

# Biological Control of Fusarium Wilt of Brinjal (*Solanum Melongena* L.) Using *Trichoderma* Spp.: A Review

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**Abstract:** *Fusarium wilt is a significant soil-borne infection of brinjal (*Solanum melongena* L.) caused by *Fusarium oxysporum* f. sp. *melongenae* resulting in heavy losses of yields in many countries across the globe. Traditional methods of control, such as fungicides, have not been effective enough given the environmental issues and the fact that the pathogen is long-term persistent in soil. The use of *Trichoderma* spp. as a biological control has become an environmentally friendly and sustainable alternative. This review presents the etiology, symptoms and disease cycle of *Fusarium* wilt as well as how and how effectively *Trichoderma* spp. are as biocontrol agents. It also addresses application procedures, current developments as well as future outlook in integrated disease management strategies..*

**Keywords:** *Solanum melongena*; *Fusarium wilt*; *Trichoderma* spp.; Biological control; Integrated disease management

## I. INTRODUCTION

Eggplant (*Solanum melongena* L.) is a vegetable crop that is widely grown in tropical and subtropical areas of the globe. It is of great nutritional and economic value, especially in such nations as India, which is one of the major producers in the world. Although it is vital, brinjal farming is severely limited by various biotic stresses that include *Fusarium* wilt that is regarded as one of the most devastating diseases in terms of yield and quality.<sup>1</sup>

*Fusarium oxysporum* f. sp. *melongenae* causes *fusarium* wilting of the brinjal. The pathogen enters the plants by infecting the root system and then invading the vascular tissues, which impedes the transportation of water and nutrients. This leads to typical symptoms like leaves yellowing, wilting, vascular browning and eventual plant death. The disease is especially hard to control since the pathogen develops long-lasting survival structures, including chlamydospores, allowing it to remain in the soil in many years even without a host plant.

The traditional approach of management such as use of chemical fungicides and resistant varieties have been relatively unsuccessful because of environmental issues, cost and the emergence of pathogen resistance. Biological control has been seen as an alternative in this regard as a promising and sustainable method. It is well known that beneficial fungi such as *Trichoderma* spp. have antagonistic effects against soil-borne pathogens. They have the capacity to suppress disease in a variety of ways and stimulate plant growth, which is why they can be useful in integrated disease management systems to ensure sustainability in agriculture.

<sup>1</sup> Howell, C. R. (2003). Mechanisms employed by *Trichoderma* species in the biological control of plant diseases. *Plant Disease*.



## II. LITERATURE REVIEW

**Mukherjee<sup>2</sup> et al. (2013)** gave an overview of the biology and uses of *Trichoderma* spp. The article talked about genetic diversity, ecological adaptability, and interaction with plant roots. *Trichoderma* was reported to increase nutrient absorption and root growth, which leads to the health and disease resistance of plants. The authors proposed its incorporation in the contemporary farming to provide sustainable crop protection.

**Singh<sup>3</sup> et al. (2014)** compared the approaches of integrated disease management of *Fusarium* wilt in vegetable crops. The research concluded that the use of *Trichoderma* spp. incorporation with organic amendments and cultural practices greatly suppressed the severity of the disease. The authors concluded that combined methods are better than individual control methods in controlling persistent soil-borne pathogens.

**Kumar<sup>4</sup> et al. (2016)** examined the impact of biological agents in the management of soil-borne pathogens. The study showed that the *Trichoderma viride* was effective in reducing the population of *Fusarium oxysporum* in soil. The authors also indicated an increase in the growth and yield of the plants which means that *Trichoderma* can be used as a sustainable substitute to the chemical fungicides.

**Pandey<sup>5</sup> et al. (2018)** examined the use of bioagents in the protection of vegetable crops. They found that *Trichoderma* spp. greatly decreased the occurrence of disease and enhanced soil health. This paper also highlighted the role of the awareness of the farmer and the appropriate application method in order to get the maximum benefits of biological control methods.

**Nair (2021)** explored the latest developments in the management of biological diseases. The research indicated the employment of enhanced formula of *Trichoderma* spp. and coexistence with other advantageous microorganisms. The conclusion was that biotechnological strategies using *Trichoderma* have the potential to increase the efficiency and reliability of biocontrol in sustainable agriculture.

