***Review Article***

**A Comprehensive Review on Diverse Roles of *Trichoderma spp*. for Sustainable Agriculture**

**ABSTRACT**

The environment and human health have suffered from the overuse of chemical pesticides and fertilizers in a number of ways. They reduce soil fertility, increase pathogen resistance, suppress microbial activity, and increase greenhouse gas emissions. Using chemical pesticides alone to manage plant diseases is both improper and impracticable. To achieve sustainability in agriculture, emphasis should be placed on using organic pesticides and fertilizers. Progressive farmers have been using *Trichoderma* more and more in recent years as a substitute for artificial pesticides and fertilizers. The main reasons for its low adoption among farmers are its slow rate of colonization and reproduction, susceptibility to biotic and abiotic stressors, inability to completely eradicate pathogens, and high cost. To get over these obstacles, distinct strains of *Trichoderma* that are quick to grow and colonize, least impacted by environmental factors, and have a broad host range of diseases should be found. To ensure its widespread use, farmers should also be educated about the value of *Trichoderma* in agriculture through a variety of extension services. Trichoderma, which functions as a biofertilizer, bioremediation, and biocontrol agent, may be a practical and sustainable substitute. However, Trichoderma's applicability at the farmer level is still lacking, and its utilization is restricted to research endeavors. Therefore, the purpose of this study, which is based on a critical analysis of research papers from researchers around the world, is to disclose the current state of *Trichoderma* use, including its significance, modes of action, application and multiplication techniques, obstacles to widespread adoption, and suitable remedies.

**Keywords:** Adoption, Bio-fertilizer, Bio-remediator, Challenges, Present scenario *Trichoderma*

**INTRODUCTION**

In the name of intensive agriculture, chemicals have been used carelessly, degrading the ecosystem and soil quality while also having a number of detrimental effects on human health. They put non-targeted organisms at danger and cause infections to become resistant to chemicals. Moreover, greenhouse gas emissions and biodiversity loss are caused by the extensive use of pesticides in agriculture (Nicolopoulos et al. 2016). In order to attain sustainability in agriculture, it is imperative that we look for methods or practices that are safe for the environment and human health. Sustainable agriculture is a comprehensive approach that strives for farming success while taking into account the environment, the well-being of people and animals, minimum economic costs and minimum risk to all contribution that farmer makes to their society (Norman et al. 2000). (Abo-Elyousr et al. 2014) shows that sustainable agriculture is essential to ensuring food security for the world's constantly growing population. Therefore, the first step in implementing sustainable agriculture is to reduce the use of heavy chemicals and prioritize the use of organic pesticides and fertilizers. In this sense, *Trichoderma* may be the best bioagent to use in order to accomplish the objective of sustainable agriculture. It can be used as a bio-control agent, bio-remediator, and bio-fertilizer, among other applications. As a result, it has enormous promise in sustainable farming practices such as organic farming, integrated pest management (IPM), and integrated nutrient management (INM).

*Trichoderma* are asexual fungi that reproduce via Chlamydia spores. They are ascosporic and may live in soil with a pH range of any pH, while their ideal temperature is between 25 and 35°C (Shah and Aafiya 2019). It has a great capability for outbreaks and is highly dominant among all fungi. It is thought to be an adversary to other fungi and is typically found with plant roots as a symbiotic and dominating fungus. By generating iron chelating compounds, which absorb soil iron compounds and cause other microbes to be iron deficient, as well as by creating an acidic soil environment that is unfavorable to other pathogenic microbes, *Trichoderma* has a high capacity to compete with other microbes, according to Benitez et al. (2004). Trichoderma's key characteristics include antibiosis, competition, and mycoparasitism, which prevent the growth of other harmful microorganisms by the biosynthesis of targeted metabolites like growth regulators, enzymes, antibiotics and siderophores (Sood et al. 2020). The majority of the 89 species of the *Trichoderma* genus, which are found all over the world, are useful in agriculture. *Trichoderma* has a long history of application in agriculture. Since the 1920s, *Trichoderma* has been known to have antagonistic activity against the majority of infections (Harman et al. 2006). In a similar vein, *Trichoderma* is increasingly being used as a biofertilizer and to prevent soil and seed-borne plant diseases. However, compared to chemical pesticides and fertilizers, its adoption rate is lower. Its global acceptance at the farmer level is still unsatisfactory. It is vital to identify any obstacles to its adoption that might be on par with or greater than those posed by chemical pesticides and fertilizers. Thus, this study aims to reveal the multipurpose uses of Trichoderma, its mode of action and methods of application along with its challenges for wide scale adoption and to provide appropriate ways to overcome those challenges through critical analysis of the situation.

