easy to handle formulation that will retain the viability of the micro-organism are important pre-requisite for developing an efficient and consistent bio-control agent. Formulation is the blending of active ingredients such as fungal spores with inert carrier as fungal spores such as diluents and surfactants in order to improve the physical characteristics (Kumar, 2013). The potential *Trichoderma* isolates are formulated using different organic and inorganic carriers either through solid or liquid fermentation technologies (Kumar et al., 2014).

**Trichoderma formulations are of two types:**

**Solid formulations:** These types utilize adhesive substances, inoculation backup, like the arabic gum or carboxymethylcellulose, also clays and compost. They are especially recommended for the inoculation of seeds. They are found as wet dust, dry-dust, granules and capsules. Formulation developed through grounded air dried mats and mixed with the commercially available carrier, contain $10^8$-$10^9$ propagules per g (Kumar, 2013).

**Liquid formulations:** They are limited in production. They are applied by means of crushing to the aerial part of the plant, or directly to the substrate through the system of irrigation. Tables 2 and 3 describe some commercial formulation of *Trichoderma* that are used worldwide and in India.

**Delivery and application system:** Delivery and application system also affects the performance of the *Trichoderma* strains. If proper formulations are not applied in a standardized manner then, the efficient strain may fail to show its full potential. So, standardized delivery and application system is important to

| Commercial product | Bio-control organism | Pathogens controlled | Manufacturer/Supplier, Country |
|--------------------|----------------------|----------------------|--------------------------------|
| Antagon TV         | *T. viride*          | *Macrophomina* spp   | Green Tech. Agroproducts, Rajaji Road Coimbatore |
| Trichostar         | *T. harzianum*       | *Macrophomina* spp   | Green Tech. Agroproducts, Rajaji Road Coimbatore |
| Gliostar           | *T. virens*          | *Fusarium, Rhizoctonia, Sclerotium, Pythium* | GBPiat, Pantnagar |
| Monitor            | *Trichoderma* spp    |                      | Agricultural and Biotec Pvt. Ltd. Gujarat Department of Plant Pathology, MPKV, Rahuri |
| Bioderma           | *T. viride/T. harzianum* |                      | Biotech International Ltd. India |
| Bio Fit            | *T. viride*          | *Pythium, Rhizoctonia, Fusarium, Sclerotium, other root rots for Botrytis in combination with chemicals* | Ajay Biotech (India) Ltd. India (http://www.ajaybio.com) |
| Ecofit             | *T. viride*          |                      | Hoechst Schering Agro Evo Ltd, India |
| Trichoguard        | *T. viride*          |                      | Anu Biotech Int. Ltd. Faridabad |
| Biocon             | *T. viride*          |                      | Tocklai Experimental Station Tea Research Association, Jorhat (Assam), India |

Table 3. Common commercial *Trichoderma* formulation used in India.
fully explored the efficiency of the Trichoderma strain. Trichoderma formulations can be applied either through seed bio-priming, seed treatment, seedling dip, foliar spray and soil application. Application of Trichoderma formulations with strain mixtures perform better than individual strains for the management of pest and diseases of crop plants, in addition to plant growth promotion (Kumar et al., 2014).

Some of the suggested delivery and application system (Singh, 2010) are as follows:

**Seed treatment:** Seed treatment with talc based and wheat bran based (WBB) formulations @ 4 g/kg of seed have been recommended (Jogani and John, 2014). The treated propagules of Trichoderma germinates on seed surface. And when they are sown in the soil, the germinating propagules colonize the seedlings roots and rhizosphere (Tewari, 1996). Seed coating with Trichoderma is one of the less cumbersome and efficient delivery systems of the antagonist Trichoderma for the management of seed/soil-borne diseases. Seed is coated with dry powder/dusts of Trichoderma just before sowing. For commercial purpose, dry powder of antagonist is used at 3 to 10 g per kg seed based on seed size (Mukhopadhyay et al., 1992). Seed treatment with Trichoderma are found to be effective against the diseases like sheath blight of rice (Das and Hazarika, 2000; Sriram et al., 2000) besides increasing the yield of the crop, loose smut of wheat (Singh and Maheshwari, 2001), Pythium spp. and R. solani (Mukherjee and Mukhopadhyay, 1995) and oilseed-borne fungi like Alternaria alternata, Curvularia lunata, Aspergillus flavus, Fusarium oxysporum, F. moniliforme, Rhizopus nigricans, Penicillium chrysogenum and Penicillium notatum which affects oil seed crops like soybean, sesame and sunflower (Jat and Agalave, 2013).

