Trichoderma Species: Versatile Bio-agents for Eco-friendly Plant Disease Management

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Abstract

Agriculture remains indispensable for feeding billions of people worldwide; however, plant pathogens consistently threaten crop production, causing substantial annual losses. Chemical pesticides have been extensively employed to protect crops from these yield reductions. Prolonged application of chemical pesticides contaminates water resources, contributes to atmospheric pollution, and sometimes leaves harmful residues that promote resistance development in target organisms. Given the adverse effects of chemical pesticides, sustainable crop production through eco-friendly management approaches has become essential in the current agricultural scenario. Among biological control options, the genus *Trichoderma* stands out as one of the most effective bioagents, demonstrating significant efficacy against diverse soil-borne, seed-borne, and foliar pathogens. These fungal species provide multifaceted benefits at various levels of agricultural systems.

Keywords: *Trichoderma* strains, mycoparasitism, antibiosis, competition, bio-control agents

Introduction

Agriculture plays a critically important role in ensuring food security, alleviating poverty, and conserving vital natural resources upon which present and future generations depend for survival and wellbeing. Agricultural crops remain vulnerable to attacks by numerous pests including bacteria, fungi, weeds, and insects, resulting in reduced yields and diminished product quality. Many plant pathogens causing significant diseases in cereals, oilseeds, pulses, vegetables, fiber crops, and fruits are seed-borne or soil-borne in nature. Continuous cultivation of the same crop on a given land parcel leads to heavy incidence of soil-borne diseases due to pathogen inoculum buildup, forcing farmers to change either crops or cultivation sites.

Fungicides play an important role in managing seed-borne and airborne pathogens. However, soil-borne plant pathogens often prove difficult to control through fungicides and conventional methods due to limitations in effectiveness against these pathogens. In recent years, indiscriminate and expensive pesticide use has created serious pollution problems in ecosystems and promoted pathogen resistance development. Farmers face pesticide residue issues in soil, air, water, and food, while broader consequences include phytotoxicity, physiological abnormalities, diseases, mortality, population shifts, genetic disorders, and gene erosion affecting plants, mammals, birds, insects, and other organisms. Consequently, biological control of pathogens has gained prominence as an integral component of integrated disease (pest) management (IDM) for sustainable agriculture, offering long-lasting and eco-friendly solutions.

Currently, several biocontrol agents have been identified and are commercially available as fungal agents including *Trichoderma* spp., *Gliocladium virens*, *G. roseum*, *Aspergillus niger*, *A. flavus*, *Chaetomium globosum*, *Ampelomyces* spp., *Candida* spp., and *Coniothyrium* spp., along with bacterial agents such as *Bacillus subtilis*, *B. cereus*, *Pseudomonas fluorescens*, *Agrobacterium radiobacter*, and others. These antagonists have demonstrated effectiveness against numerous fungal plant pathogens under both *in vitro* and *in vivo* conditions. Among these biocontrol agents, *Trichoderma* spp. represents one of the most versatile options, having long been utilized for managing plant pathogenic fungi.

Genus Trichoderma and Their Habitats

The fungal genus *Trichoderma* was first described in 1794, encompassing anamorphic fungi primarily isolated from soil and decomposing organic matter (Persoon, 1794). The term *Trichoderma* derives from two Greek words: *thrix* (hair, meaning thread-like) and *derma* (skin). This genus comprises soil-inhabiting green filamentous fungi belonging to the division Ascomycota, which reproduce asexually. In the early 1930s, *Trichoderma* was introduced as possessing biocontrol capabilities (Weindling, 1934). *Trichoderma* functions as an opportunistic, avirulent plant symbiont that acts antagonistically and parasitically against many plant pathogenic fungi, offering protection from phytopathogenic diseases. Numerous studies have confirmed that *Trichoderma* spp. serve as effective biocontrol agents for managing plant diseases (Table 1), and commercial *Trichoderma* products are currently available as biopesticides, soil amendments, or plant growth enhancers (Papavizas, 1985; Vinale et al., 2008). The efficacy of *Trichoderma* depends on various abiotic parameters including soil pH, water retention capacity, temperature, and heavy metal presence. The genus *Trichoderma* comprises more than 80 species useful for controlling phytopathogenic fungi.

