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Trichoderma in agriculture for the biocontrol of fungal Phytopathogens

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INTRODUCTION

While new agricultural technologies have increased output, certain contemporary methods harm the environment. One of the current issues facing advanced farming is raising yields in an environmentally responsible way (Weller *et al*., 2014). Numerous crop diseases can be brought on by bacteria, fungus, viruses, nematodes, and mycoplasmas. An estimated 15–17% is lost throughout the farming and harvesting process, fungi are one of the plant pathogenic organisms that seriously harm agricultural crops worldwide and lower crop yields (Weller *et al*., 2014; Pandey *et al*., 2018). Fungal contamination of food products also leads to the creation of mycotoxin. These infections have been managed using a variety of strategies, including as mechanical, cultural, and microbiological biocontrol agents, as well as the application of chemical fungicides and resistant cultivars. According to Suryanarayanan *et al*., (2016), using fungicides to treat plant diseases may have detrimental impacts on human health and the environment.

Trichoderma is a genus of soil-dwelling fungi widely used in agriculture due to its beneficial properties for plant growth and protection. These fungi are renowned for their role as biofungicides, helping to suppress various plant pathogens through mechanisms such as competition, mycoparasitism, and the production of antifungal compounds. In addition to disease control, *Trichoderma* enhances plant growth by promoting root development, improving nutrient uptake, and stimulating plant defense responses. It can decompose organic matter efficiently, contributing to soil health and fertility.

Farmers utilize *Trichoderma* formulations as eco-friendly alternatives to chemical pesticides, aligning with sustainable agricultural practices. Its adaptability, cost-effectiveness, and ability to support both crop protection and growth make *Trichoderma* an invaluable tool for modern agriculture. Chemical pesticides, the most widely used technique to shield plants from fungal diseases, have put a great deal of strain on the agricultural environment in recent decades. Despite the great efficacy of chemical plant protection agents, questions remain regarding their safe use, environmental effects, and effects on the health of humans and animals (Ghorbanpour *et al*., 2018).

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The misuse of chemical pesticides leads to soil and ground water contamination, as well as a rise in disease resistance to pesticides. Additionally, pesticides negatively impact soil microbiomes, non-target creatures (such as beneficial insects and pollinators), and the overall health of terrestrial and aquatic ecosystems (Tilman *et al*., 2002; Alizadeh *et al*., 2020). The ability of various strains to function as versatile fungi that can be found in a variety of circumstances is attributed to the genus *Trichoderma*. They typically originate from soils used for agriculture or forestry. The typical morphological characteristics of Trichoderma strains, as seen in Figure 1, include rapid development, recurrent branching, and a brilliant green conidial color.

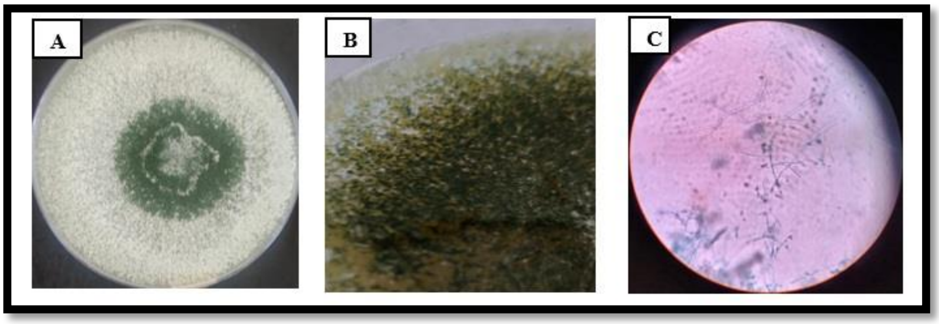

Figure.1. *Trichoderma* sp. A. *Trichoderma* sp on PDA plate; B. *Trichoderma* under micro lens; C. *Trichoderma* under 10X