**Methodology**

This study is the result of secondary sources of information obtained from a variety of literary works, such as books, journal articles, and websites. The necessary information was gathered, and a graph illustrating the most recent patterns in the application of synthetic pesticides and fertilizers was produced. Trichoderma's diverse role in agriculture, its obstacles to widespread acceptance, and appropriate remedies were all revealed by a thorough analysis of related literature.

***Trichoderma* as an alternative to chemical fertilizers and pesticides**

*Trichoderma* is extensively used to control a variety of plant pathogens, including viruses, fungi, nematodes, bacteria, and many higher plant parasites (Bigirimana et al. 1997), and its application is much more extended due to its long-term persistence on soil and other parts (Hanada 2009). It also helps to improve plant growth, development, and yield along with stem length, thickness, and chlorophyll content (Hassan 2014). If all farmers were aware of the detrimental effects of chemicals and the advantages of *Trichoderma* in Since agriculture is both affordable and environmentally friendly, they would surely choose it. (Sachdev & Singh 2020) discovered that *Trichoderma* and plants interact to produce volatile compounds that aid in pest control. Chemical pesticide residues linger in the soil for a while, damaging the ecosystem and making plants more hazardous. Unlike chemicals, *Trichoderma* can metabolize a range of high and low molecular weight polycyclic aromatic hydrocarbons and reduce or eliminate harmful substances in soil (Yao et al. 2015). In addition to reducing the number of pathogens, *Trichoderma* can also help plants become more resistant and improve a variety of physiological processes. It helps solubilize phosphates, boosts micronutrient uptake, and reduces the need for artificial NPK fertilizers (Kamala & Indira 2011). Chemical fertilizer nutrients are rapidly lost by volatilization or leaching, but *Trichoderma* persists in soil for a very long time. We can affirm that *Trichoderma* can be a sustainable and practical substitute for chemical pesticides and fertilizers in light of all these factors.

**Present scenario of the use of *Trichoderma* in agriculture**

In recent years, *Trichoderma* has become more and more popular in agriculture. To learn more about Trichoderma's function as a biofertilizer, bioremediator, and bio-control agent, hundreds of studies have been conducted. Progressive farmers that understand the value of *Trichoderma* and the detrimental consequences of chemical pesticides on agriculture are the ones who utilize it the most. As shown in Figure 1, the usage of synthetic pesticides and fertilizers is growing more slowly than it did ten years ago. The extensive usage of botanical pesticides and bio-fertilizers is the cause of this gradual rate of growth.



**Figure. 1 Trends in synthetic fertilizers and pesticides use in agriculture during 2000-2018 (Source:FAO,2020)**

**Uses of *Trichoderma* in agriculture**

***Trichoderma* as biofertilizer**

*Trichoderma* uses a variety of biological mechanisms to make nutrients available to the plants. They enhance soil characteristics and microbial activity in contrast to synthetic fertilizers. Compared to chemical fertilizers, they can preserve soil fertility for a longer amount of time. In the field, they can be used either by themselves or in combination with other chemicals and biofertilizers. According to (Haque et al. 2010), applying 50% nitrogen fertilizer and 50% *Trichoderma* enriched biofertilizer can boost tomato and mustard yields by 108.36% and 125.45%, respectively, compared to control conditions. Similar to this, (Khan et al. 2016) found that applying *Trichoderma* enriched biofertilizer to rice in an SRI system enhanced the plant's height, photosynthetic rate, chlorophyll content, stomatal conductance, and the number of tillers and panicles. *Trichoderma* also has the power to make micronutrients more accessible to plants. After 60 days of tomato plant transplantation, the 100% *Trichoderma* enhanced biofertilizer considerably increased the minerals (K, Cu, Fe, and Zn) in the roots zone compared to the required dose of NPK. When it comes to brinjal yield characteristics, *Trichoderma* enriched biofertilizers are twice as effective as farmyard manure (FYM) at the same dosage (Hossain & Akter 2020). (Wang et al. 2018) showed that, in comparison to urea, viable and nonviable T. viride may reduce ammonia volatilization by up to 42.21% and 32.42%, respectively. *Trichoderma spp*. can therefore improve soil fertility, microbial activity, and soil structure in addition to increasing fertilizer usage efficiency and thereby reducing environmental pollution.

