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TRICHODERMA: A MULTIFACETED ALLY IN PLANT GROWTH PROMOTION AND DISEASE RESISTANCE

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ABSTRACT

In order to feed the growing population, agriculture is a vital component of any country. However, diseases pose a constant threat to crop production. In the present scenario, farmers are completely relying on chemicals which can led to significant crop production The boundless use of chemicals had a negative impact on living ecosystem. To overcome the enormous use chemical, the alternative source of multifaceted bioagent have been addressed for managing plant diseases. *Trichoderma* spp. showcasing many agricultural applications due to its perspective mechanism of biological control. The utilization of *Trichoderma*-based products paying the attention of scientists and researchers to enhance the benefits of *Trichoderma* spp. Hence, the researchers exploited the successful story of *Trichoderma* spp. With respect to diseases, plant growth promotion and bioremediation. These perspective findings gaining leverages in the agribusiness in order to nurture sustainable agriculture practices.

***Keywords*:** Crop production, *Trichoderma*, diseases, plant growth promotion, Bioremediation

Introduction

The future of food production and environmental safety are in jeopardy due to issues in agriculture. The emergence of plant pathogenic microorganisms in a crop plantation caused a pandemic plant diseases phenomenon. Besides, excessive usage of pesticides and synthetic fertilizers expose the living organisms to the high toxicity of chemical compounds. Another issue such as improper management of agricultural waste also pollutes the environment when it has been burned or disposed into water bodies. The best solution to overcome these problems is the application of biological control by furnishing *Trichoderma* spp. in agricultural products. *Trichoderma* spp. significantly suppress the growth of plant pathogenic microorganisms and regulate the rate of plant growth. Recent studies have addressed that different plant disease such as damping off, wilt, root rot and fruit rot can be suppressed by *Trichoderma* spp. (Begum *et al*., 2010; El Komy *et al*., 2015; Howell, 2002; Mbarga *et al*., 2012). The secondary metabolites secreted by *Trichoderma* spp. have proven its role in suppressing the growth of pathogenic microorganisms and enhancing the plant growth (Contreras-Cornejo *et al*., 2015a, 2015b; Kubicek *et al*., 2001; Kullnig *et al*., 2000).

Trichoderma spp.

Trichoderma is a soil inhabitant, avirulent and plant beneficial fungi belonging to the family Hypocreaceae. *Trichoderma* acts as an antagonist against numerous plant pathogenic organisms. For instance, the growth of bacteria, fungi and nematodes are suppressed either by direct interactions with *Trichoderma* in terms of antibiosis, hyperparasitism and competition for space and nutrient (Zhang *et al*., 2017) or indirectly by enhancing plant growth and bolstering the stress tolerance as well as secretion of secondary metabolites, enzymes and pathogenesis related proteins (Kumar, 2013). The obstacles addressed during the identification of *Trichoderma* isolates at the species level become more imperative because of the morphological differences are rare and hard to observe.

A comprehensive note on *Trichoderma*

- To enhance secondary metabolites like endochitinase and proteolytic enzymes
- To enhance plant growth promotion
- Siderophore production
- Release of siderophore production
- Release of plant growth regulators
- Improve the uptake of micronutrients to the plant
- Solubilization of phosphorus in soil and make available to plants
- Application of *Trichoderma* as an amendment with compost gives better results than the traditional biofertilizer

Taxonomic Classification of *Trichoderma*

The genus *Trichoderma* belonging to the Phylum-Ascomycetes, Class-Sordariomycetes, Order-Hypocreales, Family-Hypocreaceae. Persoon introduced the name *Trichoderma in* 1794. The Tulasne brothers reported that *Hypocrea rufa* is the teleomorphic stage of *Trichoderma viride* Pers. in 1865. In 1969, Rifai introduced the concept of "species aggregate" and categorized *Trichoderma* strains into nine aggregates based on morphological features (Rifai, 1969). Unfortunately, some of the "species aggregate" consists of two or more morphology that was non-differentiable. In later studies, Bissett (1991) reviewed Rifai's work and attempted to integrate similar forms within the species concept based on morphology, including the characteristics of the conidiophore branching system. As a result, *Trichoderma* was classified into five sections: *Saturnisporum, Pachybasium, Longibrahiatum, Trichoderma* and *Hypocreanum*. Although the genus *Trichoderma* was first found in 1794, the evidence of its mycoparasitic and biocontrol aptitude was discovered only by the year 1932 (Weindling, 1932). Moreover, they were found to have a rapid growth characteristic on culture media (Bissett, 1991). On top of that, *Trichoderma* spp. are able to protect plants, enhance vegetative growth, and act as soil amendments. This flourishes *Trichoderma* spp. an epitome of biocontrol agents and biofertilizers (Woo *et al*., 2014).

