
Trichoderma: A biocontrol for Preventing Plant Diseases and Advancing Sustainability
(Review article)

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Abstract

Trichoderma species serve as effective biocontrol agents and successful symbiotic organisms with host plants that are also cost-effective, and helpful to the environment and they did not harm the beneficial species. In addition to boosting growth and yields, this symbiotic interaction between plants and Trichoderma also promotes nutrient uptake and efficient fertilizer use. Additionally, it causes plants to become more resistant to disease. Antibiosis, competition for nutrients and space, and mycoparasitism are a few of the primary ways that Trichoderma with other competing plants pathogens by inhibiting or blocking their growth. The production of specific metabolites, such as plant growth regulators, enzymes, siderophores, antibiotics, etc., is required for the stimulation of every process against phytopathogens. The review emphasizes the relevance of employing Trichoderma fungus for environmental purposes at the biochemical and molecular levels in the impacted root zone. It also offers a general summary of Trichoderma's utility as a biological control agent. The information presented here strongly suggests that Trichoderma could be used as a secure, environmentally acceptable, and influential biocontrol agent for many crops various.

Keywords: antibiosis; biocontrol; competition; fungi; mycoparasitism; pathogen

Introduction

The world's population is expected to reach 9.1 billion people on average by the year 2050. Therefore, an increase in agricultural food output of almost 70% is required to feed this growing global population (Raney et al., 2009). The significant increase in production of grain crops assisted in addressing the need for global food security, but issues like climate change, environmental contamination, and increase of the population have forced plants to contend with a variety of biotic and abiotic stresses that are largely to blame for yield loss and are a serious concern for the happiness and well-being of future generations. Fungi, bacteria, viruses, nematodes, weeds, and insects are examples of biotic stress factors that can reduce yield by up to 31-42% (Moustafa et al., 2020). Among these, fungus-related infections are the most serious global constraint on agricultural output. More than 10,000 different species of fungi are thought to be the cause of a wide range of plant diseases. Consequently, the principal method of disease control still involves the careless use of artificial fungicides. These substances are not only pricey but also cause hazardous levels of poisons to accumulate in our ecosystem and in humans (Raju et al., 2003; Atreya et al., 2012). Additionally, the pathogens are forced to undergo genetic alterations as a result of the fungicides' indiscriminate use, which is ultimately blamed for the selection of fungicide-resistant biotypes. For example, many phytopathogenic fungi such as *Venturia inaequalis*, *Phytophthora infestans* and *Colletotrichum musae* develop resistance to several fungicides like metalaxyl, benlate, and benzimidazole. The development of environmentally benign and economically viable plant disease management solutions has recently attracted the attention of the commercial and agronomic sectors (Panth et al., 2020). Biological control techniques are seen as crucial steps in the management of disease because chemical fungicides negatively impact other non-target organisms (Kohl et al., 2014). There are numerous lines of research that show certain microbes can impede the growth of pathogenic species by interfering with their metabolisms and/or developing parasitic relationships (Panth et al., 2020). Furthermore, using chemical fungicide treatments with low chemical concentrations and administering bioagents (BCAs) promotes disease suppression (Hyder et al., 2017). Various strains of *Trichoderma* account for about 90% of the fungal bioagents used to combat harmful phytopathogens (Hermasa et al., 2012). In 1794, *Trichoderma* was first isolated from soil and decaying organic materials (Person, 1794). *Trichoderma* is currently the source of more than 60% of effective bio-fungicides worldwide (Abbey, 2019). Since there is no known sexual stage in the life cycle of the many strains of *Trichoderma* (telomorph *Hypocrea*), they are classified as fungi with imperfections (VanWees et al., 2008). These fungi have a symbiotic connection with plants and are invasive, filamentous, opportunistic, quick colonizers, and avirulent. They not only promote plant development in pathogen-contaminated soils, but they also restrict the growth of pathogens through a number of antagonistic mechanisms (Lonto et al., 2010). Direct interactions (such as hyperparasitism, competition for nutrients and space, and antibiosis) or indirect interactions (such as increased plant development and activity, improved stress tolerance, active nutrient uptake, bioremediation of contaminated rhizosphere, and provision of plants with a variety of secondary metabolisms) that inhibit their development (Zhang et al., 2017).

