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Research Article

Optimising Bio-Fortified Compost for Effective Suppression of Soil-Borne Diseases and Boosting Tomato Yield

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Abstract

Soil-borne fungal pathogens are a major constraint in tomato cultivation, often causing severe yield losses. This study aimed to optimise the dosage of Trichoderma-fortified compost (*TFC*) as an eco-friendly strategy for disease management and growth promotion. The antagonistic potential of *Trichoderma harzianum* isolate PABT-22 (*TP-22*) was validated *in vitro*, showing >90% inhibition against *Fusarium oxysporum* f. sp. *lycopersici* (*Fo*), *Sclerotium rolfsii* (*Sr*), and *Rhizoctonia solani* (*Rs*). The most effective isolate was incorporated into poultry manure compost and tested in field experiments with eight treatments, including five *TFC* dosages (100–500 g per 6 m^2 plot). All *TFC* treatments significantly improved plant growth compared with controls, with the greatest benefits recorded in T_8 (500 g per plot ≈ 833 kg ha^{-1}). In T_8 plots, disease incidence was reduced to 12.5% for Fusarium wilt and southern blight and 14.0% for Rhizoctonia root rot, compared with high incidence in pathogen-only controls. Yield increased by 27.3% (*Fo*), 29.6% (*Sr*), and 29.1% (*Rs*) under T_8. These results confirm that a standardised dose of 500 g *TFC* per plot provides effective pathogen suppression and substantial yield, supporting its adoption as a low-cost, sustainable solution for tomato production.

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1. Introduction

Tomato (*Solanum lycopersicum* L.), a widely cultivated vegetable crop, belongs to the solanaceae family. Its global popularity continues to rise due to its diverse uses, including fresh consumption, processing into sauces, juices, and as a flavor enhancer in various food products. Despite a gradual increase in cultivated area and production in Bangladesh, tomato productivity remains low at 6.46 t/ha, significantly below the global average of 26.29 t/ha (FAOSTAT, 2021). Several factors contribute to this low productivity, with soil-borne diseases being among the most critical constraints. Tomato plants are highly susceptible to soil-borne pathogens such as *Sr*, *Rs*, *Fo*, and *Pythium* spp., which affect seedlings and mature plants in the field. The initial symptom is often a yellowing of the plant, followed by vascular blockage that disrupts nutrient and water transport. Infected seedlings develop black discolouration or rot at the collar region of the stem, which extends to the roots. In advanced stages, affected plants exhibit wilting, drying, and ultimately death. The pathogen identification is based on characteristic symptoms; *Fo* produces cotton-like mycelia at the infection site, *Sr* develops white mycelia with mustard seed-like sclerotia, while *Rs* presents dark brown to blackish sclerotia. The transmission of these pathogens varies; *Sr* and *Rs* spread through mycelia and sclerotia, while *Fo* disperses via mycelia, conidia, and chlamydospores.

To manage these diseases, chemical fungicides are widely used despite their adverse environmental and health effects. Excessive pesticide uses leads to contamination of agricultural produce, ecological imbalances, and biodiversity threats. Alternatively, *Trichoderma* spp. has emerged as a promising biocontrol agent against plant pathogens. *Trichoderma* species employ multiple antagonistic mechanisms, including mycoparasitism, antibiosis, resource competition, and induction of plant defense responses. Several studies (Nitu et al., 2016; Rubayet & Bhuiyan, 2023) have demonstrated that *TFC* effectively reduces tomato diseases while enhancing yield. One major limitation of *T. harzianum* application is the lack of a standardised method for its multiplication and field application. Developing an efficient mass production technique would enable farmers to adopt Trichoderma-based biocontrol methods effectively. This research aimed to standardise the optimal dose of *TFC* for managing soil-borne diseases, promoting plant growth, and improving tomato yield while evaluating *Trichoderma* population dynamics in field conditions. These mechanisms such as competition, antibiosis, and induced systemic resistance likely explain the reduced incidence observed.

