Biological Forum – An International Journal 16(10): 117-126(2024)

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Trichoderma as Potential Biocontrol Agenton Diseases of Soybean (*Glycine max* L.): A Comprehensive Review

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(Received: 16 July 2024; Revised: 19 August 2024; Accepted: 15 September 2024; Published: 15 October 2024)
(Published by Research Trend)

ABSTRACT: *Trichoderma* primarily treats soil-borne infections and a few leaf and panicle diseases in various plant species. *Trichoderma* not only prevents disease, but it also increases plant resistance, accelerates growth, improves nutrient uptake efficiency, and cleans the environment of agrochemical pollutants. *Trichoderma* spp. is also a safe, cost-effective, efficient, and environmentally friendly biocontrol agent for a wide range of crop species. This study examines the use of *Trichoderma* and its control effects in the management of various plant diseases. *Trichoderma*'s biological control mechanisms in plant fungal and nematode disease, such as competition, antibiosis, antagonism, and mycoparasitism, have been discussed. We also talked about how *Trichoderma* promotes plant growth while inducing plant systemic resistance. Developing a diverse range of *Trichoderma* application technologies is an important avenue for future research and development, given its potential to contribute to the agricultural sector's long-term growth.

Keywords: *Trichoderma*, plant diseases, biological control, growth promotion, action mechanism.

INTRODUCTION

Soybean (*Glycine max* L.) is a major crop in India and an important source of vegetable protein and oil (Herridge *et al.,* 2008; Prevost *et al.,* 2010). Soybean is a leguminous oil seed crop grown around the world due to its high protein (40%) and fat (20%) content. Soybean is thought to be a subtropical plant from Southeast Asia. This crop was brought to Europe and the United States in the 1700s and 1800s. Farmers in the Midwest of the United States grow roughly half of all soybeans. East Asia accounts for roughly 45% of soybean production, with the remaining 55% coming from America. Brazil, Argentina, Paraguay, China, and India are the world's leading soybean producers, in addition to the United States (Joy *et al*., 1998).

In India, it is grown as a rainfed kharif crop on 10.97 million ha, yielding 10.99 million tonnes with a productivity of 1002 kg/ha in 2016-17 (SOPA). Madhya Pradesh is India's leading soybean producer, with 54.01 lakh ha of soybean production, an average productivity of 1020 kg/ha, and a total production of 55.06 lakh tonnes in 2016-17 (SOPA). Persoon (1794) established Trichoderma as a genus in Germany, proposing four species: *Trichoderma viride, T. nigroscens, T. aureum,* and *T. roseum. Trichoderma* was first isolated from Madras, India, by Thakur and Norris in 1928.

Trichoderma can be found in all temperate and tropical soils, as well as forest, agricultural, prairie, salt marsh, and desert soils. *Trichoderma,* for example, accounted for up to 3% of total fungal propagules in a wider range of forest soils and 1.5% in pasture soils in a variety of crops (Domsch *et al.,* 1980). *Trichoderma* spp. have been known to parasitize other fungi for approximately 70 years (Table 1).

Trichoderma has been identified as saprophytic fungi found in the roots of many plants. It has been reported that antagonistic fungi produce a variety of volatile and non-volatile organic compounds (Siddiquee *et al.,* 2012; Meena *et al.,* 2017), as well as diffusible antibiotics such as *trichodermin, gliotoxin*, and *virid* (Mukherjee *et al*., 2012; Vargas *et al.,* 2014; Sharma *et al*., 2016), to control plant pathogenic fungi. During antagonistic activity, these fungi primarily compete with pathogenic fungi for nutrients and space (John *et al.,* 2010; Carvalho *et al.,* 2015).