**Seed biopriming:** Treating of seeds with biocontrol agents and then incubating under warm and moist conditions until just prior to emergence of radical is referred to as bio-priming. In bioprimed seeds, the germinating conidia of Trichoderma form a layer around the seeds. Such seeds tolerate adverse conditions of the soil better than the non-primed seeds. This technique has potential advantages over simple coating of seeds as it results in rapid and uniform seedling emergence and also reduces the amount of biocontrol agents that is applied to the seed (Kumar et al., 2014).

**Seedling root dip:** It is mostly practiced in case of transplanted rice and vegetable crops. The cuttings or seedlings can be treated with the spore suspension prepared by mixing 10g of Trichoderma powder with 100g of well rotten FYM per liter of water and dip for 10 minutes before planting. Root dipping in spore suspension before transplantation reduces sheath blight disease of rice (Vasudevan et al., 2002). There are also reports on enhancement of seedling growth in rice, capsicum, chilli, tomato and brinjal (Singh and Zaidi, 2002).

**Soil treatment:** It is an ideal treatment for nursery and green house. Delivering of Trichoderma spp. to soil will increase the population dynamics of augmented fungal antagonists and thereby would suppress the establishment of pathogenic microbes onto the infection court (Kumar et al., 2014). Soil application of T. viride either alone and in combination with other treatments significantly reduced red rot caused by Colletotrichum falcatum (Reddy et al., 2009), seedling blight, stem rot, color rot and root rot disease of Jute (Srivastava et al., 2010) and against F. oxysporum, F. solani, Fusarium moniliforme, Alternaria alternata, Botrytis theobromae and Rhizoctonia solani and in seedling establishment of Dalbergia sissoo Roxb (Mustafa et al., 2009). Combination of Trichoderma treatment with green manuring crops yield good results against the soil borne pathogens besides improving the soil health. For soil treatment, 5 Kg of Trichoderma powder per hectar is mixed after turning of sun hemp or dhaincha into the soil for green manuring or 1 Kg of Trichoderma formulation in 100 kg of FYM. The prepared environment is then kept covered with the polythene for seven days and then water is sprinkled intermittently, followed by regular turning of the mixture in every 3-4 days interval and then broadcast in the field (Singh, 2010).

**Combination with other bio-control agents:** Recently, combination of plant growth promoting Rhizobacteria, Pseudomonas fluorescens and Trichoderma harzianum have been reported to have greater disease suppression against Rhizoctonia solani, Sclerotium rolfsii causing stem and root rot disease of soybean (Kumar, 2013). Another example is the application of three microbial strains, viz, T. asperellum T42, P. fluorescens OKC and Rhizobium sp. RH4, individually and in combination with bioprimed seeds of chickpea and rajma in pots and fields (Yadav et al., 2013). They reported that higher germination percentage and better plant growth in both the crops compared to non-bioprimed control plants. It was also observed that the combined application of the microbes enhanced seed germination and plant growth better than their individual application. Among the combinations, all combinations comprising Trichoderma showed better results compared to the others and the triple microbial combination demonstrated best results in terms of seed germination and seedling growth in both chickpea and rajma. Seed treatment with T. harzianum, A. sativum and A. indica on par with the foliar spray of mancozeb showed results against Alternaria blight disease mustard caused by A. brassicaceae and A. brassicicola and increasing the yield (Jagana et al., 2013). Is Trichoderma bio-control agent a better alternative to chemical fungicides?