In Germany, Persoon (1794) published the first description of *Trichoderma* 200 years ago. Thakur and Madras' Norris (1928) was the first to isolate it in India. Elwyn, *T. Reese* termed this fungus *T. reesei* because of its capacity to decompose wood, although it was first discovered as cellulolytic during World War II as *T. viride* QM6a (Simmons, 1977). Gliotoxin, the first antimicrobial compound from *Trichoderma* species, was discovered in 1934 after the first evidence of *T. lingorum* (Tode) Harz. (*H. vitrens*) as a mycoparasite with biocontrol potential against *Rhizoctonia solani* was established in 1932 (Weindling, 1932; Weindling, 1934). In 1972, Wells *et al*., (1972) published the first field evidence of *T. harzianum* inhibiting *Sclerotium rolfsii*. Cloning studies on *Trichoderma* species have been conducted since 1983, when Shoemaker *et al*. reported cloning the first cellulase of *T. reesei*. In 1993, Geremia *et al*. reported cloning the first mycoparasitism-related genes (prb1) and inducing it via cell walls. *Trichoderma* capacity to promote plant development was initially identified in 1986 (Chang *et al*., 1986). In particular, the genus increases plant immunity by internal colonization of the root system by *Trichoderma* in 1999 (Yedidia *et al*., 1999) and resistance induction in 1997 (Bigirimana *et al*., 1997). 1989 saw the registration of Binab T, the first commercial formulation of *Trichoderma* used for biological treatment of plant diseases.

Trichoderma spp. as a biocontrol agent of plant disease:

The use of living organisms to reduce the number of pests is known as biocontrol. According to Hajek and Eilenberg (2018), it is environmentally beneficial. *Trichoderma* spp. are the most widely utilized biocontrol agents against a wide range of root, shoot, and postharvest diseases, according to Woo *et al*., (2014). According to Siemering *et al*. (2016), the fungus mostly inhabits roots, particularly along their surfaces and beneath the outermost layer of root cells. *Trichoderma* is effectively sprayed during seeding to establish the fungus in and on the plant roots. According to a number of studies, seed treatment has proven to be an effective method for guaranteeing *Trichoderma* spp. colonization on the root to benefit plants. The primary methods that *Trichoderma* spp. biologically control the pathogens are (i) identifying and invading plant pathogenic fungal-like species through disruption of the cell wall and absorption of released nutrients, a process known as mycoparasitism (Bhat, 2017); (ii) making plants resistant to diseases by altering the root architecture during the interaction with the pathogens (Kumar *et al*., 2019); and (iii) attacking the root-knot and cyst nematodes by destroying nematode eggs and second phase juveniles as well as some segments of adult nematodes (Heidari and Olia, 2016) as shown in the Figure.2.

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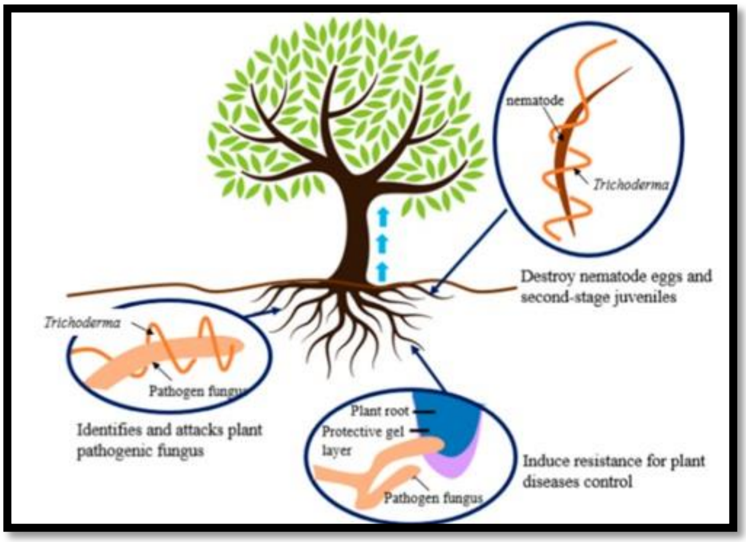

