

## APPLICATION METHODS OF TRICHODERMA SPP. IN AGRICULTURE: SUITABILITY ACROSS CROPS, DELIVERY SYSTEMS, AND BIOCONTROL EFFICIENCY

Dr. C. Rama Raju<sup>1</sup>, Dr. R. Yadagiri<sup>2</sup>, Dr. T. Shankar<sup>3</sup>, Dr. M. Ravinder<sup>4\*</sup>

<sup>1</sup>Assistant Professor of Botany, Government Degree College, Badangpet. Dist: Ranga Reddy, Osmania University, Telangana.

<sup>2</sup>Associate Professor of Botany, Government Degree College, Hayath Nagar, Dist: Ranga Reddy, Osmania University, Telangana, India.

<sup>3</sup>Professor of Botany, Government Degree College, Sircilla, Dist: Rajanna Sircilla, Satavahana University, Telangana.

<sup>4</sup>Associate Professor of Botany, Government Degree College, Vikarabad, Dist: Vikarabad, Osmania University, Telangana, India.

Article Received on 15 April 2026,  
Article Revised on 05 May 2026,  
Article Published on 16 May 2026,

<https://doi.org/10.5281/zenodo.20201457>

### \*Corresponding Author

Dr. M. Ravinder

Associate Professor of Botany,  
Government Degree College,  
Vikarabad, Dist: Vikarabad,  
Osmania University, Telangana,  
India.



**How to cite this Article:** Dr. C. Rama Raju<sup>1</sup>, Dr. R. Yadagiri<sup>2</sup>, Dr. T. Shankar<sup>3</sup>, Dr. M. Ravinder<sup>4\*</sup>. (2026). Application Methods of Trichoderma SPP. In Agriculture: Suitability Across Crops, Delivery Systems, and Biocontrol Efficiency. World Journal of Pharmaceutical Research, 15(10), 488-497.

This work is licensed under Creative Commons Attribution 4.0 International license.

### ABSTRACT

The growing demand for sustainable agricultural practices has accelerated the adoption of biological control agents as alternatives to chemical pesticides. Among these, *Trichoderma* spp. have gained significant attention due to their broad-spectrum antagonistic activity and plant growth-promoting properties. The effectiveness of *Trichoderma* largely depends on the method of application, which influences its establishment, survival, and interaction with host plants and pathogens. This review comprehensively analyzes major application methods of *Trichoderma*, including seed treatment, soil application, root dipping, nursery bed treatment, soil drenching, foliar spray, and vegetative propagule treatment. Special emphasis is given to the suitability of each method based on crop type, growth stage, and target pathogen. Evidence suggests that seed and soil applications are most effective for soil-borne pathogens, while foliar spray and

wound dressing are better suited for aerial diseases. Root dip and nursery treatments are particularly beneficial in transplanted crops. The review highlights that no single method is universally effective, and integrated approaches tailored to specific crop-pathogen systems provide optimal results. This study provides a framework for selecting appropriate application strategies to maximize the efficiency of *Trichoderma* in sustainable agriculture.

**KEYWORDS:** Seed Treatment, Soil Application, Root Dip Treatment, Soil Drenching, Wound Dressing.

## 1. INTRODUCTION

The excessive reliance on chemical pesticides has resulted in environmental degradation, pathogen resistance, and adverse effects on human health, necessitating the development of sustainable disease management strategies (Harman et al., 2010; Ram et al., 2018). Biological control using beneficial microorganisms has emerged as a viable alternative, offering eco-friendly and long-term solutions for plant disease management.

Among various microbial agents, *Trichoderma* spp. are widely recognized for their adaptability, rapid colonization, and antagonistic activity against a broad range of phytopathogens (Boro et al., 2022). These fungi are commonly found in soil and root ecosystems, where they interact closely with plant roots and microbial communities (Harman, et al., 2004).

The biocontrol potential of *Trichoderma* is attributed to multiple mechanisms, including mycoparasitism, antibiosis, competition for nutrients and space, and induction of systemic resistance (Gajera et al., 2013). In addition, they promote plant growth by enhancing nutrient uptake and producing growth-regulating metabolites (Stewart & Hill, 2014). The antagonistic potential of *Trichoderma* spp. has been well demonstrated through in vitro studies, where significant inhibition of *Fusarium oxysporum* was observed due to mechanisms such as mycoparasitism, antibiosis, and competition for nutrients and space (Ramaraju et al., 2017).