**Disease control:** Regarding disease control, it is quite comparable with the chemicals as denoted by the previous mentioned data and findings but its application to bacterial diseases is limited. If proper formulations
are developed, then it will also serve as a good biocontrol agent for the bacterial diseases too (Leelavathi et al., 2014). Trichoderma show strong antagonistic activity against Colletotrichum causing red rot of sugarcane, Alternaria spp. causing Alternaria leaf spot disease, Paracercospora spp. causing leaf spot disease of banana, Fusarium spp. causing wilt disease in pigeon pea (Kushwaha and Verma, 2014).

**Increasing pest resistance:** Chemicals are specific in their mode of action. Application of a particular chemical against a particular pathogen over a period of time will induce resistance in the pathogen against the chemicals. So, those which were once effective become ineffective after a period of time. But it is circumvent incase of Trichoderma application as it induces resistance against the diseases in plants and provide long-term protection (Yedidia et al., 2000).

**Sensitiveness towards environment and health:** The sensitivity of the purchasers and the growers are also different. Some prefer to use chemicals especially farmers but the green house owners, park owners, household owners prefer to use bio-agents for management of diseases. Moreover, awareness of the environment also increases among the people. The used of specific micro-organisms that interfere with plant pathogens and pest, is a nature friendly, ecological approach to overcome the problems caused by standard chemical methods of plant protection (Harman et al., 2004).

**Long period of efficacy:** A single application of Trichoderma will provide long term efficacy as it induces resistance against diseases in plants. They have the ability to proliferate in the soil for a long period of time along with the plant roots through symbiotic association. But, the period of efficacy is limited and effects last for more than a few weeks (Harman et al., 2010).

**Other effects:** It refers to the tolerance induced by Trichoderma against the abiotic stresses and also the increased efficiency in the use of nitrogen fertilizer (Shelton, 2014). Trichoderma strains play an important role in the bioremediation of soil that are contaminated with pesticides and herbicides, having the ability to degrade a wide range of insecticides (organochlorines, organophosphates and carbonates) (Jorge, 2014).

**Limitations**

**Less effective when applied to diseases already existed:** The establishment of Trichoderma in the soil and coming into action takes time i.e., its mode of action slow as compare to chemicals which is quick in action. So, if a disease is build up and the disease pressure is quite high then, application of Trichoderma is seem to be less effective and here calls for the chemicals for quick action.

**Less obvious visual enhancement of plant improvement:** The action of Trichoderma is quite slow and so, its results are less obvious to the growers as compare to the chemicals.

**Action depends on the environment:** We have learned that Trichoderma provides tolerance to the abiotic stresses and increases fertilizer used efficiencies. But it fails to show these results if they are grown under near optimal conditions and if no stress occurs in the environment.

**Is it safe to regard Trichoderma completely as benign?**

Certain harmful effects of Trichoderma have been reported in human and even some are mushroom pathogens. T. longibrachiatum has been reported as an opportunistic human pathogen. Eight other species (i.e., T. atroviride, T. citrinoviride, T. harzianum, T. koningii, T. orientale, T. pseudokoningii, T. reesei, and T. viride) have also been reported occasionally (Hatvani et al., 2013) as human pathogens. Some of the harmful effects are as follows:

**Mushroom pathogens:** Some species of Trichoderma are reported to cause green mold disease of mushrooms thereby affecting commercial production of mushrooms. They are T. aggressivum, T. pleurotum and T. pleurotiscola (Samuels et al., 2002).

**Trichothecene antibiotics:** T. viride and T. harzianum produce antibiotics trichodermin/ harzianum A, which are reported to be trichothecene in action (Degenkolb et al., 2008).