## III. FUSARIUM WILT OF BRINJAL

### 3.1 Causal Organism

*Fusarium oxysporum* f. sp. *melongenae* is a soil-dwelling fungus that causes the disease and generates chlamydoconidia, which allows the fungus to survive over time.

### 3.2 Symptoms

Lower leaves yellowing.

Drying out in the daytime.

Vasodilation of tissues.

Stunted growth

Severe cases: Death of plants.

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<sup>2</sup>Mukherjee, P. K., Horwitz, B. A., Herrera-Estrella, A., Schmoll, M., & Kenerley, C. M. (2013). *Trichoderma* research in the genome era. *Critical Reviews in Biotechnology*.

<sup>3</sup>Singh, R., Singh, H. K., & Singh, A. (2014). Integrated management of *Fusarium* wilt in vegetable crops.

<sup>4</sup>Kumar, S., Chaudhary, P., & Sharma, R. (2016). Biological control of soil-borne pathogens using *Trichoderma* spp.

<sup>5</sup>Pandey, R. N., Singh, R., & Singh, P. (2018). Use of bioagents in vegetable crop protection.



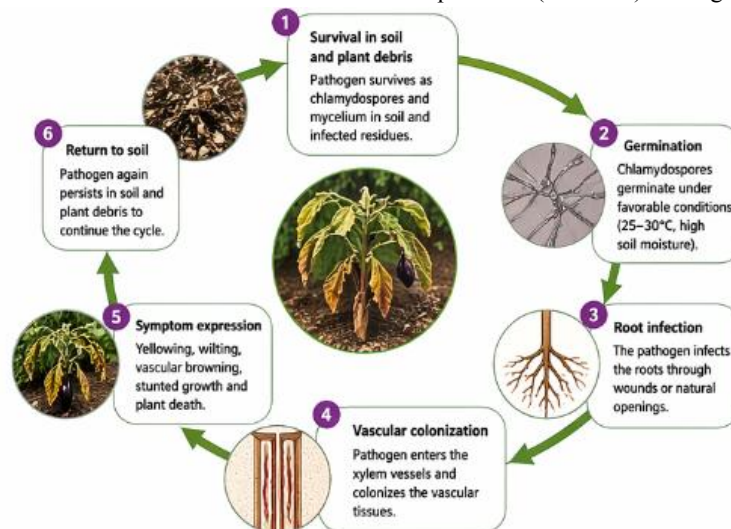
**Table 1: Symptoms of Fusarium Wilt in Solanum Melongena**

Stage	Symptoms	Typical Appearance
Early stage	Yellowing of lower leaves	
Mid stage	Wilting during the daytime	
Advanced stage	Browning of vascular tissues	
Severe stage	Stunted growth and plant death	

The visible symptoms of Fusarium wilt in brinjal vary with the stage of infection and environmental conditions. Early detection is important for effective management of the disease. These symptoms provide valuable diagnostic clues for identifying infected plants in the field. The major symptoms observed in infected plants are summarized in Table 1.<sup>6</sup>

### 3.3 Disease Cycle

The pathogen survives in soil and plant debris. It infects roots, enters the vascular system, and blocks water movement, leading to wilt symptoms. Favorable conditions include warm temperatures (25–30°C) and high soil moisture.



**Figure 1: Disease cycle of Fusarium oxysporum f. sp. Melongenae**

To come up with effective management strategies, it is necessary to understand the disease cycle of the pathogen. The pathogen is resistant to soil, enters host plants via roots and proliferates in the vascular system, resulting in the wilting symptoms. Every step adds to the creation of the disease and its sustainability in the sphere. Figure 1 shows the disease cycle of the pathogen.<sup>7</sup>

<sup>6</sup>Dubey, S. C., Suresh, M., & Singh, B. (2011). Role of *Trichoderma* in disease management. *Indian Phytopathology*.

<sup>7</sup>Elad, Y., Chet, I., & Katan, J. (2010). Biological control using *Trichoderma* spp. *Plant Pathology Journal*.



#### IV. SHORTCOMINGS OF TRADITIONAL CONTROL TECHNIQUES

**Fusarium wilt has been controlled by the use of chemical fungicides and resistant varieties. However:**

Soil-borne pathogens are not always susceptible to chemicals.