Among these, *T. harzianum*, *T. viride*, *T. hamatum*, *T. polysporum*, *T. pseudokoningii*, *T. deliquescens*, *T. aureoviride*, *T. koningii*, *T. lignorum*, *T. reesei*, *T. longibrachiatum*, and *T. virens* (formerly *Gliocladium virens*) are considered the most promising biocontrol agents. *Trichoderma* species occur worldwide and are commonly associated with roots, soil, plant debris, forest humus, and orchids. Table 2 presents some commercially available biocontrol products in the market.

Mode of Action

Trichoderma spp. function as biocontrol agents effective against fungal phytopathogens through three primary antagonistic processes:

1. Mycoparasitism/Hyper-parasitism

This mechanism involves various interactions including hyphal coiling around target organisms, penetration, haustoria production, and hyphal lysis through secretion of intercellular lytic enzymes such as glucanase, cellulase, chitinase, protease, and lipase. These enzymes disintegrate pathogen cell walls, effectively destroying the target organism.

2. Antibiosis

This process involves liberation of antibiotic-like substances or other chemical metabolites by antagonistic fungi, including compounds like *Trichodermin* and *viridin*. These metabolites harm pathogens by inhibiting or killing their growth.**3. Competition**

Competition occurs when suppression of one organism (target pathogen) results from two species struggling for limited quantities of nutrients, oxygen, space, or other requirements.

Methods of *Trichoderma* spp. Application

1. Seed Treatment

Apply 8-10 g *Trichoderma* spp. (powder formulation, 2×10^6 CFU/g) with 50 ml water for larger seeds, or 6-8 g for small seeds, treating one kg seed before sowing. For liquid formulation, apply 5-10 ml *Trichoderma* spp. per liter of cow dung slurry for treating one kg seed before sowing, particularly for cereals, pulses, and oilseeds. Shade dry treated seeds for 20-30 minutes before sowing. Seed treatment proves highly effective against seed and soil-borne diseases.

2. Seed Biopriming

Seed biopriming involves treating seeds with *Trichoderma* formulations (@ 5-10 g/kg seed) and incubating under moist, warm conditions until just before radicle emergence. Sow bioprimed seeds immediately after radicle emergence. In bioprimed seeds, germinating *Trichoderma* conidia form a protective layer around seeds, enabling better tolerance of adverse soil conditions compared to non-primed seeds. This technique offers advantages over simple seed coating by promoting rapid and uniform seedling emergence. Seed biopriming benefits crops including tomato, brinjal, chickpea, and soybean.

3. Seed Material Treatment

Apply *Trichoderma* powder @ 8-10 g with one liter water for 30 minutes to treat seed materials such as sugarcane setts, banana suckers, turmeric rhizomes, ginger rhizomes, and potato tubers before sowing. Shade dry treated materials for 20-30 minutes before sowing.

4. Soil Application

Mix 1-2 kg *Trichoderma* spp. (powder formulation) or 500-1000 ml (liquid formulation) with 25-50 kg farm yard manure (FYM). Thoroughly mix, cover with jute bags, sugarcane leaves, or paddy straw, and keep in shade for 2-3 weeks for proper multiplication. Maintain moisture and turn the mixture every 3-4 days before field broadcasting. Optimal moisture ensures better *Trichoderma* multiplication. Apply well-decomposed *Trichoderma*-enriched FYM to fields 15 days before sowing. This mixture suits furrow, pit, or pot application during transplanting or sowing, covering one acre.

5. Cutting/Seedling Root Dip Application

Dissolve 20-25 g *Trichoderma* spp. (powder formulation) or 5-10 ml (liquid formulation) in one liter water for approximately 30 minutes. Dip cuttings and seedling roots in this suspension for half an hour and transplant immediately. Root dipping effectively controls soil-borne diseases.

6. Nursery Bed Treatment

Mix 500 g *Trichoderma* spp. (powder formulation) with 10-15 kg well-decomposed FYM, compost, or vermicompost. Broadcast over one acre during evening hours under proper moisture conditions. For liquid formulation, 5-10 ml per liter water suffices for soil drenching.

7. Soil Drenching

Mix 1-2 kg *Trichoderma* formulation in 200 liters water for drenching one acre, or use 8-10 g per liter water for nursery soils with periodic applications. Maintain optimal soil moisture during application.