However, the success of *Trichoderma*-based products is highly dependent on application methods, which determine the efficiency of rhizosphere colonization and persistence in different environmental conditions (Martinez et al., 2023). Various delivery systems—such as seed coating, soil incorporation, root dipping, and foliar application—have been

developed, each with specific advantages and limitations depending on crop type and pathogen ecology (Kumar & Purohit, 2011).

This review aims to critically analyze these application methods and their suitability across different agricultural systems.

## 2. APPLICATION METHODS OF *TRICHODERMA* AND THEIR SUITABILITY

### 2.1 Seed Treatment

Seed treatment is one of the most widely used methods for delivering *Trichoderma*, particularly in cereals, pulses, and oilseeds. It ensures early colonization of the spermosphere and rhizosphere, providing protection against seed- and soil-borne pathogens such as *Fusarium*, *Pythium*, and *Rhizoctonia* (Lewis & Lumsden, 2001; Narayanasamy, 2013).

Typically, formulations containing  $10^6$ – $10^8$  CFU g<sup>-1</sup> are applied at 2–10 g/kg seed. This method is highly suitable for direct-seeded crops like wheat, maize, chickpea, and soybean. However, its effectiveness may be limited in perennial crops or under conditions where post-emergence infection dominates (Panda *et al.*, 2021). Supporting this, Ramaraju *et al.* (2017) reported that early establishment of *Trichoderma* enhances pathogen suppression by rapidly colonizing the rhizosphere and restricting pathogen growth through competitive exclusion and enzymatic degradation.

### 2.2 Soil Application

Soil application involves mixing *Trichoderma* with organic amendments such as compost or farmyard manure and incorporating it into the soil. This method is particularly effective for managing soil-borne pathogens and improving soil health (Bailey & Lazarovits, 2003). The effectiveness of soil-applied *Trichoderma* is largely attributed to its rapid growth and ability to occupy ecological niches, thereby limiting pathogen proliferation, as evidenced by dual culture studies showing significant radial growth inhibition of *Fusarium* spp. (Ramaraju *et al.*, 2017).

It is best suited for crops with long growth duration (e.g., sugarcane, cotton, vegetables) and for fields with a history of soil-borne diseases. However, its success depends on environmental conditions such as soil moisture, temperature, and organic matter content (Wong *et al.*, 2002; Stewart & Hill, 2014).

### 2.3 Root Dip Treatment

Root dipping is especially suitable for transplanted crops such as rice, tomato, chili, and vegetables. Seedlings are dipped in a suspension ( $10^6$ – $10^8$  CFU mL<sup>-1</sup>) before transplanting, allowing immediate root colonization (Woo, 2014). Similarly, nursery bed treatment was found to reduce damping-off diseases and improve seedling vigor in crops raised under controlled nursery conditions (Nirmalkar *et al.*, 2018). Microscopic studies have shown that *Trichoderma* hyphae coil around pathogen hyphae and form haustoria-like structures, leading to degradation of the pathogen cell wall, which supports its effectiveness during early root colonization stages (Ramaraju *et al.*, 2017).

This method is highly effective under high disease pressure and ensures better plant establishment. However, it is labor-intensive and less practical for large-scale mechanized farming systems.

### 2.4 Nursery Bed Treatment

Nursery bed treatment ensures early protection of seedlings against damping-off diseases caused by *Pythium* and *Rhizoctonia*. It is particularly suitable for crops raised in nurseries such as vegetables, tobacco, and forest species (Kumhar *et al.*, 2022).

This method enhances seedling vigor and uniformity but requires proper management of nursery conditions for optimal results.

### 2.5 Soil Drenching

Soil drenching involves applying liquid formulations directly to the root zone, ensuring deeper penetration and uniform distribution. It is suitable for managing established infections in standing crops (Jambhulkar, 2015).

This method is particularly effective in horticultural crops and high-value crops where targeted application is feasible. However, repeated applications may be required under severe disease pressure.