Similarly, fungi such as *Trichoderma* colonize plant roots, allowing them to protect against biotic stresses such as pathogenic infection (John *et al.,* 2010; Carvalho *et al.,* 2015; Jogaiah *et al.,* 2018) while also promoting plant growth. Biological control is primarily used to control harmful organisms in plants by utilizing beneficial organisms and their products to control plant diseases and effectively reduce the use of chemical fertilizers and pesticides. *Trichoderma*, a biological fungus commonly used for plant pest control, lives in the soil, air, plant surface, and other ecological environments and can effectively control a wide range of plant diseases (Haouhach *et al.,* 2020; Zheng *et al.,* 2021; Wang *et al.,* 2022). *Trichoderma* is primarily used to control soil-borne diseases in plants, as well as certain leaf and spike diseases (Vicente *et al.,* 2020; Abbas *et al.,* 2022). *Trichoderma* has been shown to prevent disease, promote plant growth, improve nutrient utilization, improve plant resistance, and repair agrochemical pollution (Tilocca *et al.,* 2020; Fontana *et al.,* 2021; Sanchez-Montesinos *et al.,* 2021; Al-Surhanee, 2022; Tyskiewicz *et al.,* 2022).

Trichoderma is a biocontrol fungus that is widely distributed throughout the world. Tyskiewicz *et al.* (2022) found that *Trichoderma* has significant potential for biological disease control in plants. *Trichoderma* use to control plant diseases has been studied all over the world. *T. viride* and *T. harzianum* inhibit 29 species of plant pathogenic fungi from 18 genera, including *Botrytis, Fusarium*, and *Rhizoctonia,* in varying degrees. *Trichoderma* controls a wide range of plant pathogenic fungi, including *Rhizoctonia solani, Pythium ultimum, Fusarium oxysporum, Sclerotinia sclerotiorum, Botrytis cinerea, Pseudocercospora* spp., and *Colletotrichum* spp.(Alvarez-García *et al.*, 2020; Andrade-Hoyos *et al.*, 2020; Carro-Huerga *et al.,* 2020; Damodaran *et al.,* 2020; Zhang *et al.,* 2020, 2021; Al-Askar *et al.,* 2021; Chen *et al.,* 2021; Degani and Dor 2021; Dugassa *et al.*, 2021; Intana *et al.,* 2021; Zhang *et al.*, 2022; Zhang *et al.*, 2022). *Trichoderma* has been widely used for biological control of cotton verticillium wilt, crop grey mold, tomato graymold, melon wilt, potato dry rot, tobacco root rot, and other plant diseases.(Andrade-Hoyos *et al.,* 2020; Alfiky and Weisskopf 2021; Lazazzara *et al.,* 2021; Leal *et al.*, 2021; Manganiello *et al.,* 2021; Degani *et al.,* 2021a; Pollard-Flamand *et al.,* 2022; Rees *et al.*, 2022; Risoli *et al.*, 2022).

Aside from biotic stress protection, *Trichoderma* reduces abiotic stress such as drought and salinity (Mastouri *et al.,* 2010; Contreras-Cornejo *et al.,* 2014). *Trichoderma* strains influence bioactive metabolite production (Garnica-Vergara *et al.,* 2016). *Trichoderma* spp. also improves nutrient availability for plants, allowing them to better withstand biotic and abiotic stresses. Several *Trichoderma* species have been used in leguminous plants as biocontrol agents and growth promoters. John *et al.* (2010) investigated *T. viride* ability to significantly reduce soil-borne pathogens while also improving root systems. Chickpea *(Cicer arietinum)* inoculated with *T. harzianum* and *Aspergillus niger* showed significant increases in shoot and root length and weight (Yadav *et al.*, 2011).

Table 1: Different *Trichoderma* species effective against plant disease causing Pathogens.