2. Trichoderma-Plants Interactions

Trichoderma fungus provides plants with sugar and several beneficial effects on plants because of its ability grown on both fungicides and fertilization. The acceleration of plant development and production, an enhancement in nutrient uptake, rhizosphere change, and a rise in resistance to both biotic and abiotic stressors should be highlighted among them (Lopez B. et al., 2015). Trichoderma responds to chemical cues sent out by a plant's root. to initiate the symbiosis Trichoderma must first connect to, penetrate, and colonize the plant roots. Proteins called hydrophobin are facilitate the process of fungi to connect with the plant's roots, which are cysteine-rich, help plant roots anchor (Samolski et al., 2012). After a successful connection, proteins similar to expansin are released, which aids in root invasion. They display endopolygalacturonase activity and show cellulose binding modules (Moran-D. et al., 2009). Additionally, Trichoderma quickly colonizes root tissues and effective plant defenses including phytoalexin synthesis, as was previously seen in *Lotus japonicus* roots after *T.koningii* penetrations (Masunaka et al., 2009). Furthermore, Trichoderma spp. collaborates with other helpful beneficial microbial communities in pathogen-contaminated soil to improve plant development and survival(Omomowo and Babalola, 2019).

2.1. Plant Morphology Modification

Numerous studies have shown that, adding Trichoderma spp. to plant rhizospheres improves a variety of plant morphological characteristics, including root-shoot length, biomass, height, number of leaves, tillers, branches, and fruits (Sajeesh et al., 2015). For instance, the application the cucumber roots by *T. harzianum* boosted the root development (Contress-C. et al., 2009). Moreover, when applied to plants cultivated in a greenhouse, *T. longipile* and *T. tomentosum* greatly increased the totally leaves area and shoot weight in cabbage seedlings(Rabeendran et al., 2000).

2.2. Plant Physiology Modifications

A wide range of physiological activities in plants is regulated positively by the fungus Trichoderma spp., including photosynthesis stomatal conductance, air exchange, nutrient absorption effective water usage etc. As previously mentioned, Trichoderma spp. enhance both root development and soil nitrogen absorption. Treatment with Trichoderma spp. greatly increase Mg absorption, a crucial component of chlorophyll that is also necessary for regulating photosynthesis-related genes and catalyzing enzymatic activities. In addition, rice plants treated with Trichoderma showed considerably higher levels of photosynthetic rate (threefolds), stomatal conductance (threefolds), and water usage efficiency (two folds) than plants treated with conventional fertilization of NPK (Nitrogen, Phosphorus, and Potassium) (Doni et al., 2014). Additionally, the application of Trichoderma with rice plants increases plant resistance against drought stress, enhance plant water-retention capacity and delays plant withering phenomenon (Shukla et al., 2012).

2.3. Effects on the Solubilization and Absorption of Nutrients

Plants treated with *Trichoderma* showed enhanced mineral absorption and increased soil exploration in their roots. according to Harman et al.(2004) various strains of *Trichoderma*, release a variety of acids, including coumaric, glucuronic, and citric acids, which aid in the liberation of phosphorus ions, which appear to be inaccessible to plants in the majority of soils (Altomare et al.,1999). The availability of P, as well as Fe and Zn, is increased in liquid media by the addition of *T. harzianum* strain 1295-22 in soil (Altomare et al.,1999). Additionally,*Trichoderma* inoculation causes the development of root and shoot system, which promotes the absorption of micronutrients elements.Iron deficiency in alkaline soil poses a significant barrier to the production of agricultural crops. *Trichoderma* may be able to produce siderophores, which might be employed to address this issue. Harman et al., (2004) found that the application of *T. asperellum* (T-6) to cucumber roots enhanced the chelating ion compound in the soil and increased Fe⁺² concentration and Fe⁺² and Fe⁺³ activity of chelate reductase. In addition, Colla et al. (2015) observed that the MUCL45632 strain of *T.atroviride* generated hydroxamate and catechol as siderophores. These experiments show that adding *Trichoderma* to the soil helps the plant convert Fe⁺³ to Fe⁺², which increases its dissolving and absorption.

2.4. Resulting Changes in Abiotic Stress Tolerance

Plant growth and reproduction under challenging circumstances are improved by soil inoculation with several strains of *Trichoderma*. As an illustration, biopriming rice with *T.harzianum* decreased the negative effects of salt stress on plants and enhanced plant development(Rawat et al.,2012). Similar results were also seen in plants that had been subjected to salt stress, such as cucumbers treated with *T.asperellum* Q1(Qi and Zhao, 2013).*Trichoderma* spp., are also essential in the reduction of heat and cold stressors. For instance, *T. harzianum* AK20G strains were used to reduce the chilling stress in tomato plants (Ghorbanpour et al.,2018). Similar to this, transgenic *A. thaliana* plants containing *T. harzianum* T34 hsp70 genes showed increased tolerance to heat stress(Montero B. et al., 2010). Additionally, several *Trichoderma* species are well-known for their functions in reducing plant oxidative stress. In fact, a considerable increase in the gene expression of antioxidants including SOD (superoxide dismutase), CAT (catalase), and POD (peroxidase) was seen in wheat plants that had been infected with *T. longibrachiatum* and exposed to saline (Zhang et al., 2016).

