STM JOURNALS

International Journal of
Fungi

ISSN: 3049-1509
Volume 2, Issue 2, 2025
July–December
DOI (Journal): 10.37591/IJF

https://journals.stmjournals.com/ijf

Review IJF

Trichoderma: Beneficial Fungus for Sustainable Agriculture

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Abstract

As environmentally beneficial substitutes for chemical pesticides, Trichoderma species are being utilized in agriculture more and more. Disease suppression, increased plant growth, and increased tolerance to environmental stress are just a few advantages they provide. These fungi are used in a wide range of cropping systems and formulations around the world. Their use is growing worldwide, particularly in Asia and Europe. In contemporary crop management, items derived from Trichoderma are essential as sustainable approaches gain traction. Harzianolide, a compound derived from Trichoderma harzianum SQR-T037, was studied for its effects on plant growth and defense. It significantly enhanced tomato seedling growth and root development at low concentrations. The compound also activated defense-related enzymes and induced key immune genes. Treated plants showed improved resistance to Sclerotinia sclerotiorum. This highlights harzianolide's potential as a natural growth promoter and resistance inducer in crops. Because of their various antagonistic mechanisms, Trichoderma species are efficient biocontrol agents against plant diseases. These consist of direct parasitism of other fungus, competition for nutrition, and the release of enzymes and antibiotics. They also trigger natural defensive mechanisms and encourage plant growth. Environmental factors, pathogen species, and strain type all affect efficacy. Improved biological formulations for long-term crop protection can be developed thanks to insights into these mechanisms. Plant pathogen biocontrol and industrial enzyme production are just two uses for the adaptable fungus Trichoderma species. According to recent research, they act as endophytes, promoting immunity, stress tolerance, and plant growth. Understanding the genome has helped identify important genes related to secondary metabolite synthesis, mycoparasitism, and plant interaction. Their use in agriculture stems from their capacity to alter root architecture and elicit defense responses. These developments connect fundamental biology to creative biotechnology applications in this special issue. Soil degradation and enhanced disease resistance are just two of the major health and environmental issues brought on by the overuse of chemical pesticides and fertilizers. In contemporary agriculture, the helpful soil fungus Trichoderma has become a viable and environmentally responsible substitute. It suppresses dangerous infections and promotes plant growth in a variety of ways, including as a biocontrol agent, biofertilizer, and bioremediator. It is a perfect part of organic farming and integrated pest control systems because of its capacity to promote soil health, increase nutrient uptake, and break down contaminants. Its efficacy in crop protection is further increased by its compatibility with nanotechnology. Trichoderma has a lot of potential to lessen reliance on chemicals and promote environmentally friendly farming methods. With its ability to promote plant growth, prevent disease, and clean up the environment, Trichoderma shows great promise as a multipurpose bioagent in agriculture. It functions by inducing plant defense responses, nutritional competition, mycoparasitism, and antibiosis. Its uses include biofertilizer, biocontrol agent, and bioremediator. It also contributes to the production of environmentally acceptable nanoparticles. Because of these characteristics, Trichoderma is a useful substitute for chemical inputs. Its adoption can have a major positive impact on environmentally friendly and sustainable farming methods.

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Received Date: July 25, 2025
Accepted Date: July 30, 2025
Published Date: August 30, 2025

Citation: Arpit Dixit. *Trichoderma*: Beneficial Fungus for Sustainable Agriculture. International Journal of Fungi. 2025; 2(2): 25–29p.

Keywords: biocontrol, biofertilizer, bioremediation, nanotechnology, sustainable agriculture, Trichoderma spp.

