**Compatibility of Trichoderma asperellum with Different Fungicides: An integrated disease management approach**

**Abstract –** The effectiveness of biological control agents in integrated disease management programs may be weakened by the use of fungicides to treat plant diseases. Applying fungicides must not impede the action of efficient biocontrol agents. Among these, Trichoderma species have long been known to have the ability to suppress a variety of plant pathogens via different mechanisms. In the present study, the compatibility of *Trichoderma asperellum* with nine chemical fungicides was evaluated under *in vitro* conditions at three different concentrations to assess their impact on the mycelial growth of Trichoderma. In the present study, the compatibility of Trichoderma asperellum with nine chemical fungicides was evaluated under *in vitro* conditions at three different concentrations to assess their impact on the mycelial growth of Trichoderma. The results revealed that Carbendazim 50 WP (50, 100, 150 ppm), Carbendazim (12%)+Mancozeb (63%) 75 WP (50, 100, 200 ppm), Hexaconazole 5 SC, and Tebuconazole 25.9% EC (25, 50, 100 ppm) were incompatible with Trichoderma asperellum, inhibiting its growth significantly. In contrast, Metalaxyl 35 SD, Mancozeb 75 WP (250, 500, 750 ppm), Thiram 75 WP (50, 100, 200 ppm), Copper oxychloride 50 WP (250, 500, 750 ppm), and Thiram + Carboxin 75 WS (50, 100, 200 ppm) were found highly compatible, allowing effective growth of Trichoderma even at higher concentrations. The necessity of choosing compatible fungicides when implementing Trichoderma in integrated disease management programs was highlighted by the general trend of decreased mycelial growth with increasing fungicide concentration.

**Key words** – *Trichoderma*, biocontrol, fungicides, compatibility, management

**Introduction**

*Trichoderma*, a common soil and root ecosystem organism, has gained immense importance over the last few decades due to its biological control ability against several plant pathogens (Chet and Inbar, 1994), especially soil borne plant pathogens (Dominguesa *et al*., 2000). *Trichoderma'*s biocontrol activity is vital not only to agriculture and its crops but also to the environment, as it does not accumulate in the food chain and thus does not harm plants, animals, or humans. Biological control using antagonistic microorganisms, particularly species of Trichoderma, has emerged as an eco-friendly, cost-effective, and sustainable approach for managing soil-borne plant pathogens.

*Trichoderma spp*., also known as Teleomorph: *Hypocrea*, is a common ascomycete fungus with industrial and biocontrol applications. The sexual stage *Hypocrea* species was postulated in 1865, years after this fungus was first identified as *Trichoderma* in 1794 (Persoon, 1794). Scholars have undertaken a number of investigations to explore the diversity of indigenous *Trichoderma* species and their potential for combating significant plant pathogens (Kumar *et al*., 2012; Devi *et al*., 2021; Jambhulkar *et al*., 2024). *Trichoderma* is a global genus that consumes both decaying wood and plant matter. In a variety of settings, *Trichoderma* species are frequently the dominating members of the soil microflora. This may be because *Trichoderma* species have a wide range of metabolic capacities and are fiercely competitive. *Trichoderma asperellum*, *Trichoderma atroviride*, *Trichoderma harzianum*, *Trichoderma hamatum*, *Trichoderma koningii*, *Trichoderma virens*, and *Trichoderma viride* are among the *Trichoderma* species that can be found in nature. *Trichoderma* species are well known biocontrol agents and have gained much attention for their ability to inhibit plant pathogens in many ways including competing with adversaries, killing them and producing antifungal metabolites. However, several factors affect the efficacy of *Trichoderma* as a biocontrol agent such as nutrient availability and compatibility with other agro input like fungicides. In order to explore the full potential of *Trichoderma* mediated bio products, optimization of nutrient media and compatibilities of fungicides should be done. Multiple scientists have noted that different strains of *Trichoderma* may tolerate different amounts of harsher chemical pesticides in the field (Silva *et al*., 2018). The present study was undertaken to evaluate the compatibility of *Trichoderma asperellum* with different fungicides commonly used in plant disease management under *in vitro* conditions. For successful integration of Trichoderma in disease management programs, it is essential to identify fungicides that are compatible with the biocontrol agent, ensuring that chemical control does not inhibit the growth, survival, and antagonistic activity of Trichoderma in the rhizosphere. Fungicide-biological control agent compatibility studies are therefore crucial to develop effective integrated disease management (IDM) strategies that combine the quick action of fungicides with the long-term, sustainable effects of biocontrol agents. This study aimed to assess the impact of different concentrations of selected fungicides on the mycelial growth of *Trichoderma asperellum* to determine their compatibility, thereby providing insights for their integration into IDM strategies for sustainable and effective plant disease management.

