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A Review on Trichoderma - An Important Fungus in Agriculture and the Environment

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Abstract: The major challenge for modern farming has been to increase yields while being environmentally benign. While new technologies have boosted agricultural productivity in all regions, some modern methods have negative environmental consequences. Beneficial microbes, their genes, and/or products, such as metabolites, are used in biological control to minimize the detrimental impacts of plant diseases and stimulate positive plant responses. Among the many species utilised as biocontrol agents, including fungus and bacteria, the fungal genus *Trichoderma* generates a variety of enzymes that are important in biocontrol activities such as cell wall breakdown, resistance to biotic or abiotic stimuli, hyphal development, and so on. *Trichoderma* spp. are primarily asexual fungus that may be found in a variety of agricultural soils as well as rotting wood. Plants develop defensive responses or systemic resistance responses as a result of the biocontrol activity including mycoparasitism, antibiosis, and nutritional competition. *Trichoderma* spp. are currently being utilised in a sustainable disease management strategy to control plant diseases. This review summarises existing research on Trichoderma as a biocontrol agent, its biocontrol activity, commercial production, and use in plant disease management programmes.

Keywords: Biocontrol, *Trichoderma* spp., Antibiosis, Mycoparasitism, Competition, Disease management.

INTRODUCTION

One of the most significant issues facing agriculture production today is meeting the needs of quality and quantity for both the producer and the customer while minimising environmental impact. Various pathogenic agents affect crops, the most devastating of which are filamentous fungus, resulting in significant economic losses (Singh. 2014). The significant increase in food grain production has aided in meeting global food security needs, but issues such as global warming, environmental pollution, and increase in population have pushed plants towards various kinds of biotic and abiotic stresses, which are causing significant yield loss and are a major source of concern for future generations. Fungi, bacteria, virus, nematodes, weeds, and insects are examples of biotic stress factors, which can result in yield losses of up to 31-42% (Moustafa-Farag. *et al.* 2020).

Plant disease control and yield enhancement utilising traditional approaches such as chemical pesticides, herbicides, or fertilisers are not environmentally friendly since they include different aromatic groups or methylated and ethylated compounds that have severe environmental consequences. To address these issues, researchers are exploring alternatives such as the use of bio control agents (BCA) for disease control, either alone or in combination with other chemicals, for environmentally benign and long-term disease management. Several bio control agents have been identified and are available, including bacterial agents such as *Pseudomonas*, *Bacillus*, and *Agro-bacterium*, as well as fungal agents such as *Aspergillus*, *Gliocladium*, *Trichoderma* and *Coniothyrium* (Papavizas, 1985; Koumoutsi. *et al*., 2004; Mavrodi. *et al*., 2002).

These bio control agents are among them. *Trichoderma* spp. is a versatile biocontrol agent that has been used to manage plant pathogenic fungus for a long time. The capacity of fungi of the genus Trichoderma belonging to Division - Ascomycota, Order - Hypocreales, Family - Hypocreaceae) to act as biocontrol agents (BCA) against plant diseases has been recognised since the 1920s (Samuels, 1996). These fungi are non - virulent plant symbionts that act as parasites and antagonists to several phytopathogenic fungi, defending plants against illness. *Trichoderma* spp. have been investigated extensively and are commercially available as biopesticides, biofertilizers, and inorganic fertilizers (Harman, 2000; Harman. *et al*., 2004; Lorito. *et al*., 2004).

Morphological Characteristics of *Trichoderma*

Trichoderma spp. identification based on morphology is a significant way of identification, although it is not a precise approach for distinguishing between species diversity (Zhang. *et al*., 2005). *Trichoderma* spp. develop quickly at temperatures between 25 and 30 degrees Celsius (Latifian. *et al*., 2007). The conidiophore is not clearly defined, although it is generally branching, with single celled conidia and phialides at the tip of the branched hyphal system that are not visible on 7 days old media (Lu. *et al*., 2004). Conidia are

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ellipsoidal to oblong in form, with certain Trichoderma species having globose to subglobose conidia (Bissett. *et al*., 2003; Jaklitsch. *et al*., 2006). The colour of conidia varies by species, although they are usually green, however they can also be grey, white, or yellow (Jaklitsch. *et al*., 2006).

