J. Farm Sci., 33(2): (159-172) 2020
REVIEW ARTICLE

Trichoderma: A potential millennium microbe for sustainable management of field and horticulture crop diseases: An overview

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(Received: March, 2020 ; Accepted: May, 2020)

Abstract: Biological control is gaining importance in modern agriculture due to limitations of chemical farming and its effect on environment and human health. In this context, sustainable management of crop diseases is the need of hour for long term innovative farming. Among different bio-agents used *Trichoderma* forms as the most potent and diversified bioagent used in crop disease management. *Trichoderma* readily colonizes plant roots and some strains are rhizosphere competent *i.e.* able to grow on roots as they develop. *Trichoderma* spp. also attack, parasitize and otherwise gain nutrition from other fungi. They have evolved numerous mechanisms for both attack of other fungi and for enhancing plant and root growth. Different strains of *Trichoderma* control almost every pathogenic fungus for which control has been sought. However, most of *Trichoderma* strains are more efficient for control of some pathogens than others and may be largely ineffective against some fungi. *Trichoderma* spp. as a biocontrol agents are used for foliar application, seed treatment and soil treatment for suppression of various disease causing fungal pathogens. The present paper deals with various aspects of *Trichoderma* application in the management of disease of field and horticultural crops.

Key words: Crop diseases, Integrated Disease Management, Microbe, Millennium, *Trichoderma*

Introduction

The novel technologies in all areas of agriculture have improved agricultural production, but some modern practices affect the environment. The recent challenge faced by advanced farming is to achieve higher yields in environment friendly manner. Thus, there is an immediate need to find eco-friendly solutions such as wider application of biocontrol agents. Among various types of species being used as biocontrol agents, including fungi and bacteria, fungal genus *Trichoderma* produces different kinds of enzymes which play a major role in biocontrol activity like degradation of cell wall, tolerance to biotic or abiotic stresses, hyphal growth *etc*. Fungi in genus *Trichoderma* (Division - Ascomycota, Sub-division - Pezizomycotina, Class - Sordariomycetes, Order - Hypocreales, Family - Hypocreaceae) have been known since 1920s for their capability to function as biocontrol agents (BCA) against plant pathogens (especially the soil borne). They can be used either to improve health of crop plant or to increase the natural ability to degrade toxic compounds by some plants in soil and water. The different species of this genus have long been known not only for the control of plant disease but also for their capability to enhance plant growth and development, elevated reproductive ability, capacity to modify the rhizosphere, capability to grow under adverse conditions, competence in the use of nutrients, strong aggressiveness against phytopathogenic fungi and efficacy in supporting plant growth and enhanced defense mechanisms. These properties have made *Trichoderma* a omnipresent genus able to grow in wider habitats and at high population densities.The first real generic description of *Trichoderma* was proposed based on colony growth rate and microscopic characters by Rifai, 1969. The genus was sub-divided into nine species, distinguished from each other primarily on the basis of conidiophore branching patterns and conidium morphology. The nine species-aggregates proposed were (1) *T. piluliferum*, Webster and Rifai, (2) *T. polysporum* (link ex Pers.) (3) *T. hamatum* (Bon.) Bain. (4) *T. koningii* Oudemans (5) *T. aureoviride* Rifai (6) *T. harzianum* Rifai (7) *T. longibrachyatum* Rifai (8) *T. pseudokoningii* Rifai and (9) *T. viride* (Pers. Ex. Fr.). A different member of this genus produces a broad array of pigments from bright greenish-yellow to reddish in colour but some are colourless.

Model depicting mode of action of *Trichoderma* spp. against pathogen and plant growth improvement

Competition

The most common reason for the death of many microorganisms growing in the vicinity of *Trichoderma* strains is the starvation and scarcity of limiting nutrients. This can be effectively used in biological control of fungal phytopathogens. Carbon and iron are two essential elements in most of the filamentous fungi required for viability. Competition for carbon is effective mode not only in *Trichoderma* but also some other fungi such as strains of *Fusarium oxysporum* (Sarrocco *et al*., 2009). Under iron starving conditions most fungi produces small size ferric-iron specific chelators to mobilize iron from surrounding environment. *T. harzianum* T35 also controls *F. oxysporum* by competing for both rhizosphere colonization and nutrients. The proficient utilization of accessible nutrients is resulting from the capability of *Trichoderma* to acquire ATP from the diverse types of sugars, such as those derived from polymers widely available in fungal environments: cellulose, glucan and chitin and others, all of them turning into glucose.

Antibiosis

Small size diffusible compounds or antibiotics produced by these species inhibit the growth of other microorganisms. Strains of *T. virens* able to produce glioviridin involved in antibiosis making it efficient biocontrol agent. A mutant of *T. harzianum* strain 2413 with elevated levels of extracellular enzymes and of α-pyrone increased resistance than the wild type against *Rhizoctonia solani* and in assays of grape protection against *Botrytis cinerea* under different controlled environmental conditions (Rey *et al*., 2001). Coconut smell is typical of *T. viride* isolates suggesting the presence of volatile compounds that are inhibitory to pathogen growth. These metabolites include harzianic acid, alamethicins, tricholin, peptaibols, antibiotics, 6-penthyl-α-pyrone, massoilactone, viridin, glioviridin, glisoprenins, heptelidic acid.

Mycoparasitism

Mycoparasitism is one of the main mechanisms involved in the antagonisms of *Trichoderma* as a biocontrol agent. The process apparently include, chemotropic growth of *Trichoderma,* recognition of the host by the mycoparasites, secretion of extra cellular enzymes, penetrations of the hyphae and lysis of the host. *Trichoderma* recognizes signals from the host fungus, triggering coiling and host penetrations. The process of mycoparasitism involves direct attack of one fungal species on another one. This complex process includes sequential events, involving cycle of recognition of fungal strain by *Trichoderma* spp., attack on cellular machinery and subsequent penetration inside the host and finally killing of the host. *Trichoderm*a spp. even can grow towards fungal host by recognizing them. Such remote sensing activity is partially because of the sequential production of pathogenesis related proteins, mostly glucanase proteases and chitinase. Constitutive secretion of exochitinases at low level which degrade fungal cell-walls releasing oligomers plays a central role in growth inhibition of pathogenic fungal strains (Gajera *et al*., 2013).

Induced resistance

The first clear demonstration of induced resistance with *T. harzianum* strain T-39 showed that treated soil made leaves of bean plants resistant to diseases caused by the fungal pathogens such as *B. cinerea* and *Colletotrichum lindemuthianum*, even though T-39 was applied only on the roots and without any on the foliage. Induced resistance was found to be beneficial in more than 10 different dicots and monocots to infection by fungi (*B. cinerea*, *R. solani, Colletotrichum* spp., *Phytophthora* spp., *Alternaria* spp., *Magnaporthe grisea*, *etc.*), bacteria (*Xanthomonas* spp., *Pseudomonas syringae*, *etc*.), and even some viruses like CMV. The soil treated with *T. harzianum* strain T-39 was also effective against fungal pathogens *B. cinerea* and *C. lindemuthianum* in bean plants. At a molecular level, resistance to different pathogens is due to increase in the activity of defensive mechanisms producing higher concentration of related metabolites and enzymes, such as chalcone synthase (CHS) and phenylalanine ammonio lyase (PAL), chitinase, glucanase and some proteins from cerato-platanin (CP) family and phytoalexins (HR response) synthesizing enzymes such as PKS/NRPS hybrid enzyme. These comprise pathogenesis related proteins (PR) and enzymes involved in the response to oxidative stress (Gajera *et al*., 2013).

Endophytes

Endophytic activity of many microorganisms (growth inside plant tissue without any harm) may useful to host plant by stimulating of plant growth, a postponement to the beginning of drought stress and the obstruction to pathogens. Recently, there are reports showing *Trichoderma* isolates acting as endophytic plant symbionts in some woody plants (Chaverri and Gazis, 2011). Interestingly, strains forming association with roots are altering the gene expression pattern in shoots. These changes are the key points in altering plant physiology and this can be exploited in the improvement of many important traits like uptake of nitrogen fertilizer, abiotic/ biotic stress resistance and photosynthetic efficiency leading to higher yields.

Beneficial effect of *Trichodema* in sustainable management of crop diseases

Disease control: *Trichoderma* is a potent biocontrol agent and used extensively for soil borne diseases. It has been used successfully against many plant pathogenic fungi belonging to various genera, *viz. Fusarium, Phytopthara, Sclerotium etc.*

Plant growth promoter: *Trichoderma* strains solubilize phosphates and micronutrients. The application of *Trichoderma* strains with plants increases the number of deep roots, thereby increasing the plant's ability to resist drought.

Biochemical elicitors of disease: *Trichoderma* strains are known to induce resistance in plants. Three classes of compounds that are produced by *Trichoderma* and induce resistance in plants are now known. These compounds induce ethylene production, hypersensitive responses and other defense related reactions in plant cultivars.

Transgenic plants: Introduction of endochitinase gene from *Trichoderma* into plants such as tobacco and potato plants has increased their resistance to fungal growth. Selected transgenic lines are highly tolerant to foliar pathogens such as *Alternaria alternata, A. solani,* and *B. cinerea* as well as to the soil-borne pathogen, *Rhizoctonia* spp.

Bioremediation: *Trichoderma* strains play an important role in the bioremediation of soil that are contaminated with pesticides and herbicides. They have the ability to degrade a wide range of insecticides: organochlorines, organophosphates and carbonates.

Delivery methods

The method of application forms an important factor that decides the long term effect of any given bioagent. Several workers have developed effective delivery methods in application of *Trichoderma* in field and horticultural crops. The various devilver methods employed are;

Seed treatment: Mix 10 g of *Trichoderma* formulation per litre of cow dung slurry for treatment of 1 kg of seed before sowing, particularly for cereals, pulses and oilseeds.

Nursery treatment: Apply 10 - 25 g of *Trichoderma* powder per 100 m^2 of nursery bed. Application of neem cake and FYM before treatment increases the efficacy or drench nursery beds with @ *Trichoderma* formulation 5 g per litre of water before sowing.

Cutting and seedling root dip: Mix 10 g of *Trichoderma* powder along with 100 g of well decomposed FYM per liter of water and dip the cuttings and seedlings for 10 minutes before planting.