Pollution and health hazards.

Strains of resistant pathogens.

High cost and unsustainability.

These restrictions require other methods such as biological control.

**Table 2: Comparison of Traditional and Biological Control Methods**

Parameter	Chemical Control	Biological Control ( <i>Trichoderma</i> )
Environmental Impact	High	Low (Eco-friendly)
Cost	High	Moderate
Residue Issues	Present	Absent
Sustainability	Low	High
Resistance Development	High	Low

A comparison between traditional and biological control methods is presented in Table 2, highlighting differences in environmental impact, cost, sustainability, and effectiveness, with *Trichoderma*-based approaches offering safer and more sustainable disease management.

#### V. BIOLOGICAL CONTROL AND ITS SIGNIFICANCE

**Biological control is the application of living things to control plant pathogens. It offers:**

Eco-friendly disease management

Reduced chemical usage

Long-term sustainability

Improved soil health

*Trichoderma spp.* are some of the widely studied and used biocontrol agents.

**Table 3: Advantages of Using *Trichoderma spp.***

Advantage	Description
Eco-friendly	Reduces chemical usage
Soil Health	Improves microbial balance
Plant Growth	Enhances root development
Disease Control	Suppresses pathogens
Sustainability	Long-term effectiveness

#### VI. TRICHODERMA SPP. BIOCONTROL AGENTS

##### 6.1 General Characteristics

The genus *Trichoderma* is a genus of filamentous fungi that is widespread in soil and root environments. Important species include:

*Trichoderma harzianum*

*Trichoderma viride*

*Trichoderma asperellum*

They have a high reproduction capacity, rapid growth and antagonistic power.<sup>8</sup>

<sup>8</sup> Harman, G. E. (2006). Overview of mechanisms and uses of *Trichoderma spp.* *Phytopathology*, 96(2), 190–194.



## VII. Trichoderma Mechanisms of Biological Control

Table 4: Mechanisms of Action of Trichoderma Spp

Mechanism	Description
<b>Mycoparasitism</b>	Direct attack on pathogen hyphae by coiling and degradation using lytic enzymes.
<b>Antibiosis</b>	Production of antibiotics and secondary metabolites that inhibit pathogen growth.
<b>Competition</b>	Competition for nutrients and space in the rhizosphere, limiting pathogen establishment.
<b>Induced Systemic Resistance (ISR)</b>	Activation of plant defense pathways leading to enhanced resistance against pathogen.
<b>Plant Growth Promotion</b>	Enhancement of root growth, nutrient uptake and overall plant health.

Trichoderma spp. uses various mechanisms to subdue plant pathogens and enhance the health of plants. These entire mechanisms act together to suppress the growth of pathogen and increase the host resistance. These processes should be well understood in order to be effectively applied in managing diseases. Table 4 shows the important biological control mechanisms of Trichoderma.<sup>9</sup>

### 7.1 Mycoparasitism

The trichoderma has a direct effect of attacking pathogenic fungi by wrapping around their hyphae and destroying them with the help of enzymes such as chitinases and glucanases.

### 7.2 Antibiosis

The growth of the pathogens is inhibited by the production of secondary metabolites (antibiotics) like gliotoxin and viridin.

### 7.3 Competition

Trichoderma also competes with pathogens in nutrients and space in rhizosphere, which decreases the establishment of pathogens.

### 7.4 Systemic Resistance (ISR) Induced

It increases the defense mechanism of plants by stimulating the resistance pathways, rendering the plants to be more resistant to infections.<sup>10</sup>

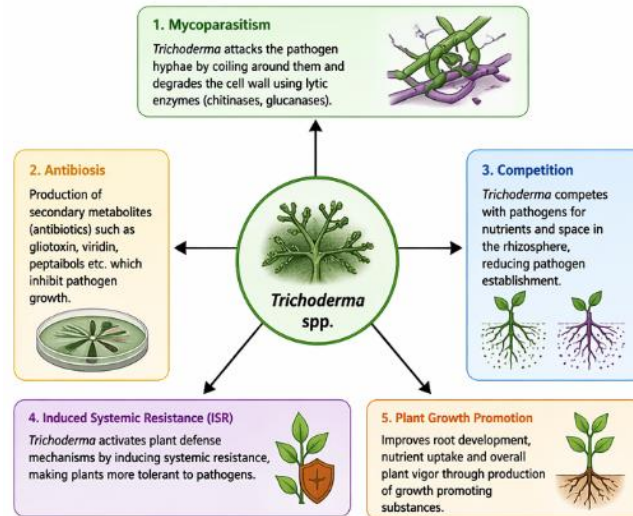
### 7.5 Plant Growth Promotion

Trichoderma enhances the growth of roots, nutrient absorption and general plant health.