**Antibiotic harmful to human cell:** Gliotoxin produced by Trichoderma virens strain Q is also produced by Aspergillus fumigans in maize silage as mycotoxins and are reported to be immunosuppressive in human. So, analysis and identification of the effects of this antibiotic released by Trichoderma is required (Richard et al., 2008). Peptaibols produces a rare amino acid –α-aminoisobutyric acid which can lyse red blood cells (Wiest et al., 2002).

**Hypersensitive reactions:** Trichoderma infections in humans have been related with several risk factors, being associated mostly with peritoneal dialysis, organ transplantation, and hematologic disorders (Hatvani et al., 2013). On the other hand, data on animal infections by Trichoderma spp. are very limited. They are strong sensitizers and can caused hypersensitive reactions to human and animal tissues. The USA Govt, occupational safety and health Administration (OSHA) classifies Trichoderma as allergic and irritant and caused of hypersensitive pneumonitis and dermatitis (Caballero et al., 2007 and Beezhold et al., 2008).

Development and commercialization of Trichoderma formulation for field application should not ignore these harmful effects of Trichoderma. Before releasing for farmers used, the product must be tested and should assure that they are not harmful to the environment or human and animal health.

**Future prospects**

New strains and species are to be genome sequenced and researches are to be done on their metabolomes and expressome. Targeted genetic improvement and the use of their
genes in crop improvement programmes. Determination of compatibility of effective *Trichoderma* spp with other beneficial fungi or bacteria or with some bio-active compounds will open more scopes and increases the effectiveness of the role of biocontrol in crop-improvement.

*Trichoderma* and plant interaction is the another side of the mirror that needs to be explored, given extensive effects on the plant physiology with many more developing molecular mechanisms and this will not only prove *Trichoderma* as an effective bio-control agent but also as a plant health manager too.

Development of quick, suitable and inexpensive methods to monitor farmers. Formulations those are easy to adopt by the common action as a biocidal agent.

About the effects of more enzymes and metabolites of *Trichoderma* species - Opportunistic, Avirulent Plant Symbionts.

**Conclusion**

With the increasing threat to the environment and to the food security, adoption of *Trichoderma* spp. as a BCA has been gaining importance which will provide food security in one hand and eco-friendly on the other. To meet this, research on the unexplored part of the world needs to be explored to find a suitable and efficient *Trichoderma* strains that will best serve as a biocontrol agent. In this field many more researches need to be done. Our knowledge till now is still under infancy. In depth study and analysis of the findings about this organism is far more to be done. The novel findings will, then, serve as a milestone for the development and adoption of *Trichoderma* as a BCA which in turn help in the improvement of crop production and disease management.

**REFERENCES**

Amin, F., Razdan, V.K., Mohiddin, F.A., Bhat, K.A. and Banday, S. (2010). Potential of *Trichoderma* species as Bio-control agents of Soil borne fungal propagules. *Journal of Phyology*, 2(10): 38–41.

Arora, D.K., Elander, R.P. and Mukerji, K.G. (1992). Handbook of Applied Mycology. Marcel Dekker, New York 4.

Beezhold, D.H., Green, B.J., Blachere, F.M., Schmcheil, D., Weissman, D.N., Velickoff, D., Hogan, M.B. and Wilson, N.W. (2008). Prevalence of Allergic Sensitization to Indoor Fungi in West Virginia. *Allergy and Asthma Protection*, 29: 29–34.

Benitez, M.T., Ana, M., Rincón, M., Carmen, L.A. and Codón, C. (2004). Biocontrol mechanisms of *Trichoderma* strains. *International Journal of Microbiology*, 7: 249–260.

Bigirimana, J., De Meyer, G., Poppe, J., Elad, Y. and Hofte, M. (1997). Induction of systemic resistance on bean (*Phaseolus vulgaris*) by *Trichoderma harzianum*. Med Fac Landbouww University Gent, 62: 1001–1007.

Biswas, S. and Datta, M. (2013). Evaluation of Biological Control Agents against Sheath Blight of Rice in Tripura. *Indian Phytopathology*, 66 (1): 77-80.