Positive Aspects of Trichoderma

Trichoderma Spp. As Plant Growth Promoter Agent

According to (Hyakumachi and Kubota. 2003), Plant growth-promoting fungi (PGPF) are microorganisms that promote plant development. Major effects of this PGPF are frequently seen on crop growth, ultimate yield quality, and productivity. *Trichoderma* spp. has recently been discovered to be a good PGPF. Trichoderma spp. promote overall plant health by generating a conducive environment and producing a substantial number of secondary metabolites, according to the majority of research.

Table 1: Positive aspects of *Trichoderma* spp. on Plant growth and development

Trichoderma strain	Effect	Crop	References
T. harzianum N47	Increase the number of lateral roots and the length of the roots.	Pea(*Pisum sativum*)	(Naseby. *et al*., 2000)
T.harzianum	Increase in cumulative root length, root surface area, and root tip count.	Cucumber(*Cucumis sativus*)	(Yedidia. *et al*., 2001)
T. harzianum strain M10	Tomato seed germination was enhanced, and seedling development was improved.	Tomato (*Solanum licopersicum*)	(Vinale. *et al*., 2013)
T.harzianum strain SQR-T037	Improve root growth in order to increase root length and tips.	Tomato (*Solanum licopersicum*)	(Cai. *et al*., 2013)

Yield Improvement

Treatment with several *Trichoderma* species ensures good yield output in crops such as rapeseed, wheat, maize, tuberose, cane, tomato, okra, and others (Haque. 2012). Seed bio-priming with *Trichoderma* spp. spores improves crop production significantly in greenhouse environments. Similarly, treatments with *T. harzianum* and *T. viride* on marigold, petunia, and lavender resulted in a considerable rise in the number and quantity of flowers (Ousley. 1994).

Impacts on Plant Morphology

Many studies show that applying *Trichoderma* spp. to the rhizosphere of plants improves plant morphological features as root-shoot length, biomass, tallness, leaf number, tillers, shoots, fruits, and so on (Halifu. 2019; Sajeesh. 2015). For example, inoculating soil with *T. atroviride*, increased the quantity of root hairs and lateral roots in *A. thaliana. T. harzianum* was also applied to cucumber roots, which boosted biomass and lateral root development. Similarly, when *T. longipile* and *T. tomentosum* were applied to cabbage seedlings in a greenhouse, they dramatically increased leaf surface area and fresh and dry weight compared to untreated plants (Rabeendran. 2000).

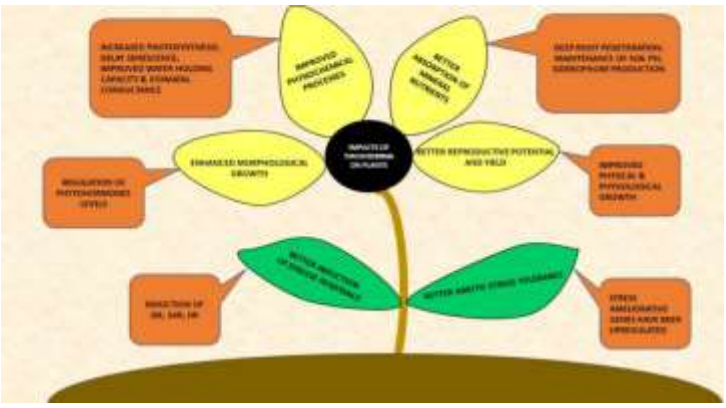

Fig 1: The affects of *Trichoderma* spp. on plants in the rhizosphere are depicted graphically (Hermosa, 2012).

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Impacts on Plant Physiology

Photosynthesis, transpiration rate, gas exchange, absorption of nutrients and assimilation, water usage efficiency, and other physiological processes in plants have all been shown to be favourably regulated by *Trichoderma* spp. *Trichoderma* spp. increased both root development and mineral nutrient intake from soil, as previously observed. Mg absorption was dramatically enhanced after treatment with Trichoderma spp., a major chlorophyll ingredient also involved in catalysing enzymatic activity and regulating photosynthesis genes. Furthermore, *T. harzianum* treatment of rice plants boosted water retention capacity, improved water deficit tolerance, and delayed plant aging (Shukla. 2012). After applying Trichoderma spp. to rice, a comparable senescence delay was found (Mishra. 2011).