Sr. No.	Crop/Plant	*Trichoderma* spp.	Pathogens	References
1.	Tomato	*T. viride,* *T. harzianum*	*Fusarium solani* *Rhizoctonia solani*	Haggag and El-Gamal (2012)
2.	Soybean	*T. viride*	*Fusarium oxysporum* f. sp. *adzuki*	John *et al.* (2010)
3.	Rice	*T. viride,* *T. koningii,* *T. harzianum*	*Rhizoctonia solani* *Fusarium* spp.	Bhat *et al.* (2009); Gomathinayagam *et al.* (2010); Chakravarthy *et al.* (2011); Bhramaramba and Nagamani (2013); Biswas and Datta (2013); Gangwar and Sharma (2013)
4.	Potato	*T. virens* *T. harzianum*	*Rhizoctonia solani* *Fusarium sambucinum*	Ru and Di (2012) Basu (2009); Selvakumar (2008); Pandey and Pundhir (2013)
5.	Mungbean	*T. harzianum* *T. viride* *T. virens*	*Rhizoctonia bataticola*	Dubey *et al.* (2009)
6.	Onion	*T. viride* *T. harzianum* *T. reesei*	*Alternaria alternata* *Alternaria porri* *Alternaria tenuissima*	Mishra and Gupta (2012); Prakasam and Sharma (2012); Yadav *et al.* (2013); Shahnaz *et al.* (2013)
7.	Maize	*T. harzianum*	*Penicillium notatum, Rhizoctonia solani* *Fusarium oxysporium* *Alternaria alternata*	Bhandari and Vishunavat (2013); Pal *et al.* (2013)
8.	Chilli	*T. viride,* *T. harzianum* *T. pseudokoningii*	*S. rolfsii* *F. oxysporum* *Pythium* spp., *R. solani*	Rini and Sulochana (2006); Kapoor (2008); Vasanthakumari and Shivanna (2013)

Biocontrol Mechanisms of *Trichoderma*. Nowadays, *Trichoderma* spp. are promising biocontrol agents against fungal phytopathogens. Examples of such interactions include *T. harzianum* action on *Fusarium oxyporum, F. roseum, F. solani, Phytophthara colocaciae,* and *Sclerotium rolfsii*. In general, bio-control agents grow naturally on the root surface and thus affect root disease in particular, but they can also be effective against foliar diseases (Leaf rot) and bark diseases (*Citrus gummosis*). They can act indirectly by competing for nutrients and space, changing environmental conditions, or promoting healthy plant growth, plant defensive mechanisms, and antibiosis, or directly through mechanisms like mycoparasitism. Increase Dry matter production increased significantly. Provide natural, long-term immunity to crops and soil (Papavizas, 1985, Howell, 2003; Vinale *et al.,* 2008).

Benefits of *Trichoderma*

(a) Disease control: *Trichoderma* is a biocontrol agent that is widely used for both soil-borne and foliar diseases (Harman *et al.,* 2010). It also produces cell wall degrading enzymes against pathogenic fungi from various genera, including *Rhizoctonia Fusarium, Phytopthara, Scelerotiinia* and *Colletotrichum. Trichoderma* species have been shown to control a variety of diseases (Table 2).

Table 2: Diseases controlled by *Trichoderma.*

Sr. No.	Crop	Diseases	Pathogen	References
1.	Rice	Sheath blight, Bacterial leaf blight, Bakanae	*Rhizoctonia solani* *Fusarium moniliforme*	Biswas and Datta (2013); Ng *et al*. (2015)
2.	Wheat	Leaf blight Loose smut	*Alternaria triticina* *Ustilago segetum*	Parveen and Kumar (2004); Singh (2004)
3.	Chickpea	Wilt complex, Root rot	*Fusarium* spp., *Sclerotium* spp., *Rhizoctonia solani*	Gupta *et al.* (2005)
4.	Pigeon pea	Wilt	*Fusariumudum*	Chaudhary and Prajapati (2004)
5.	Apple	Ring rot White root rot	*Botryosphaeria berengeriana* *Dematophora necatrix*	Kexiang *et al.* (2002) Tapwal *et al*. (2005)
6.	Guava	Die back	*Lasiodiplodia theobromae*	Yadav and Majumdar (2005)
7.	Chilli	Dry root rot	*Rhizoctonia solani*	Bunker and Mathur (2001)
8.	Tomato	Fusarium wilt Crown, stem and root rot diseases, Collar rot of tomato	*Fusarium oxysporumf.* sp. *lycopersici* *Rhizoctonia solani, Sclerotinia* spp. and *Pythium* *Sclerotium rolfsii*	Komy *et al.* (2015); Marzano *et al.* (2013); Amin *et al.* (2010)
9.	Potato	Damping off, Black Scurf, Charcoal Rot, Bacterial brown rot.	*Rhizoctonia solani* *Fusarium* and *Phoma* spp.	Gogoi *et al.* (2007)
10.	Beans	web blight of beans	*Sclerotinia sclerotiorum*	Amin *et al.* (2010)

(b) Plant Growth Promoter: *Trichoderma* strains dissolve phosphates and micronutrients. The application of *Trichoderma* strains to plants increases the number of deep roots, improving the plant's ability to withstand drought.