8. Horticultural Crops

Mix 50-100 g *Trichoderma* formulation with sufficient FYM, compost, vermicompost, or field soil. Apply mixture per plant in the effective root zone of fruit trees. Adjust doses based on plant age.

9. Foliar Application

Spray 8-10 g/L water *Trichoderma* spp. (powder formulation) or 3-5 ml/L water (liquid formulation) on diseased plants during cooler hours at 10-12 day intervals.

Benefits

1. *Trichoderma* strains effectively combat numerous seed-borne and soil-borne plant pathogenic fungi through mycoparasitism and antibiosis mechanisms.
2. These strains decompose organic farm wastes, solubilize soil phosphorus and micronutrients, reclaim adverse soils, enhance nutrient absorption, improve soil fertility, and protect soil ecosystems.
3. Application reduces crop losses while increasing plant growth, yield, and farmer income.
4. *Trichoderma* use minimizes reliance on harsh and expensive chemical fungicides.
5. These fungi remain compatible with organic manures and bio-fertilizers including *Azospirillum*, *Rhizobium*, *Bacillus subtilis*, mycorrhizae, phosphorus-solubilizing bacteria, and other bioagents.
6. Treatment increases seed germination rates and percentages, promotes root and shoot growth, and builds systemic resistance against diseases, pests, and drought conditions.
7. *Trichoderma* strains play crucial roles in bioremediation of pesticide and herbicide-contaminated soils through their ability to break down chemical residues. This bioremediation capability extends to various insecticide groups including organochlorines, carbamates, and organophosphates.
8. Being eco-friendly, *Trichoderma* benefits the environment while ensuring user safety for farming communities. It proves effective in organic farming systems for disease management.

Precautions in *Trichoderma* Formulation Use

1. Avoid chemical fungicide application for 4-5 days after *Trichoderma* treatment.
2. Do not apply *Trichoderma* in dry soil, as moisture remains essential for its growth and survival.
3. Keep *Trichoderma*-treated seeds protected from direct sunlight.
4. Avoid prolonged storage of treated FYM.
5. Always combine *Trichoderma* formulations with organic manure or slurry for optimal effectiveness.

References

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Table 1: Disease management through *Trichoderma* spp.

Crop Name	Disease Name	Causative agent	Effective *Trichoderma* spp.	Mode of application
Cereal crops				
Rice	Sheath blight	*Rhizoctonia solani*	*Trichoderma viride, T. harzianum, T. virens*	Seed, soil, seedling treatment and foliar spray
	Brown spot	*Drechslera oryzae*	*Trichoderma viride*	Seed treatment
	Bunt	*Neovossia indica*	*Trichoderma viride, T. harzianum, T. virens*	Seed treatment
	Kernel smut	*Tilletia barclayana*	*Trichoderma viride, T. harzianum, T. virens*	Seed, soil, seedling treatment
Barley	Foot and root rot	*Sclerotium rolfsii, Fusarium, Curvularia, Pythium, Penicillium, Aspergillus*	*Trichoderma viride, T. pseudokoningii*	Seed treatment
Wheat	Root rot	*Sclerotium rolfsii, Fusarium oxysporum*	*Trichoderma harzianum*	Seed and soil treatment