Soil treatment: Apply 5 kg/ha of *Trichoderma* powder after turning of sun hemp or dhaincha into the soil for green manuring, or mix 1 kg of *Trichoderma* formulation in 100 kg of farmyard manure and cover it for 7 days with polythene. Sprinkle the heap with water intermittently. Turn the mixture in every 3-4 days interval and then broadcast into the field.

Plant treatment: Drench the soil near stem region with 10 g *Trichoderma* powder mixed in a liter of water.

Uses

Used in damping off caused by *Pythium* sp. and *Phytophthora* sp., root rot caused by *Pellicularis filamentosa,* seedling blight caused by *Pythium*, collar rot caused by *Pellicularia rolfsii,* dry rot caused by *Macrophomina phaseoli*, charcoal rot caused *by M. phaseoli,* loose smut caused by *Ustilago segetum*, karnal bunt diseases, black scurf caused by *R. solani*, foot rots of pepper and betel vine and capsule rot of several crops. Effective against silver leaf on plum, peach and nectarine, dutch elm disease on elm's honey fungus (*Armillaria mellea*) on a range of tree species, botrytis caused by *B. cinerea*, effective against rots on a wide range of crops, caused by *Fusarium, Rhizoctonia* and *Pythium* and *Sclerotium* forming pathogens such as *Sclerotinia* and *Sclerotium.*

Precautions to be taken while use of *Trichoderma*

- Don't use chemical fungicide after application of *Trichoderma* for 4-5 days.
- Don't use *Trichoderma* in dry soil. Moisture is a essential factor for its growth and survivability.
- Don't put the treated seeds in direct sun rays.
- Don't keep the treated FYM for longer duration.

Compatibility of *Trichoderma* with other agents

- *Trichoderma* is compatible with organic manure *Trichoderma* is compatible with biofertilizers like *Rhizobium, Azospirillum, Bacillus subtilis* and *Phosphobacteria.*
- *Trichoderma* can be applied to seeds treated with metalaxyl or thiram but not mercurials. It can be mixed with chemical fungicides as tank mix.

Commercial products

Commercial products of *Trichoderma* species available in India are presented in Table 1.

Disease management in field crops using different *Trichoderma* species

Howell *et al.* (1997) conducted studies on field control of cotton seedling diseases with *Trichoderma virens* in combination with fungicide seed treatments. The treatment of cotton seed with *T. virens* plus metalaxyl resulted in greater seedling stands than those in untreated control and equal to those of the fungicide control, except where disease pressure was very heavy or light.

Vazquez *et al.* (2000) studied the interactions between arbuscular mycorrhizal fungi (AMF) and other microbial inoculants (*Azospirillum, Pseudomonas* and *Trichoderma*) and their effects on microbial population and enzyme activities in the rhizosphere of maize plants. Mycorrhizal colonization induced qualitative changes in the bacterial population depending on the inoculant combination involved. Esterase activity was particularly increased by *G. mosseae* (256 %), phosphatase activity by natural AMF (166 %), chitinase by *G. mosseae* (197 %), *G. deserticola* (152 %) and natural AMF (151 %), and trehalase by

Table 1. Commercial products of *Trichoderma* species available in India

Trichoderma spp.	Trade name	Formulation	Distributor / Company
Trichoderma viride	Bio Protectore	WP	ManiDhara Biotech Pvt. Ltd.
	Agrigold Trichogold	WP, Liquid	Agri Gold Organics Pvt. Ltd.
	Anoka	WP	K N Bio Sciences Pvt. Ltd, Ranga Reddi
	BioAgent ST-9	Seed treatment, soil	Shree Biotech & Research Inputs
	Antagon- Trichoderma	WP - seed treatment, root dip, soil treatment	Omega Ecotech Products
	Bioveer	WP	Ambika Biotech
	Sanjeevni	WP	Internationl Panaacea Ltd.
	Ecosom-TV*	WP, Liquid, Lyophilized	Agri Life SOM Phytophara (India) Ltd.
Trichoderma harzianum	Tricone V	WP	Neuscire Biolab
	Bioharz	Liquid	International Panaacea Ltd.
	Sardar EcoGreen	WP	Gujrat State Fertilizers & Chemicals Ltd.
	Ecosom-TH** Lyophilized	WP, Liquid	Agri Life SOM Phytophara (India) Ltd.
Trichoderma viride/ Trichoderma harzianium	Neemoderm A	WP	Shri Ram Solvent Extraction Private, Ltd., Jaspur, India

*TNAU Strain; **IIHR-Th-2; WP: Wettable powder

G. deserticola (444 %). As a result of mycorrhizal colonization and microbial inoculation, modifications of the microbial community structure and ecology were found.

Prasad *et al.* (2002) studied the effect of soil and seed application of *T. harzianum* on pigeonpea wilt caused by *Fusarium udum* under field conditions. soil amendment with *T. harzianum* at 10 g resulted in about 30 per cent disease reduction. In seed treatment plots, disease control ranged between 4.36 and 13.7 per cent. In general, soil application of *T. harzianum* was found to be more effective than seed treatment for disease suppression.

Harman *et al.* (2004) studied the interaction between *T. harzianum* strain T22 and maize Inbred Line Mo17 and effects of these interactions on diseases caused by *Pythium ultimum* and *Colletotrichum graminicola*. Seedlings grown in the presence of T22, either in treated or untreated soil, were larger than those produced in its absence. Infestation of soil with *P. ultimum* had little effect upon growth of Mo17. The presence of T22 increased protein levels and activities of β-1,3 glucanase, exochitinase, and endochitinase in both roots and shoots, even though T22 colonized roots well but colonized shoots hardly at all. With some enzymes, the combination of T22 plus *P. ultimum* gave the greatest activity. Plants grown from T22-treated seed had reduced symptoms of anthracnose following inoculation of leaves with *C. graminicola*, which indicates that root colonization by T22 induces systemic resistance in maize.

Jyotsna *et al.* (2008) studied on growth promotion and charcoal rot management in chickpea by *T harzianum* and the results showed that *T. harzianum* strain 25-92 significantly increased the fresh and dry weights by 50 - 63 and 24 - 42 per cent, respectively, whereas strain 29-92 increased the fresh weight of chickpea cv. Radhey and Vishwas by 12-30 per cent. The reduction in disease was more pronounced at higher inoculum concentrations of *T. harzianum* (10^7-10^8 cfu/g). Overall, *Trichoderma* strain 25-92 improved plant growth and reduced damage in presence of the pathogen. Abdollahzadeh *et al.* (2006) studied biological control of sclerotium stem rot of sunflower using *Trichoderma* spp. The result revealed that combination of *T. harzianum* and *T. virens* using incorporation of conidial suspension mixed with compost into the soil had most efficiency on biocontrol of stem rot and reduced disease incidence upto 50 per cent. Ramesh and Korikanthimath (2006) studied management of groundnut root rot caused by *M. phaseolina* using biocontrol agents *viz.*, *T. viride* and *Pseudomonas fluorescens*. Seed treatment with biocontrol agents significantly increased the germination percentage and reduced disease incidence significantly. Treatment with *T. viride* and *P. fluorescens* increased pod yield and over control, respectively. Disease reduction was on par with the carbendazim seed treatment and hence, use of biocontrol agents as seed treatment with and without soil application could be an effective strategy to reduce root rot disease and enhance yield of groundnut under rainfed conditions.

Lamba *et al.* (2008) noted biochemical changes in sunflower plants due to seed treatment/spray application with biocontrol agents. The application of *T. harzianum* and *P. fluorescens* led to increases in dry matter content, starch, total soluble sugars (TSS) and reducing sugar contents in leaves of sunflower when done as seed treatment or coupled with spray. Application of biocontrol agents to sunflower plants initiated certain biochemical changes, which can be considered to be part of the plant's defense response.

Singh *et al.* (2008) conducted study on bioefficacy of antagonists *T. viride*, *T. harzianum, Bacillus subtilis* and *P. fluorescens* against root-rot fungus *M. phaseolina* of safflower. The antagonist-coated seeds improved safflower germination and proved effective in protecting safflower from root-rot. Moreover, it also resulted in significant increase in root length and high vigour index. Shanmugaih *et al.* (2009) reported effect of single application of *Trichoderma viride* and *P. fluorescens* on growth promotion in cotton plants. *Trichoderma viride* was found to be more effective than *P. fluroescens* on shoot and root length elongation. Seed germination percentage, root length, shoot length, fresh weight, dry weight and vigour index were significantly increased by *T. viride* and *P. fluroescens* and *T. viride* inoculated cotton plants increased 2.7 and 2.4 fold, where as *P. fluorescens* increased 2 and 1.8 fold for shoot and root length, respectively. Bhattacharya *et al.* (2016) opined that *T. aureoviridae* a potential organism for bio-prospecting against *M. phaseolina* in jute. *Trichoderma aureoviridae* enhanced the biomass production of jute, showed 72 per cent *in vitro* and 62 per cent *in vivo* growth inhibition of pathogen in this crop and has the great potential to induce plant defence system under stress condition and for further application in jute production.

Niranjana *et al.* (2009) reported that *T. harzianum* and *P. fluorescens* are the two major fungal biocontrol agents found in the soil and the rhizosphere of various crop systems. They used different agricultural waste bases such as wheat bran, rice bran, paddy straw and neem cake for mass-multiplying *T. harzianum* and *P. fluorescens*. Ten isolates each of *T. harzianum* and *P. fluorescens* were isolated from rhizosphere soil samples collected from various pigeonpea-growing fields. Further, evaluated the efficacy of these isolates, both in increasing seed quality variables of pigeonpea and in inhibiting the mycelial growth of *Fusarium udum* Butler. *T. harzianum* isolate 4 and *P. fluorescens* isolate 3 were selected and mass-multiplied using different agricultural waste products as bases. Among the latter, boiled rice bran was found to increase the growth of both biocontrol agents. Talc and sodium alginate formulations of mass-multiplied biocontrol agents were prepared and evaluated for their affects against fusarium wilt under greenhouse conditions. Fresh cultures of both biocontrol agents were found to increase seedling emergence and reduce fusarium wilt disease incidence when compared to the control and the formulations.