<sup>9</sup> Woo, S. L., Ruocco, M., Vinale, F., Nigro, M., Marra, R., Lombardi, N., ...Lorito, M. (2014). *Trichoderma*-based products and their widespread use in agriculture. *Open Mycology Journal*, 8, 71–126.

<sup>10</sup> Sharma, P., Kaur, M., Sharma, S., Puri, A., & Sharma, P. (2012). Bio-control of plant diseases using *Trichoderma* spp. *Journal of Agricultural Science*.





**Figure 2: Mode of Action of Trichoderma Spp**

The multi-pronged activities of *Trichoderma* spp. are responsible of its efficacy as a biocontrol agent, as it has multiple modes of action, such as direct and indirect interactions with the pathogens and plants. All these processes help in the suppression of diseases and also increase the growth of plants. To understand the mode of action of *Trichoderma* spp. better, Figure depicts it.<sup>11</sup>

### VIII. APPLICATION METHODS OF TRICHODERMA

**Table 5: Application Methods of Trichoderma Spp**

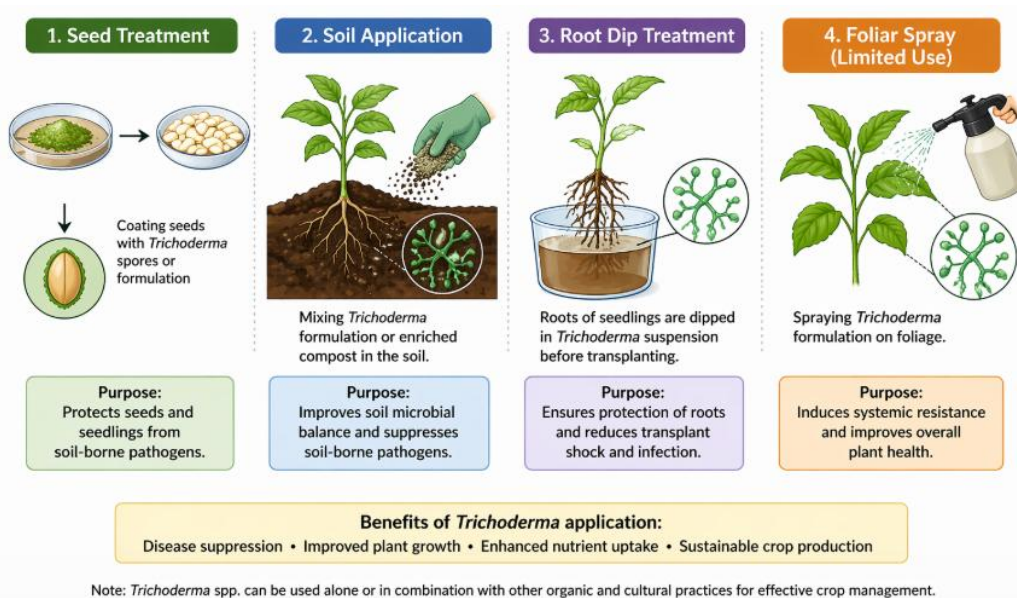
Method	Procedure	Purpose
Seed treatment	Coating seeds with <i>Trichoderma</i> spore powder or suspension before sowing.	Protects seeds and seedlings from early infection.
Soil application	Application of <i>Trichoderma</i> enriched compost, granules or formulations in soil.	Improves soil microbial balance and suppresses pathogen.
Root dip treatment	Dipping roots of seedlings in <i>Trichoderma</i> suspension before transplanting.	Provides protection during transplanting shock and infection.
Foliar spray (Limited use)	Spraying <i>Trichoderma</i> formulation on foliage.	Enhances systemic resistance and plant vigor.