	Loose smut	*Ustilago segatum tritici*	*Trichoderma viride, T. harzianum, T. virens, T. lignorum, T. koningii*	Seed treatment
	Spot blotch	*Drechslera sorokiniana*	*Trichoderma viride, T. reesei, T. pseudokoningii*	Foliar spray
	Take-all	*Gaeumanomyces graminis var. tritici*	*Trichoderma harzianum*	Seed treatment
	Karnal bunt	*Neovossia indica*	*Trichoderma viride, T. harzianum, T. virens, T. deliquescens, T. koningii*	Seed treatment
Maize	Charcoal rot, Banded blight	*Macrophomina phaseolina, R. solani*	*Trichoderma* spp.	Seed treatment and foliar spray
Pulse crops				
Chickpea	Wilt, seed rot, root rot	*Fusarium oxysporum* f. sp. *ciceris, R. bataticola, Pyhtium sp.*	*Trichoderma harzianum*	Seed and soil treatment
	Grey mould	*Botrytis cineria*	*Trichoderma* spp.	Foliar spray
	Stem rot	*Sclerotinia sclerotiorum*	*Trichoderma harzianum*	Seed treatment
Pigeon pea	Wilt	*Fusarium udum*	*Trichoderma viride, T. harzianum, T. koningii*	Seed and soil treatment
	Seed borne diseases	*Alternaria alternata, Curvularia lunata*	*Trichoderma viride*	Seed treatment
Mung bean	Root rot	*Macrophomina phaseolina*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Lentil	Wilt complex, Collar rot	*R. solani, F. oxysporum, S. rolfsii*	*Trichoderma virens, T. viride, T. harzianum*	Seed and soil treatment
Cowpea	Wilt	*F. oxysporum* f. sp. *ciceris*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
	Charcoal rot	*Macrophomina phaseolina,*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Moth bean	Blight	*Macrophomina phaseolina,*	*Trichoderma viride, T. harzianum*	Foliar spray
Oilseed crops				
Mustard	Damping off	*Pythium aphanidermatum*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Sesamum	Blight	*Phytophthora sp.*	*Trichoderma viride, T. harzianum*	Seed treatment
	Root rot	*Macrophomina phaseolina*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Safflower	Root rot	*Macrophomina phaseolina*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Sunflower	Blight	*Alternaria helianthii*	*Trichoderma virens*	Seed treatment
	Root rot, collar rot	*Sclerotium rolfsii, R. solani, Sclerotinia sclerotiorum*	*Trichoderma viride, T. harzianum*	Seed treatment
Groungnut	Wilt complex, seed rot, root rot, stem rot	*Sclerotium rolfsii, F. solani, F. oxysporum, R. solani,*	*Trichoderma viride, T. harzianum, T. virens*	Soil treatment
	Leaf rust	*Puccinia arachidis*	*Trichoderma harzianum*	Foliar spray
	Collar/root/crown/stem/pod rot	*Aspergillus flavus, S. rolfsii, A. niger*	*Trichoderma viride, T. harzianum*	Soil treatment
Fruit crops				
Mango	Fruit rot	*Lasiodiplodia theobromae, Rhizopus arrhinus*	*Trichoderma* spp.	Fruit treatment
Apple	White root rot	*Dematophora necatrix*	*Trichoderma viride, T. harzianum*	Soil treatment
Citrus group	Root rot	*Phytophthora nicotianae*	*Trichoderma viride, T. harzianum, T. virens*	Soil treatment
Banana	Wilt (Panama disease)	*F. oxysporum* f. sp. *cubense*	*Trichoderma viride*	Soil and Rhizome treatment
Orange	Blue mould	*Penicillium italicum*	*Trichoderma harzianum*	Fruit dip
Guava	Antharcnose	*Colletotrichum gloeosporioides, Pestalotia psidii*	*Trichoderma harzianum*	Foliar spray