Dubey *et al.* (2011) studied on integration of soil application and seed treatment formulations of *Trichoderma* species for management of wet root rot of mungbean caused by *R. solani.* A combination of soil application with PBP 16G (*T. virens*) and seed treatment with Pusa 5SD (*T. virens*) + carboxin was superior to increasing seed germination, shoot and root lengths and grain yield and reducing wet root rot incidence in mungbean. Seed treatment was more effective than soil application for all the evaluated parameters. Srivatsav *et al.* (2010) studied the management of *Macrophomina* disease complex in jute by *T. viride*. The treatment with soil application of *T. viride* was found best in controlling seedling blight, collor rot, stem rot and root rot diseases giving minimum per cent disease incidence as compared to control. Mean dry fibre yield was highest (25.70 q ha^{-1}) in the plots when the soil was treated with *T. viride* , while it was lowest in control (17.76 q ha^{-1}) and in carbendazim treatment it was 22.23 q ha^{-1}. Khalili *et al.* (2012) conducted studies on biological control of rice brown spot with native isolates of three *Trichoderma* species and revealed that, *Trichoderma* isolates can inhibit mycelium growth of pathogen *in vitro* by producing volatile and nonvolatile metabolites.

Khan *et al.* (2014) studied the field performance of *Trichoderma* species against wilt disease complex of chickpea caused by *Fusarium oxysporum* f. sp. *ciceri* and *R. solani.* Chickpea cultivar Avrodhi, grown in plots inoculated with *F. oxysporum* f. sp. *ciceri* and *R. solani*, showed chlorosis of leaves and wilting of foliage and exhibited a 22-25 per cent decrease in yield. Soil application of biocontrol agents checked the severity of wilt by 25-56 and 39-67 per cent and increased the yield of chickpea by 12-28 and 8-24 per cent in the two years, respectively. The disease control and yield enhancement were highest with *T. harzianum*, followed by *T. hamatum* and *T. viride.*

Doni *et al.* (2014) conducted study on physiological and growth response of rice plants to *Trichoderma* spp. inoculants. This study indicated that, *Trichoderma* spp. SL2 inoculated rice plants exhibited greater net photosynthetic rate, internal CO_2 concentration, water use efficiency, plant height, tiller number, root length and root fresh weight compared to the plants treated with other *Trichoderma* isolates tested. Sharma *et al.* (2014) conducted experiment on plant growth promoting effect of *Trichoderma* on groundnut it has been speculated that the seed application of *T. harzianum* + *T. viride* increased seed germination, chlorophyll content, shoot and root length and dry weight of leaves, shoot and root in groundnut. The seed treatment of *T. harzianum* + *T. viride* either alone or in combinations performed well to increase number and weight of pods as well as test weight of kernels in groundnut. Rudresh *et al.* (2005) conducted study on effect of combined application of rhizobium, phosphate solubilizing bacterium and *Trichoderma* spp. on growth, nutrient uptake and yield of chickpea. Combined inoculation of these three organisms showed increased germination, nutrient uptake, plant height, number of branches, nodulation, pea yield, and total biomass of chickpea compared to either individual inoculations or an uninoculated control. Increased growth and yield parameters were more pronounced when *T. harzianum*-PDBCTH 10 was inoculated along with the phosphate solubilizing bacterium and Rhizobium.

The results of biocontrol mechanisms of *T. harzianum* against soybean charcoal rot caused by *M. phaseolina* revealed that in the greenhouse experiments in the seed treatment with *T. harzianum* isolates was significantly lower than that of the soil treatment (Khaledi and Taheri, 2016).

Javaid *et al.* (2017) conducted experiment on biological control of charcoal rot of mung bean by *T. harzianum* and shoot dry biomass of *Sisymbrium irio*. The application of *S. irio* leaf amendment and *T. harzianum* generally enhanced leaf protein, sugar and chlorophyll contents, and catalase activity. This study concludes that *T. harzianum* in combination with 1 per cent dry leaves of *S. irio* as a soil amendment can be used to achieve the best grain yield under biotic stress of *M. phaseolina* under *in vitro*, *T. harzianum WKY1* isolate showed superiority in terms of inhibition of both mycelial growth and spore germination of *Colletotrichum sublineolum*, the causative agent of sorghum anthracnose, as well as induction of the sorghum seed germination over *T. harzianum WKY5* isolate. Under greenhouse conditions, application of *T. harzianum WKY1* and/or its filtrate reduced greatly the disease severity as well as improved the plant growth of sorghum (Saber *et al.,* 2017).

Ghante *et al.* (2019) studied the efficacy of bioagents against *F. oxysporum* f. sp. *udum* causing wilt disease of pigeonpea. *Trichoderma viride* was found most effective with least linear mycelial growth under *in vitro* condition. In field evaluation under normal soil and semi sick soil condition, *T. viride* has shown minimum wilt incidence and recorded maximum yield followed by *T. harzianum*.

Jessica *et al.* (2018) conducted research on promotion of seedling growth and production of wheat by using *Trichoderma* spp. In the treatments *T. harzianum* ESALQ 1306 and *T. asperellum* URM5911 were considered satisfactory, since they provided grain yield superior to 2,000 kg ha^{-1}. In addition, *T. harzianum* ESALQ 1306 provided the best results for percentage of germination, root length, shoot length, total length, fresh root mass, fresh shoot mass, total fresh mass, dry root mass, dry shoot mass, total biomass, root mass ratio, shoot mass ratio and aerial part/root system ratio. Mahato *et al.* (2018) conducted experiment to find out the effects of *T. viride* on growth and yield of wheat. The results showed that *T. viride* increased the plant height, root weight, leaf length, panicle weight, number of grains, grain yield, biological yield and biomass yield over control. Hasan *et al.* (2019) conducted study on potential of *T. harzianum* as a biocontrol agent against *Striga hermonthica* in sorghum. The combinations of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly reduced *S. hermonthica* dry weight, increased sorghum shoot and root dry weight significantly as compared to the control. Ikram *et al.* (2019) *Trichoderma reesei* improved the nutrition status of wheat crop under salt stress. Results also showed that *T. reesei* treated plants showed higher IAA, GA, Ca and K, while lower ABA, H_2O_2, Phenol, sugar, proline, electrical conductivity, malondialdehyde (MDA), Na+ and Cl^-. The results concluded that the integrative use of *T. reesei* might help the wheat plants to stand salt stress. Khadka and Uphoff (2019) evaluated the effects of *Trichoderma* inoculation of rice plants under SRI management compared with transplanted and flooded rice plants. The results indicated significantly better performance associated with *Trichoderma* inoculation. The yield increase with *Trichoderma* treatments across all trials was 31 per cent higher than in untreated plots. With regard to varietal differences, under SRI management *Trichoderma* inoculation of the improved variety Sukhadhan-3 recorded 26 per cent higher yield and with the heirloom variety Tilkidhan, yield was 41 per cent higher. Aditya and Hegde (2019), studied the Effect of plant growth promoting microorganisms (PGPMs) in groundnut and revealed that the early leaf spot, late leaf spot and rust can be successfully managed and also yields can also be increased compared to the untreated control. They also opined that plant height, number of nodules in root system, number of pods per plant can also be enhanced in the PGPMs treated treatments. Hassan *et al.* (2019) reported that application of the 3 inoculums at 2 hours reduced germination percentage more than at 4 hours. Filtrate and culture inoculums at 2 hours reduced germination by 79 and 68 per cent, respectively. The combination of compost 100 % + *T. harzianum* + BMP + Flavobacterium reduced germination by 68 per cent. The greenhouse results showed that the combination of compost plus BMP+ Flavobacterium gave lowest number of *S. hermonthica* emergence and the highest sorghum plant height. The combinations of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly reduced *S. hermonthica* dry weight, increased sorghum shoot and root dry weight insignificantly as compared to the control.

Disease management in fruit and vegetable crops using different *Trichoderma* species

Mukherjee *et al.* (1989) studied the biological control of *Pythium* damping-off of Cauliflower by *T. harzianum*. Soil application of wheat bran saw dust preparation of *Trichoderma* gave 32.4 per cent control of damping-off under glass house conditions. Seed coating with *Trichoderma* (1.6 x 10 spores/ml) resulted in 31 per cent control of thc disease. WBSD preparation of *T. harzianum,* either live or killed, promoted the growth and vigour of cauliflower seedlings. Integration of fungicidal seed treatment with soil application of *T. harzianum* resulted in 66.4 to 90 per cent control of damping-off. Biological and chemical control of grey mould was tested by Elad (1994) in vineyards of table and wine grapes. Treatments with *T. harzianum* (0.5-1.0 g l^{-1}), dicarboximide fungicides (vinclozolin or iprodione) (0.5 g 1^{-1}) or diethofencarb plus carbendazim (0.25 g 1^{-1}) resulted in up to 78 per cent disease reduction. *T. harzianum* and iprodione applied alone in the vineyard reduced the postharvest rot of grapes in one of two experiments. Alternation of *T. harzianum* with diethofencarb plus carbendazim, or its mixture with iprodione in the vineyard, resulted in a 64-68 per cent reduction in postharvest rot caused by *B. cinerea*. Dutta and Das (2002) studied the management of collar rot of tomato by *Trichoderma* spp. and chemicals to know the efficiency of three *Trichoderma* spp. and two seed dressing fungicides for the management of collar rot of tomato. Soil application of inoculum of *Trichoderma* spp. at the time of transplanting, reduced the disease incidence and increased dry mass of root and shoot (g/plant) and yield (g/plant). Application of FYM culture of *T. harzianum* resulted in minimum disease incidence and enhanced dry mass of root and shoot and yield during both the years of experimentation followed by *T. viride* and *T. koningii* as compared to control. Jadhav and Ambadkar and Jadhav (2007) conducted experiment on effect of different bioinoculants on seed germination of Rangpur lime using rolled towel method. At 20th day of observation, seed treatment with Acetobacter diazotrophicus recorded maximum seed germination (64.66) highest seedling emergence (93.75 %) and lowest seedling mortality (6.25 %) followed by the mortality reduction in the plots inoculated with *T. viride* (10.00 %) and *T. harzianum* (10.75 %).