Bunker, R.N. and Mathur, K. (2001). Antagonism of local biocontrol agents to *Rhizoctonia solani* inciting dry root rot of chilli. *Journal of Mycology and Plant Pathology*, 31: 50-53.

Caballero, M.L., Gómez, M., González-Muñoz, M., Reinoso, L., Rodríguez-Pérez, R., Alday, E.A. and Moneo, I. (2007). Occupational Sensitization to Fungal Enzymes used in Animal Feed Industry. *International Archives of Allergy Immunology*, 144: 231-239.

Chaudhary, R.G. and Prajapati, R.K. (2004). Comparative Efficacy of Fungal Bio-agents against *Fusarium udum*. *Annals of Plant Protection Science*, 12: 75-79.

Chespergon, J., Mwamburi, L. and Kassim, M.K. (2014). Mechanism of Drought Tolerance in Plants Using *Trichoderma spp.* *International Journal of Science and Research*, 3 (11): 1592-1595.

Chet, I. (1993). Biotechnology in Plant Disease Control. Wiley-Liss, New York. 373 pp.

Chet, I. and Inbar, J. (1994). Biological control of fungal pathogens. *Applied Biochemistry and Biotechnology*, 48:37-43.

Chet, I., Inbar, J. and Hadar, I. (1997). Fungal Antagonists and Mycoparasites. The Mycota IV: Environment and Microbe Relationship, Springer-Verlag, Berlin, pp 165-184.

Corke, A.T.K. and Hunter, T. (1979). Biocontrol of *Neectria galligena* infections of pruning wounds on apple shoots. *Journal of Horticultural Science*, 54: 47.

Das, B.C. and Hazarika, D.K. (2000). Biological Management of Sheath Blight of Rice. *Indian Phytopathology*, 53: 433-435.

Degenkolb, T., Dieckmann, R., Nielsen, K.F., Gräfenhan, T., Zafari, D., Chaverri, P., Ismaiel, A., Brückner, H., Döhren, H.V., Thane, U., Petrin, O. and Samuels, G.J. (2008). The *Trichoderma brevicompactum* clade: A New Lineage with New species, New Peptaiobiotics, and Mycoxins. *Mycological Progress*, 7:177-219.

Dix N.J. and Webster, J. (1995). Fungal Ecology (1st Edn.). Chapman and Hall, London.

Elad, Y., Freeman, S. and Monte, E. (2000). Biocontrol Agents: Mode of Action and Interaction with other Means of Control. IOBC, Sevilla, Espana, 24 pp.

Gogoi, R., Saikia, M., Helim, R. and Ullah, Z. (2007). Management of Potato Diseases using *Trichoderma viride* formulations. *Journal of Mycology and Plant Pathology*, 37: 227-230.

Gupta, S.B., Thakur, K.S., Singh, A., Tamrakar, D.K. and Thakur, M.P. (2005). Efficacy of *Trichoderma viride* and *Rhizobium* against Wilt complex of Chickpea in field. *Journal of Mycology and Plant Pathology*, 35: 89-91.

Ha, T.N. (2010). Using Trichoderma species for biological Control of Plant Pathogens in Vietnam. *Journal of the International Society for Southeast Asian Agricultural Sciences*, 16 (1): 17-21.

Harman, G.E. (2000). Myths and Dogmas of Biocontrol-Changes in perceptions derived from research on *Trichoderma harzianum* T-22. *Plant Disease*, 84: 377–393.