(c) Biochemical Elicitors of Disease: *Trichoderma* strains have been found to cause plant resistance. Three types of compounds produced by *Trichoderma* that cause plant resistance have been identified. In plant cultivars, these compounds cause ethylene production, hypersensitivity, and other defensive reactions.

(d) Transgenic Plants: The introduction of *Trichoderma* endo chitinase gene into plants like tobacco and potatoes has increased their resistance to fungal growth. Selected transgenic lines are highly tolerant to foliar pathogens such as *Alternaria alternata, A. solani, and Botrytis cirerea*, as well as the soil-borne pathogen *Rhizoctonia* spp.

(e) Bioremediation: *Trichoderma* strains play an important role in bioremediation of pesticide and herbicide-contaminated soil. They can degrade a diverse range of insecticides, including organochlorines, organophosphates, and carbonates.

Application of *Trichoderma* in biological control of plant fungal diseases:

1. Seed treatment: Before sowing, mix 6-10 grams of *Trichoderma* powder per kilogram of seed.

2. Nursery treatment: Apply 10 to 25 g of *Trichoderma* powder per 100 square meters of nursery bed. The efficacy of neem cake and FYM is increased when applied prior to treatment.

3. Cutting and seedling root dip: Mix 10g of *Trichoderma* powder with 100g of well-rotten FYM per liter of water, then dip the cuttings and seedlings for 10 minutes before planting.

4. Soil treatment: Apply 5 kg of *Trichoderma* powder per hectare after incorporating sun hemp into the soil for green manuring. Alternatively, mix 1kg of Trichoderma formulation in 100kg of farmyard manure and cover with polythene for 7 days.

5. Sprinkle the heap with water intermittently: Turn the mixture in every 3-4 days and then broadcast in the field.

6. Plant Treatment: Drench the soil near the stem with 10g *Trichoderma* powder mixed in 1 liter of water.

Precautions taken during *Trichoderm*a Application:

1. Avoid using chemical fungicides for 4-5 days following Trichoderma application.
2. Do not use Trichoderma on dry soil. Moisture is essential to its growth and survival.
3. Avoid directly exposing treated seeds to sunlight.
4. Avoid storing treated FYM for extended periods of time.

***Trichoderma* as a potential biological control agent.** The term 'biocontrol' was coined in 1914 with a focus on plant pathogens and insects, respectively. Biocontrol is the process of reducing plant pest populations using naturally occurring organisms as part of integrated disease management. A variety of biocontrol agents or bio-fungicides exist in the ecosystem, and they must be isolated before being used because biocontrol agents are low-cost to produce, have a long-lasting effect on pathogen growth, and have no effect on human health. *Trichoderma* was first described as a bio-control agent by Weindling (1932); *Trichoderma* species are free-living, cosmopolitan fungi found in soils, decaying organic and vegetable matter (Harman *et al.,* 2004a).

Several *Trichoderma* species show potential for biological control of plant pathogenic fungi. *Trichoderma viride* inhibited the growth of soil-borne *Pythium debaryanum, Sclerotium rolfsii, Fusariumlini, F. Culmorum,* and *Fomusanosus* (Wright 1956). *Trichoderma viride* is commonly used in commercial orchard oils to control *Armillaria mellea* (Bliss, 1951). *Trichoderma viride* has been shown in vitro and in vivo to be an antagonist against *Venturi inaequalis*, the causative agent of apple scab (Lindow, 1985). *Trichoderma viride* was discovered to be an antagonist to *Drechslera sorokiniana*, the causative agent of wheat root rot, seedling, and foliar blights (Prasad *et al.,* 1978). Singh *et al.* (1991) found that using *Trichoderma viride* culture filtrate reduced germination of *N. indica* teliospores and sporidia significantly.