Trichoderma species were evaluated for their potential regulatory effect in Okra (*Abelmoschus esculentus* L.) seeds were coated with spore suspension of each test species of *T. harzianum* supplemented with 2 per cent of starch (w/v) as an adhesive (Mukhtar, 2008). Among the three species, *T. harzianum* was found to be highly effective to enhance the germination percentage in okra seeds. However, the species *T. viridi* and *T. koningii* were also significantly effective as compared to control. Okra seeds also gave the highest germination index values with *T. harzianum* which confined to better germination. Seed treatment with *T. harzianum* can be useful to enhance the germination percentage of okra seeds as well as reduce lose due to delayed germination. Biological control of anthracnose with *Trichoderma* in strawberry fields (Porus *et al*., 2009). *Trichoderma* spp. were applied *via* drip irrigation and dip, by addition to the soil 7-days before planting (10^8 conidia/m^2), and by dipping strawberry roots in a suspension of *Trichoderma* (10^6 conidia/ml) prior to planting. Plants from the nursery were examined during October to detect latent infections of *Colletotrichum* spp. The highest percentage of anthracnose-infected transplants was detected in the second year. Crown infections were initiated in the nursery but were not apparent until after plants were set in production fields. The fungus continued to grow in infected plants, which later died suddenly following warm weather in the fall and the following spring. *Trichoderma* applications reduced anthracnose disease incidence and, consequently, plant mortality. Muthukumar *et al.* (2011) studied on exploitation of *Trichoderma* species on the growth of *Pythium Aphanidermatum* and revealed that *Trichoderma* species isolated from chili rhizosphere (TVC_3) was found to be highly effective in inhibiting the mycelial growth of pathogen and increased the plant growth. Management of Armillaria root rot (ARR) of perennial crops is challenging and requires an integrated approach. In this study, *T. asperellum* and *T. gamsii* formulated as Remedier WP were drenched onto peach trees 3 to 12 days after planting and biannually thereafter in spring and fall for a total of three years in two commercial replant sites of South Carolina. Results showed that in soils with heavy ARR inoculum levels, biannual drenches of *Trichoderma* spp. formulated as remedier WP starting at planting are ineffective for ARR control of peach (Schnabel *et al*., 2011). Biological control of fungal leafy vegetable diseases through antagonistic fungi in vitro potential of *T. viride* was evaluated against ten fungal pathogens of leafy vegetables by dual culture technique. Maximum percent inhibition and coiling structure were recorded in *F. moniliforme* and *S. verruculoscum*. *F. roesum* and *H. sativum* were found to be most susceptible to *T. viride* (Shinde *et al*., 2011).

Abdel-Kader *et al*. (2012) studied biological approach for controlling foliar diseases of some vegetables under greenhouse the results revealed that foliar spray with bioagents can have a considerable activity against powdery and downy mildews of cucumber, cantaloupe, pepper and early, late blights of tomato under open greenhouse conditions. Application with either *T. harzianum* and *B. subtilis* showed significant reduction in diseases incidence comparing with the other applied bio-agents. Thilagavathi *et al*. (2012) examined vermicompost-based bioformulations of bacterial and fungal biocontrol agents against sugar beet root rot caused by *Sclerotium rolfsii*. The result showed that the *P. fluorescens* strain Pf1 in combination with either *Trichoderma* strain TTH1 or *B. subtilis* strain EPCO-16 performed better in reducing disease next to the chemical difenoconazole. Similarly, enhanced yield was observed in the same combination treatments under both pot and field conditions. Suhanna *et al.* (2013) used *Trichoderma* sp. as a biological control agent in the post-harvest treatment of mango stem-end rot. This study was initiated to investigate the potential use of fungal antagonist (*Trichoderma* sp.) against *B. theobromae* and its effectiveness as compared to fungicides. The mango cultivar Sala was used. When *B. theobromae* was inoculated on mango, spore concentration of *Trichoderma* 1×10^6 and 1×10^8 conidia/ml showed good potential to control stem-end rot but control levels were not as high as using propiconazole. All the fruits without inoculation with *B. theobromae* did not develop any disease symptom until day 4 for all treatments. Treating the mangoes by spraying with three different spore concentrations of *Trichoderma* sp. and 500 ppm propiconazole did not have significant effect as compared to untreated (control) mango. Disease started to develop at day 6 for fruits sprayed with all the three concentrations. All treatments including control showed that the percentage of lesion had a value ranging from 0-2 per cent. Result revealed that fungal antagonist of *Trichoderma* sp. with spore concentration of 1×10^8 and 1×10^6 conidia/ml has the potential for postharvest disease control. Management of postharvest disease of mango anthracnose incited by *C. gleosporioide*. Among the seven fungal (*Gliocladium virens, T. hamatum, T. harzianum, T. koningii, T. longibrachiatum, T. pseudokoningii and T. viride*) and two bacterial (*B. subtilis* and *P. fluorescens*) antagonists screened against *C. gloeosporioides* under *in vitro* conditions, *T. harzianum* exhibited maximum inhibition followed by *P. fluorescens* at 5 days after incubation. These fungal and bacterial antagonists were selected for application to fruits infected with pathogens. Fruits inoculated with *C. gloeosporioides* were dipped in spore/cell suspensions of fungal/bacterial antagonists and kept for different durations. Hegde and Kulkarni (2001) in their pot studies recorded the potential of *T. harzianum* and *P. fluorescens* in management of damping off disease of chilli. The fungal antagonists *T. harzianum* and *P. fluorescens* were effective in checking the spread of pathogens on fruits compared with the pathogen-inoculated control (Prabakar *et al*., 2015). Bastakoti *et al*. (2017) conducted experiment with *Trichoderma* species against soil borne fungal pathogens. Inhibition percentage of radial growth of *S. rolfsii* by three of the *Trichoderma* isolates was found to be 100 per cent about 62 and 68 per cent of maximum inhibition was observed against *R. solani* and *F. solani,* respectively whereas *S. sclerotiorum* was inhibited maximum up to 23 per cent and concluded that it can be incorporated for integrated disease management of soil borne plant pathogens. Hegde, *et al.* (2019) studied the efficacy of biocontrol agents for management of mildews of cucumber under polyhouse condition and the studies revealed that, three consecultive application of *T. harzianum* @10 g l^{-1}, *P. fluorescens* @ 10 g per litre and *B. subtilis* @10 g l^{-1} was found promising in managing powdery and downey mildew disease of cucumber. Sindushree and Hegde, (2019) evaluated various botanicals, antagonists and ITKs against early blight and septoria leaf spot of tomato under *in vitro* conditions and the results revealed that, *T. harzianum* (IOF strain) was found superior in inhibiting conidia of early blight and septoria leaf spot of tomato.

The studies conducted on tomato fungal foliar disease management in polyhouse by Sindushree and Hegde, (2019a) revealed that, *T. harzianum* (IOF strain) used at 1 per cent is one of the most potential biocontrol agents in managing erly blight, septoria leaf spot, leaf mould diseases when used in integration with cow urine (10 %) and garlic leaf extract (10 %).

Ering and Simon (2017) conducted pot experiments for the evaluation of *Trichoderma* species against root knot nematode (*Meloidogyne incognita*) in tomato. The results revealed that, the treatments involving *Trichoderma* proved to be the most effective treatment that showed better larval mortality (54.55 % @ 24 hrs and 65.12 % @ 48 hrs) and reduction in nematode population (113.33 %) and root gall/ root system (74.89 %). The treatment of the soil with the antagonistic fungus improved nematode control as the isolates significantly reduced the nematode populations. The fungus enhanced plant growth and yield in all the treated pots. Trocoli *et al*. (2017) conducted experiment on field applications of *Trichoderma* which has reduced pineapple fusariosis severity and increased fruit weight. In this study, biological control with endophytic *Trichoderma* was investigated under field conditions to manage the disease. *Trichoderma* isolates TC26, TC59 and TC07 reduced disease severity by 70, 52.5 and 47 per cent and increased fruit weight by 56.5, 30.3 and 54.6 per cent, respectively. The best performing isolates were identified as *T. koningiopsis* and *T. harzianum* based on partial sequences of the tef-1α gene. These results indicate that *Trichoderma* isolates may be used to control fusariosis under field conditions.

Gade and Lad (2018) studied the biological management of major citrus diseases in central India. The *in vitro* antagonism by *T. harzianum* and *T. virens* (84.96 %) has suppressed *P. parasitica* significantly. Intensity of antagonism was different as per medium but, there was a continuous reduction in pathogen population from 41 to 8 propagules/g soil with reduction in root rot /collar rot in *Citrus jambhiri*. The results of systemic inducing resistance against late blight by applying antagonist *T. viride* showed that glucanase activity and total phenol content in plants treated with *T. viride* and fungicide (1587 µg/g and 1934 µg/g) significantly increased (Purwantisari *et al*., 2018). *T. viride* enhanced induced systemic resistance on potato plant and increased potato yield. Efficacy of *Trichoderma* against *Colletotrichum capsici* causing fruit rot due to anthracnose of chilli (*Capsicum annum* L.) Five *Trichoderma* species/strains, *T. virens* IMI-392430, *T. pseudokoningii* IMI-392431, *T. harzianum* IMI-392432, *T. harzianum* IMI-392433 and *T. harzianum* IMI-392434 were tested against anthracnose and fruit rot of chilli. Effect of *Trichoderma* species in suppressing anthracnose and fruit rot as well as the growth and yield of chilli were evaluated. (Rahaman *et al*., 2018). Chilli seeds treated with spore suspension or secondary metabolites of each *Trichoderma* species/strain and *C. capsici* separately. These results implied that *T. harzianum* IMI-392433 can effectively control fruit rot of chilli caused by *C. capsici* through host resistance and antifungal metabolite activity. The fruit yield was increased due to the influence of *T. harzianum* IMI-392433 on vigorous physiological growth of plants as well as efficacy against the disease. The efficacy of two biocontrol agents (*Bacillus subtilis* and *T. harzianum*), and a commercially formulated mixture of the chemicals fludioxonil plus mancozeb, applied as seed treatments in combination with different management practices. Results showed that the biological control agents *B. subtilis* and *T. harzianum* provided good control of sprout rot and seed piece decay caused by *F. sambucinum*, when seed was re-stored under optimal conditions or not restored at all. Under optimal conditions, treatment with *B. subtilis* reduced sprout rot and seed piece decay on average by 66 and 84 per cent, respectively. Treatment with *T. harzianum* reduced sprout rot and seed piece decay on average by 70 and 81 per cent, respectively (Muniroh *et al*., 2019). Hegde *et al.* (2019) studied the role of PGPR for multiple disease resistance in Tomato under protected cultivation that has resulted in lower incidence of early blight, septoria leaf spot and powdery mildew with maximum yields of tomato and also benefitted in increasing the plant height, number of fruits per clusters and number of pickings to tomato fruits. Hegde *et al.* (2020) reported influence of PGPRs against foliar diseases of tomato under protected cultivation.