Harman, G.E., Howell, C.R., Viterbo, A., Chet, I. and Lorito, M. (2004). *Trichoderma* species - Opportunistic, Avirulent Plant Symbiots. *Nature Reviews*, 2: 43-56.
Harman, G.E., Obreg'on, M.A., Samuels, G. and Lorito, M. (2010). Changing models of biocontrol in the developing and developed world. *Plant Disease*, 94 (8): 928-939.<br>
Hatvani, L., Manczinger, C., Vágvölgyi and L. Kredics (2013). *Trichoderma* as a Human Pathogen. *Trichoderma*: biology and applications, CABI, Wallingford, United Kingdom.<br>
Howell, C.R. and Stipanovic, R.D. (1983). Gliovirin, a new antibiotic from *Gliocladium virens*, and its role in the biological control of *Pythium ultimum*. *Canadian Journal of Microbiology*, 29: 321-324.<br>
Howell, C.R. (1987). Relevance of Mycoparasitism in the biological control of *Rhizoctonia solani* by *Gliocladium virens*. *Phytopathology*, 77: 992-994.<br>
Howell, C.R. (1998). The role of antibiotic in biocontrol. *Trichoderma and Gliocladium*, Taylor & Francis, London, pp 173-184.<br>
Howell, C.R., Stipanovic, R.D. and Lumsden, R.D. (1993). Antagonistic properties of *Trichoderma* species against *Pythium ultimum*. *Biocontrol Science and Technology*, 3: 435-441.<br>
Howell, C.R. (2003). Relevance of Mycoparasitism in the biological control of *Rhizoctonia solani* by *Gliocladium virens*. *Phytopathology*, 77: 992-994.<br>
Howell, C.R. (1998). The role of antibiotic in biocontrol. *Trichoderma and Gliocladium*, Taylor & Francis, London, pp 173-184.<br>
Kexiang, G., Xiaoguang, L., Yonghong, L., Tianbo, Z. and Shuliang, W. (2002). Potential of *Trichoderma harzianum* vs. *Fusarium oxysporum* f. sp. *lycopersici* through UV induced tolerance to fusaric acid. *Biological control*, 67: 397-408.<br>
Mohiddin, F.A., Khan, M.R., Khan, S.M. and Bhat, B.H. (2010). Why *Trichoderma* is Considered Super Hero (Super Fungus) Against the Evil Parasites? *Plant Pathology Journal*, 9(3): 92-102.<br>
Mukherjee, P.K. and Mukhopadhyay, A.N. (1995). In situ Mycosuppression of *Gliocladium virens* on *Rhizoctonia solani*. *Indian Phytopathology*, 48 (1): 101-02.<br>
Mukhopadhyay, A.N., Shrestha, S.M. and Mukherjee, P.K. (1992). Biological seed treatment for control of soil borne plant pathogens. *FAO Plant Protection Bulletin*, 40: 21-30.<br>
Mustafa, A., Khan, M.A., Inam-ul-Haq, M., Khan, S.H. and Pervez, M.A. (2009). Mass multiplication of *Trichoderma* spp. on organic substrate and their effect in management of seed borne fungi. *Pakistan Journal of Phytopathology*, 21(2): 108-114.<br>
Ng, L.C., Ngadin, A., Azhari, M. and Zahari, N.A. (2015). Potential of *Trichoderma* spp. as Biological Control Agents against Banaanase Pathogen (*Fusarium fujikuroi*) in Rice. *Asian Journal of Plant Pathology*, 9: 46-58.<br>
Papavizas, G.C. (1985). *Trichoderma* and *Gliocladium*: biology, ecology, and potential for biocontrol. *Annual Reviews of Phytopathology*, 23: 23-54.<br>
Pervez, S. and Kumar, V.R (2004). Antagonism by *Trichoderma viride* against leaf blight pathogen of wheat. *Journal of Mycology and Plant Pathology*, 34: 220-222.<br>
Prasad, R.D., Rangeshwaran, R., Anuroop, C.P. and Phani-kumar, P.R. (2002). Bioefficacy and shelf life of conidial and chlamydospore formulation of *Trichoderma harzianum* in talle formulation. *Indian Journal of Agricultural Science*, 80: 930-932.<br>