2. Materials and Methods

2.1 Isolation of Trichoderma spp. and pathogens

Trichoderma isolates were collected from vegetable fields at Gazipur Agricultural University and the Bangladesh Agricultural Research Institute. The isolates were obtained using the standard soil dilution plate and the root washing method. A total of 100 *T. harzianum* isolates were identified using standard morphological keys (Barnett & Hunter, 1972). Pathogenic isolates of *Sr* 2, *Rs* 13, and *Fo* 7 were sourced from the Plant Pathology laboratory stock culture at Gazipur Agricultural University. The specific isolate used was *T. harzianum* PABT-22, collected from tomato rhizosphere soil.

2.2 In vitro screening of Trichoderma isolates

The antagonistic activity of *Trichoderma* isolates against the test pathogens was evaluated on PDA medium using standard dual culture techniques (Bell et al., 1982; Sundar et al., 1995). Based on these screenings, *TP* 22 was selected for further study.

2.5 Preparation of TFC

Compost was prepared using poultry refuse (40 kg per pit) in six designated pits (1.0m × 1.0m × 1.5m). The decomposed poultry refuse was inoculated with wheat grain-colonised *Trichoderma* inoculum at five different concentrations (4, 6, 8, 10, and 12%). A control pit was maintained without *Trichoderma* inoculum. The compost was covered with polythene sheets for 45 days to ensure proper decomposition and *Trichoderma* proliferation.

2.6 Field experiment and treatment application

A randomized complete block design (RCBD) with three replications was implemented, using 2m × 3m plots. Healthy tomato seedlings from the Horticulture Research Centre (BARI) were transplanted with a spacing of 70 cm between plants and 90 cm between rows. Test pathogens were introduced into designated plots, followed by the application of *TFC* at varying doses. The trial included three replications per treatment with 10 plants per plot.

2.7 Observations

Disease incidence was recorded at different growth stages (30, 55, 85, 105, and 120 days after transplanting) based on characteristic symptoms (Shamshiri et al., 2018). Growth parameters, including plant height, number of leaves, fresh/dry shoot weight, and root weight, were recorded. Yield was assessed at harvest, and percentage increases were calculated relative to the control.

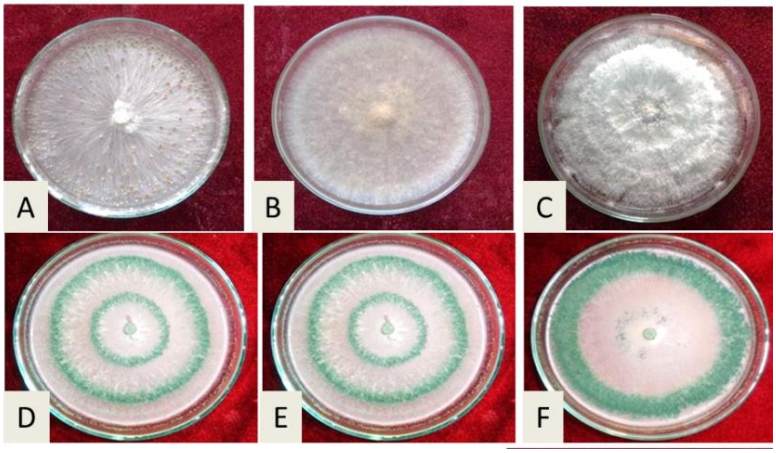
2.8 Data analysis

Data were analysed using ANOVA (STATISTIX 10) and means separated by Duncan's Multiple Range Test (DMRT) at α=0.05.