INTRODUCTION

Trichoderma - a Multifaceted Fungus

Since 1920, it has been recognized that the fungi in the genus *Trichoderma* (Division: Ascomycota, Subdivision: Pezizomycotina, Class: Sordariomycetes, Order: Hypocreales, Family: Hypocreaceae) can act as biocontrol agents against numerous plant infections.They can be used to either augment some plants' natural capacity to break down harmful chemicals in soil and water or to improve the health of agricultural plants [1]. The effectiveness of the plant's ability to absorb nutrients is a result of the interaction between *Trichoderma spp*. and plants, which successfully regulates root architecture and lengthens primary and lateral roots [2]. The filamentous fungal genus Trichoderma is well-known for its ecological diversity and advantageous relationships with plants. Many strains were first identified as soil residents, however it is now known that they may coexist symbiotically with plant roots to affect defense and growth. Among their many uses are stress resistance, nutrient absorption improvement, and biocontrol. Their molecular signaling and secondary metabolite production have been better understood because to genetic advancements. These fungi also produce enzymes, particularly cellulases, on an industrial scale. The expanding knowledge of Trichoderma biology creates new prospects for biotechnology and sustainable agriculture [3]. Agricultural losses are significant due to plant diseases, particularly those caused by fungus that are carried in the soil. Fungicides made of conventional chemicals frequently result in resistance and unexpected environmental damage [4]. A safer and more sustainable option is biological management, especially with Trichoderma species. These fungi encourage the growth of plants and are efficient opponents of plant diseases. Their ability to grow quickly, withstand harsh environments, and produce bioactive substances are some of the adaptive qualities that contribute to their success. This paper examines the various ways that Trichoderma improves plants and controls illness. Public concern over the harmful impacts of chemical pesticides has led to growing interest in biological alternatives. *Trichoderma* species have emerged as powerful microbial agents in sustainable agriculture due to their ability to suppress plant pathogens and enhance plant growth. These fungi function through diverse mechanisms such as mycoparasitism, competition, and stimulation of plant defense responses. European policies now promote reduced pesticide use and encourage integrated pest management practices. Biocontrol agents like *Trichoderma* are central to achieving these goals [5]. Their broad application and effectiveness support their expanding role in crop protection and productivity [1]. The ability of Trichoderma species to inhibit plant diseases and improve crop health has long been known. Originally prized for their mycoparasitic properties, studies have subsequently identified a number of processes, such as competition, induced plant resistance, and enzyme synthesis. These fungi interact favorably with plants by colonizing their root systems [6]. They are useful instruments in integrated pest management plans because of their adaptability. Our knowledge of their biological action has greatly increased over time. Their growing application in sustainable agriculture is supported by this progression. In addition to harming the environment and public health, the overuse of chemical pesticides and fertilizers has deteriorated soil quality. These substances harm non-target species and cause pathogens to become more resistant. Eco-friendly substitutes that are both safe and efficient are necessary for sustainable agriculture. Trichoderma is a helpful fungus that has several uses in farming. It serves as a bioremediator, biocontrol agent, and biofertilizer. Organic farming and Integrated Pest Management (IPM) are two methods that Trichoderma supports. It increases crop growth, inhibits plant diseases, and strengthens the soil. By encouraging its use, we can lessen our reliance on dangerous agrochemicals and promote sustainable farming practices. Trichoderma is a fungus that lives in soil and is well-known for its quick development, versatility, and advantageous relationships with plants. It enhances plant health without causing illness by organically colonizing the rhizosphere and even functioning as an endophyte [7]. Through processes including mycoparasitism, competition, and the synthesis of enzymes and antibiotics, it is ecologically essential in regulating soil-borne pathogens. Trichoderma promotes improved root development and plant growth by increasing nutrient availability and improving soil structure. Additionally, it regulates soil ecology and promotes microbial diversity. It aids in the bioremediation of contaminated soils by breaking down dangerous materials. It is appropriate for a variety of agroecosystems due to its adaptability to different environmental circumstances. All things considered, Trichoderma plays a significant role in encouraging environmentally friendly and sustainable farming methods [8].

SIGNIFICNCE OF TRICHODERMA

- It can regulate root architecture.
- It can lengthen primary root and lateral roots.
- Disease can be controlled by *Trichoderma spp.*
- It can suppress the growth of pathogen.
- It has a tendency to increase the fertility of soil.
- Naturally suppresses plant diseases.
- Encourages the health and growth of plants.
- Increases the activity of the rhizosphere, or root zone, and soil.
- Increases the resistance of plants to stress.
- Helps plants "remember" stress so they can react to it in the future.
- Minimizes the need for chemical inputs.
- Creates advantageous root linkages.
- Supports environmentally sustainable agricultural methods [9].