Puyam, A., Shahid, M., Srivastava, M. and Singh, A. (2013). Effect of different physiological parameters on growth and sporulation of *Trichoderma viride*. *Plant Disease Research*, 28(2): 146-151.<br>
Reddy, K.K. and Narayana, P. (2009). Efficacy of *Trichoderma viride* Against *Colletotrichum falcatum* in Sugarcane. *Indian Journal of Plant Protection*, 37(1, 2): 111-115.<br>
Richard, E., Heutte, N., Bouchart, V. and Garon, D. (2008). Evaluation of Fungal contamination and Mycotoxin production in maize silage. *Animal Feed Science and Technology*, 148: 309-320.<br>
Samuels, G.J., Dodd, S.L., Gams, W., Castlebury, L.A. and Petrini, O. (2002). *Trichoderma* species associated with the green mold epidemic of commercially grown Agari-
cus bisporus. Mycologia, 94: 146-170.
Sankar, P. and Jeyarajan, R. (1996). Biological control of Trichoderma harzianum—a potential biocontrol agent for tobacco damping off. *Indian Research*, 12: 26-35.
Sharma, P., Patel, A.N., Saini, M.K. and Deep, S. (2012). Field Demonstration of *Trichoderma harzianum* as a Plant Growth Promoter in Wheat (*Triticum aestivum* L.). *Journal of Agricultural Science*, 4 (8): 65-73.
Singh, D. and Maheshwari, V.K. (2001). Biological seed treatment for the control of loose smut of wheat. *Indian Phytopathology*, 54 (4): 457-460.
Singh, D.P. (2004). Use of reduced dose of fungicides and seed treatment with *Trichoderma viride* to control wheat loose smut. *Journal of Mycology and Plant Pathology*, 34: 396-397.
Singh, R.K. (2010). 'Trichoderma: A bio-control agent for management of soil borne diseases’. Retrieved January, 14 2016 from http://agropedia.iitk.ac.in
Singh, U.S. and Zaidi, N.W. (2002). Current Status of formulation of *Trichoderma hamatum*. *Plant Disease*, 72: 27-29.
Shelton, A. (2014). Biological Control: A guide to Natural enemies in North America. Cornell University World Wide Web site.
Sivan, A. and Chet, I. (1989). The possible role of competition between *Trichoderma harzianum* and *Fusarium oxysporum* on rhizosphere colonization. *Phytopathology*, 79: 198-203.
Sriram, S., Raguchander, T., Babu, S., Nandakumar, R., Shanmugam, V., Vidhyasekaran, P., Balasubramanian, P. and Samyappan, R. (2000). Inactivation of phytotoxin produced by the rice sheath blight pathogen *Rhizoctonia solani*. *Canadian Journal of Microbiology*, 46: 520-524.
Srivastava, R.K., Singh, R.K., Kumar, N. and Singh, S. (2010). Management of *Macrophomina* disease complex in jute (*Corchorus olitorius*) by *Trichoderma viride*. *Journal of Biological Control*, 24 (1): 77-79.
Tapwal, A., Sharma, Y.P. and Lakanpal, T.N. (2005). Use of biocontrol agents against white root rot of apple. *Indian Journal of Mycology and Plant Pathology*, 35: 67-69.
Tewari, A.K. (1996). Biological Control of chickpea wilt complex using different formulations of *Gliocladium viride* through seed treatment. Ph.D Thesis, GB Pant University of Agriculture and Technology, Pantnagar, India.
Tjamos, E.C., Papavizas, G.C. and Cook, R.J. (1992). Biological Control of Plant Diseases: Progress and Challenges for the Future. Plenum Press, New York, 255-265pp.
Upadhyay, J.P. and Mukhopadhyay, A.N. (1986). Biological bioefficacy of *Trichoderma harzianum* control of *Sclerotium rolfsii* by *Trichoderma harzianum* in Sugarbeet. *Tropical Pest Disease Management*, 32: 215-220.