**Induction of Plant Resistance by *Trichoderma spp.***

*Trichoderma spp*. increase the expression of plant genes linked to the synthesis of chitinase, glucanase, and peroxidase, which strengthens the plants' defenses against harmful bacteria, according to a number of studies (Adnan et al. 2019, Yedidia et al. 2023, Hanson et al. 2004). *Trichoderma* biopriming of seeds increases plants' resistance to pathogenic attacks (Harman et al. 2004). Effective disease management is made possible by Trichoderma's quick growth and spore production as well as its well-timed invasion (Kumar et al. 2020 & Kumar et al. 2021). *Trichoderma spp*. gain competitive supremacy by secreting antibiotics and having enzymes that break down cell walls, such as glucanases, chitinases, and cellulases (Ghasemi et al. 2019). Additionally, *Trichoderma* species pretreatment of plants causes induced systemic resistance (ISR), systemic acquired resistance (SAR), and hypersensitive reaction (Gupta et al. 2020 & Benítez et al. 2004)). For instance, tomato plants exposed to *Trichoderma* had significant physiological changes that improved their resistance to disease (Alfano et al. 2007). A study by Yedidia et al. 2003, preconditioning cucumber plants with *Trichoderma spp*. caused systemic reactions including defense genes that express phenylalanine and hydroperoxide lyase, as well as the systemic accumulation of phytoalexins that fight Pseudomonas syringae pv. lachrymans. SAR and ISR mechanisms were elicited as a result of this priming, which also caused a hypersensitive reaction (Gupta et al. 2020, Benítez et al. 2004, Vinale et al. 2006). Such interactions demonstrate Trichoderma's ability to outcompete microbial rivals and defend its ecological niche, making it a potent enemy of pathogenic fungus and a prospective biocontrol agent (Spiegel et al. 1988 and Navazio et al. 2007).

**Competitive Interaction**

Competition between microbes for scarce resources is a basic aspect of biological regulation. Long-term difficulties may arise when a foreign opponent establishes itself in the presence of native microflora (Vinale et al. 2006). *Trichoderma* species are strong competitors for resources due to their persistent conidia and broad spectrum of substrate usage (Sood et al. 2020).

**Nutrient and Space Competition**

*Trichoderma spp*. are rapidly proliferating fungi with persistent conidia and a broad substrate utilization capacity. They present robust competition for nutrients and space against other microorganisms that contribute to plant diseases (Tyśkiewicz et al. 2022). Weaker competitors among microorganisms often perish due to starvation. Trichoderma's competition for nutrients has been identified as a biocontrol mechanism against various plant pathogens. These fungi produce siderophores that sequester iron, hindering pathogenic microorganism growth by rendering iron inaccessible once cheated. Importantly, *Trichoderma* strains, also, compete for space and essential exudates from seeds and roots that trigger the germination of propagules of plant pathogenic fungi in soil. Moreover, they possess the capability to utilize a wide array of substrates including herbicides, fungicides, and phenolic compounds. The ability of *Trichoderma* to reduce abiotic stresses and the exact mechanisms involved, as well as its capacity to manage various plant stresses like osmotic, salinity, chilling, and heat stress, have all been the subject of recent publications. *Trichoderma* is now used in genetic engineering for the creation of transgenics. This study includes a compilation of the most current developments and advances in our understanding of the various roles played by these antagonist fungi and their metabolites in interactions with plants, as well as how these alterations result in significant improvements for plants that help defend them from various threats. *Trichoderma* species have been recognized as capable of harming other fungi for more than 60 years. Additionally, researchers are aware of them as potential biological control agents (Naher et al. 2014 & Sundaramoorthy et al. 2013). Some studies have discovered that *Trichoderma* species can eliminate plant diseases and promote plant growth (Ibrahim et al. 2020 & Garnica‐Vergara et al. 2020). Besides, *Trichoderma spp*. has been proven able to detoxify toxic compounds and fasten the degradation of organic material (Yadav et al. 2021 & Sharma et al. 2012). *Trichoderma* to speeds up growth, takes up nutrients, and alters the rhizosphere under field conditions all contributing to their success in the soil ecosystem and their function as natural decomposers. Additionally, the potential to withstand adverse conditions and have tremendous effectiveness against plant pathogenic diseases (Benítez et al. 2004 & Harman 2004). According to (Halifu et al. 2019), *Trichoderma spp*. exude cell walldegrading enzymes such as cellulase, xylanase, and glucanases, which interfere with microbial cells' ability to assimilate nutrients in the rhizosphere. This review gives insights into various mechanisms used by *Trichoderma* to alleviate the stresses with special emphases on how it induces resistance and various uses of *Trichoderma* in plant disease management.