MODE OF ACTION OF TRICHODERMA

- *Mycoparasitism:* Trichoderma affixes itself to plant pathogens' hyphae and uses enzymes like chitinases and glucanases to break down their cell walls [5].
- *Antibiosis:* Generates antimicrobial compounds that prevent the growth of dangerous bacteria and fungi, such as peptaibols and polyketides [3].
- *Competition:* Especially in the rhizosphere (root zone), it outcompetes pathogens for nutrients and space [4].
- *Plant defense mechanisms are stimulated by Induced Systemic Resistance (ISR):* which increases resistance to biotic and abiotic challenges in the future [6].
- *Production of Siderophores:* This process sequesters iron and reduces the amount of it that bacteria can access [10].
- *Enzyme Secretion:* To break down organic materials and pathogens, extracellular enzymes such as cellulases and proteases are released.
- *Biofilm Formation:* Protects plants from pathogen invasion by forming protective biofilms on the surfaces of roots [11].
- *Nanoparticle Biosynthesis:* Trichoderma also produces antimicrobial metal nanoparticles (such as AgNPs and ZnONPs) that help reduce pathogens.
- *Endophytes:* They cause the expression of numerous plant genes involved in stress responses [7].

BIOCONTROL MECHANISM OF TRICHODERMA

Various *Trichoderma* Biocontrol Strain and Their Control Mechanism

- *T.virens:* it protect plant by inducing phytoalexins toxic to fungi it is effective against *Rhizoctonia solani* pathogens [8].
- *T.asperellum:* they modulate the expression of proteins related to jasmonic acid/ethylene signaling and it is effective against *Pseudomonas syringae pv.lachrymans.*
- *T.atroviride:* they secreate proteins –Sm1 and Epl1 both induced systemic acquired resistance it is effective against *Alternaria solani* pathogens [12].
- *T.harzianum:* they have a tendency to activate defense related mechanism and improved phytoalexins capsidiol toxic to pathogen and it effective against *Botrytis cinerea Pers, B.cinerea* and many more (Figure 1) [13].

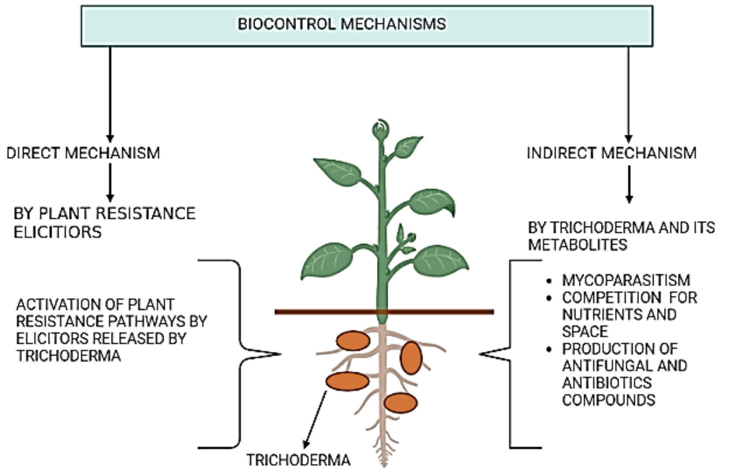

Figure 1. Biocontrol mechanism of *Trichoderma.*

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CONCLUSION

It is widely recognized that *Trichoderma* strains are effective biocontrol agents for a variety of harmful microorganisms. Not only that, but the most recent research revealed that this fungus also improves plant resistance, growth, and development, increasing yield production. *Trichoderma* can also be employed in waste/organic material decomposition and area purification. They also play a significant role in reducing diseases and enhancing plant growth. The combined study highlights the diverse function of Trichoderma species in contemporary farming. These fungi serve as growth boosters and immune-boosting agents for plants in addition to being effective biocontrol agents against a variety of plant diseases. Trichoderma uses a variety of tactics, including mycoparasitism, enzymatic activity, competition, and the creation of systemic resistance, according to mechanistic research. Their efficacy across a range of crops and environmental situations is further confirmed by field applications and commercial formulations. Trichoderma-based technologies present viable, environmentally acceptable substitutes for chemical inputs as sustainable agriculture gains international attention, promoting both agricultural yield and environmental well-being.

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