Disease management in flower crops using different *Trichoderma* species

Dubsky *et al.* (2002) studied on Dual inoculation of peat-based horticulture substrate with a mixture of four species of arbuscular mycorrhizal fungi and fungal biocontrol agent *T. harzianum* which has showed a significant positive effect on the growth and flowering of cyclamen plants. Inoculation substantially decreased plant mortality caused by spontaneous infection by the fungal pathogen *Cryptocline cyclaminis*. Plant mortality was also reduced by separate inoculation with arbuscular mycorrhizal fungi. Both separately inoculated agents positively affected the plant growth, although to a lesser extent. Very few significant effects of inoculation were observed on the growth of poinsettia plants cultivated from cuttings. Use of arbuscular mycorrhizal fungi together with the introduction of *Trichoderma* was found effective. Sant *et al*. (2010) effect of *T. asperellum* strain T34 on *Fusarium* wilt and water usage in carnation grown on compost-based growth medium. The amendment of formulated grape marc compost with *T. asperellum* T34 improved the suppressive capacity of this growth medium against *Fusarium* wilt in carnation. It is a better alternative for plant and disease control than the standard chemicals used. Culture filtrates of *T. harzianum*, *T. viridi* and *P. fluorescence* were evaluated to control powdery mildew and black spot disease of rose plants. Culture filtrates of the mentioned biocontrol agents were used as 25, 50 and 75 per cent. *In vivo* evaluation of bioagents revealed that *P. fluorescence* was significantly superior followed by *T. viride* (both at 75 % concentration) whereas, *T. virens* was found to be least effective. The studies of two consecutive cropping seasons showed the superiority of *P. flourescence* in managing the disease effectively followed by *T. viride.* The biocontrol sprays also improve the quality of cut flowers (Dhakad, 2014).

Efficacy of *T. harzianum*, *Anearobacillus migululanas*, slow sand filtration, and ultraviolet (UV) treatment and sand filtration in eliminating *F. oxyporum*, artificially added in the recirculating nutrient solution, was evaluated with *Rosea* hybrid plants grown in closed soilless systems. The dynamics of these fungi in the recirculating nutrient solution and in the sand filter was also investigated (Nosir, 2016). *Trichoderma harzianum*, *A. migululanas*, UV treatment and slow sand filtration were effective in reducing *Fusarium* root rot. Slow sand filtration may be a more feasible disinfection method than UV because of lower costs of installation and maintenance and for its adaptability to a wide range of production systems. Disinfection techniques can be successfully combined with the application of antagonistic microorganisms.

Vinodkumar *et al.* (2017) used *T. asperellum* (NVTA2) as a potential antagonist for the management of stem rot in carnation under protected cultivation. *Trichoderma asperellum* (NVTA2) was superior in inhibiting the growth and development of stem rot pathogen up to 53.7 per cent *in vitro.* Crude metabolite extracted from *T. asperellum* (NVTA2), effectively inhibited the mycelial growth of *S. sclerotiorum* up to 374.4 mm^2. GC/MS profiling of crude extract revealed the presence of antifungal compounds including aliphatic hydrocarbons, terpenes and fatty acids. Root dipping and soil application of talc formulations of the *Trichoderma* spp. revealed that *T. asperellum* (NVTA2) effectively suppressed disease incidence up to 11.8 (PDI-Percent Disease Incidence) compared to the control (37.9 PDI), resulting in approximately 69 per cent reduction.

Prasanna *et al.* (2018) studied on *T. harzianum*, a fungus that controls soilborne pathogens, can enhance growth of several vegetable and floriculture crops. Zero, 5, or 25 g of *T. harzianum* (isolate T-12) peat-bran amendment was added per kilogram medium in an effort to enhance the rooting of four chrysanthemum [*Dendranthema* × *grandiflorum* (Ramath Kitamura] cultivars, two considered easy to root ('Davis' and 'White Marble') and two considered hard to root ('Dark Bronze Charm' and 'Golden Bounty'). Adding the *T. harzianum* amendment at both rates tested increased root and shoot fresh weights during 21 days of rooting, relative to the control. Amin *et al.* (2018) studied black spot, incited by the fungus *Diplocarpon rosae wolf*, and powdery mildew caused by *Sphaerotheca pannosa var. rosae* is a major problem in growing successful healthy rose gardens. Culture filtrates of *T. harzianum, T. viride* and *P. fluorescence* were evaluated to control powdery mildew and black spot disease of rose plants. Culture filtrates of the aforementioned biocontrol agents were used as 25, 50 and 75 per cent. Bioassays were conducted under field conditions during the two successive seasons of 2011 and 2012 at the experimental farm of the Faculty of Agriculture (FMAP) SKUAST-Kashmir to test the efficacy of these culture filtrates applied to protect rose plants from powdery mildew and black spot diseases. *In vivo* evaluation of bioagents revealed that *P. fluorescence* was significantly superior followed by *T. viride* (both at 75 % concentration) whereas, *T. virens* was found to be least effective. The studies of two consecutive cropping seasons from 2010-2011 to 2011-12 showed the superiority of *P. flourescence* in managing the disease effectively followed by *T. viride.* The biocontrol sprays also improve the quality of cut flowers.

Disease management in plantation crops using different *Trichoderma* species

The endophytic potential of biocontrol agent *T. stromaticum* was studied by De-Souza *et al.* (2008) in both shoot and root tissues of sterile and non-sterile cacao and bean seedlings. Agar plate and light and electron microscopy studies showed that *T. stromaticum* is able to colonize extensively both cacao and bean plants grown under sterile conditions. However, colonization was lower when plants were grown under non-sterile conditions, especially in the shoot tissues.

Mulaw *et al.* (2013) investigated the presence and the antagonistic activity of endophytic *Trichoderma* isolated from roots of healthy coffee plants (*Coffea arabica*) and results showed that community of *Trichoderma* spp. (*T. flagellatum* and *T. viridae*) in roots of *C. arabica* contains fungi from coffee rhizosphere, as well as putatively obligate endophytic fungi. They also found that strains of these species are also highly antagonistic against other phytopathogenic fungi, such as *A. alternata*, *Botryotinia fuckeliana* and *Sclerotinia sclerotiorum*.The dual inoculation with endomycorrhizae and *T. harzianum* had a significant effect on the growth of date palm plants. The average values of aerial fresh weight (38.99 g), number of leaves (6.7), the plant length (38 cm), and the stem diameter (1.2 cm) of the plant inoculated with AMF and *T. harzianum*, were higher than those inoculated only with AMF or just with *T. harzianum*. The mycorrhizal intensity of roots inoculated only with AMF (82 %) was higher than that of plants inoculated with AMF and *T. harzianum* (60 %), thus it seems that *T. harzianum* reduced root colonization by mycorrhizal fungi (Sghir *et al.*, 2014). Four native *Trichoderma* spp. (three *T. viride* and one *T. harzianum*) exerted inhibitory influence on the radial growth of *Corticium invisium* and *Pestalotiopsis theae* of tea. *T. viride* isolate 1, 2 and 3 caused inhibition of radial growth of *P. theae* in the range of 55- 63 and *C. invisum* in the range of 55-66 per cent. Maximum inhibition of radial growth of *C. invisum* (77 %) and *P. theae* (75 %) was caused by*T. harzianum* (Kabir *et al.*, 2016). Promwee *et al.* (2017) conducted experiment on effectiveness of controlling rubber leaf fall disease by indigenous *T. harzianum* application. The results indicated that the*T. harzianum* strain FR-NST-009, isolated from the rhizosphere soil of rubber trees, is more effective at inhibiting the mycelial growth of *P. palmivora* (66.22 %) than the Thai commercial strain *T. harzianum* CB-Pin-01 (63.51 %) with a dual culture technique. This result is clear from the mycoparasitism of the *T. harzianum* strain FR-NST-009 under scanning electron microscope.

Ahmed (2018) evaluated *in vitro* antifungal efficacy of the bioagents against all the pathogens causing root rot of date palm, where *T. harzianum* was the most effective as it caused 87.10, 81.55, 77.60 and 68.55 per cet reduction in the radial growth of *F. solani*, *F. oxysporum*, *R. solani* and *M. phaseolina*, respectively. *In vivo* assays under field conditions, all tested biotic treatments significantly reduced severity of root rot diseases caused by the concerned pathogens. Where *T. harzianum* was the most effective bioagent as it showed an increase in date palm survival of about 82.35 and 86.67 per cent. Neeraja *et al.* (2018) used different bioagents to control basal stem rot of coconut in light soils of Andhra Pradesh. Among different treatments tested, soil application of talc based formulation of 125 g of *T. reesei* and 125 g of *P. fluorescens* + 5 kg of Neem cake/ palm/year was found effective in reducing the disease index from 28.44 to 4.23 within a period of three (2014-2017) years and also found the increasing trend of the nut yield under field conditions. Biocontrol agents (BCA) like *P. aeruginosa* and *T. asperellum* were screened for their antagonistic properties against Basal stem rot (*Ganoderma boninense*) of oil palm, plant growth promoting traits and enzymatic activities. The result of dual culture test indicated that both BCAs were able to inhibit *G. boninense* growth with the percentage of inhibition radial growth (PIRG) values of 71.42 and 76.85 per cent, respectively. Besides that, both showed positive results for phosphate solubilizing activity and indole acetic acid (IAA) production. However, for siderophore production test, only *T. asperellum* exhibited positive siderophore production. These BCAs were also tested for their ability in producing hydrolytic enzymes such as chitinase, cellulose, and 1, 3, β-glucanase (Muniroh *et al.*, 2019). Among the biocontrol agents tested against fruit rot disease of arecanut, microbial consortia containing *T. harzianum* (IMI304056), *P. fluoroscens* (NCB19046) and *Bacillus megatarium* (NCTC9848) was found to be most effective in reducing the disease incidence as well as enhancing the development of new roots, increase in number of leaves and yield per palms indicating the merits of using bio agents (Naik *et al*., 2019). On the field, the application of *T. harzianum* suspension reduced the percentage of fruit infection and disease intensity for 48.57 and 46.04 per cent at 12 weeks after application (WAA), respectively in cacao plants. Based on the percentage reduction in the area of the spot between the metabolites *of T. harzianum* suspension and control were 47.24 and 27.46 per cent at 87 WAA, respectively. In addition, *T. virens* suppressed the percentage of infected fruit and the intensity of infected fruit for 40.61 and 38.02 per cent at 12 WAA (Sriwati *et al.,* 2019).