Biocontrol agent to barley seeds reduced *Helminthosporium* infection on coleoptiles by 87%. *Trichoderma viride* culture filtrate inhibited chlamydospore germination and suppressed the mycelial growth of *Ustilagoseg tum tritici.* Field tests also demonstrated the agent's biocontrol potential against wheat loose smut (Aggarwal *et al.,* 1993). *Trichoderma harzianum* has been shown to inhibit the growth of *S. rolfsii*, the causative agent of root rot in many crops. Wells *et al.* (1972) applied this species' inoculum to rows of tomato seedlings to protect the crop from *S. rolfsii.* It has also demonstrated potential for biocontrol of *Macro phominaphaseolina* (Elad *et al.,* 1986).

Trichoderma harzianum has also been shown to have biocontrol potential against *F. solani* (Calvet *et al.,* 1990), *Fusarium oxysporumciceris*, *Pythium aphanidermatum* (Bhardwaj and Gupta 1987), *Rhizoctonia solani* (Wilson *et al.,* 1988; Cole and Zrinyka 1988), and *S. rolfsii* (Deve and Dutta 1988). In a study of *Trichoderma harzianum* effect on fungal pathogens infecting wheat and black oat straw, the antagonist reduced the incidence of *Cochliobolus sativus*. This antagonist's culture filtrate inhibited the germination of teliospores and spordia of *N. indica* (Singh *et al.,* 1991) and chlamydospores of *U. segetum tritici*. *Trichoderma koningii* has shown biocontrol potential against *U. segetum tritici* and *Drechslera sorokiniana*, *T. reesi* against *D. sorokiniana* and *T. pseudokoningii* against karnal bunt.

Table 3: Biocontrol agents of some fungal Plant diseases by different *Trichoderma* spp.

Sr. No.	Trichoderma spp.	Fungal plant pathogen	Plant Diseases
1	*Trichoderma harzianum* Rifai	*Sclerotium rolfsii*	Southern stem blight of soybean
2	*Trichoderma harzianum* Rifai	*Sclerotium rolfsii*	Rotting of common vegetables
3	*Trichoderma harzianum* Rifai	*Sclerotium rolfsii*	Collar rot of lentil
4	*Trichoderma harzianum* Rifai	*Sclerotinia sclerotiorum*	Sunflower head rot
5	*Trichoderma harzianum* Rifai	*Macrophomina phaseolina*	Root rot of blackgram
6	*Trichoderma harzianum* Rifai	*Fusarium oxysporum f. splycopersici*	Fusarium wilt of tomato
7	*Trichoderma harzianum* Rifai	*Fusarium oxysporum f. sp gladioli*	Fusarium wilt & corm rot of gladioli
8	*Trichoderma viride* Pers. Ex Fr.	*Fusarium udum*	Pigeon pea wilt
9	*Trichoderma viride* Pers. Ex Fr.	*Rhizopus oryzae*	Cotton seedling disease
10.	*Trichodermavirens* (Miller, Giddens & Foster) v.Arx	*Serpula lacrymans*	Wood decay
11.	*Trichoderma virens* (Miller, Giddens & Foster) v.Arx	*Colletotrichum truncatum*	Brown blotch disease of cowpea
12.	*Trichoderma lignorum* (Tode) Harz	*Rhizoctonia solani*	Damping-off of bean
13.	*Trichoderma Koningii* Oudem	*Sclerotium cepivorum*	White rot disease of onion roots

***Trichoderma* as biocontrol agent for different soybean diseases.** Soybean (*Glycine max* L.) is the third-most important oilseed crop. Several researchers developed integrated management schedules for root, seed, and foliar diseases. According to Singh and Thapliyal (1998), seed treatment with Vitavax 200 plus *Trichoderma harzianum* or *Gliocladium virens* effectively manages pre- and post-emergence seedling rot.