3. Results

3.1 Screening of Trichoderma spp. against the selected test pathogens

Several isolates of *T. harzianum* demonstrated antagonistic effects against the tested soil-borne pathogens in vitro (Figure 1 and Tables 1-3). All tested isolates exhibited antagonism above 55%, corresponding to Bell's Scale 3 or higher against the three pathogens. Three isolates such as, BU 7, PABT 22, and PABT 24 were identified as highly antagonistic, ranking as Bell's Scale 1 against all tested pathogens (Table 1). Against *Fo*, 35 isolates were categorised in Bell's Scale 2, while 60 isolates were classified under Bell's Scale 3 (Table 1). Similarly, against *Rs*, 60 isolates were placed in Bell's Scale 2, and 37 in Bell's Scale 3. For *Sr*, 8 isolates were grouped into Bell's Scale 2, and 85 into Bell's Scale 3. Only four isolates, ComT-14, GAZT-53, GBRT-4, and GBRT-31 were classified under Bell's Scale 4 for *Sr*, while no isolates fell into Bell's Scale 4 for *Fo* and *Rs*. The antagonistic activity of the stock culture isolates was consistent with observations reported by Salam (2017). Based on these results, the PABT 22 isolate was selected for using in field experiments.



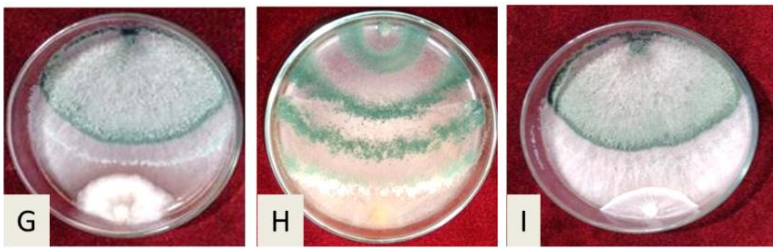


Figure 1. Dual culture of the virulent pathogenic isolates with highly antagonist T. harzianum isolates. Virulent pathogen isolates were A) Sr; B) Rs; and C) Fo. Three highly antagonist T. harzianum isolates, such as D) PABT 22; E) PABT 24; F) BU 7. Antagonism of selected pathogen and TP 22, such as G) Sr vs TP 22; H) Rs vs TP 22; and I) Fo vs TP 22.

Table 1. Antagonism of Trichoderma isolates Fo, Sr, and Rs following dual Plate culture technique on PDA

Name of the pathogen	Antagonism Bell's Scale	No.	*Trichoderma* isolates
F. oxysporum f. sp. *lycopersici*	1	3	BU 7, PABT-22, PABT-24
	2	35	BU 1, BU 2, BU 6, BU 8, BU 9, BI 1, BI 2, BI 3, BBUT- 70, GAZT-55, PABT-16, BBUT-77, COMT-6, BBUT-78, GAZT-54, BBUT-89, PABT-18, GAZT-41, BBUT-69, BBUT-73, BBUT-72, GAZT-51, Ran 9, BBUT-91, GAZT-56, BBUT-83, PABT-31, BBUT-84, BBUT-76, NOAT-63, GAZT-42, BBUT-74, COMT-8, PABT-29, PABT-34
	3	62	BI 4, BI 5, BI 6, BI 7, BI 8, BI 9, BI 10, BU 3, BU 4, BU 5, BU 10, COMT-5, GAZT-58, PABT-19, GAZT-53, GAZT-49, COMT-3, BBUT-75, Syl 06, Jes 2, Far 6, AZT- 45, GAZT-59, GAZT-38, PABT-27, PABT-28, GAZT-50, COMT-14, Far 4, BBUT-81, Raj 9, NOAT-61, GAZT- 40, COMT-12, PABT-32, COMT-9, GBRT-31, Din 4, BBUT-68, PABT-23 , COMT-13, GAZT-48, COMT-1, COMT-11, PABT-33, Ran 8, GAZT-60, PABT-25, Syl 07, BBUT-79, COMT-2, BBUT-71, PABT-26, GAZT-46, BBUT-80, COMT-10, BBUT-86, BBUT-88, BBUT-66, JES 10, GAZT-43, BBUT-85,
	4		
	5		
Rhizoctonia solani	1	3	BU 7, PABT-22, PABT-24
	2	60	BI 1, BI 2, BI 3, BI 4, BI 5, BI 6, BI 10, BU 1, BU 2, BU 6, BU 8, BU 9, BBUT-83, PABT-23, Raj 9, BBUT-80, BBUT-87, PABT-16, PABT-19, PABT-27, GAZT-60, GAZT-51, COMT-12, PABT-18, PABT-25, PABT-26, GAZT-58, BBUT-82, BBUT-85, , COMT 70, COMT-14, SYL 07, GAZT-41, NOAT-63, COMT-13, GAZT-59, Far 4, Ran 9, PABT-33, GAZT-38, GAZT-55, PABT-32, PABT-34, GAZT-42, BBUT-88, PABT-31, GAZT-56, Ran 8, GAZT-39, GAZT-50, COMT-6, GAZT-45, NOAT-61 COMT-8, BBUT-76, Din 4, COMT-9, JES 10, GAZT-43, BBUT-74
	3	37	BI 7, BI 8, BI 9, BU 3, BU 4, BU 5, BU 10, SATT-65, BBUT-72, BBUT-78, BBUT-68, BBUT-81, GAZT-40, GAZT-47, GAZT-49, BBUT-71, BBUT-84, GAZT-46, PABT-28, BBUT-73, Far 6, GAZT-53, Syl 06, BBUT-75, BBUT-77, OMT-3, BBUT-66, BBUT-69, GAZT-54, GBRT-31, COMT-10, COMT-2, Jes 2, GAZT-48, COMT-11, BBUT-91, BBUT-70,