Disease management in spices using different *Trichoderma* species

Vijayan *et al*. (1994) isolated exotic and native *T. viride*. and *T. harzianum* and were tested against the pathogen under *in vitro* conditions. These isolates were further evaluated in disease-prone areas in the cardamom field. Results showed that all the isolates tested showed antagonistic activity through hyphal coiling, penetration and lysis of the hyphae of the pathogen besides inducing growth inhibition of the latter. Among the nine isolates tested in the field, eight were found effective in controlling the disease incidence. An exotic isolate of *T. harzianum* and a native isolate of *T. viride* were found to be most effective, the reduction in disease incidence being upto 52 to 69 per cent. An experiment was conducted to assess the eficacy of a *T. herzianum* formulation on the wilt disease of cumin caused by *F. oxysporum* f. sp. *cumilli* and crop yield. The results showed that in *Trichoderma* seed treatment plots, per cent wilt disease was 9.2 to 23.8 and 8.5 to 21.4 compared to 68.3 and 69.67 in control during 1st and 2nd years of experiment, respectively. In *Trichoderma* treatment the yield recorded was 6.17 to 6.73 and 6.33 to 6.89 q/ha compared to 4.39 and 4.73 q/ha in untreated control during 1st and 2nd years of experiment, respectively (Singh *et al.,* 2007).

A study by Gupta *et al*. (2010) concluded that the combination of *T. harzianum* + *P. fluroscens* + *Glomus*

Table 2. Impact of PGPF on plant growth and development: Indian experiences (Srikant Kulkarni *et al.*, 2004 and Jahagirdar *et al.*, 2019)

Crop	Pathogen/Disease	Specific effect of BCA/Endophyte	Reference
Banana	*Fusarium oxysporium* f sp.*cubense*/wilt	BCAs such as *Trochoderma viride, Pseudomonas fluorescens and Bacillus subtilis* suppressed pathogens both *in vitro* and *in vivo.* Plant growth promotion and disease suppression	Jahagirdar *et al*., 2000
Black pepper	*Phytophthora capsici*/ Phytophthora foot rot	Soil application of *T.viride* (75 g/plant)+spraying with metalaxyl (1.25 g/l)+Akomin (4 ml/l) or MPG 3 (10^1); PGP activity.	Jahagirdar *et al*., 2000
Tomato	*F. o*. f sp. *lycopersici/* Damping off of tomato in nursery and main field	MPG-3 as PGPR component and ISR activity	Bhaskar Padmodaya, 1994 and Jahagirdar *et al.,* 2003
Chickpea	Fusarium wilt	Seed treatment with *Trichoderma harzianum* 4 g/kg seeds	Jahagirdar *et al.,* 2002
Soybean	*Phakopsora pachyrhizi*/ Asian soybean rust	*Trichoderma harzianum* @ 6 g/kg+ Spray with Cow urine @ 10%+*T.harzianum* @ 0.5%: Upregulation defense genes reflected by isozyme studies and PGP activity	Jahagirdar *et al*., 2013
Pineapple	Heart rot of Pineapple	Among various treatments the treatment *viz*, soil application of neem enriched *Trichoderma* @ 20g/hill followed by sucker treatment with Metalaxyl MZ @ 0.3 percent and two sprays with fosetyl-Al @ 0.1 % resulted in significant reduction in disease incidence (21.22%) followed by soil application of neem enriched *Trichoderma* @ 20 g/hill followed by sucker treatment with Metalaxyl MZ @ 0.3 % and two sprays of fosetyl-Al @ 0.1 % and subsequent spray with metalaxyl MZ @ 0.1 % (22.77%).	Hegde, 2015
Nothopadytes nimmoniana (Mappia)	*Cylindrosporium mappiae*	Role of PGPR in the management of Leafspot disease of an anti cancer drug yielding tree.	Shweta and Hegde, 2019
Cucumber	Powdery mildew and Downy mildew	Efficacy of biocontrol agents against fungal foliar diseases of vegetables in organic cultivation under protected condition.	Hegde, 2019

mosseae, whose performance was superior to individual strains in reducing rhizome rot and promoting growth of ginger under greenhouse condition.

The highly efficient antagonists *viz*., *T. viride*- II, *T. harzianum*- II and *P. fluorescens* were also studied to know their biocontrol efficiency under pathogen sick soil (pot) condition in coriander. Both the fungal antagonist controlled disease more efficiently when used individually rather than their combination. *T. viride*- II found to be the most effective (Bhaliya, 2011). Nine isolates of *T. viride* namely TK_1, TK_3, TK_4, TK_6, TK_8, TK_9, TK_{10}, TK_{11} and TK_{15} were isolated from soils of different Saffron orchard plantations of Kashmir valley on modified *Trichoderma* specific medium. The isolates TK_1, TK_3, TK_4, TK_8, TK_9, TK_{11} and TK_{15}, were found fully overgrown on all corm rot pathogens of saffron, where as the isolates TK_{13} failed to inhibit the *Phytophthora* sp. (Hassan *et al*., 2011). *In vitro* studies on biocontrol agents against turmeric rhizome rot pathogen *Pythium aphanidermatum* revealed that fungal bioagent was inhibiting the growth of pathogen. *T. viride* (79 mm) was found in effeictive inhibiting the colony growth of *Pythium aphanidermatum.* (Maheshwari and Sirchabai, 2011). An experiment was conducted by Bhat *et al*. (2016) to control the *Fusarium* wilt of chilli. The result revealed that, *T. harzianum* isolates 1, 2 and 5 and *T. viride* isolate 2 has completely overgrew *F. solani* and inhibited mycelia growth by 40-50 per cent *in vitro*. *T. viride* gave moderate effect against wilt and increased yield upto 30 per cent in Haveri district, while at Ballari, *T. harzianum* isolate 1 reduced wilt incidence by 39.7 per cent.

The novel isolates, *T. asperellum* strain AFP, *T. asperellum* strain MC1, *T. brevicompactum* MF1 and *T. harzianum* strain CH1 were tested for their efficacy in managing various soil-borne phytopathogens such as *F. oxysporum*, *R. solani* and *P. capsici* in black papper and ginger. The results of antimycotic activity of these isolates showed that *T. harzianum* exhibited maximum mycelial growth inhibition over *F. oxysporum* (78.3 %) and *Phytophthora capsici* (65.3 %) than *T. asperellum* (Strain AFP and MC1) and *T. brevicompactum* (MF1) (Dutta and Das, 2019). The impact of PGPF on plant growth and development: Indian experience are presented in Table 2.

Future Thrust

Registration requirement need to be revised and include fact that *Tricoderma* bio-fungicides are entering market as plant growth promoters. The research need to be more focussed on developing consortium of the different species or isolates of *Tricoderma* itself and *Tricoderma* as well as other microbes which can be effectively intigrated in different integrated management modules currently used by farmers.

References

Abdel-Kader M M, Nehal S El-Mougy, Aly M D E, Lashin S M, 2012, Integration of biological and fungicidal alternatives for controlling foliar diseases of vegetables under greenhouse conditions. *International Journal of Agriculture and Forestry*, 2(2): 38-48.

Abdollahzadeh J, Mohammadi Goltapeh E and Rouhani H, 2006 , Biological control of Sclerotinia stem rot (*S. minor*) of sunflower using *Trichoderma* species. *Plant Pathology Journal,* 5: 228-232.

Aditya S and Hegde G M, 2019, Effect of PGPMS on the management of fungal foliar diseases and in growth promotion of groundnut. Presented In: *ISMPP 40th Annual Conference and National Symposium on Microbial Strategies for Improvement of Soil and Plant Health,* 24-26 September, 2019, Karnataka University, Dharwad.

Ambadkar C V and Jadhav V T, 2007, Effect of different bioinoculants on seed germination, seedling emergence and seedling mortality of Rangpur lime. *International Journal Plant Science*, 2(1): 72-74.

Amin F, Qazi N A, Banday S, Dar S H and Shahnaz E, 2018, Biological control of powdery mildew and black spot diseases of rose. *Journal of Pharmacognosy and Phytochemistry*, 7(3): 2826-2828.

Ahmed M F A, 2018, Management of date palm root rot diseases by using some biological control agents under organic farming system. *Novel Research in Microbiology Journal*, 2(2): 37-47.

Bastakoti S, Belbase S, Manandhar S and Arjyal C, 2017, *Trichoderma species* as biocontrol agent against soil borne fungal pathogens. *Nepal Journal of Biotechnology,* 5(1): 39-45.

Bhaliya C M, 2011, Management of coriander (*Coriandrum sativum* L.) root rot caused by Fusarium solani (Mart.) Sacc. *M. Sc. (Agri.) Thesis,* Junagadh Agricultural University, Junagadh, Gujarat, India.

Bhat M N, Mesta R, Yenjerappa S T, Tatagar M H, Sardana H R, Singh D, Vennila S, Sabir N and Ahmad M, 2016, Biological control of *Fusarium* wilt of chillies using *Trichoderma* spp. *Indian Journal of Horticulture*, 73(1): 74-77.

Bhattacharyya S K, Sengupta C, Adhikary N K and Tarafdar J, 2016, *Trichoderma aureoviridae*: a potential organism for bio-prospecting against *Macrophomina phaseolina* (Tassi) Goid. in jute. *Bangladesh Journal of Botany,* 45(5): 1219-1223.

Bhaskar Padmodaya, 1994, Integrated management of Fusarium wilt of tomato, *Ph. D. Thesis* University of Agricultural Sciences, Bengaluru, Karnataka, India.

Chaverri P and Gazis R, 2011, *Trichoderma amazonicum*, a new endophytic species on *Hevea brasiliensis* and *H. guianensis* from the Amazon basin. *Mycologia,* 103: 139-151.