2.5. Creating Disease Resistance

The introduction of various species of *Trichoderma* into a plant's rhizosphere has been shown to enhance plant defense against a variety of pathogenic organisms, including viruses, bacteria, and fungi(Harman et al., 2004). This was accomplished by encouraging the onset of various resistance mechanisms, primarily stimulating three types of resistance include induced resistance, acquired resistance, and hypersensitive (Figure 1). Various kinds of metabolites may be made based on a number of publications, which highlights their importance as elicitors or resistance inducers in the *Trichoderma*-plant interactions(Ahluwadia et al., 2015). Non-virulent

genes produce protein-like gene products, such as xylanases and chitinases, and low molecular composites created as a result of hydrolytic enzymatic breakdown of fungal cell walls are all included in the metabolites (Ahluwadia et al., 2015). The increase in the quantities of protective metabolites and enzymes is what causes resistance to be induced. These mostly comprise glucanases and biosynthesis of phytoalexin which depends on the activity of the metabolism of phenylpropanoid enzymes and chalcone synthase (CHS) (Melntyre et al., 2004; Stacey and Keen, 1999). Chitinases are another group of enzymes that help plants fight pests. The antioxidative defense response involves enzymes that include pathogenesis-related proteins (PR) (Stacey and Keen, 1999). For instance, *Hordeum* species inoculated with *Trichoderma atroviride* showed induced resistance to the infection by the pathogen *Fusarium* spp. by increasing activity of the endochitinase Ech42 enzyme (Melntyre et al., 2004). Similarly, when tobacco and potato plants were treated with chitinase (Chit42) derived by *T. harzianum* and expressed in them, that led to create of transgenic lines with high toleranance or entirely resistantanc to the foliar pathogens such as *Alternaria alternata*, *A. solani*, and *Botrytis cinerea*. (Howell et al., 2003). In another study by showed that, Yedidia et al.(1999) cucumber roots injected with *T. harzianum* enhanced production of the activity of peroxidase and chitinase enzymes, which enhanced plant resistance against the pathogenic assaults.

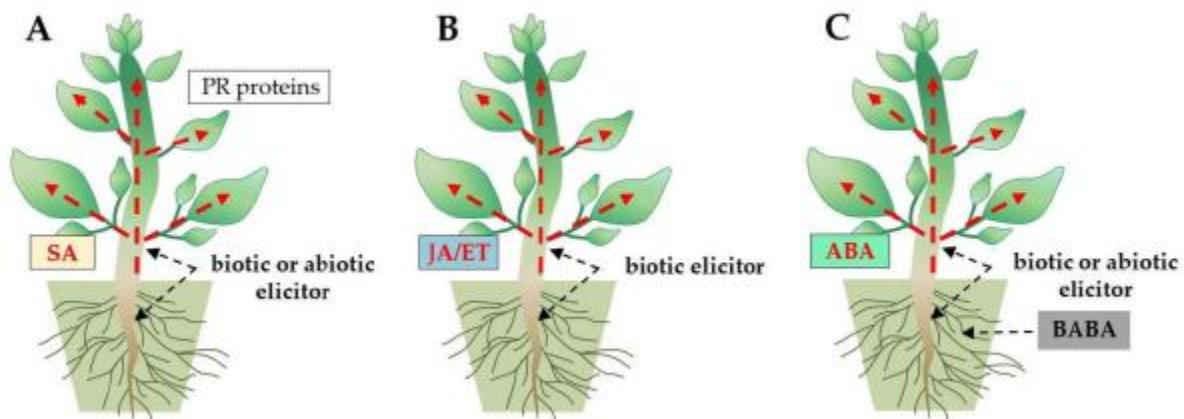


Figure 1. Plants can develop one of three different types of systemic resistance: (A) acquired (SAR), (B) induced (ISR), and (C) induced resistance (IR), which are triggered by *Trichoderma* spp. SAR, ISR, and IR immunity are mediated by signaling molecules, including the salicylic acid (SA), jasmonic acid (JA)/ethylene (ET), and abscisic acid (ABA) phytohormones (Adopted from Ty'skiewicz et al., 2022).