The classification taxa of *Trichoderma*

Kingdom	Fungi
Phylum	Ascomycota
Class	Sordariomycetes
Order	Hypocreales
Family	Hypocreaceae
Genus	*Trichoderma*

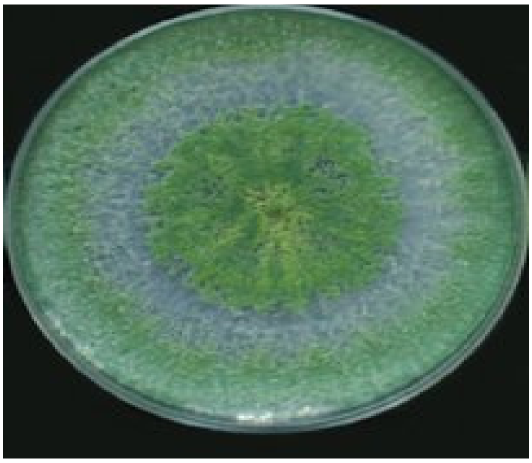

Fig. 1a: The growth of mycelium of *Trichoderma*

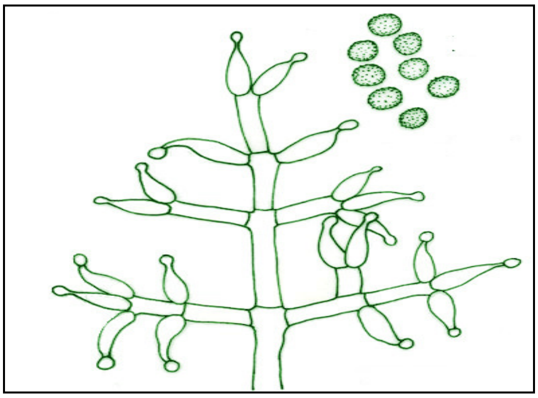

Fig. 1b: The schematic diagram of morphology of *Trichoderma*

Role as biocontrol agent

The biocontrol agents have been addressed to shield crops from diseases and pests (Abdul *et al*., 2004). In reference to the current study, several plant diseases can be managed through biological means (Susanto *et al*., 2005). The biocontrol mechanisms of *Trichoderma* spp. include (1) mycoparasitism; (2) production of secondary metabolites; (3) competition for nutrients and space (4) induction of plant defense responses (Mukhopadhyay & Kumar, 2020). As a consequence, *Trichoderma* spp. are crucially addressed as an alternative to control pests and plant pathogens and reducing the reliance of chemicals.

Mycoparasitism

One of the crucial modes of action of *Trichoderma* spp. is mycoparasitism where one fungus parasitic toward other fungi. Mycoparasitism takes place following a sequence of events: (1) growth of *Trichoderma* spp., (2) recognition of prey using diffusible signals, (3) formation of appressoria and coiling, (4) secretion of hydrolytic enzymes, (5) penetration of the hyphae of prey (6) lysis of prey (Mukhopadhyay & Pan, 2012; Singh *et al*., 2018). The microparasitic activities encompass the release of extracellular cell wall-degrading enzymes which are required for the penetration of hyphae and this will eventually cause the lysis of the pathogen. Along with that, a high activity of β-1,3 glucanase and chitinase was reported when *Trichoderma* spp. were co-cultured with pathogenic fungi. Both of the said enzymes hydrolyse chitin which is a major component of most fungi. As a result, the co-culturing caused the growth of the pathogenic fungi to be inhibited (Alias *et al*., 2011; Hirpara *et al*., 2017; Baiyee *et al*., 2019).