Pant and Mukhopadhyay (2001) described how to manage soybean seed and seedling rot caused by *R. solani* using biocontrol agents *Gliocladium virens* and *Trichoderma harzianum.* (Ray *et al*., 2007) discovered that they improve seed germination and reduce seedling rot in soybeans. Another study found *Trichoderma viride* to be effective against two fungal pathogens that infect soybeans, *Fusarium oxysporum* and *Pythium arrhenomanes* (John *et al*., 2010). Khodke and Raut (2010) investigated the management of root rot or collar rot through seed treatment and fungicide application to the soil.

Trichoderma and plant growth-promoting rhizobacteria, *P. fluorescens*, were tested under glasshouse and field conditions against many soil-borne plant pathogens, including *R. solani, S. rolfsii,* and *M. phaseolina*, which cause root and stem rot disease in soybeans (Mishra *et al.,* 2011). *Trichoderma* species inhibited the growth of oilseed-borne fungi such as *Aspergillus flavus, Alternaria alternata, Curvularia lunata, Fusarium moniliforme, Fusarium oxysporum, Rhizopus nigricans, Penicillium notatum,* and *Penicillium chrysogenum*, which harm oil seed crops such as soybean, sesame, and sunflower (Jat and Agalave 2013).

Antibiosis effect of *Trichoderma:* The term "antibiosis" refers to *Trichoderma* ability to secrete antagonistic substances that prevent plant pathogenic fungi from growing (Kottb *et al.,* 2015; Izquierdo-Garcia *et al.,* 2020; Moran-Diez *et al.,* 2020; Shobha *et al.,* 2020; El-Hasan *et al.,* 2022). *Trichoderma* produces numerous antimicrobial secondary metabolites, including gelatinomycin, trichomycin, chlorotrichomycin, and antibacterial peptides (Maruyama *et al.,* 2020). According to Nawrocka *et al.* (2018), secondary metabolites can promote plant growth, act as antibacterial agents, and provide valuable resources for the development of agricultural antibiotics.

With a 54.81% inhibition rate, Naglot *et al.* (2015) discovered that *T. viride* metabolites significantly inhibited the wilt-specific form of *F. oxysporum*. Manganiello *et al*. (2018) discovered that when exposed to *T. viride* TG050 609's volatile secondary metabolites, *P. nicotianae* mycelium can grow erratically, fracture, or even dissolve. This suggests that *T. viride* has antibiosis activity against *P. nicotianae*. Furthermore, the majority of *Trichoderma* strains can produce antimicrobial compounds such as pentaibols, which can inhibit a variety of plant pathogenic fungi and work in tandem with their cell wall-degrading enzymes to effectively stop their growth (Debode *et al.,* 2018; Mayo-Prieto *et al.,* 2019; Kovacs *et al*., 2021; Martinez-Salgado *et al.,* 2021).

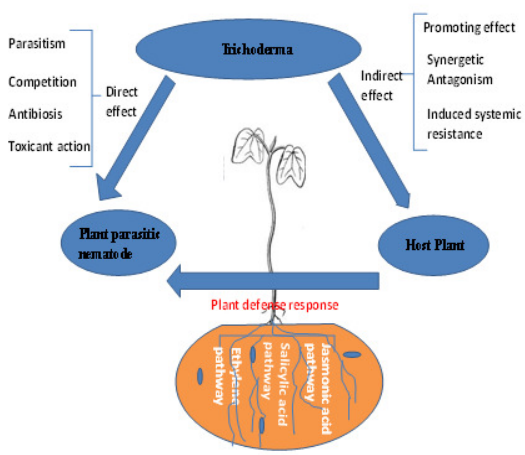

Fig. 1. Schematic diagram of the mechanism of action of *Trichoderma* in plant disease control.