Various procedures of using *Trichoderma* spp. have been established to enhance maximum effectiveness in the field. These practices differ with crop stage, environmental conditions, and each approach has its own role of preventing and controlling diseases. Table 5 lists different application methods of *Trichoderma*.<sup>12</sup>

<sup>11</sup>Khan, R. A., &Javaid, A. (2020). Management of Fusarium wilt of vegetables using biological control agents. *Egyptian Journal of Biological Pest Control*, 30(1), 1–10.

<sup>12</sup>Li, Y., Sun, R., Yu, J., Saravanakumar, K., & Chen, J. (2019). Antagonistic and plant growth-promoting effects of *Trichoderma* spp. *Microbiological Research*, 223–225, 1–10





**Figure 3: Application methods of *Trichoderma* spp. in crop management**

### 8.1 Seed Treatment

The *Trichoderma* spores are applied to seeds to inhibit premature infection of seedlings.

### 8.2 Soil Application

Use of *Trichoderma* enhanced composts or formulations enhances microbial balance of soils.

### 8.3 Root Dip Treatment

Transplantation of seedlings is done into *Trichoderma* suspension.

### 8.4 Foliar Spray (Limited Use)

Systemic resistance may be improved by foliar sprays, although predominantly applied to the soil.

## IX. FUNGAL WILT RESISTANCE

The effectiveness of *Trichoderma* spp. in the control of *Fusarium* wilt in brinjal has been established in many studies:

Decrease in disease occurrence.

Better development and production of plants.

Reduction of population of pathogens in soil.

Additional use with organic amendments is also more effective.