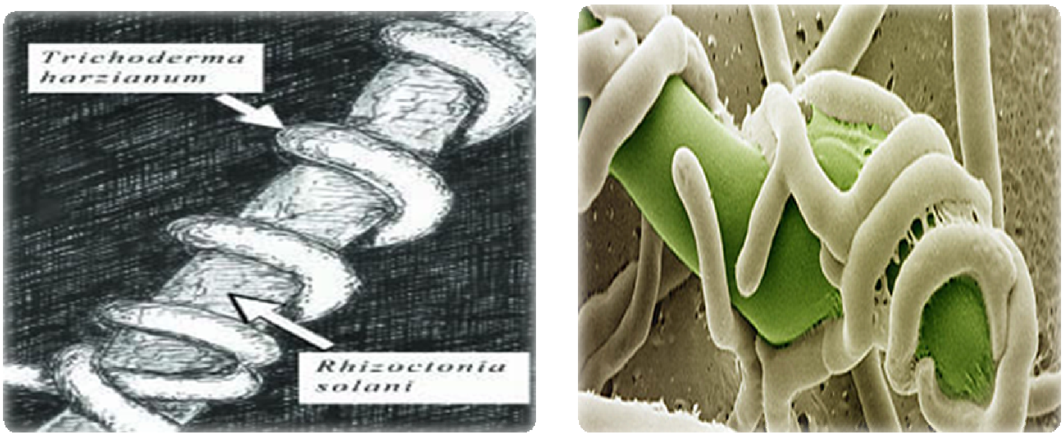

Fig. 2 : The *Trichoderma* coiling around the hypha of *Rhizoctonia solani*

Table 1 : Mechanism of parasitism of *Trichoderma* spp. on different plant pathogenic fungi

Plant pathogen	Mode of antagonism
Botrytis cinerea	Hyphal interaction
Helminthosporium teres	Inhibition by contact action
Fusarium oxysporum	Hyphal interaction
Pythium aphanidermatum	Hyphal interaction, coiling, penetration, antibiotic and lysis of hyphal cells
Rhizoctonia solani	Hyphal interaction, penetration, cell wall lytic enzymes
Sclerotium rolfsii	Hyphal interaction, coiling, penetration of sclerotia, antibiotic and lysis of hyphal cells
Seiridium cardinale	Production of toxic metabolites, strong inhibition of conidial germination, germ tube development and mycelial growth

Production of secondary metabolites

Among the variety of secondary metabolites produced by *Trichoderma* spp., some were found to inhibit the formation of the cell walls of other pathogenic fungi (Table 1). For an instance, Weindling (1934) reported that secondary metabolites released from one organism (*T. lignorum*) was toxic to another organism (phytopathogen). In addition, peptaibols released by *Trichoderma* spp. had proved to inhibit the crucial enzyme β-1,3 glucan synthase, which can be used for synthesis of cell wall (Nawrocka & Maloepsza, 2013). Moreover, *Trichoderma* spp. mainly addressing for plant growth promotion and disease resistance by production of gliovirin, gliotoxin, koninginins, trichothecenes, and 6-pentyl-α-pyrone (6-PAP) (Koli & Adusumilli, 2020).

Competition for nutrient and space

Another mechanism of *Trichoderma* spp. is competition, for instance competition for source of nutrition and oxygen highly amendable for a significant reduction of germination of plant pathogenic fungi. Besides, *Trichoderma* spp. aggressively colonize the roots of a plant (Howell, 2003). *Trichoderma* spp. notably addressed for abatement of plant pathogens by secreting a siderophore, a compound that chelates to iron. This, in turn, will suppress the growth of the pathogen as iron is an essential nutrient for the growth of other microorganisms (Singh *et al.*, 2018). The nutrient uptake by *Trichoderma* spp. is compatible by their relationship with the plant host. The *Trichoderma* colonized into healthy root tissues so that they can absorb the plant nutrients. Simultaneously, the penetrated root tissues enabled the host plant to uptake macro and micronutrients in a greater amount.