**Root Colonization**

In agricultural regions, *Trichoderma spp*. are essential for improving plants' absorption of macro- and micronutrients. Solubilizing nutrients and guaranteeing the availability of micronutrients like iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) as well as important elements like phosphorus (P) are how this improvement is accomplished. *Trichoderma* uses four different processes to solubilize nutrients: chelation using siderophores, redox reactions driven by ferric reductase, acidification utilizing organic acids, and enzymatic hydrolysis aided by phytase. *Trichoderma* can solubilize a variety of minerals, such as phytase, CuO, and metallic zinc, thanks to this array of processes. Organic acids like lactic acid, citric acid, tartaric acid, and succinic acid have been found in *Trichoderma* cultures using analytical methods such high performance liquid chromatography (HPLC). Additionally, when compared to untreated controls, plants treated with *Trichoderma* show notable increases in copper uptake (42%) and plant biomass dry matter (92%). Interestingly, some isolates of *Trichoderma* show a greater capacity to solubilize insoluble tricalcium phosphate, especially in chickpeas. It has been discovered that T. harzianum increases the absorption of phosphorus in treated plants. Furthermore, *Trichoderma* secretes citric and gluconic acids that contribute to soil acidification and aid in the solubilization of mineral components such as iron, magnesium, and manganese, as well as phosphates and micronutrients (Ghazanfar et al. 2018, Benítez et al. 2004 & Vinale et al. 2008).

**Methods of application of *Trichoderma***

*Trichoderma* is an efficient biological control agent for the management of plant pathogenic fungi due to its fungicidal properties. Certain disorders may not respond well to a single strain of Trichoderma. Therefore, combining *Trichoderma* with other bio-control agents at the time of application leads to improved control of the associated illnesses (Bhattacharjee et al. 2014).The most popular and efficient ways to apply *Trichoderma* include foliar application, soil treatment, and seed and seedling treatment.

**Seed and seedling treatment**

 Seed treatment with biocontrol agents is considered as effective method of controlling seed/soil borne pathogens. Wetting of the seeds before treating with *Trichoderma* followed by the mixing of treated seeds in a plastic box or sheet helps in improving the resistance of plants against diseases. According to (Mastouri et al. 2010), when seeds treated with T. harzianum were exposed to physiological, biotic, or abiotic stresses, the positive response to the treatment was noticed.

**Soil treatment**

The best way to apply *Trichoderma* for the control of soil-borne illnesses is by soil treatment (Kumar et al. 2011). Applying *Trichoderma* together with some organic materials, such as FYM, neem powder, and/or vermicompost, can promote colonization. Cucumber fusarium wilt was significantly reduced when T. harzanium was added to both nursery soil and transplanted soil, diversifying the microbial population (Chen et al. 2012). suggested using T. harzianum alone or in combination with compost material to effectively suppress Rhizoctonia root rot of soybeans, which is caused by Rhizoctonia solani (Hassan 2014). Jute stem rot, seedling blight, and root rot disease were all effectively suppressed by T. viride applied to the soil (Srivastava et al. 2010).

**Foliar application**

*Trichoderma* species that can inhibit a wide variety of plant pathogenic fungi are also favored for lowering foliar plant disease. Typically, a foliar treatment of 10 g of *Trichoderma* diluted with 1 liter of water is sprayed on the aerial sections. The primary purpose of foliar application, according to (Sawant 2014), is to suppress grey mold on a variety of crops that is brought on by Botrytis cinerea and powdery mildew infections. It also extends the shelf life of grapes by controlling downy mildew. Under commercial greenhouse conditions, an isolate T39 of T. harzianum effectively controls the foliar pathogens B. cinerea, Pseudoperonospora cubensis, Sclerotinia sclerotiorum, and Sphaerotheca fusca in cucumbers (Elad 2000). The foliar application of *Trichoderma* has positive effect on titratable acidity, pH and electrical conductivity of fruits and increases the quality of tomato (Palacios et al. 2019).