Name of the pathogen	Antagonism Bell's Scale	No.	*Trichoderma* isolates
	4		
	5		
Sclerotium rolfsii	1	3	BU 7, PABT-22, PABT-24
	2	8	BI 1, BI2, BU2, BBUT-77, COMT-13, PABT-16, PABT-24, COMT-70
	3	85	BI 3, BI 4, BI 5, BI 6, BI 7, BI 8, BI 9, BI 10, BU 1, BU 3, BU 4, BU 5, BU 6, BU 8, BU 9, BU 10, BBUT-86, COMT-12, GAZT-60, Raj 9, Ran 8. PABT-26, BBUT-75, PABT-28, COMT-6, PABT-27, PABT-33, BBUT-89, PABT-32, BBUT-83, BBUT-85, Far 4, BBUT-88, Far 6, Ran 9, PABT-18, COMT-8, PABT-23, PABT-25, GAZT-41, GAZT-56, COMT-3, COMT-9, PABT-19, Jes 10, , GAZT-50, GAZT-55, BBUT-72, BBUT-84, BBUT-74, BBUT-81, BBUT-91, GAZT-59, GAZT-40, GAZT-42, GAZT- 59, BBUT-69, BBUT-78, GAZT-58, BBUT-80, COMT-2, GAZT-45, GAZT-43, NOAT-61, BBUT-68, BBUT-79, Din 4, GAZT-49, BBUT-73, GAZT-38, SATT-65, BBUT-66, , BBUT- 71, Jes 2, GAZT-46, GAZT-48, GAZT-51, COMT-1, COMT-5, Syl 07, GAZT-54, COMT-10, Syl 06, COMT-11, GAZT-57
	4	4	COMT-14, GAZT-53, GBRT-4, GBRT-31
	5		

Seedling mortality of tomato by different pathogens: Significant variation was recorded in the % seedling mortality at different doses of *TP 22* fortified compost. The highest seedling mortality (35.8, 35.5 and 16.7% for *Fo, Rs,* and *Sr*, respectively) was observed in Control 2 (artificial pathogen inoculated plot). Whereas the lowest seedling mortality (8.4, 8.3 and 6.5% for *Fo, Rs,* and *Sr*, respectively) was recorded in the treatment T_8 (Figure 2). Interestingly, similar seedling mortality was recorded for T_7 applied plots where *Rs,* and *Sr*, respectively were artificially inoculated. However, this dose was not effective in the *Fo* applied plot. Minimum mortality was also observed in the treatment T_7 where 400 g wheat grain colonized *TFC* was applied. In the treatment T_3 and T_4 where only poultry refused and only 200 g wheat grain colonized *Trichoderma* were applied seedling mortality was also abruptly low in comparison to control 2. The highest dose of *TFC* in the treatment T_8 was significantly superior in controlling seedling mortality caused by all the pathogens. Similar observations were also recorded by Rahman et al. (2024).