Figure.2. Plant disease management by *Trichoderma* sp. (Zin *et al*., 2020)

Trichoderma is a beneficial fungus widely used in plant disease management due to its ability to control a broad range of plant pathogens. It acts through multiple mechanisms, including **mycoparasitism**, where it attacks and degrades pathogenic fungi by producing enzymes like chitinases and glucanases. Trichoderma also exhibits **antibiosis** by producing antibiotics that inhibit pathogen growth and competes with harmful microbes for nutrients and space, effectively suppressing their development. Additionally, it enhances plant health by inducing **systemic resistance (ISR)**, stimulating the plant's immune system, and promoting growth through the production of hormones like auxins and gibberellins. Trichoderma is effective against pathogens like *Fusarium*, *Rhizoctonia*, *Pythium*, and *Sclerotinia*. It can be applied through seed treatment, soil application, root drenching, or foliar sprays. Its eco-friendly nature, cost-effectiveness, and ability to improve soil health make *Trichoderma* an essential tool in sustainable agriculture. In order to suppress plant pathogens, *Trichoderma* species used a mixed mode of action that involved multiple mechanisms for antagonistic interaction. These mechanisms could be direct, such as mycoparasitism, competition, and antibiosis, or complex indirect, such as promoting induced systemic resistance (ISR), nutrient solubilization and sequestration, nutrient uptake, and plant growth enhancement as illustrated in Figure.3.

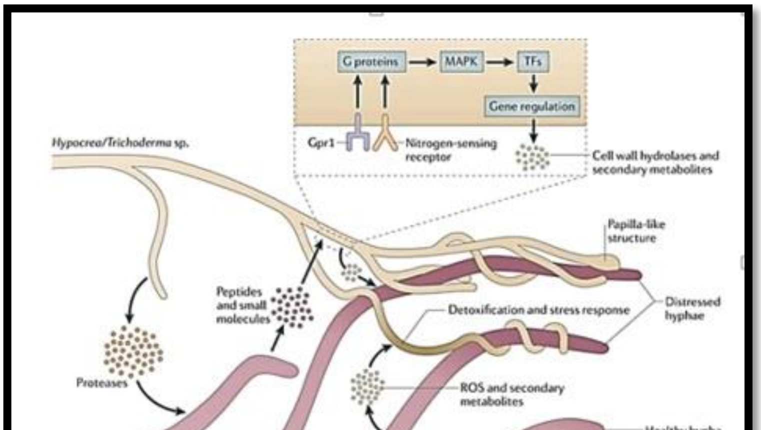

Figure.3. Mode of action of *Trichoderma* sp. (Dutta *et al*., 2022)

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In addition to their capacity to improve nutrient uptake, resistance to abiotic stressors, crop productivity, and shoot and root growth (Dutta and Das, 1999), *Trichoderma* species are renowned for their abundant production of extracellular enzymes, proteins, fungitoxic compounds, antibiotics, and defense-related substances (Howell, 2003).

CONCLUSION:

Trichoderma has proven to be a highly effective biocontrol agent for managing fungal phytopathogens in agriculture. Its ability to suppress plant diseases through mechanisms such as mycoparasitism, competition for nutrients and space, and the production of antifungal compounds makes it a valuable alternative to chemical fungicides. The use of *Trichoderma* not only enhances crop protection but also promotes soil health and sustainability, aligning with environmentally friendly agricultural practices. Despite its potential, factors such as strain specificity, environmental conditions, and application methods need to be optimized for consistent results. Future research focusing on strain improvement, formulation development, and field-level studies will further enhance the efficacy and commercial viability of *Trichoderma* in integrated pest management systems. By harnessing the potential of *Trichoderma*, farmers can reduce their reliance on synthetic fungicides, minimize environmental impact, and promote resilient and productive agricultural systems.

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