3. Effects of *Trichoderma* on Pathogens

The relations between the plant-bioagent and pathogenic populations result in disease control, which is aided by biocontrol mediators. *Trichoderma* spp. are among the most studied fungal BCAs because of their capacity to protect plants and suppresses pathogen populations in a variety of soil environments (Lorito et al., 2010; Harman et al., 2004). *Trichoderma* spp. are also used

commercially as soil enhancers, biofertilizers, and biocontrol agents. Many species in this genus are "rhizosphere competent," which means they can break down xenobiotic pesticides, hydrocarbons, chlorophenolic chemicals, and polysaccharides (Li et al., 2009). Mycoparasitism (Karupiah et al., 2019), competition (Ahluwadia et al., 2015), and antibiosis (Druzhinina et al., 2011) are the main biocontrol mechanisms that *Trichoderma* develops in direct combat with fungal pathogens (Figure 2).

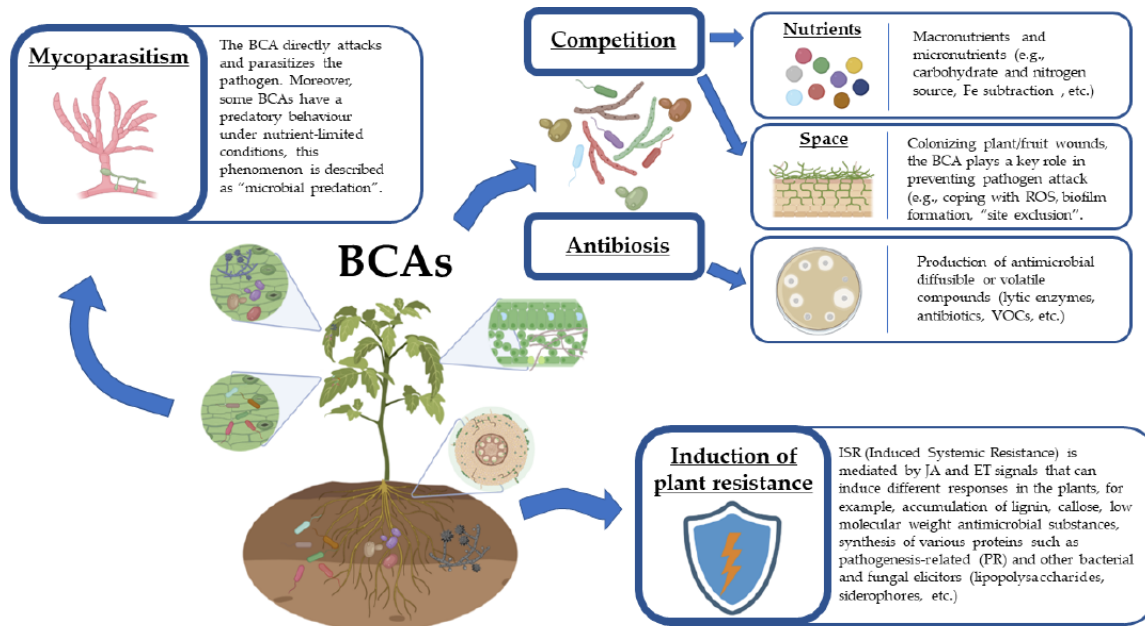


Figure 2. The primary mechanisms by which biocontrol agents (BCAs) combat plant diseases (Adopted from Ty'skiewicz et al., 2022).

3.1. Mycoparasitism

One of the most significant antagonistic strategies shown by *Trichoderma* spp. is mycoparasitism, which connotes the direct attack of one fungus species on another. There have been reports of about 75 *Trichoderma* spp., with mycoparasitic capability. Numerous studies have shown that different strains of *Trichoderma* targets and destroys a variety of plant pathogenic fungi, including root and shoot diseases pathogens (Howell et al., 2004; Druzhinina et al., 2011; Harwoka et al., 2019). Weindling (1932) was the first to record this mycoparasitic response almost 70 years ago. This intricate method involves a series of actions. The first step in distinguishing *Trichoderma* from the target fungus is the binding of *Trichoderma*'s cell wall carbohydrates to the lectins of the other. The formation of the appressoria and hyphal twirling, which include more osmotic substances like glycerol, come next. Following successful penetration, *Trichoderma* spp., produces many enzymes that are toxic to pathogenic fungi, which work to destroy the cell walls of pathogenic fungi called cell wall degrading enzymes (CWDEs), including glucanases, chitinases, and proteases (Harman et al., 2004). Then, these CWDEs start their assault on the host's cellular infrastructure. The cumulative effect of these substances