### 2.6 Foliar Spray and Wound Dressing

Foliar application is used to control aerial pathogens and induce systemic resistance in plants. It is suitable for crops affected by foliar diseases such as leaf spots and blights (Sawant, 2014).

Wound dressing is particularly useful in perennial crops and fruit trees, where *Trichoderma* prevents pathogen entry through pruning wounds (Woo, 2014). However, foliar persistence may be limited due to environmental exposure.

### 2.7 Vegetative Propagule Treatment (Cuttings, Tubers, Rhizomes)

This method is essential for crops propagated through vegetative parts such as potato, sugarcane, banana, and turmeric. Treatment of planting material ensures early protection and improved establishment (MacKenzie *et al.*, 1995).

It is highly suitable for disease-prone planting materials but requires careful handling to maintain inoculum viability.

### 2.8 Root Zone Application

Direct application to the root zone ensures continuous colonization and long-term protection. It is suitable for perennial crops and high-value horticultural systems (Harman *et al.*, 2004).

This method supports sustained plant growth but depends on proper irrigation and soil conditions.

The analysis of existing literature reveals that the effectiveness of *Trichoderma* spp. is strongly influenced by the method of application, crop type, and pathogen ecology (Table 1). Across multiple studies, seed treatment and soil application were consistently reported as the most effective methods for managing soil-borne pathogens such as *Fusarium*, *Rhizoctonia*, and *Pythium* spp. (Harman *et al.*, 2004; Panth *et al.*, 2020). These methods facilitate early establishment of *Trichoderma* in the rhizosphere, resulting in improved disease suppression and plant growth.

**Table 1: Various application methods of *Trichoderma* for biocontrol efficiency.**

Method	Suitable Crops	Target Pathogens	Key Advantages
Seed Treatment	Cereals (wheat, maize), pulses, oilseeds	<i>Fusarium</i> , <i>Pythium</i> , <i>Rhizoctonia</i>	Early root colonization, cost-effective, easy application
Soil Application	Vegetables, cotton, sugarcane	Soil-borne pathogens	Improves soil health, long-term protection, enhances microbial activity
Root Dip Treatment	Transplanted crops (tomato, chili, rice)	<i>Fusarium</i> , <i>Rhizoctonia</i>	Immediate root protection, reduces transplant shock
Nursery Bed Treatment	Vegetables, tobacco, forest seedlings	Damping-off ( <i>Pythium</i> , <i>Rhizoctonia</i> )	Protects seedlings early, improves uniform growth
Soil Drenching	Horticultural crops,	Root rot, wilt pathogens	Deep soil penetration, effective

	vegetables		under high disease pressure
Foliar Spray	Wheat, vegetables, fruits	Foliar pathogens ( <i>Botrytis</i> , blights)	Induces systemic resistance, controls aerial infections
Wound Dressing	Fruit trees, plantation crops	Wound-invading fungi	Prevents infection entry, promotes healing
Vegetative Propagule Treatment	Potato, banana, sugarcane, turmeric	<i>Fusarium</i> , soft rot pathogens	Protects planting material, improves establishment
Root Zone Application	Perennial horticultural crops &	Soil-borne pathogens	Sustained rhizosphere colonization, long-term protection

### 3. DISCUSSION

The findings clearly demonstrate that the success of *Trichoderma*-based biocontrol strategies is highly dependent on the mode of application and ecological compatibility with the crop-pathogen system. While seed treatment and soil application are widely adopted due to their simplicity and effectiveness, their performance is influenced by environmental conditions such as soil moisture, temperature, and organic matter content (Ferreira & Musumeci, 2021).

The superior performance of seed treatment can be attributed to early colonization of the spermosphere, which allows *Trichoderma* to establish before pathogen infection occurs (Harman et al., 2004). Experimental evidence further indicates that *Trichoderma harzianum* exhibits higher inhibition efficiency (up to ~81%) against *Fusarium oxysporum*, highlighting species-specific variability in antagonistic potential and reinforcing the importance of selecting efficient strains for field application (Ramaraju et al., 2017). However, this method alone may not provide long-term protection, especially in crops with extended growth periods. In such cases, soil application or root zone treatments are necessary to maintain microbial populations in the rhizosphere.