Recent Advances of *Trichoderma* in Control of Late Wilt Disease of Hybrid Maize

Corn (*Zea mays*, maize) is one of the world's most significant grain crops, with the United States and China ranking first and second, respectively, in maize production. Corn is an important crop in Israel's open plains. The severe illness late wilt (LWD), caused by the fungal pathogens *Magnaporthiopsis maydis* and *Harpophora maydis*, is threatening Israel's corn growth. The fast wilting of sweet and feed maize, primarily from the tasseling stage to soon before maturity, is a symptom of LWD (Degani, O; Movshowitz, D; Dor, S; Meerson, A; Goldblat, Y; Rabinovitz. 2019).

Using members of the fungus genus *Trichoderma* to combat LWD is one of the options. Several plant species can create mutualistic endophytic partnerships with members in this genus. Microalgae, *Chlorella vulgaris* extracts, and each of the Trichoderma species, *T. virens*, and *T. koningii*, were recently demonstrated to be effective treatments for LWD in greenhouse and field circumstances (Elshahawy. 2018). In the greenhouse, these measures resulted in a 72 percent reduction in disease incidence and a 2.5-fold increase in grain output in field conditions.

Mechanism of *Trichoderma* Spp.

The study of processes ranging for control of phytopathogens and plant infections in which pathogen antagonised by biocontrol agent comes from diverse forms of interactions between organisms is the most significant and exciting element of Trichoderma (Pal and Gardener, 2006). The followings are the mechanisms to control plant pathogens.

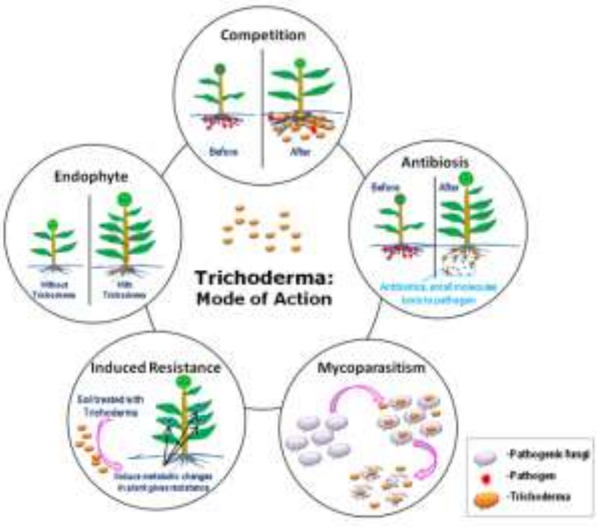

Fig 2: Model demonstrating *Trichoderma* spp. method of action against pathogens and plant growth enhancement (Waghunde. *et al*., 1955).

Mycoparasitism

Mycoparasitism refers to a direct attack by one fungus species on another, as it's one of *Trichoderma* spp.'s most significant antagonistic mechanisms. Weindling (1932) was the first to detect *Trichoderma* spp. as a biocontrol agent, and he also observed *T. lignorum (viride)* hypae coiling and killing *R. solani* simultaneously time (Wells. 1988). *Trichoderma* spp. produces and regulate lytic enzymes such chitinases, glucanases, and proteases, which are important in mycoparasitism (Mukherjee. *et al*., 2008).

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Mycoparasitism is a complicated process involving the synthesis of a cell wall lytic enzyme. According to (Chet. *et al*., 1998,) the mycoparasitism process consists of four steps: chemotropism and identification, adhesion and coiling, cell wall puncture, and host cell digesting. *Trichoderma* strains detect other fungi, grow directly towards them, and release hydrolytic cell wall degrading enzymes in a sequential manner. *Trichoderma* adheres to the host, coiling hyphae around it, forming appressoria on the host's surface, penetrating the host cell, and collapsing the hyphae (Steyaert. *et al*., 2003).

Competition

Starvation and paucity of limiting nutrients are the most typical causes of mortality of numerous microorganisms living near *Trichoderma* strains. This may be utilised to efficiently manage fungal phytopathogens biologically. Carbon and iron are two important ingredients for the survival of most filamentous fungus. Competition for carbon is an efficient mechanism in *Trichoderma*, as well as certain other fungus, like *F. oxysporum* strains (Sarrocco. *et al*., 2009. Most fungi create tiny ferric-iron specific chelators to mobilise iron from the surrounding environment when they are iron deficient.