**Material and Methods**

***In-vitro* compatibilityevaluation of fungicides with *Trichoderma* isolate**

 Compatibility of efficient isolates of *Trichoderma spp.* to selected fungicides were evaluated using Poisoned food technique (Nene and Thapliyal, 1993) with appropriate three different concentrations. 50 ml was poured in Erlenmeyer flasks (250 ml capacity) and sterilized. The required concentrations of fungicides was prepared by serial dilution and finally made to 50 ml volume for each concentration with the help of sterile distilled water and mixed with 50 ml PDA in flask aseptically. This made a final volume of 100 ml in each flask.

Aliquots of 20 was poured in Petri dishes (90 mm diameter) and allowed to solidify. After solidification, plates were centrally inoculated with mycelia disk (6mm) cut from 3 days old culture of *Trichoderma spp*. Three replications will be kept for each ten treatments along with control in CRD design where no chemical was added. Petri dishes were incubated at 28±1° C till the control plates will full with fungal growth. The linear growth of the colony was measured in two directions at right angles to each other.

**Observation recorded**

 In poisoned medium the radial growth of *Trichoderma* was recorded at the time when mycelium growth reached 90 mm in control. Percent inhibition of mycelium growth of the fungus was calculated by using the formula described by Vincent (Vincent, 1947). The data were analyzed statistically.

$$I= \frac{C-T}{C}×100$$

Where,

 I = Percent inhibition,

 C = Average radial growth in control,

 T = Average radial growth in treated (fungicide)

**Result**

The compatibility of nine fungicides was assessed under *in vitro* condition at three different concentrations with *Trichoderma* isolate (*Trichoderma asperellum*) on PDA medium by following standard procedure of poisoned food technique as mentioned in Material and Methods. Among the tested fungicides, Metalaxyl 35% SD, Mancozeb 75% WP, and Copper oxychloride 50% WP at concentrations of 250, 500, and 750 ppm exhibited compatibility with *T. asperellum*, allowing substantial growth of the isolate across all concentrations, thereby indicating their safe use in integrated disease management strategies where *Trichoderma* is employed as a biocontrol agent. Similarly, Thiram 75% WP and the combination formulation of Thiram 37.5% + Carboxin 37.5% 75 WS at lower (50 ppm) and higher concentrations (100 and 200 ppm) were also found to be compatible, suggesting that seed treatments or soil applications involving these fungicides may not negatively affect the establishment and activity of *T. asperellum* in the field.

Conversely, Carbendazim 50% WP, Carbendazim 12% + Mancozeb 63% WP, Hexaconazole 5% SC, and Tebuconazole 25.9% w/w EC were observed to be incompatible with *T. asperellum* at all tested concentrations. The fungicides in this group resulted in significant inhibition of the radial mycelial growth of *T. asperellum*, as depicted in Table 1 and Plate 1, indicating that these fungicides suppress the growth of the biocontrol agent, which could limit its field effectiveness if used simultaneously or in close succession with *Trichoderma* applications.

Furthermore, a clear dose-dependent trend was noted, wherein an increase in fungicide concentration corresponded with increased inhibition of mycelial growth of *T. asperellum* across most fungicides, underlining the concentration sensitivity of *Trichoderma* to chemical fungicides. These findings underscore the importance of careful selection of compatible fungicides while integrating *Trichoderma* in disease management programs to avoid antagonism between chemical control and biological control measures.