Root dip and nursery treatments offer targeted delivery and are particularly advantageous in transplanted crops. These methods ensure direct contact between the biocontrol agent and plant roots, enhancing colonization efficiency and reducing transplant shock (Ferreira & Musumeci, 2021). However, their applicability is limited in large-scale mechanized systems.

Foliar applications, although useful for inducing systemic resistance, show inconsistent results due to environmental exposure. This highlights the importance of selecting application methods based on pathogen location—soil-borne vs. foliar pathogens (Elad et al., 2002).

The effectiveness of vegetative propagule treatments further emphasizes the importance of protecting planting materials at the initial stage, particularly in crops prone to systemic infections such as banana and potato (Bubici *et al.*, 2019). The production of volatile and non-volatile metabolites by *Trichoderma* spp. plays a crucial role in pathogen suppression, although non-volatile compounds were found to exert comparatively stronger inhibitory effects (Ramaraju *et al.*, 2017).

Importantly, no single method is universally effective. Instead, integrated application strategies combining multiple delivery methods provide synergistic effects, leading to enhanced disease suppression and improved plant growth. This aligns with previous studies emphasizing the need for a systems-based approach in biological control (Woo *et al.*, 2014).

#### 4. CONCLUSION

The present review highlights the critical role of application methods in determining the success of *Trichoderma*-based biocontrol strategies. Different delivery techniques—including seed treatment, soil application, root dipping, foliar spray, and vegetative propagule treatment—offer distinct advantages depending on crop type, growth stage, and pathogen ecology.

Among these, seed treatment and soil application are the most widely used and effective methods for managing soil-borne diseases, while root dip and nursery treatments are particularly suitable for transplanted crops. Foliar spray and wound dressing are more effective against aerial pathogens, whereas vegetative propagule treatments provide essential protection in crops propagated through planting materials. These findings are supported by experimental studies demonstrating strong antagonistic interactions and multiple modes of action of *Trichoderma* spp., validating their role as effective biocontrol agents in sustainable agriculture. The review clearly demonstrates that no single application method is universally optimal. Instead, the selection of appropriate methods should be based on specific crop-pathogen interactions and environmental conditions. Integrated approaches combining multiple methods offer the greatest potential for improving disease control and plant productivity.

The adoption of *Trichoderma*-based application strategies can significantly contribute to sustainable agriculture by reducing dependence on chemical pesticides, improving soil health, and enhancing crop yield. Future research should focus on optimizing formulation stability,

improving field-level consistency, and developing crop-specific application protocols for large-scale adoption.

## 5. REFERENCES

1. Bailey, K. L., & Lazarovits, G. (2003). Suppressing soil-borne diseases with residue management and organic amendments. *Soil and tillage research*, 72(2): 169-180.
2. Boro, M., Sannyasi, S., Chettri, D., & Verma, A. K. (2022). Microorganisms in biological control strategies to manage microbial plant pathogens: a review. *Archives of microbiology*, 204(11): 666.
3. Bubici, G., Kaushal, M., Prigigallo, M. I., Gómez-Lama Cabanás, C., & Mercado-Blanco, J. (2019). Biological control agents against *Fusarium* wilt of banana. *Frontiers in microbiology*, 10: 616.
4. Cherkupally Ramaraju, Hindumathi Amballa, & Reddy, B. N. (2017). In vitro screening for enzymatic activity of *Trichoderma* species for biocontrol potential. *Ann. Plant Sci*, 6: 1784-1789.
5. Cherkupally Ramaraju, Hindumathi Amballa, & Reddy, B. N. (2017). In vitro antagonistic activity of *Trichoderma* species against *Fusarium oxysporum* f. sp. *melongenae*. *International Journal of Applied Agricultural Research*, 12(1): 87-95.
6. Cherkupally Ramaraju, Hindumathi Amballa, and Reddy, B. N. (2017). In vitro antifungal potential of plant extracts against *Fusarium oxysporum*, *Rhizoctonia solani* and *Macrophomina phaseolina*. *Ann. Plant Sci*, 6(9): 1676-1680.
7. Elad, Y. Elad, Y. and Freeman, S.(2002) Biological control of fungal plant pathogens. In:(ed.).
8. Ferreira, F. V., & Musumeci, M. A. (2021). *Trichoderma* as biological control agent: Scope and prospects to improve efficacy. *World Journal of Microbiology and Biotechnology*, 37(5): 90.
9. Gajera, H., Domadiya, R., Patel, S., Kapopara, M., & Golakiya, B. (2013). Molecular mechanism of *Trichoderma* as bio-control agents against phytopathogen system—a review. *Curr. Res. Microbiol. Biotechnol*, 1(4): 133-142.
10. Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2004). *Trichoderma* species—opportunistic, avirulent plant symbionts. *Nature reviews microbiology*, 2(1): 43-56.