dissolves the host's cell walls, which ultimately leads to the target fungus becoming parasitic. Gaps that are created at the site of the appressoria development have been observed to allow *Trichoderma* hyphae directly penetrate to the target fungus's lumen, where they kill the pathogenic fungus (Kumar, 2013). Furthermore, pathogenic fungi's enzymes, such as pectinases and other compounds, are inactivated by biocontrol agents, which prevents them from colonizing and penetrating plant tissues. Chitin and 1,3-glucan make up the majority of the fungal cell walls, as is well known (Harman et al., 2004). It is believed that *Trichoderma* spp. produce a number of the lytic enzymes (chitinases and 1,3-glucanases) which are thought to have mycoparasitic effects that cause the breakdown of phytopathogenic fungal cell walls (Siven and Chet, 1989). Additionally, *Trichoderma* spp., have the ability to completely and effectively degrade fungal mycelial or conidial walls which is further ensured by other CWDEs, such as those that hydrolyze minor polymers (such as proteins, 1,6-glucans, 1,3-glucans, etc.) (Geremia et al., 1993). A *Trichoderma harzianum* mycoparasitic strain has previously been shown to include a subtilisin-type serine proteinase that is activated by chitin (Siven and Chet, 1989). Additionally, 1,6-glucanases (EC3.2.1.75) have been shown to breakdown cell walls in bacteria, filamentous fungus, and yeast (Rombouts and Pha, 1976). According to a previous study by Zeilinger et al. (1999) *Trichoderma* may detect the presence of pathogenic mycelium in the rhizosphere and spread in the direction of the pathogen region, the regulatory sequences for the genes encoding endo- and exochitinase were moved downstream to make room for the gene encoding the green fluorescent protein. This research showed that the gene of endochitinase is activated before attached to the target fungus occurs during the *Trichoderma*-fungal interaction. The activation of exochitinase enzyme, on the other hand, occurred only after the contact (Brunner et al., 2003). *Trichoderma* continuously releases modest quantities of exochitinase, although the fact that different forms may pursue different patterns of stimulation. This enzyme's transmission encourages the target fungus to produce cell wall fragments. These fragments appear to engage *Trichoderma*'s cell wall or plasma membrane receptors in an interaction that encourages the development of fungitoxic CWDEs (Viterbo et al., 2002). Before actual contact has been formed, these CWDEs in turn utilize and begin the assault on the target fungus (Rombouts and Pha, 1976). Once attachment has been established, the mycelium of *Trichoderma* spp. coils and creates appressoria on the fungus pathogen wall. *Trichoderma* also releases peptaibol antibiotics, which are fungitoxic, in addition to CWDEs (Dotson et al., 2018). These components must work together for the target fungus's cell walls to dissolve and to become parasitized. This function is obviously being carried out by about 20–30 recognized genes, proteins, or metabolites (Figure 3) (Benitez et al., 1998).

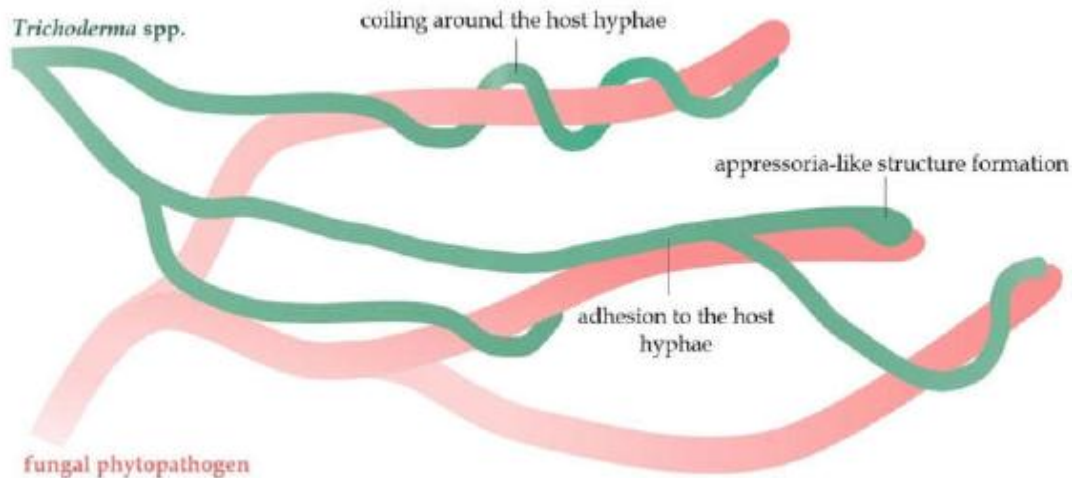


Figure 3. An illustration of the mycoparasitic interaction between the hyphae of Trichoderma and the hyphae of fungal pathogens. (Adopted from Ty'skiewicz et al., 2022)