CONCLUSION AND FUTURE SCOPE

Chemical control is currently the primary method for controlling plant diseases, and it is accomplished by misting fungicides and pesticides. Despite the fact that chemical pesticides have a positive and beneficial effect on agricultural productivity, their improper application has seriously contaminated the environment and increased pathogen resistance. Numerous studies have shown that *Trichoderma* can reduce the use of chemical pesticides while also providing beneficial biological control effects. More efficient and appropriate strains must be discovered to join the biocontrol team, as there are currently few *Trichoderma* biocontrol agents on the market (Nieto-Jacobo *et al.,* 2017; Fiorentino *et al.,* 2018; Lopez *et al*., 2019; Nawrocka *et al*., 2019; Poveda *et al*., 2019; Cabral-Miramonte *et al.,* 2019).

While *Trichoderma* has many applications in agriculture, there are still some issues with its development and application (Rubio *et al.,* 2014; Zhang *et al.,* 2018; Phoka *et al.,* 2020; Santos *et al.,* 2020; Wang *et al.,* 2022). When applied in the field, the *Trichoderma* spore preparation is typically a living fungal preparation that is frequently influenced by various natural factors such as humidity, temperature, soil acidity, alkalinity, and the soil microbial community, reducing the biological control effect and making field test performance unstable. Furthermore, biological control agents have a limited shelf life, and some microorganisms must be refrigerated to maintain a viable concentration at the time of application.

A prospective investigation into the biological and environmental safety of transgenic *Trichoderma* should be conducted concurrently with additional research on the organism (Li *et al.,* 2021). The identification of *Trichoderma* elicitors to recognize plant targets or receptors, the balance regulation of *Trichoderma* colonizing host and plant immune response, the long-distance and trans-growth period transduction mechanism of systematically induced plant disease resistance and its defence signals, and the mechanism of *Trichoderma*-induced plant endophytic microbiome to synergistically stimulate plant immune response have all recently attracted attention from researchers. Research is beginning to emerge on the mechanism of cross-border miRNA transduction between pathogenic microorganisms, plants, and *Trichoderma,* as well as the regulation of the host process and plant immune response to *Trichoderma* colonization.

Combining *Trichoderma* and other microorganisms has made it possible to broaden the target spectrum of microbial metabolites, develop new biopesticides and biostimulants based on metabolites, and discover new metabolites with specific microorganism functions (Wang *et al.,* 2022). It is expected that developing new plant immune-activating protein pesticides and molecularly modifying the *Trichoderma* multi-stimulator fusion protein will open up new avenues for the development of macromolecular biopesticides. Currently, there is an urgent need to identify the synergistic relationships that exist between *Trichoderma,* plants, and pathogenic microorganisms in order to induce disease resistance on a cross-genome level. Furthermore, new biostimulant or products based on *Trichoderma* and other microbial symbiotic agents must be developed in order to treat diseases and pests.

Compound biocontrol fungi outperform single-life biocontrol fungi in terms of disease resistance, environmental adaptation, and control efficacy. Although there are numerous preparations containing various *Trichoderma* species that are used in sustainable agricultural crops, their application is still expensive and not available to all farmers. In the process of developing biocontrol agents, the use of compatible or affinity multiple microorganisms for compounding has grown popular. *Trichoderma* can form alliances with a variety of microorganisms, including fungi and bacteria, to improve plants ability to manage and prevent disease. The primary areas of research for *Trichoderma* as a biocontrol fungus may be as follows.

The ability of the biocontrol agent *Trichoderma* to withstand stressors such as high temperatures, drying, UV radiation, and storage conditions such as more than a year at room temperature is critical for commercial application. At the moment, two primary technologies exist. There are two ways to induce *Trichoderma* to produce stress-resistant chlamydospores: one involves lowering the acidity and controlling oxygen utilization, and the other involves adding chemical additives (such as copper) to the inoculum. The secret to understanding how *Trichoderma* induces plant immunity is to examine how its effectors interact with plant cell receptors. Prospective studies on the biological and environmental safety of transgenic *Trichoderma* should take place concurrently with the advancement of transgenic research.

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How to cite this article: Manjula, Aishwarya, Ajay Kumar Gautam and Anupam Kumar (2024). *Trichoderma* as Potential Biocontrol Agenton Diseases of Soybean (*Glycine max* L.): A Comprehensive Review. *Biological Forum – An International Journal, 16*(10): 117-126.