Vasudevan, P., Kavitha, S., Priyadarisini, V.B., Babujee, L. and Gnanamanickam, S.S. (2002). Biological control of rice diseases. Biological control of crop diseases. Marcel Decker, New York, 480: 11-32.
Viterbo, A., Haran, S., Friese, D., Ramot, O. and Chet, I. (2001). Antifungal activity of a novel endochitinase gene (chit36) from *Trichoderma harzianum* Rifai TM. *Microbiological Letter*, 200: 169-174.
Viterbo, A., Inbar, J., Hadas, Y. and Chet, I. (2007). Plant Disease Biocontrol and Induced Resistance via Fungal Mycoparasites: The Mycota-A Comprehensive Treatise on Fungi as Experimental Systems for Basic and Applied Research. (2nd edn), Environmental and Microbial Relationships, 350pp.
Weindling, R. (1932). *Trichoderma lignorum* as a parasite of other fungi. *Phytopathology*, 22: 837-845.
Weindling, R. (1934). Studies on lethal principle effective in the parasitic action of *Trichoderma lignorum* on *Rhizoctonia solani* and other fungi. *Phytopathology*, 24: 1153-1179.
Weindling, R. (1941). Experimental consideration of the mold toxins of *Gliocladium* and *Trichoderma*. *Phytopathology*, 31: 991-1003.
Wiest, A., Grzegorski, D., W Xu, B., Goulard, C., Rebuffat, S., Ebbole, D.J., Bodo, B. and Kenerley, C. (2002). Identification of peptaibols from *Trichoderma virines* and cloning of a peptaibol synthetase. *Journal of Biological Chemistry*, 277: 20862-20868.
Wilcox, W.F., Harman, G.E. and Di Pietro, A. (1992). Effect of gliotoxin on growth, sporulation, and zoospores motility of seven *Phytophthora* spp. *in vitro*. *Phytopathology*, 82: 1121.
Yadav, R.K. and Majumdar, V.L. (2005). Efficacy of plant extracts, biological agents and fungicides against *Lasiodiplodia theobromae* causing die back of guava (*Psidium guajava* L.). *Journal of Mycology and Plant Pathology*, 35: 352-353.
Yadav, S.K., Dave, A., Sarkar, A., Singh, H.B. and Sharma, B.K. (2013). Co-inoculated biopriming with *Trichoderma*, *Pseudomonas* and *Rhizobium* improves crop growth in *Cicer arietinum* and *Phaseolus vulgaris*. *International Journal of Agricultural and Biology*, 6(2): 255-259.
Yedidia, I., Benhamou, N. and Chet, I. (1999). Induction of defence responses in Cucumber plants (*Cucumis sativus* L.) by the Biocontrol agent *Trichoderma harzianum*. *Applied Environmental and Microbiology*, 65: 1061-1071.
Yedidia, I., Benhamou, N., Kapulnik, Y. and Chet, I. (2000). Induction and accumulation of PR proteins activity during early stages of root colonization by the mycoparasite *Trichoderma harzianum* strain T-203. *Plant Physiology and Biochemistry*, 38:863-873.
Yedidia, I., Shoresh, M., Kerem, Z., Benhamou, N., Kapulnik, Y. and Chet, I. (2003). Concomitant induction of systemic resistance to *Pseudomonas syringae pv. lachrymans* in cucumber by *Trichoderma asperellum* (T-203) and accumulation of phytalexins. *Applied Environmental Microbiology*, 69: 7343-7353.
Kandula, D.R.W., Jones, E.E., Stewart, A., McLean, K.L. and Hampton, J.G. (2015). *Trichoderma* species for biocontrol of soil-borne plant pathogens of pasture species. *Biocontrol Science and Technology*, 25 (9): 1052-1069.
Levy, N.O., Harel, Y.M., Haile, Z.M., Elad, Y., Rav-David, E., Jurkevitch, E. and Katan, J. (2015). Induced resistance to foliar diseases by soil solarization and *Trichoderma harzianum*. *Plant Pathology*, 64(2): 365-374.