3.2. Competition

The growth of phytopathogens and the management of fungal communities occur naturally as a result of the scarcity of resources and the competition for them (Mahmood and Kataoka, 2018). When bioagents Trichoderma and pathogens interact, competition for macro-nutrients elements becomes the key factor (Zhang et al., 2017). In the rhizosphere of plants, Trichoderma species are known to compete with pathogens for nutritional resources, ecological niches, or sites of infection (Ahluwalia et al., 2015). Despite the fact that nutrients including amino and organic acids, vitamins, Fe, etc. are particularly abundant in the rhizosphere and the exudates from the roots, it was thought that the competition for these important nutrients between Trichoderma and several fungal pathogens such as *Rhizoctonia solani*, *F. oxysporium*, etc. for carbon (C) was particularly important (Sarocco et al., 2009). Fe ions are essential nutrients for plant growth and development, acting as cofactors for numerous types of enzymes (Miethke et al., 2013). In an aerobic environment, Fe has a tendency to produce the insoluble ferric oxide, which ultimately hinders it from being absorbed by roots, according to Miethke et al. (2013). The siderophore compounds a substance released by Trichoderma spp., chelates iron and stops the fungal pathogen from progressing and growing (Srivastava et al., 2018). This complex binds to the insoluble iron (Fe^{+3}) and changes it into the soluble form (Fe^{+2}), which is more readily absorbed from host plants (Figure 4). Siderophore simultaneously reduces the sources of Fe in the soil, inhibiting the growth of the target fungus and enhancing the availability of Fe to plants (Srivastava et al., 2018). Fusarinines, coprogens, and ferrichromes are the three families into which the majority of the fungal siderophores that have been discovered so far may be divided (Kubicek et al., 2011).

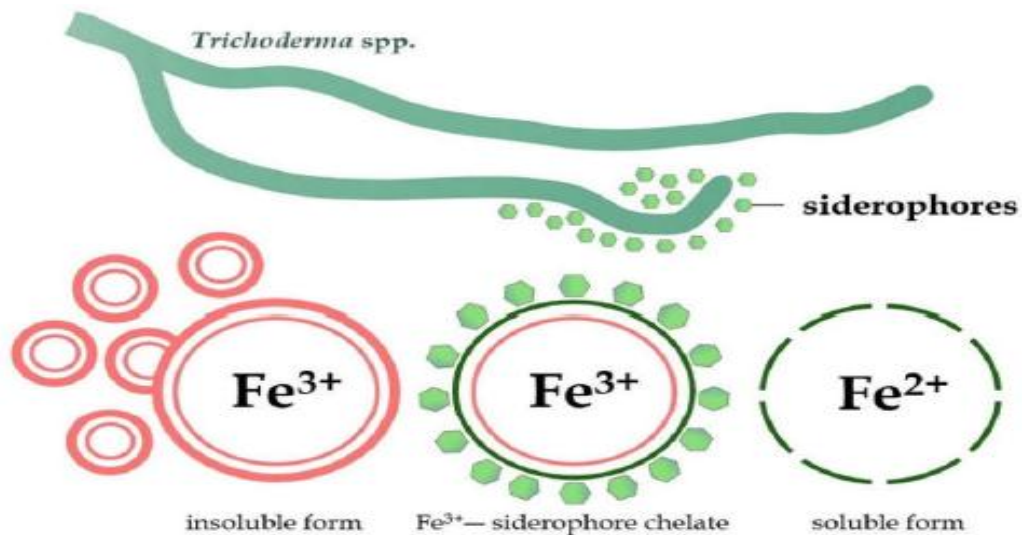


Figure 4. Siderophore produced by the Trichoderma fungus converts the insoluble iron form of (Fe³⁺) into the soluble (Fe²⁺) and is readily absorbed from plant (Adopted from Ty'skiewicz et al. 2022)