Recently, the antifungal characteristics of *Trichoderma* strain filtrates were employed to suppress *Ceratocystis paradoxa*, which causes Pineapple disease of sugarcane (Rahman. *et al*., 2009). Proteins that are important for *Trichoderma's* root colonisation are also discovered to be important in competing with other root invaders (Saloheimo. *et al*., 2002; Viterbo. *et al*., 2004; Brotman. *et al*., 2008) and some of them aid in the establishment of symbiotic associations with host plants (Samolski. *et al*., 2012).

Antibiosis

Trichoderma spp. produce antimicrobial chemicals that induce phyto-pathogenic fungus to degrade without any physical contact between microorganisms. This process is known as "antibiosis," and secondary metabolites are a set of chemically diverse natural substances that may be linked to survival activities for the producing organism, such as symbiosis, differentiation, and competing against organisms (Wu. *et al*., 2014). Over 180 secondary metabolites from different groups of chemical compounds have been identified from *Trichoderma* spp. (Masi. 2018; Reino. 2008).

T. viride isolates have a coconut odour, indicating the presence of volatile chemicals that impede pathogen development. Harzianic acid, alamethicins, tricholin, peptaibols, antibiotics, 6-penthyl-pyrone, massoilactone, viridin, gliovirin, glisoprenins, and heptelidic acid are some of these metabolites (Vey. *et al*., 2001; Raaijmakers. *et al*., 2009).

Trichoderma antibiotics' chemical structures might indicate two alternative modes of action. The generation of low molecular weight, non-polar, volatile compounds results in a greater concentration of antibiotics in the soil environment, with an impact on the microbial population over a reasonably long distance. On the other hand, polar antibiotics and peptaibols operating in close proximity to the generating hyphae may cause a short-distance impact (Lorito. *et al.*, 1996b).

Mode of Action

Trichoderma can be used as a biocontrol agent in a variety of ways

- Nutrient competition occurs when one organism grows faster or uses its food supply more efficiently than the pathogen, thus pushing out the disease and seizing control.
- A biocontrol agent may emit a substance termed antibiosis that inhibits or delays the development of diseases in the surrounding region.
- It may directly feed on or be parasitized by a pathogenic species.
- Induced resistance occurs when a plant produces a substance that protects it from the disease.
- They may develop in other species as an endophyte, supporting plant growth.

Mass Production of *Trichoderma*

Mass production and use of bio control agents has now become a reality as a result of growing interest in bio control and increased awareness of pesticide hazards. There have been several reports of successful use of *Trichoderma* formulations in the green house as well as in the field for the control of various diseases, particularly soil borne pathogens. *Trichoderma* spp. must be replicated on some acceptable and inexpensive media that may give a food foundation for the commencement of the growth in order to be widely distributed in the fields. The two most often utilised species, *T. harzianum* and *T. viride*, have been reported to be effective on 87 different crops in India (Sharma. *et al*., 2014). *Trichoderma* spp., the most extensively

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employed fungal antagonists, have been mass multiplied on solid substrate such as wheat straw, sorghum grains, wheat bran, coffee husk, diatomaceous earth granules saturated with molasses, etc.

By using molasses and brewer's yeast in a liquid fermentation, (Papavizas. *et al*., 1984) created biomass of fungal antagonists. (Montealegre. *et al*., 1993) presented a liquid fermentation technique for *T. harzianum* production on a wide scale using molasses, wheat bran, and yeast. Due to its intrinsic advantages under Indian circumstances, the solid substrate fermentation (SSF) procedure was favoured over the other because Trichoderma sporulates slowly in liquid medium and sporulates effectively on diverse solid substrates.

Solid State Fermentation

Sorghum was the most beneficial and cost-effective grain for the formation of nucleus culture, whereas farm yard manure and seasoned press mud were the best organic matter. Press mud has shown to be a highly valuable and appropriate supply, particularly in the sugar plant sector. Wheat bran and paddy straw were recommended as the most potential sources for the bulk proliferation of Trichoderma among the agricultural wastes evaluated.