Overall, the study provides critical insights for the development of integrated disease management practices, emphasizing that Metalaxyl, Mancozeb, Copper oxychloride, and Thiram-based fungicides can be safely used in combination with *T. asperellum*, while caution should be exercised with Carbendazim, Carbendazim + Mancozeb, Hexaconazole, and Tebuconazole to prevent potential suppression of biocontrol activity in the field.

**Discussion**

The present investigation revealed that among the nine fungicides tested for compatibility with *Trichoderma asperellum*, Metalaxyl 35% SD and Mancozeb 75% WP at 250, 500, and 750 ppm exhibited high compatibility, showing colony diameters of 90.00, 44.67, 23.00 mm and 90.00, 80.00, 20.33 mm, respectively. Thiram 75% WP at 50, 100, and 200 ppm also showed high compatibility, maintaining colony diameters of 90.00, 78.67, and 22.00 mm, respectively, followed by Copper oxychloride 50% WP (90.00, 24.33, 15.67 mm) and Thiram 37.5% + Carboxin 37.5% 75 WS (90.00, 23.67, 21.00 mm). The results clearly indicated that the mycelial growth of *T. asperellum* decreased with an increase in the concentration of fungicides, emphasizing a concentration-dependent relationship.

These findings are in agreement with earlier studies where compatibility of *Trichoderma* with Mancozeb and Copper oxychloride was reported (Bagwan, 2010; Ranganathaswamy et al., 2012). Recently, Sumiya et al. (2024) reported the compatibility of Mancozeb with *Trichoderma* spp., supporting the present results. The compatibility of Thiram and Thiram + Carboxin with *T. asperellum* found in this study is consistent with the observations of Rajesh et al. (2023), further strengthening the practical feasibility of using these fungicides in combination with *Trichoderma* in integrated disease management. In contrast, the systemic fungicides Carbendazim 50% WP, Carbendazim 12% + Mancozeb 63% WP, Tebuconazole 25.9% w/w EC, and Hexaconazole 5% SC exhibited complete incompatibility at all tested concentrations, leading to substantial suppression of *T. asperellum* growth. These findings corroborate the results reported by Bindu et al. (2011), Maheshwary (2020), and Khore et al. (2025), where the inhibitory effects of Tebuconazole and Carbendazim on *Trichoderma* growth were well documented. The incompatibility of Carbendazim + Mancozeb with *Trichoderma* as observed in this study aligns with the observations made by Maheshwary (2020).

Interestingly, Dinkwar et al. (2023) found that *Trichoderma* was highly compatible with Vitavax (Carboxin 37.5% + Thiram 37.5% DS), aligning with our findings regarding the compatibility of Thiram + Carboxin with *T. asperellum*. Further, recent studies by Patil et al. (2024) have emphasized the practical integration of *Trichoderma* with compatible fungicides, indicating enhanced field-level biocontrol efficacy without compromising the effectiveness of chemical control in managing soil-borne pathogens. Additionally, Sharma et al. (2025) reported the safe use of contact fungicides like Mancozeb and Copper oxychloride in seed and soil treatment with *Trichoderma* spp., highlighting their non-inhibitory nature and potential to support early colonization of the biocontrol agent in the rhizosphere. Moreover, Kumar et al. (2025) have recently documented that the use of compatible fungicides with *Trichoderma* not only supports its establishment but also aids in reducing the pathogen load in the soil, thereby improving plant health and yield in integrated disease management frameworks.

Overall, the present study demonstrates that *Trichoderma asperellum* can be effectively integrated with non-systemic contact fungicides like Mancozeb, Copper oxychloride, and Thiram formulations, providing a sustainable and eco-friendly approach for the management of soil-borne pathogens. However, caution should be exercised while using systemic fungicides like Carbendazim and Tebuconazole, which may suppress the growth and activity of *Trichoderma*, thereby limiting its biocontrol potential in field applications.