3.3. Antibiosis

Antibiosis is primarily focused on the creation of secondary metabolites that have an inhibitory or lethal effect on a phytopathogenic. The ability of Trichoderma species to produce a variety of protective metabolites known as polyketides through a series of processes mediated by an enzyme complex called polyketide synthases (PKSs) has also been demonstrated. Trichoderma viride produce a wide range of antibiotics such as trichotoxins A and B, trichodecenins, trichorovins, and trichocellins. Trichorzianins A and B, trichorzins, HA, and MA were also detected in *T. harzianum*. Longibrachins and trichokonins were identified from *T. koningii*, whereas atroviridins A–C and neotroviridins A–D were derived from *T. atroviride* cultures. *T. longibrachiatum* produced Tricholongins BI and BII (Reino et al., 2008). Furthermore, *T. koningii*, *T. harzianum*, *T. aureoviride*, *T. viride*, *T. virens*, *T. hamatum*, and *T. lignorum* cultures were used to identify other antibiotic compounds, such as koningins, viridin, dermadin, trichoviridin, lignoren, and koningic acid (Zeilinger et al., 2016). One of Trichoderma's most important secondary metabolites that is associated to the P and Q group strains, respectively, is gliotoxin. However, P group strains of Trichoderma virens (Gliocladium) do not negatively impact *R. solani*. When it comes to *R. solani*, however, the Q group is more active (Howell et al., 2000). *T. harzianum* produce Harzianic acid, which exhibits antibiotic activity against *Pythium irregulare*, *Sclerotinia sclerotiorum*, and *R. solani* (Manganiella et al., 2018). Antibiotic action typically works in tandem with lytic enzymes. Their combined action provides a higher degree of antagonistic activity than either antibiotics or enzymes working alone (Monte, 2003). Howell et al. (2003) noted that the first destruction of cell walls by lytic enzymes in the case of *B. cinerea* and *F. oxysporum* improves the entry of antibiotics into the target hypha.

4. Plant resistance development in response to biotic stress

In biological plant protection, the ability of *Trichoderma* strains' to grow in the rhizosphere and build a strong and enduring association with plants is very important. By stimulating the local or systemic defense systems of plants, Fungi of this genus may indirectly influence dangerous microbes (Zeilinge et al., 2016). Plant resistance is the outcome of the activity of different elicitors (triggers for the protective reaction) produced by microbial cell walls (exoelicitors) and plant tissues (endoelicitors). There are two types of elicitors: (1) race-specific elicitors that only activate gene-to-gene type defense in a small number of host cultivars, and (2) general elicitors produced by both virulence-pathogenic and non-virulence-pathogenic fungi that trigger the non-race-specific defenses of host and the organism. In the presence of *Trichoderma* non-pathogenic fungus, a number of plant species exhibit elevated immune response activity (Shoresh et al., 2005). According to Jones and Dangl (2006), the identification of preserved scopes, such as the pathogen-associated molecular pattern (PAMP) or the microbe-associated molecular pattern (MAMP), serves as the foundation for the major mechanism of plant defense. Both MAMP-triggered immunity (MTI)/PAMP-triggered immunity (PTI) and effector-triggered immunity (ETI) are induced by these domains in plants, triggering their internal or external defenses (Figure 5) (Sarrocco et al., 2009; Zeillinge et al., 2005). The activity of numerous elicitors (triggers for the protective reaction) produced by the microbes (exoelicitors) and plant tissues (endoelicitors) results in the development of plant resistance. Oligosaccharides, proteins, and peptides, glycolipids, and lipophilic substances are among the different classes of elicitors characterized. As a result of signal transduction pathways being activated by elicitors, plants go through physical, biochemical, and molecular changes. These modifications include the production of reactive oxygen species (ROS), adjustments to the ion flow across membranes, the construction of a physical barrier to prevent the propagation of phytopathogens, including callose buildup and plant cell wall fortification, and the production of various defensive substances, such as phytoalexins, volatile chemical compounds, enzymes, and phytohormones (Harman et al., 2004).

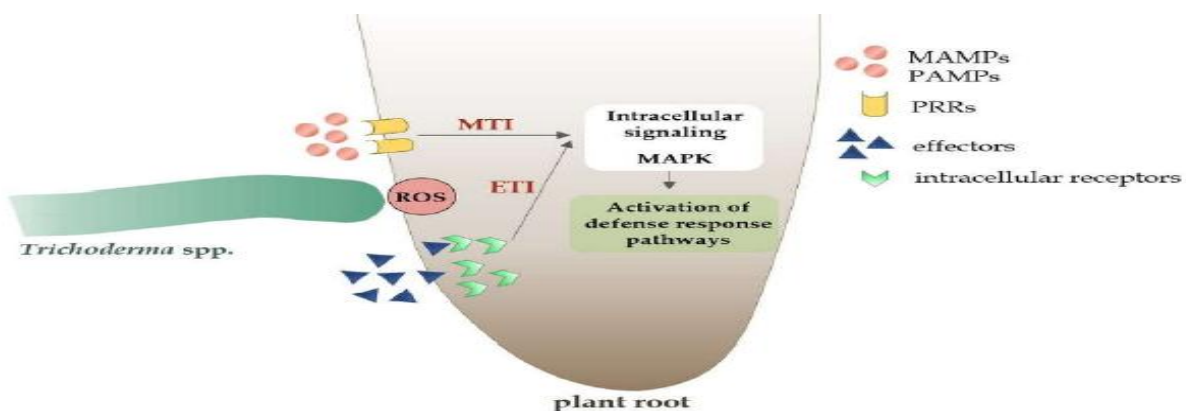


Figure 5. mechanisms for plant defense in response to *Trichoderma* spp. effectors and molecules are known as microbe-associated molecular patterns (MAMPs). (Adopted from Ty'skiewicz et al., 2022).