Das M M, Haridas M and Sabu A, 2019, Biological control of black pepper and ginger pathogens, *Fusarium oxysporum*, *Rhizoctonia solani* and *Phytophthora capsici*, using *Trichoderma* spp. *Biocatalysis Agricultural Biotechnology*, 17(1): 177-183.

De-Souza J T, Bailey B A, Pomella A W V, Erbe E F, Murphy C A, Bae H and Hebbar P K, 2008, Colonization of cacao seedlings by *Trichoderma stromaticum*, a mycoparasite of the witches' broom pathogen, and its influence on plant growth and resistance. *Biological Control*, 8(2): 1-10.

Dhakad J K, 2014, Plant growth promoting effect of *Trichoderma* on groundnut. *International Journal of Research,* 3(4): 342-352.

Doni F, Isahak A, Zain C R C M and Yusoff W M W, 2014, Physiological and growth response of rice plants (*Oryza sativa* L.) to *Trichoderma* spp. inoculants. *AMB Express*, 4(1): 45-52.

Dubey S C, Bhavani R and Singh B, 2011, Integration of soil application and seed treatment formulations of *Trichoderma* species for management of wet root rot of mungbean caused by *Rhizoctonia solani*. *Pest Management Science,* 67(9): 1163-1168.

Dubsky M, Sramek F and Vostka M, 2002, inoculation of Cyclamen *persicum Euphorbia pulcherrima* with arbuscular mycorrhizal fungi and *Trichoderma harzianum. Agronomie,* 48(2): 63-68.

Dutta P and Das B C, 2002, Management of collar rot of tomato by *Trichoderma* spp. and chemicals. *Indian Phytopathology*, 55(2) : 235-237.

Elad Y, 1994, Biological control of grape grey mould by *Trichoderma harzianum*. *Crop Protection*, 13: 35-38.

Ering M and Simon S, 2017, Effect of *Trichoderma spp.* against Root-Knot nematode (*Meloidogyne incognita*) on tomato (*Lycopersicon esculentum* L.) *International Journal of Current Microbiology and Applied Sciences,* 7(12): 746-753.

Gade R M and Lad R S, 2018, Biological management of major citrus diseases in central India. *International Journal of Current Microbiology and Applied Sciences,* 6: 296-308.

Gajera H, Domadiya R, Patel S, Kapopara M and Golakiya B, 2013, Molecular mechanism of *Trichoderma* as bio-control agents against phytopathogen system - a review. *Current Research in Microbiology and Biotechnology,* 1: 133-142.

Ghante P H, Kanase K M, Gaikwad P A, Pawar S V and Magar S J, 2019, The efficacy of bioagents against *Fusarium oxysporum* f. sp. *udum* causing wilt disease of Pigeonpea. *Journal of Pharmacognosy and Phytochemistry,* 8(1): 1966-1971

Gupta M, Dohroo N P, Gangta V and Shanmugam V, 2010, Effect of microbial inoculants on rhizome disease and growth parameters of ginger. *Indian Phytopath*ology, 63(4): 438-441.

Harman G E, Petzoldt R, Comis A and Chen J, 2004, Interactions between *Trichoderma harzianum* strain T22 and maize inbred line Mo17 and effects of these interactions on diseases caused by *Pythium ultimum* and *Colletotrichum graminicola*. *Phytopathology*, 94(2): 147-153.

Hassan M G, Devi L S, Ahmad S, Manojkumar V and Williams P, 2011, Antagonistic potential of native isolates of *Trichoderma viride* on corm rot pathogen complex of saffron (*Crocus sativus*) in Kashmir. *Plant Pathology Journal*, 10(2): 73-78.

Hassan M M, Azrag M A, Rugheim A M, Abusin R M, Elnasikh M H, Modawi H I, Ahmed M M, Abakeer R A, Osman A G, Abdelgani M E and Babiker A G E, 2019, Potential of *Trichoderma harzianum* as a biocontrol agent against *Striga hermonthica* in sorghum. *International Journal of Current Microbiology and Applied Sciences,* 8(3): 195-206.

Hegde G M, 2015, Integrated management of heart rot of pineapple. *The Bioscan*, 9(3):1229-1232.

Hegde G M and Kulkarni S, 2001, Seed treatment to control damping off of chilli caused by *Colletotrichum capsici. Karnataka Journal of Agricultural Sciences,* 14 (3): 829-830.

Hegde G M, 2019, Efficacy of biocontrol agents against fungal foliar diseases of vegetables in organic cultivation under protected condition. IPS - *National Symposium on Transdesciplinary approaches to Plant Pathology Research, Education and Extension in response to Changing climate: The way ahead*, 6-7 December, 2019, University of Agricultural Sciences, Raichur, Karnataka, India.

Hegde G M, Kulkarni Sripad, Malligawad L H and Sreenivasa M N, 2019, Bioactive compounds for management of mildews of cucumber under polyhouse condition. IPS- *National Symposium on Transdesciplinary Approaches to Plant Pathology Research, Education and Extension in response to Changing climate: The way ahead*, 6-7 December, 2019, University of Agricultural Sciences, Raichur, Karnataka, India.

Hegde G M, Malligawad L H and Sreenivasa M N, 2020, Influence of PGPR against fungal foliar disease of tomato under protected cultivation. *7th International Conference on Phytopathology in Achieving UN Sustainable Development Goals.* January 16-20, 2020, New Delhi, India.

Howell C R, DeVay J E, Garber R H and Batson W E, 1997, Field control of cotton seedling diseases with *Trichoderma virens* in combination with fungicide seed treatments. *Journal of Cotton Science,* 1: 15-20.

Ikram M, Ali N, Jan G, Iqbal A, Hamayun M, Gul Jan F, Hussain A and Lee I J, 2019, *Trichoderma reesei* improved the nutrition status of wheat crop under salt stress. *Journal of Plant Interaction,*14(1): 590-602.

Javaid A, Afzal L and Shoaib A, 2017, Biological control of charcoal rot of mungbean by *Trichoderma harzianum* and shoot dry biomass of *Sisymbrium irio. Planta Daninha*, 3(5): 1-12

Jahagirdar S, Ravikumar M R and Siddaramaiah A L, 2003, Traditional methods in the management of plant diseases. *Agricultural Reviews*, 24 (2): 142-146.

Jahagirdar Shamarao, Yenjerappa S T, Ravikumar M R and Jamadar M M, 2002, Field screening of biocontrol agents against chick pea wilt. *Legume Research*, 25: 299-300.

Jahagirdar S, Siddaramaiah A L and Chandrappa H M, 2000, Eco friendly integrated management of foot rot of black pepper (*Piper nigrum* L.), *Mysore Journal of Agricultural Sciences*, 34: 47-54.

Jahagirdar S, Siddaramiah A L and Ramaswamy G R, 2000, Influence of biocontrol agents and MPG-3 on *Fusarium oxysporum* f.sp. cubense as incitant of panama disease of banana. *Plant Disease Reporter,* 15: 241-243.

Jahagirdar S, Sachin K, Ramesh B, Basavaraja G T and Yogesh B, 2013, Biointensive management of Asian soybean rust caused by *Phakopsora pachyrhizi* Syd. *Research on Crops,* 14(1): 182-188.

Jahagirdar S, Kambrekar D N, Navi S S and Kunta M, 2019, Plant growth promoting fungi: Diversity and classification. In: *Bioactive Molecules in Plant Defense Signaling in Growth and Stress* (Ed. Sudisha Jogaiah, Mostafa Abdelrahman), Springer International Publishing, UK, pp. 200-225.

Jessica B O, Paulo Henrique P C, Muniz, Gustavo Henrique S, Peixoto, Thiago A S de Oliveira Elizabeth A A, Duarte, Fabrício Rodrigues and Daniel Diego C Carvalh, 2018, Promotion of seedling growth and production of wheat by using *Trichoderma* spp. *Journal of Agricultural Science*, 10(8): 267-276.

Jyotsna, Srivastava A, Singh R P, Srivastava A K, Saxena A K and Arora D K, 2008, Growth promotion and charcoal rot management in chickpea by *Trichoderma harzianum*. *Journal of Plant Protection Research*, 48(1): 1-12.

Kabir S E, Debnath S, Mazumder A, Dey T and Bera B, 2016, *In vitro* evaluation of four native *Trichoderma* spp isolates against tea pathogens. *Indian Journal of Fundamental and Applied Life Sciences*, 6(2): 1-6.

Kader M M A, Mougy N S E, Aly M D E, Lashin S M F and Kareem A, 2012, Greenhouse biological approach for controlling foliar diseases of some vegetables. *Advances in Life Sciences,* 2(4): 98-103.

Khadka R B and Uphoff N, 2019, Effects of *Trichoderma* seedling treatment with System of Rice Intensification management and with conventional management of transplanted rice. *Peer J - the Journal of Life and Environmental Sciences,* 7(1): 5877-5889.

Khaledi N and Taheri P, 2016, Biocontrol mechanisms of *Trichoderma harzianum* against soybean charcoal rot caused by *Macrophomina phaseolina*. *Journal of Plant Protection Research*, 56(1): 21-31.

Khalili E, Sadravi M, Naeimi S and Khosravi V, 2012, Biological control of rice brown spot with native isolates of three *Trichoderma* species. *Brazilian Journal of Microbiology,* 43(1): 297-305.

Khan M R, Ashraf S, Rasool F, Salati K M, Mohiddin F A and Haque Z, 2014, Field performance of *Trichoderma* species against wilt disease complex of chickpea caused by *Fusarium oxysporum f.* sp. *ciceri* and *Rhizoctonia solani*. *Turkish Journal of Agriculture and Forestry,* 38(4): 447-454.

Mahato S, Bhuju S and Shrestha J, 2018, Effect of *Trichoderma viride* as biofertilizer on growth and yield of wheat. *Malaysian Journal of Sustainable Agriculture*, 2(2): 1-5.

Maheswari N U and Sirchabai T P, 2011, Effect of Trichoderma species on *Pythium aphanidermatum* causing rhizome rot of turmeric. *Biosciences Biotechnology Research Asia,* 8(2): 17-25.

Mukherjee P K, Upadhy J P and Mukhopadhyay A N, 1989, Biological control of pythium damping-off of cauliflower by *Trichoderma harzianum*. *Journal of Biological Control,* 3(2): 119.124.