	Wilt	*Fusarium oxysporum*	*Trichoderma viride, T. harzianum*	Soil treatment
Vegetable crops				
Tomato	Damping off	*Pythium indicum*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
	Seedling wilt	*Fusarium oxysporum* f. sp. *lycopersici*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Potato	Black scurf	*R. solani*	*Trichoderma viride*	Tuber treatment
Brinjal	Wilt, damping off	*F. solani, P. aphanidermatum*	*Trichoderma viride, T. harzianum, T. virens*	Seed and soil treatment
	Collar rot	*Sclerotinia sclerotiorum*	*Trichoderma viride, T. virens*	Soil treatment
Chilli	Root rot	*Sclerotium rolfsii*	*Trichoderma harzianum, T. viride*	Soil treatment
Radish	Seedling rot, damping off, seed rot	*Pythium sp., R. solani*	*Trichoderma harzianum, T. hamatum*	Seed treatment
Pea	Seed and collar rot	*Pythium sp., R. solani*	*Trichoderma harzianum, T. hamatum*	Seed treatment
	Wilt	*Fusarium oxysporum f. sp. pisi*	*Trichoderma harzianum, T. viride*	Soil treatment
Cauliflower	Damping off	*R. solani, P. aphanidermatum*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Cabbage	Damping off	*R. solani*	*Trichoderma harzianum, T. viride*	Seed treatment
Bean	Seedling rot	*Pythium sp., S. sclerotiorum, R. solani, B. cineria*	*Trichoderma koningii*	Seed treatment
Plantation crops				
Rubber	Brown rot	*Phellinus noxius*	*Trichoderma viride, T. harzianum, T. hamatum*	Soil treatment
Coffee	Collar rot	*R. solani*	*Trichoderma harzianum*	Seed and soil treatment
Mulberry	Cutting rot	*Fusarium solani*	*Trichoderma viride, T. virens, T. pseudokoningii*	Cutting and soil treatment
	Stem canker, die back	*Botryodiplodia spp.*	*Trichoderma viride, T. virens, T. pseudokoningii*	Cutting and soil treatment
Cash crops				
Sugarcane	Red rot	*Colletotrichum falcatum*	*Trichoderma viride, T. harzianum*	Soil treatment and spray
	Root rot, Seedling rot	*Pythium graminicola*	*Trichoderma viride, T. harzianum*	Soil treatment
	Wilt	*Fusarium monilifomae*	*Trichoderma viride, T. harzianum, T. longibrachiatum*	Sett treatment
Sugarbeet	Damping off	*P. aphanidermatum*	*Trichoderma harzianum*	Seed and soil treatment
	Wilt and root rot	*S. rolfsii*	*Trichoderma harzianum*	Soil treatment
Cotton	Root rot	*Rhizoctonia sp., M. phaseolina*	*Trichoderma viride, T. harzianum*	Soil treatment
Spices crops				
Ginger	Rhizome rot	*F. oxysporum* f. sp. *Zingiberi, Pythium myriotylum, F. solani*	*T. harzianum, G. virens*	Rhizome treatment
Coriander	Wilt	*Fusarium oxysporum* f. sp. *corianderii*	*Trichoderma viride, T. harzianum*	Seed and soil treatment
Pepper	Collar rot	*Phytophthora capsici*	*Trichoderma viride, T. harzianum*	Soil treatment, Dernching
Cardamum	Damping off	*F. moniliformae, Pythium vexans, P. aphanidermatum*	*Trichoderma viride, T. harzianum*	Soil treatment, Dernching
	Capsule rot	*Phytophthora meadii*	*Trichoderma viride, T. harzianum*	Soil treatment

Table 2: Common commercial *Trichoderma* formulation used in India.

Trade Name	*Trichoderma* strains/species	Manufacturer
Ecofit	*Trichoderma viride*	Hoechest and Schening Agro. Evo. Ltd. Mumbai, India
Funginil	*Trichoderma viride*	Crop Health Bioproduct Research Centre, Ghaziabad, Uttar Pradesh, India
Trichogourd	*Trichoderma viride*	Anu Biotech International Ltd., Bangalore, India
Defence SF	*Trichoderma viride*	Wockhrtd Life Science Ltd., Mumbai, India
Bioderma	*Trichoderma viride* + *T. harzianum*	Biotech International Ltd., New Delhi, India
Bio-fit	*Trichoderma viride*	Ajay Biotech (India) Ltd., Pune, India
Biocon	*Trichoderma viride*	Tocklai Experimental Station Tea Research Association, Jorhat (Assam), India
Antagon TV	*Trichoderma viride*	Green Tech, Agroproducts, Rajaji Road Coimbatore, India
Trichostar	*Trichoderma harzianum*	Green Tech, Agroproducts, Rajaji Road Coimbatore, India
Gliostar	*Trichoderma virens*	GBPUAT, Pantnagar, Uttarakhand, India
Monitor	*Trichoderma spp.*	Agricultural and Biotech Pvt. Ltd. Gujarat, Department of Plant Pathology, MPKV, Rahuri
Tricho-X	*Trichoderma viride*	Excel Industries Ltd., Mumbai, India
Biogourd	*Trichoderma viride*	Krishi Rasayan Export Pvt. Ltd., Solan (HP), India
Ecoderma	*Trichoderma viride* + *T. harzianum*	Morgo Biocontrol Pvt. Ltd., Bangalore, India
Trieco	*Trichoderma viride*	Ecosense labs, India
Tricon	*Trichoderma viride*	Green Max, India

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