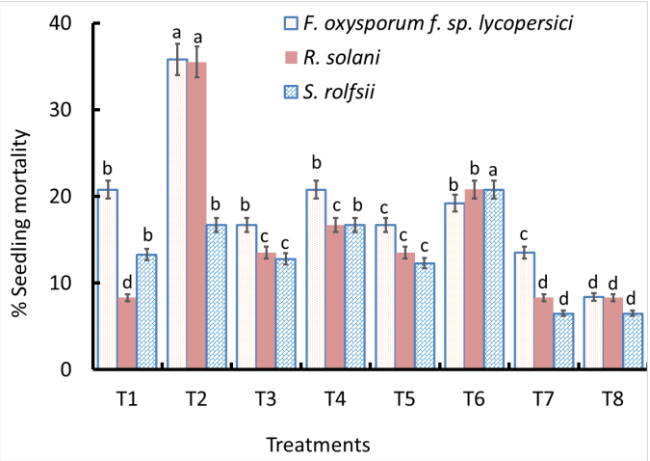


Figure 2. Percent seedling mortality at different of TFC applied field after artificial inoculation of three specific soil-born pathogen

Disease incidence: Different *TFC* significantly reduced the selected three disease incidences (Collar rot and southern blight, Rhizoctonia dry root rot, Fusarium wilt) compared to Control 2 (Figure 3A). Therefore, the % reduction of those selected diseases over Control 2 also significantly varied accordingly (Figure 3B). The lowest collar rot and southern blight incidence (12.5%) was recorded from T_8 and T_7 applied plots. The highest disease incidence (58.3%) was recorded in an artificially inoculated plot (T2). Whereas the disease incidence of the naturally infected plots (T_1 and T_3) was significantly lower (37.5 and 29.2%, respectively) than the T_2 plot. The T_6 also reduced the disease incidence (16.7%) compared to all three controls (29.2 to 58.3%) but was statistically higher than T_7 and T_8. The collar rot and southern blight incidence in T_5 (29.2%) was statistically like the naturally infected control. Whereas the T_4 (54.2%) did not reduce the specific disease symptoms compared to the other fortified composts (Figure 3C).

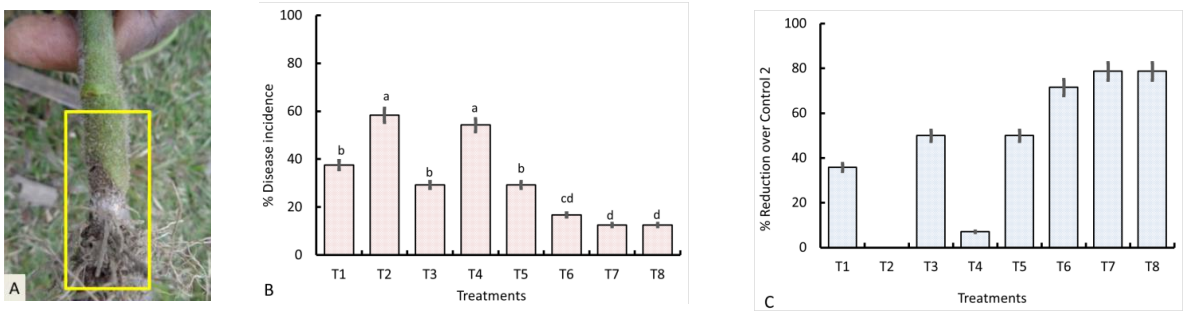


Figure 3. Effect of different TFC on collar rot and southern blight incidence in an artificially Sr inoculated plot. A) Collar rot and southern blight symptom in the experimental field, B) Collar rot and southern blight incidence of different plot and, C) %reduction of collar rot and southern blight symptom over artificially Sr inoculated control plot T_2. Note, T_2= artificially Sr inoculated plot, T_1=Naturally infected plot, and T_3= Naturally infected and TFC applied plot