**Conclusion**

Present investigation demonstrated that out of the nine fungicides tested, Metalaxyl 35% SD, Mancozeb 75% WP, Thiram 75% WP, Thiram + Carboxin 75 WS, and Copper oxychloride 50% WP were found to be compatible with *Trichoderma asperellum* at different tested concentrations. The findings highlight the potential for integrating *T. asperellum*, a promising biocontrol agent, with these non-systemic, contact fungicides for the effective management of *Sclerotium rolfsii*, the causal agent of collar rot in chickpea and other crops. The compatibility observed with these fungicides ensures that the application of *T. asperellum* alongside these chemicals will not hinder its growth and colonization in the rhizosphere, allowing it to express its antagonistic potential through mechanisms like mycoparasitism, competition, and antibiosis.

This study confirms the dual advantage of employing *T. asperellum* in an integrated disease management framework, where it can work synergistically with compatible fungicides to reduce pathogen load while minimizing chemical fungicide dependence. The incompatibility of systemic fungicides like Carbendazim, Tebuconazole, and Hexaconazole with *T. asperellum* observed in the study also underlines the need for careful selection and scheduling of fungicides to avoid compromising the activity of biocontrol agents in the field.

However, while the *in vitro* findings of compatibility are promising, further field-based validation under diverse agro-climatic conditions and cropping systems is essential to confirm the efficacy and consistency of *T. asperellum* when used in combination with these compatible fungicides. Such studies will help develop robust integrated management modules for collar rot and other soil-borne diseases, supporting sustainable and environmentally friendly plant disease management strategies that safeguard crop health while reducing the adverse impacts of chemical pesticides.

**Ethical Approval**

This study did not involve any human participants or animal experimentation. The research was conducted under laboratory conditions following standard microbiological and plant pathology procedures, and thus, ethical approval was not required.

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| --- | --- | --- | --- | --- |
|  | **Treatment** | **Concentration** | **Mycelial Growth\* (mm)** | **Percent Inhibition\* (%)** |
| T1 | Metalaxyl 35 SD |  250 | 90.00  | 0.00(0.00)\*\* |
| 500 | 44.67 | 50.37(45.21) |
| 750 | 23.00 | 74.44(59.63) |
| T2 | Carbendazim 50 WP | 50 | 0.00 | 100(90.00) |
| 100 | 0.00 | 100(90.00) |
| 150 | 0.00 | 100(90.00) |
| T3 | Mancozeb 75 WP | 250 | 90.00 | 0.00(0.00) |
| 500 | 80.00 | 11.11(19.47) |
| 750 | 20.33 | 77.40(61.62) |
| T4 | Thiram 75 WP | 50 | 90.00 | 0.00(0.00) |
| 100 | 78.67 | 12.59(20.78) |
| 200 | 22.00 | 75.56(60.36) |
| T5 | Carbendazim (12%) + Mancozeb (63%) 75 WP | 50 | 0.00 | 100(90.00) |
| 100 | 0.00 | 100(90.00) |
| 200 | 0.00 | 100(90.00) |
| T6 | Thiram 37.5% + Carboxin 37.5% 75WS | 50 | 90.00 | 0.00(0.00) |
| 100 | 23.67 | 73.70(59.14) |
| 200 | 21.00 | 76.66(61.11) |
| T7 | Copper oxychloride 50 WP | 250 | 90.00 | 0.00(0.00) |
| 500 | 24.33 | 72.96(58.66) |
| 750 | 15.67 | 82.59(65.34) |
| T8 | Hexaconazole 5 SC | 25 | 0.00 | 100(90.00) |
| 50 | 0.00 | 100(90.00) |
| 100 | 0.00 | 100(90.00) |
| T9 | Tebuconazole 25.9% w/w EC | 25 | 0.00 | 100(90.00) |
| 50 | 0.00 | 100(90.00) |
| 100 | 0.00 | 100(90.00) |
| T10 | Control | - | 90.00 | 0.00(0.00) |
|  | S Em± |  0.408  |
|  | CD at 0.05 |  1.16  |

**Table 1-** **Compatibility of antagonist Trichoderma isolate with fungicides under *in vitro* condition**

\*Average of three replications, \*\*Figures in parentheses are Arc sine transformed values.

**Plate 1 - Compatibility of different fungicides with *Trichoderma* *asperellum***