5. Conclusions and Future Perspectives

Biocontrol is the technique of using living organisms, genes with genetic changes, or their derivatives to lessen the effects of undesired creatures and to promote species that seem to be beneficial to humans. *Trichoderma* spp. are well known for their ability to produce a wide variety of antibiotic compounds that possess the capacity to parasitize many harmful fungus in the soil, as was covered in this article. *Trichoderma* spp. also produce a number of metabolites that stimulate localized and systemic resistance as well as stress tolerance in plants, all of which have a significant impact on plant development. For a comprehensive, in-depth understanding of this multifaceted bioagent, more research addressing the biochemical and physiological mechanisms through which *Trichoderma* spp. function as a bioagent against various fatal fungus is required. Additionally, *Trichoderma*'s compatibility with chemical fungicides has to be assessed for the goal of integrated disease control. It's critical to broaden farmers' acceptance of *Trichoderma*-based disease control formulations. To confirm a database for *Trichoderma*'s safe and long-term usage, it is necessary to assess the ecological impact of widespread applications of biocontrol agents and their secondary metabolites in biological control. The genomes of *Trichomonium* can be a very helpful origin of nominee genes for creating transgenic plants that display resistance to both stressors the biotic and abiotic. Considering all available data presented in this study, using of *Trichoderma* species needs to encourage as a viable contemporary economy's alternative to chemical pesticides, and also strives to protect the ecology and promote human health.

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الفطر *Trichoderma* : عامل تحكم بيولوجي للوقاية من أمراض النبات وتعزيز الاستدامة

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الخلاصة

قدرة الفطر *Trichoderma spp.* في مجال مكافحة الحبيوية تكون أما بصورة مباشرة أو غير مباشرة ضد مجاميع متنوعة من مسببات الامراض النباتية المتوطنة في التربة يزيد الاهتمام باستخدام الفطر في مجال المكافحة الحبيوية. ان الفطر *Trichoderma* عديم الفوعة اي انه لا يسبب اية اضرار الى النباتات كما انه يعيش بصورة تكافلية مع النباتات. المبيدات الحبيوية المصنعة باستخدام هذا الفطر تكون رخيصة التكلفة وصديقة للبيئة ولها القدرة على كبح نشاط المسببات الممرضة للنباتات. يعيش الفطر *Trichoderma spp.* بصورة تكافلية مع جذور النباتات وهذه المعيشة تجعله قادر على اكساب النباتات المضيفة صفة المقاومة ضد المسببات المرضية كما يعمل على تحسين نمو النباتات من خلال زيادة جاهزية امتصاص العناصر الغذائية من قبل جذور النبات. يعد انتاج المضادات الحبيوية والمنافسة على استغلال منطقة الجذور المتأثرة بشكل قوي يمنع نشاط المسببات المرضية فيها تعتبر كلها من اليات المكافحة الناجحة للفطر *Trichoderma spp.* إضافة الى قدرة الفطر على تحفيز النبات على التخليق الحيوي لعدد من المركبات مثل منظمات النمو والانزيمات والمضادات الحبيوية وانتاجه لماسكات ايون الحديد تجعل من الفطر *Trichoderma spp.* مرشح قوي للاستخدام في مجال المكافحة الحبيوية. تلخص هذه المراجعة فعالية الفطر *Trichoderma spp.* في مجال المكافحة الحبيوية كما تلقي الضوء على التقدم السريع في تحديد اهمية استخدام الفطر *Trichoderma spp.* في البيئة على المستوى الكيموحيوي والجزيئي في منطقة الجذور المتأثرة وكذلك فوائد التعايش مع النبات العائل من حيث المستويات الكيموحيوية والفسيلوجية من وجهة نظر تطبيقه حيث تدعم الادله المقدمة بقوة امكانية استخدام الفطر *Trichoderma spp.* كعامل مقاومة حيوية ضد المسببات المرضية المختلفة وغير ضار للبيئة وغير مكلف اقتصاديا.

الكلمات المفتاحية: المضادات الحبيوية ؛ المكافحة الحبيوية ؛ المنافسة ؛ الفطريات ؛ الطفيليات الفطرية ؛ الممرض