Similarly, three doses of *TFC* reduced Rhizoctonia dry root rot incidences compared to the controls (Figure 4A). The lowest disease incidence (16.7%) was recorded from T_8 plot. The disease incidence recorded from T_6 and T_7 (20.8 and 25.0%, respectively) was also lower compared to the controls and it is statistically similar with the former plot. All the three control plots provided higher disease incidence (37.5 to 50.8%), of which the highest incidence was recorded from the artificially inoculated plot (50.8%) (Figure 4B). Likewise, the highest % of Rhizoctonia dry root rot control of T_2 was also recorded from the T_8 plot. Data was recorded for all the test pathogens in the treatment T_8 where 500 g wheat grain colonised *TFC* was applied in the pathogen-inoculated field.

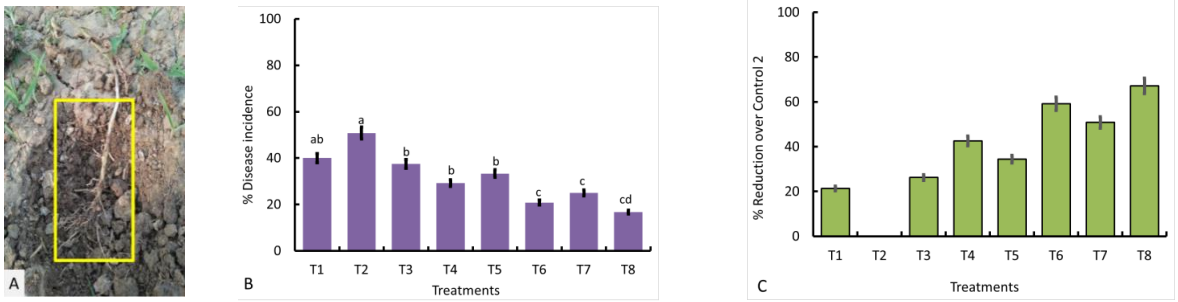


Figure 4. Effect of different TFC on Rhizoctonia dry root rot incidence in an artificially R. solani inoculated plot. A) Rhizoctonia dry root rot symptom in the experimental field, B) Rhizoctonia dry root rot incidence of different plot and, C) %reduction of Rhizoctonia dry root rot symptom over artificially Rs inoculated control plot T_2. Note, T_2= artificially Rs inoculated plot, T_1=Naturally infected plot, and T_3= Naturally infected and TFC applied plot

In the experiment with *Sr* inoculation, treatment T_8, where 500 g of wheat grain colonised with *TFC* was applied, showed the greatest effectiveness in minimising sclerotial diseases. The incidence of collar rot, southern blight, and sclerotial rot on tomato plants was significantly reduced in treatments T_1, T_3, and T_5, which were on par with each other. These treatments outperformed T_6, where 300 g of wheat grain colonised *TFC* was applied. On the other hand, treatment T_4, which consisted solely of wheat grain and *Sr*, did not demonstrate any notable effect in reducing these sclerotial diseases and showed similar results to Control 2. This pattern was consistent in the other two experiments, where only *Rs* and *Fo* were used as pathogen inoculants in Control 2. In the *Rs* inoculated experiment, the most significant reduction in Rhizoctonia dry root rot (67.1%) was seen in T_8. T_6 and T_7 treatments showed similar disease reduction, both significantly more effective than treatments T_1, T_3, T_4, and T_5. Disease incidence was consistently lower in all treated plots compared to Control 2 (which was inoculated with only *R. solani*).