Liquid State Fermentation

To make spores from fungal strains, liquid state fermentation is often used. When compared to the other substrates studied, degraded press mud was shown to be the most efficient for mass multiplication of *T. viride*, *T. harzianum,* and *T. longibrachiatum* (Gohil. 1993). For direct soil and nursery bed treatments, (Ramanujam and Sriram. 2009) devised a unique approach including talc blended proportionally with FYM (1:10).

Table2: Substrates successfully used for *Trichoderma* production.

Species	Substrates	References
T. harzianum and T. Viride	Sorghum	Rini and Sulochana, 2007
T.viride	Sorghum, wheat	Bhagat. *et al*., 2010
T. harzianum (T5), T. viride, T. hamatum (T16)	Cotton cake	Sharma N, Trivedi, 2005
T. harzianum, T. viride and T. Virens	Spent Malt	Gopalkrishnan. *et al*., 2003
T. hamatum, T. harzianum, T. Virid	Molasses and Brewers yeast	Papavizas, 1984
T. harzianum Rifai	V8 juice, potato Dextrose Broth, as well as molasses yeast medium	Prasad, 2002

Commercial Level Production

Many commercial companies make and commercialise bacterial-based BCAs, which are accessible on the global market (Velivelli. *et al*., 2014). Commercial BCA formulations for agricultural applications should offer numerous desirable characteristics and solid proof to persuade farmers. These include an excellent market potential, simple preparation, simple application, high stability during transit and storage, a large number of viable propagules with a long shelf life, long-term effectiveness, and a reasonable price. Because it functions as a food foundation, a variety of carrier materials proved suitable in the development of *Trichoderma*-based BCAs (Table 3). Talc is the most frequent carrier material recommended for commercialized *Trichoderma* production across the world.

Table 3: Various formulations of *Trichoderma* spp

S.No.	Formulations	Ingredients
1.	Talc based	1 litre of *Trichoderma* culture biomass with media, 2 kilogramme of Talc (300 mesh, white colour), and 10 g of CMC
2.	Vermiculite-wheat bran based	Vermiculite: 100 g, Wheat bran: 33 g, Wet fermentor biomass: 20 g and 0.05N HCL: 175 ml
3.	Wheat bran based	Wheat flour: 100 g, Fermentor biomass: 52 ml and Sterile water: sufficient enough to form a dough

Adapted from Pandya. 2012.

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Role of *Trichoderma* against Various Diseases

An appropriate application of this BCA and compost onto a field, as per (Imran. *et al*., 2020), can decrease or become an alternative to costly chemical fertilisers. Use of Trichoderma is a fantastic sustainable strategy to preserving soil health. Plant pathogenic organisms like *Pythium* spp., *Rhizoctonia solani*, *Fusarium oxysporum*, *Alternaria tenuis*, and *Botrytis cinerea* are suppressed by *Trichoderma* spp., according to research.

Table 4: Examples of bio control of plant pathogen mediated by beneficial fungi

Name of disease	Crop	Causal agent	Bio control strain	Reference
Root rot disease	Brinjal(*Solanum melongena*)	*Macrophomina phaseolina*	*T.harzianum T.polysporum,viride*	Ramezani(2008)
Damping off	Pepper(*Capsicum annum*)	*Phytophthora capsici*	*T.harzianum*	Ezziyyani. *et al.* (2007)
Wilt	Tomato(*Solanum lycopersicum*)	*Fusarium oxysporum*	*T. asperellum*	El Komy. *et al*., 2015
Brown spot	Tobacco (*Nicotiana tabacum*)	*Alternaria alternata*	*T. harzianum*	Gveroska and Ziberoski, 2012

CONCLUSION

Trichoderma spp. have a wide range of properties that could be useful in agriculture, such as reducing abiotic stresses, improving physiological stress responses, reducing nutrient uptake in plants, increasing nitrogen-use efficiency in various crops, and assisting in improving photosynthetic efficiency. *Trichoderma* spp. genomes have been thoroughly studied and shown to have many valuable genes, as well as the capacity to create a wide range of expression patterns, allowing these fungi to adapt to a wide range of habitats. When the biocontrol agent effectively manages the relationship between the host and pathogen, a biocontrol programme is developed. *Trichoderma's* capacity to successfully handle this interaction has been widely documented. Plants' defence responses have also been shown to be enhanced by fungus. As a result, the employment of Trichoderma as a biocontrol agent will almost surely assure long-term disease management.

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