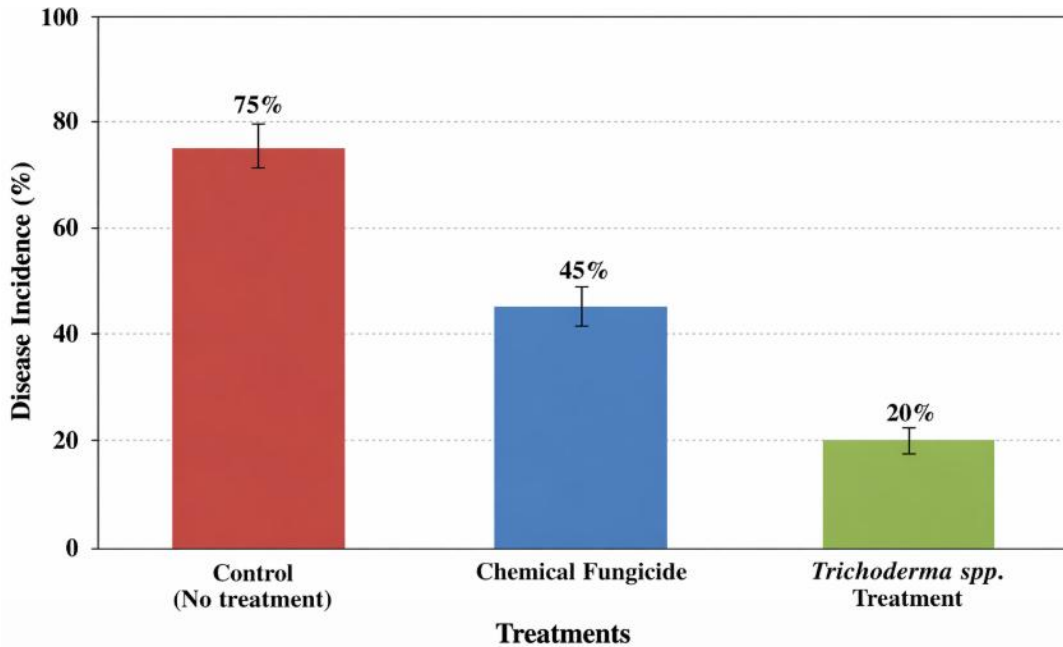


Figure 4: Reduction in Fusarium Wilt Incidence by *Trichoderma spp.*

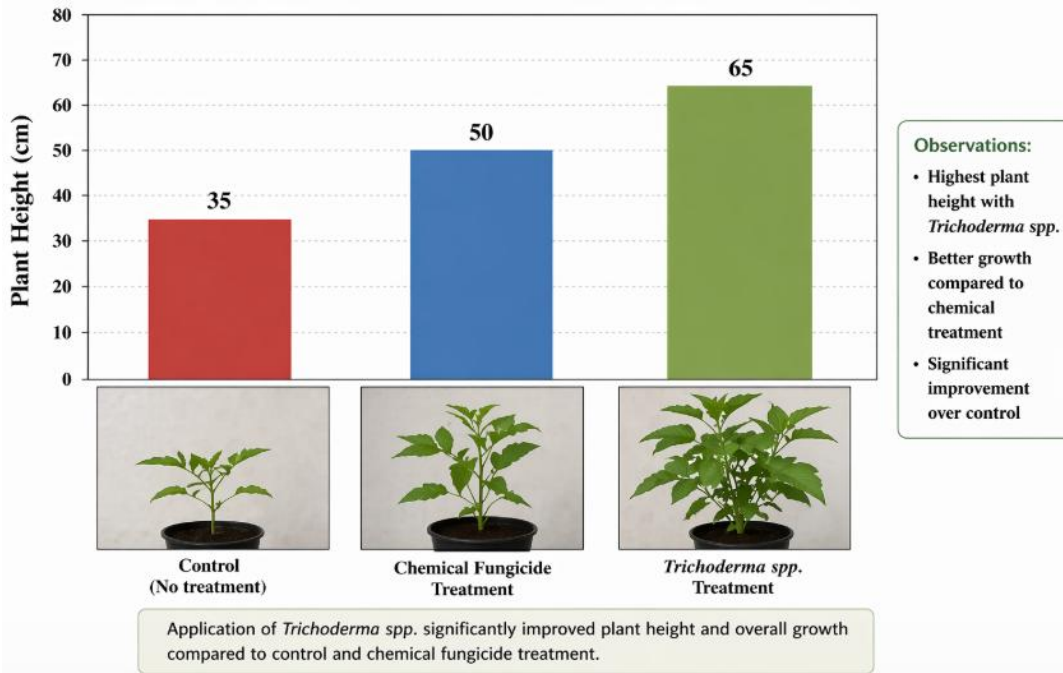


Figure 5: Effect of *Trichoderma spp.* on plant growth

**X. COEXISTENCE WITH THE OTHER MANAGEMENT PRACTICES**

The biological control is better when combined with:

Crop rotation



Resistant varieties

Organic amendments

Soil solarisation<sup>13</sup>

This is an integrated disease management (IDM) system that is long-term sustainable.

#### **XI. CHALLENGES AND LIMITATIONS**

**Although these are the benefits of biological control, it has some challenges:**

Variable field performance

Sensitivity to environmental conditions.

Poor shelf-life of formulations.

Incident of ignorance among farmers.

#### **XII. RECENT ADVANCES**

Design of better formulations (granules, bio-pellets)

Use of molecular tools to increase strain efficiency.

Co-location with other useful microbes (PGPR)

Genetic enhancement of *Trichoderma* strains.

#### **XIII FUTURE PROSPECTS**

**The research needs to consider in the future should be:**

Strain enhancement towards greater efficacy.

Formulation of stable formulations.

Farmer-friendly application methods

Large-scale field validation<sup>14</sup>

#### **XIV. CONCLUSION**

Fusarium wilt is still a major challenge to the production of brinjal. *Trichoderma* spp. can be used as a biological control in place of chemical control, which is promising and environmentally friendly. It is a versatile agent in the management of diseases with its various modes of action such as mycoparasitism, antibiosis, and induced resistance. Nevertheless, to be successful regularly, it must be incorporated into other cultural practices. Widespread adoption requires further research and awareness.<sup>15</sup>

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<sup>13</sup>Poveda, J. (2021). *Trichoderma* as biocontrol agent against pests: New uses for a mycoparasite. *Biological Control*, 159, 104634.

<sup>14</sup>Zin, N. A., & Badaluddin, N. A. (2020). Biological functions of *Trichoderma* spp. for agriculture applications. *Annals of Agricultural Sciences*, 65(2), 168–178.

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