A similar trend was observed in the Fusarium wilt experiment. The lowest disease incidence (12.5%) occurred in the T8 treatment. In contrast, Control 2 (inoculated only with *Fo*) showed the highest Fusarium wilt incidence (54.2%). Treatment T_1 had a 33.3% disease incidence. Interestingly, *TFC* applied in T_1 also exhibited lower disease incidence (20.8%) compared to Control 2. While treatments T_4, T_5, T_6, and T_7 reduced Fusarium wilt compared to Control 2, they were not significantly different from T_1 and T_3. The highest reduction in Fusarium wilt was recorded in T_8 (76.9%) and T3 (61.6%).

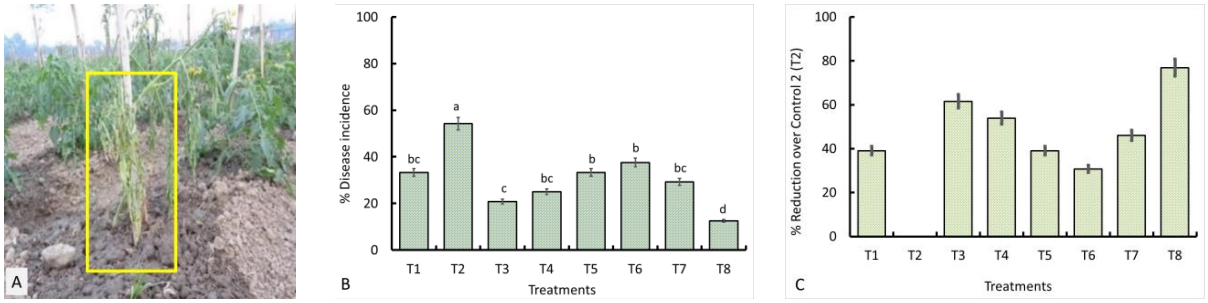


Figure 5. Effect of different TFC on Fusarium wilt incidence in an artificially Fo inoculated plot. A) Fusarium wilt symptom in the experimental field, B) Fusarium wilt incidence of different plot and, C) %reduction of Fusarium wilt symptom over artificially Fo inoculated control plot T_2. Note, T_2= artificially Rs inoculated plot, T_1=Naturally infected plot, and T_3= Naturally infected and TFC applied plot

Figure 6. Sclerotium fruit rot of disease tomato (middle) and Sr infected tomato fruits at soil level (Right) in the field

In the field inoculated with *Fo*, all treatments showed a significant improvement in growth parameters compared to the untreated controls (T_1 and T_2). The greatest increase in all recorded growth parameters, including plant height (cm), number of branches, number of leaves, fresh shoot weight (g), dry shoot weight (g), fresh root weight (g), and dry root weight (g), was observed in treatment T_8. This treatment involved the highest amount of wheat grain colonised with *Trichoderma* mixed into the compost. Treatments T_6 and T_7, where 300 g and 400 g of *TFC* were applied, showed similar results. The growth parameters for treatments T_1, T_3, T_4, and T_5 were comparable, with most parameters showing significant improvement compared to Control 2, which was inoculated with only the pathogen (Table 2).

Table 2. Effect of (TFC) on growth parameters of tomato for Fo inoculated field

Treatments	Plant height (cm)	No.of branch	No.of leaf	Fresh Shoot wt. (g)	Dry Shoot wt. (g)	Fresh Root wt. (g)	Dry Root wt. (g)
T_1	21 c	13.1 c	5.67 bc	290.2 c	92.4 bc	39.2 c	10.1 bc
T_2	17 d	11.2 d	5.43 c	227.9 d	85.2 c	32.12 d	8.1 d
T_3	20.1 bc	14.2 bc	6.1 ab	306.7 bc	93.2 b	41.2 bc	9.9 c
T_4	22.5 bc	16.3 ab	6.34 ab	333.6 bc	96.9 ab	44.1 b	10.2 bc
T_5	24.2 b	15.9 bc	5.9 b	342.8 b	98.1 ab	43.2 bc	10.3 bc
T_6	26.1 ab	17.4 ab	6.1 ab	352.9 ab	104.2 ab	47.5 ab	11.8 ab
T_7	27.9 ab	19.4 a	6.2 ab	359.6 a	105.1 a	49.2 a	12.6 a
T_8	30.2 a	19.8 a	6.9 a	358.9 a	106.7 a	50.2 a	12.8 a