Induction of plant defense responses

Aside from combating plant pathogens, *Trichoderma* spp. exploited in such a way that could enhance the defense response in plant. The resistance in the plant will be triggered as soon as the *Trichoderma* spp. colonized by the hypha in plant roots. The plant defense responses are induced as the elicitors secreted by *Trichoderma spp.* and the receptors of the plant host interact with each other. The systemic acquired resistance (SAR) stimulates the production of salicylic acid, which is a defense chemical compound, for addressing signal transduction in plants (Harman, 2006). Moreover, *Trichoderma* spp. are elicitating for the production of proteins in plants, these proteins can activate the defense response in plants (Ali Nusaibah & Musa, 2019). In 2011, Contreras-Cornejo *et al.* investigated colonization of *Trichoderma* in plant roots for the production of salicylic acid and jasmonic acid, which can act as a signal molecule for enhancement of plant defense mechanism. As a consequence, the study proved that the colonized roots exhibited a significant production of both the molecules (Contreras-Cornejo *et al.*, 2011).

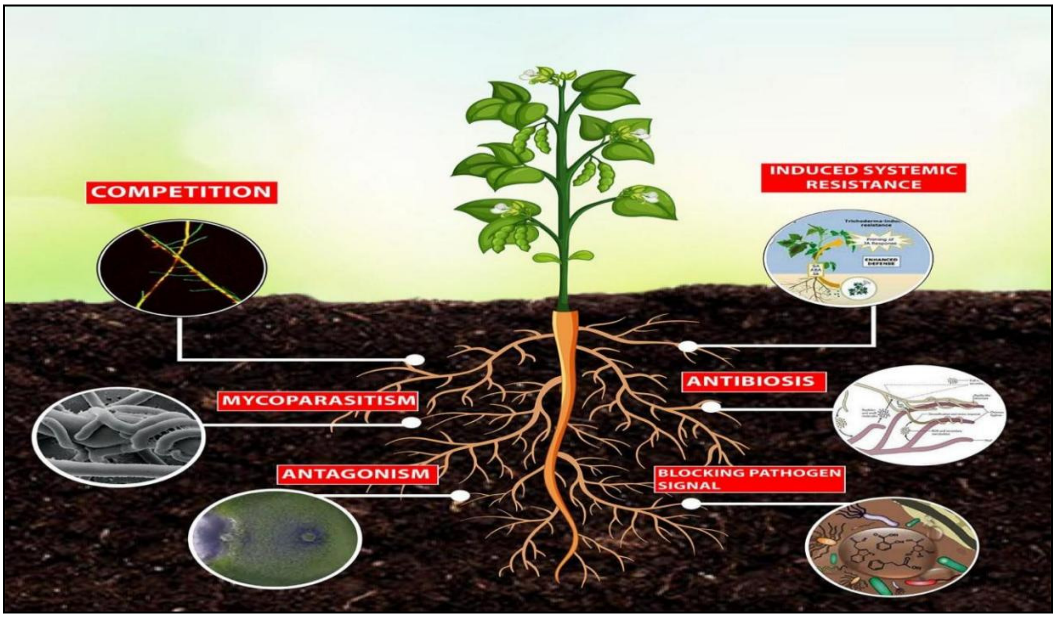

Fig. 3 : Mechanism of *Trichoderma* as a biocontrol agent

Table 2 : Effects of *Trichoderma* spp. in enhancing host plant tolerance against abiotic stress

Trichoderma species	Abiotic stress	Crop	Enhancement of abiotic stress tolerance
T. hamatum	Drought	Cacao	Delay onset of drought
T. asperelloides	Salinity	Arabidopsis and cucumber	Improve seed germination and upregulation of osmo-protection genes
T. harzianum	Salinity	Mustard	Increase in biomass, pigment, proline and oil content
T. virens	Heavy metal and hydrocarbon	Tobacco	Enhance tolerance to cadmium and anthracnose
T. asperellum	Heavy metal	Onion	Reduce copper accumulation in shoot and increased proline content
T. longibrachiatum	Heavy metal	Sunflower	Increase antioxidant enzyme levels in lead oxidative stress