**Multiplication method of *Trichoderma***

The significance of biocontrol agents for the efficient control of illnesses linked to plants and for fostering plant growth and development is being investigated by researchers. The large-scale production of *Trichoderma* is one of its main limitations. In order to find alternatives that have a less significant impact on plants than the use of chemical fertilizers and pesticides, research has turned its attention to the mass production of *Trichoderma spp*. According to (Sabalpara 2014), scientists have tried using a variety of substrates and methods to multiply and introduce *Trichoderma* into the soil. The many substrates and methods used to produce *Trichoderma* in large quantities can be divided into:

**Solid state fermentation**

Grain, organic materials, and agricultural waste are examples of solid-based substrates used in solid state fermentation for the mass proliferation of Trichoderma. Sorgham was found to be more successful than wheat when both were utilized as solid substrates for the bulk generation of T. viride (Bhagat et al. 2010). Using the solid fermentation approach, maize was effectively employed as the substrate for the mass production of T. harzianum.The solid substrates used for T. viride multiplication included FYM, vermicompost, poultry manure, goat dung, decomposed coconut, and coir pith. Of these, FYM was determined to be the most promising. Wheat straw, paddy straw, shelled maize cob, paper waste, saw dust, sugarcane bagasse, spent straw, wheat bran, rice bran were successfully used as the substrates for the mass production of T. harzianum and wheat bran and paddy straw were found to be the most effective (Tewari & Bhanu 2004).

**Liquid state fermentation**

Spores from fungal strains are typically produced in large quantities using the liquid state fermentation method of *Trichoderma* manufacturing. For operations where soluble ingredients in water are utilized for microbial growth, the liquid fermentation method of mass production is utilized [60]. The liquid-based substrate for T. harzianum Rifai's mass multiplication was potato dextrose broth, V8 juice, and molasses yeast medium (Hassan 2014).

**Mode of action of *Trichoderma***

*Trichoderma* as a biocontrol agent controls the plant disease through different mechanisms. The mode of action to control foliar pathogens may differ from that of the root and soil pathogens. Sometimes involvement of more than one mechanism in the interaction is also observed. The various mode of action employed by *Trichoderma* are described below:

**Mycoparasitism**

*Trichoderma* species have special ability to parasitize other fungi and involves direct attack of one fungal species (say Trichoderma) on another one and the process is called as mycoparasitism. This process involved different complex sequential events from recognition of the fungal strain by Trichoderma, effective penetration into the host fungi, attack on cellular machinery to finally killing of the host (Waghunde et al. 2016). (Verma et al. 2007), production of various enzymes by species of *Trichoderma* helps in penetration of cell by hydrolysing polysaccharides, β-glucans, cellulose and chitin present in the cell walls of the plant pathogenic fungi. Development of biocontrol strategies were enhanced by the discovery of mycoparasitic ability of *Trichoderma* over other important economic fungi (Harman et al. 2004).

**Antibiosis**

Antibiosisis mode of action is a biological interaction mainly observed in between microorganisms in which one is adversely affected. (Kucuk & Kivank 2003) stated that *Trichoderma* species have potential to produce number of antibiotics such as trichodernin, trichodermol, harzianun and harzianolide which helps in controlling the plant pathogens. (Benitez et al. 2004), in case of *Trichoderma* the mechanism of antibiosis involves the production of small sized diffusible compounds by *Trichoderma* species called antibiotics that inhibits the growth of other microorganisms. (Bhattacharjee & Dey 2014) reported the control of Pythium spp. with the use of virdin antibiotic produced by T. Viride colonizing Pea seeds.

**Induced resistance**

When the plant is treated with the biocontrol chemical, *Trichoderma* species use a different method to cause resistance. Even though the biocontrol agent (T-39) was only administered to the roots, the soil treated with it caused the leaves to become resistant to fungal infections including B. cinerea and C. lindemuthianum. Later, it was discovered that applying T. harzianum isolate T39 to soil caused plants to develop systemic resistance, which reduced foliar diseases like powdery mildew. Additionally, applying a biocontrol agent to dead root cells created foliar resistance against pathogens (Elad 2000). According to other research, such as (Saksirirat et al. 2009), an isolate of T. harzianum (T9) was able to induce resistance in tomato plants (cv. Sida cultivar) against bacterial spot (Xanthomonas campestris pv. vesicatoria), lowering disease incidence by up to 69.32% 14 days after inoculation. (Harman 2000) proposed that the compost amended medium's generated systemic resistance was efficient in promoting the growth of *Trichoderma spp*.