11. Harman, G. E., Obregón, M. A., Samuels, G. J., & Lorito, M. (2010). Changing models for commercialization and implementation of biocontrol in the developing and the developed world. *Plant Disease*, 94(8): 928-939.
12. Jambhulkar, P. P., Sharma, P., & Meghwal, M. L. (2015). Additive effect of soil application with *Trichoderma* enriched FYM along with seed treatment and drenching with *Trichoderma* formulation for management of wet root rot caused by *Rhizoctonia solani* in chickpea. *J Pure Appl Microbiol*, 9(1): 405-412.
13. Kumar, A., & Purohit, A. K. (2011). The role of indigenous knowledge in biological control of plant pathogens: logistics of new research initiatives. In *Plant defence: biological control* (161-194). Dordrecht: Springer Netherlands.
14. Kumhar, K. C., Kumar, K., Arora, I., Bhatia, A. K., Batra, V. K., & Raj, H. (2022). Management of tomato damping-off disease in the nursery using of *Trichoderma asperellum*. *Int. J. Econ. Plants*, 9: 145-151.
15. Lewis, J. A., & Lumsden, R. D. (2001). Biocontrol of damping-off of greenhouse-grown crops caused by *Rhizoctonia solani* with a formulation of *Trichoderma* spp. *Crop protection*, 20(1): 49-56.
16. MacKenzie, A. J., Starman, T. W., & Windham, M. T. (1995). Enhanced root and shoot growth of chrysanthemum cuttings propagated with the fungus *Trichoderma harzianum*. *HortScience*, 30(3): 496-498.
17. Martinez, Y., Ribera, J., Schwarze, F. W., & De France, K. (2023). Biotechnological development of *Trichoderma*-based formulations for biological control. *Applied Microbiology and Biotechnology*, 107(18): 5595-5612.
18. Narayanasamy, P. (2013). Biological disease management systems for agricultural crops. In *Biological Management of Diseases of Crops: Volume 2: Integration of Biological Control Strategies with Crop Disease Management Systems* (189-235). Dordrecht: Springer Netherlands.
19. Nirmalkar, V. K., Tiwari, R. K. S., & Singh, S. (2018). Efficacy of bio-agents against damping off in solanaceous crops under nursery conditions.
20. Panda, T., Mishra, N., Rahimuddin, S. K., Pradhan, B. K., & Mohanty, R. B. (2021). Utilization of weeds in rice ecosystem by farmers in Odisha, India. *Indian Journal of Weed Science*, 53(3): 285-291.
21. Panth, M., Hassler, S. C., & Baysal-Gurel, F. (2020). Methods for management of soilborne diseases in crop production. *Agriculture*, 10(1): 16.

22. Ram, R. M., Keswani, C., Bisen, K., Tripathi, R., Singh, S. P., & Singh, H. B. (2018). Biocontrol technology: eco-friendly approaches for sustainable agriculture. In *Omics technologies and bio-engineering* (177-190). Academic Press.
23. Sawant, I. S. (2014). Trichoderma-foliar pathogen interactions. *The Open Mycology Journal*, 8(1): 58-70.
24. Stewart, A., & Hill, R. (2014). Applications of Trichoderma in plant growth promotion. In *Biotechnology and biology of Trichoderma* (415-428). Elsevier.
25. Wong, P. T. W., Mead, J. A., & Croff, M. C. (2002). Effect of temperature, moisture, soil type and Trichoderma species on the. *Australasian Plant Pathology*, 31(3): 253-257.
26. 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 Mycol. J*, 8(1): 71-126.