Role as biofertilizer

Adverse environmental conditions are one of the significant factors in the diminishing of the growth and yield attributes of crops. Abiotic stresses under adverse climatic condition such as temperature, carbon dioxide and prolonged drought posing drastic impact on crop productivity (Zhang *et al*., 2022). In addition, the density and dispersal of plant diseases and pests are highly affected when imposed to both biotic and abiotic condition (Kashyap *et al*., 2017). Genetically modified crop varieties are usually susceptible to infestation caused by non-native pests and pathogens (Govindaraj *et al*., 2015, Bebber, 2015). Moreover, the irrigation practice in arid lands led to negative impact on soil nutrients and increases salinization (Kashyap *et al*., 2017). Salinization is associated with reduced soil microbial activity and it also affects the physical properties of soil, such as causing soil compaction. Root growth is affected in compacted soil with low oxygen content, limiting nutrient and water uptake, and this negatively impacts the productivity of plants (Colombi & Keller, 2019, Zhang *et al*., 2020). Consequently, reports indicate up to 50% of losses in the average yield of major crops (Kashyap *et al.*, 2017). This is critical as a steady increase in global food production is vital to sustaining the growing world population, predicted to reach nearly 10 billion people in the year 2050 (Jaggard *et al*., 2010). As a result, *Trichoderma* spp. application as biofertilizer offers a sustainable and eco-friendly alternative for maintaining crop yield and productivity under different environmental stresses (Kashyap *et al*., 2017). Besides playing a significant role as a biocontrol agent that protects plants against various pathogens attacks (Shoresh *et al*., 2010).

Enhancement of plant growth and yield attributes

The exploitation of *Trichoderma* spp. can be successfully employed in various number of crops such as mustard, wheat, tomato, cabbage, and rice (Doni *et al*., 2017; Haque *et al*., 2011; Mahato *et al*., 2018; Molla *et al*., 2012; Topolovec-Pintaric *et al*., 2013). In addition, it also enhances the significant increase of seed germination (Shoresh *et al*., 2010). Bezuindenhout *et al*. (2012) reported that *T. harzianum* secrete gliotoxin which synonymously worked as gibberellic acid by the plant system and in turn, seed germination was induced. The colonization of *Trichoderma spp.* in plants enhancing growth, yield parameters and nutritional benefit and fostering the photosynthesis ability as well. The utilization *Trichoderma* spp. in colonized roots plants bestow the uptake of nutrients in plant can be used either directly by releasing molecules on plants or indirectly altering the surrounding environment (Kashyap *et al*., 2017, Shoresh *et al*., 2010). Tandon *et al*., (2020) successfully worked on the mode of Phosphate (P) solubilisation by a selected *T. koningiopsis* strain under high pH and drought stress *in-vitro*. Secretion of organic oxalic acid and alkaline phosphatase enzyme were ascertained under alkaline and drought conditions respectively.

Table 3 : Examples of biological control by introduced antagonists

Host plant and disease	Pathogen	Antagonist
Chickpea wilt	*Fusarium oxysporum* f. sp. *ciceri*	*Trichoderma harzianum*
Cotton root rot	*Rhizoctonia solani*	*Trichoderma harzianum*
Damping off of bean, cotton, cruciferous and solanaceous vegetables	*Pythium* spp.	*Trichoderma harzianum*
Phytophthora blight of pigeon pea	*Phytophthora drechsleri* f. sp. *cajani*	*Trichoderma harzianum*
Wilt of lentil	*Sclerotium rolfsii*	*Trichoderma viride*
Stem rot of tomato	*Sclerotium rolfsii*	*Trichoderma harzianum*

Conclusion and future prospects

The use of biocontrol agents can be addressed as genetically altered genes or their byproducts to mitigate the destructive plant pathogens. As discussed in this review, it is well-known that *Trichoderma* spp. may produce a wide spectrum of antibiotic compounds that that have the potential to parasitize a broad range of pathogenic fungi in the rhizosphere. Furthermore, *Trichoderma* spp. produce a copious number of metabolites which have a significantly impact on promote both systemic and localized resistance as well as stress tolerance in plants. Plant receptors recognize *Trichoderma* elicitors which employ signaling and regulation of host genetic machinery. For a comprehensive understanding of this multifaceted biocontrol agent, the review study mainly focused on the physiological and biochemical aspects of *Trichoderma* spp. Lastly, by taking into consideration all the information provided in this review, the use of *Trichoderma* species should be promoted as a substitute to pesticides, which aims at promoting human health and environmental safeguarding.

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