Mukhtar I, 2008, Influences of *Trichoderma* species on seed germination in okra. *Mycopathology,* 6(1): 47-50.

Mulaw T, Druzhinina I S and Kubicek C, 2013, Novel endophytic *Trichoderma* spp. isolated from healthy *Coffea arabica* roots are capable of controlling coffee Tracheomycosis. *Diversity*, 5: 750-766.

Muniroh M S, Nusaibah S A, Vadamalai G and Siddique Y, 2019, Proficiency of biocontrol agents as plant growth promoters and hydrolytic enzyme producers in *Ganoderma boninense* infected oil palm seedlings. *Current Plant Biology,* 20: 1-9.

Muthukumar A, Eswaran A, and Sanjeev K, 2011, Exploitation of *Trichoderma* species on the growth of *Pythium Aphanidermatum* in chilli. *Brazalian Journal of Microbiology,* 42(4): 1598-1607.

Naik B G, Maheshwarappa H P, Nagamma G and Latha S, 2019, Management of fruit rot disease of arecanut (*Areca catechu* L.) caused by (*Phytophthora meadii* Mc Rae.). *International Journal of Current Microbiology and Applied Sciences*, 8(4): 837-847.

Neeraja B, Snehalatharani A, Maheshwarappa H P, Ramanandam N B V, Chalapathi Rao and Padma E, 2018, Management of basal stem rot (*Ganoderma* wilt) in coconut with effective bioagents under field condition. *International Journal of Current Microbiology and Applied Sciences,* 7(9): 1051-1060.

Niranjana S R, Lalitha S and Hariprasad P, 2009, Mass multiplication and formulations of biocontrol agents for use against fusarium wilt of pigeonpea through seed treatment. *International Journal of Pest Management,* 55(4): 317-324.

Nosir W S, 2016, *Trichoderma harzianum* as a growth promoter and bio-control agent against *Fusarium oxysporum* f. sp. *tuberose*. *Advances in Crop Science and Technology*, 4: 2-7.

Porras M, Barrau C and Romero F, 2009, Biological control of anthracnose with *Trichoderma* in strawberry fields. *Acta Horticulturae,* 842: 351-354.

Prabakar K, Raguchander T, Kumar S D, Muthulakshmi T, Prathiban V and Prakasham V K, 2015, Management of postharvest disease of mango anthracnose incited by *Colletotrichum gleosporioides*. *Archives of Phytopathology and Plant Protection,* 16(2): 75-87.

Prasad R D, Rangeshwaran R, Hegde S V and Anuroop C P, 2002, Effect of soil and seed application of *Trichoderma harzianum* on pigeonpea wilt caused by *Fusarium udum* under field conditions. *Crop Protection*, 21(4): 293-297.

Prasanna R, Saxena G, Singh B, Ranjan K, Buddhadeo R, Velmourougane K, Ramakrishnan B, Nain L, Singh M C, Hasan M and Shivay Y S, 2018, Mode of application influences the bio fertilizing efficacy of cyanobacterial biofilm formulations in chrysanthemum varieties under protected cultivation. *Horticultural Science,* 30(1): 478-89.

Promwee A, Yenjit P, Issarakraisila M, Intana W and Chamswarng C, 2017, Efficacy of indigenous *Trichoderma harzianum* in controlling Phytophthora leaf fall (*Phytophthora palmivora*) in Thai rubber trees. *Journal Plant Disease Protection*, 124(1): 41-50.

Purwantisari S, Priyatmojo A, Sancayaningsih R P, Kasiamdari S R and Budihardjo K, 2018, Systemic inducing resistance against late blight by applying antagonist *Trichoderma viride*. *IOP Conference Series: Journal of Physics*, 1025: 1-6.

Rahman M A, Ansari T H, Alam M F, Moni J R and Ahmed M, 2018, Efficacy of *Trichoderma* against *Colletotrichum capsici* causing fruit rot due to anthracnose of chilli (*Capsicum annum* L.) *The Agriculturists*, 16(02): 75-87.

Ramesh R and Korikanthimath V S, 2006, Management of groundnut root rot by *Trichoderma viride* and *Pseudomonas fluore*scens under rainfed conditions. *Indian Journal of Plant Protection*, 34(2): 239.

Rifai M A, 1969, A revision of genus *Trichoderma.* In: Mycological Series 116. Pub. Kwe : Commonwealth Mycological Institute.

Rey M, Delgado-Jarana J and Benitez T, 2001, Improved antifungal activity of a mutant of *Trichoderma harzianum* CECT 2413 which produces more extracellular proteins. *Applied Microbiology and Biotechnology*, 55: 604-608.

Rudresh D L, Shivaprakash M K and Prasad R D, 2005, Effect of combined application of *Rhizobium,* Phosphate solubilizing bacterium and *Trichoderma spp.* on growth, nutrient uptake and yield of chickpea (*Cicer aritenium* L.). *Agriculture, Ecosystems and Environment,* 28(2): 139-146.

Saber W I, Ghoneem K M, Rashad Y M and Al-Askar A A, 2017, *Trichoderma harzianum* WKY1: an indole acetic acid producer for growth improvement and anthracnose disease control in sorghum. *Biocontrol Science and Technology*, 27(5): 654-676.

Sant D, Casanova E, Segarra G, Avilés M, Reis M and Trillas M I, 2010, Effect of *Trichoderma asperellum* strain T34 on Fusarium wilt and water usage in carnation grown on compost-based growth medium. *Biological Control*, 53(3): 291-296.

Sarrocco S, Guidi L, Fambrini S, Del'Innocenti E and Vannacci G, 2009, Competition for cellulose exploitation between *Rhizoctonia solani* and two *Trichoderma* isolates in the decomposition of wheat straw. *Journal of Plant Pathology*, 91: 331-338.

Schnabel G, Rollins A P and Henderson G W, 2011, Field evaluation of *Trichoderma* spp. for control of Armillaria root rot of peach. *Plant Health Progress,* doi.org/10.1094/PHP-2011-1129-01-RS.

Sghir F, Chliyeh M, Touati J, Mouria B and Ouazzani A, 2014, Effect of a dual inoculation with endomycorrhizae and *Trichoderma harzianum* on the growth of date palm seedlings. *International Journal of Pure and Applied Bioscience*, 2(6): 12-26.

Shanmugaiah V, Balasubramanian N, Gomathinayagam S, Manoharan P T and Rajendran A, 2009, Effect of single application of *Trichoderma viride* and *Pseudomonas fluorescens* on growth promotion in cotton plants, *African Journal of Agricultural Research,* 4(11): 1220-1225.

Sharma P, Raja S M and Shanmugam V, 2014, Status of *Trichoderma* research in India: A review. *Indian Phytopathology,* 67 (1) : 1-19.

Shweta V R and Hegde G M, 2019, Role of PGPR in the management of leaf spot disease of Nothopadytes nimmoniana an anti cancer drug yielding tree. Presented In: ISMPP 40th *Annual Conference and National Symposium on Maicrobial Strategies for Improvement of Soil and Plant Health*, 24-26 September 2019, Karnataka University, Dharwad, Karnataka, India.

Singh H B, Shishir S, Singh A and Katiyar R S, 2007, Field efficacy of *Trichoderma harzianum* application on wilt disease of cumin caused by *Fusarium oxysporum* f. sp. *cumini*. *Journal of Biological Control,* 21(2): 317-319.

Singh V, Ranaware A M and Nimbkar N, 2008, Bioefficacy of antagonists against root-rot fungus *Macrophomina phaseolina* of safflower. In: *Safflower: Unexploited Potential and World Adaptability* (Eds. Knights S E and Potter T D), Proceedings of the 7th International safflower Conference, Wagga Wagga, New South Wales, Australia.

Srikant Kulkarni, 2004, *Trichodema*-A potential bioagent of millennium. Paper Presented in *13th Southern Regional Conference on Microbial Inoculants. Microbes; Wheels of Organic Farming*, Agril. College, Bijapur, 3-5, December, 2004, pp. 36-44.

Sindhushree D R and Hegde G M, 2019, *In vitro* evaluation of botanicals, antagonists and ITKs against ealry blight and septoria leafspot of Tomato. IPS- *National Symposium on Transdesciplinary Approaches to Plant Pathology Research, Education and Extension in response to Changing climate: The way ahead,* 6-7 December 2019, University of Agricultural Sciences, Raichur, Karnataka, India.

Sindhushree D R and Hegde G M, 2019a, Eco-friendly management of fungal foliar diseases of Tomato by using botanicals, bioagents and ITKs under protected cultivation. IPS- *National Symposium on Transdesciplinary Approaches to Plant Pathology Research, Education and Extension in response to Changing climate: The Way ahead*, 6-7 December 2019, University of Agricultural Sciences, Raichur, Karnataka, India.

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.

Sriwati R, Chamzurn T, Soesanto L and Munazhirah M, 2019, Field application of *Trichoderma* suspension to control cacao pod rot (*Phytophthora palmivora*). *Journal of Agricultural Sciences*, 41(1): 13-21.

Suhanna, Aifaa Y. and Shazalwardi S, 2013, *Trichoderma* sp. as a biological control agent in the postharvest treatment of mango stem-end rot. *Acta Horticulturae,* 1012: 775-781.

Trocoli R O, Monteiro F P, Santos P O and Souza J T, 2017, Field applications of *Trichoderm*a reduce pineapple fusariosis severity and increase fruit weight. *Journal of Plant Pathology*, 99 (1): 225-228.

Vazquez M M, Cesar S, Azcon R and Barea J M, 2000, Interactions between arbuscular mycorrhizal fungi and other microbial inoculants (*Azospirillum, Pseudomonas, Trichoderma*) and their effects on microbial population and enzyme activities in the rhizosphere of maize plants. *Agriculture Ecosystems and Environment,* 15(3): 261-272.

Vijayan A K, Thomas J, Dhanapal K and Naidu R, 1994, Field evaluation of *Trichoderma* isolates in the bio-control of rhizome rot disease of small cardamom. *Journal of Biological Control*, 8: 111-114.

Vinodkumar S, Indumathi T and Nakkeeran S, 2017, *Trichoderma asperellum* (NVTA2) as a potential antagonist for the management of stem rot in carnation under protected cultivation. *Journal of Biological Control*, 113(3): 58-64.