**Challenges for the adoption of *Trichoderma* over chemicals fertilizers and pesticides**

The usefulness of *Trichoderma* and its contribution to bettering agricultural practices around the world have been highlighted in numerous papers. However, aside from the realm of words, its use in the actual agricultural sector is fairly restricted. Despite the fact that numerous researchers have examined biocontrol agents and written thousands of publications on the subject, commercial agriculture still uses biocontrol agents sparingly (Hoitink et al. 2006). Despite having the potential to transform agriculture as described in various research publications, there is now no practical or cost-effective method for integrating *Trichoderma* into the agricultural sector. (Topolovec-Pintaric 2019), outlined the poor usage of biocontrol agents such as *Trichoderma* in underdeveloped nations with an agricultural economy. When compared to chemical use, the cost of biocontrol agent products is too high and the conditions for full-scale production, marketing, and certification are unfavorable. Using biological agents like *Trichoderma* in a system where chemical fungicides offer a more effective and cost-effective solution is the main difficulty. (Harman 2000) identified four main causes for businesses' lack of interest in bringing biological agents to market as a seed treatment to preserve seeds. These factors included (i) the availability of chemical pesticides that were very effective at protecting seeds, (ii) the fact that these chemicals were less expensive than biologicals, (iii) the fact that seeds treated with chemicals had a longer shelf life than seeds treated with biologicals, and (iv) the fact that chemical effects could tolerate a greater range of temperatures and other environmental conditions than biologicals. Chemical pesticides and fertilizers work quickly and can have an impact in a little amount of time. Additionally, chemical-based insecticides have the power to totally eradicate pest populations. However, compared to conventional pesticides and fertilizers, *Trichoderma* usually takes longer to develop, can only be used under favorable conditions, and usually just lowers a pest population rather than totally eradicates it. Furthermore, the pesticides companies do not want to take risk by investing in commercializing bio control agents as there are already a lot of better market-favored short term alternatives of bio-control agents.

**Conclusion**

Only by emphasizing organic insecticides and fertilizers will agriculture become more sustainable. Trichoderma, a biofertilizer, bioremediator, and biocontrol agent, is a desirable substitute for artificial pesticides and fertilizers. Its capacity to outcompete various other harmful organisms has improved its application in managing a wide range of plant diseases, including bacteria, viruses, nematodes, and fungus. *Trichoderma* may be useful in managing plant diseases through a variety of mechanisms (mycoparasitism, competition, antibiosis, induced resistance, etc.). *Trichoderma* also plays a part in improving the effectiveness of chemical fertilizers and aiding in the absorption of soil nutrients. It enhances microbial activity and improves soil characteristics. Numerous *Trichoderma* species have been found to act as bioremediators of environmental contaminants, including petroleum products and heavy metals. It has been demonstrated to be a successful biocontrol agent against a variety of plant diseases. We can infer from these arguments that it has a great deal of potential to fulfill the objective of sustainable agriculture. Despite these benefits, it is not as commonly used as chemical insecticides and fertilizers. The main obstacles to its widespread use are its slow rate of action, inability to completely eradicate plant diseases, expensive cost, and requirement for a favorable environment. Future studies should therefore focus on isolating and characterizing distinct strains of *Trichoderma* that are efficient against a variety of pathogens, biotic and biotic stress tolerant, and have a high rate of colonization and reproduction. At the farmer level, information about the benefits of *Trichoderma* and the negative impacts of artificial pesticides and fertilizers should be shared. Additionally, for the widespread use of Trichoderma, attention should be placed on strategies like integrated pest management (IPM) and organic farming.

**Recommendation**

Trichoderma's ability to multiply and colonize in the specified habitat, as well as its persistence and reaction time, are directly related to how well it works. Therefore, the identification of distinct strains of *Trichoderma* that are long-lasting, least impacted by environmental factors, and have a high rate of survival, multiplication, and colonization should be the main focus of future study. The ability to encapsulate it in formulations for low-scale trials has opened the way for additional advances that will lead to its global adoption. The research that was done to examine and evaluate the efficacy of several strains of *Trichoderma* was done in isolation. Researchers must figure out how to formulate it effectively on a broad scale. (Atieno et al. 2020), observed the farmer's belief and inclination to use chemical fertilizers rather than biological ones in an attempt to increase crop productivity. Therefore, farmers need be made aware of Trichoderma's advantages over chemical fertilizers and pesticides in terms of managing plant diseases and increasing crop output in order for it to be commercialized and widely adopted.

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