In the *Rs* inoculated field (Table 3), similar results to those observed in the *Fo* and *Sr* inoculated fields were found. All treatments significantly improved growth parameters compared to the untreated controls (T_1 and T_2). The highest increases in growth parameters, including plant height (cm), number of branches, fresh shoot weight (g), dry shoot weight (g), fresh root weight (g), and dry root weight (g), were observed in treatment T_8, which involved the highest amount of wheat grain colonized with *Trichoderma* mixed into the compost. Treatments T_7, T_6, T_5, T_4, and T_3 also showed similar improvements in growth parameters. Control 2 (T_2) exhibited the lowest plant growth parameters when compared to all other treatments.

Table 3. Effect of Trichoderma fortified compost on growth parameters of tomato for Rhizoctonia inoculated field

Treatments	Plant height (cm)	No.of branch	No.of leaf	Fresh Shoot wt.(g)	Dry Shoot wt.(g)	Fresh Root wt.(g)	Dry Root wt.(g)
T_1	19.1 bc	12.4 c	5.12 c	299.6 c	91.3 c	37.3 c	7.2 c
T_2	18 c	12.1 d	6.1 b	244.6 d	89.2 d	34.7 d	6.9 d
T_3	21.9 bc	15.6 bc	5.9 bc	309.5 bc	93.01 bc	40.7 bc	9.7 bc
T_4	23.9 b	16.4 bc	6.9 a	331.2 bc	97.1 bc	45.1 b	9.8 bc
T_5	24.1 b	17.6 ab	6.7 a	345.4 ab	98.3 ab	44.4 bc	11.3 ab
T_6	26.4 ab	18.7 ab	6.2 ab	337.2 ab	98.2 ab	47.3 ab	11.2 ab
T_7	26.9 ab	19.7 a	5.8 d	370.2 a	108.1 a	49.3 ab	11.6 a
T_8	29.1 a	20.4 a	6.3 ab	372.4 a	108.6 a	57.8 a	11.1 ab

In the *Sr* inoculated field (Table 4), all treatments significantly improved growth parameters compared to the untreated controls (T_1 and T_2). The greatest increases in growth parameters, including plant height (cm), number of branches, fresh shoot weight (g), dry shoot weight (g), fresh

root weight (g), and dry root weight (g), were recorded in treatment T_8, where the highest amount of wheat grain colonized with *Trichoderma* was incorporated into the compost. Treatments T_7, T_6, T_5, and T_4 showed similar improvements in growth parameters. Control 2 (T_2) exhibited the lowest growth parameters for most traits, except for plant height, where T_2 showed slightly higher values than some treatments. Treatment T_1 had the lowest plant height compared to all other treatments.

Table 4. Effect of Trichoderma fortified compost on growth parameters of tomato for S. rolfsii inoculated field

Treatments	Plant height (cm)	No.of branch	No.of leaf	Fresh Shoot wt.(g)	Dry Shoot wt.(g)	Fresh Root wt.(g)	Dry Root wt.(g)
T_1	20.1 d	11.9 c	4.81 bc	295.3 c	93.7 c	38.6 c	8.2 c
T_2	21 c	11.4 d	4.34 c	248.4 d	87.4 d	30.2 d	7.2 d
T_3	22.4 bc	15.1 bc	6.3 ab	308.1 bc	92.6 c	40.8 bc	8.7 bc
T_4	24.3 ab	16 b	6.34 a	301.4 bc	95.9 bc	43.2 b	10.6 b
T_5	23.9 b	17.2 ab	6.2 ab	344.9 ab	99.9 bc	45.3 ab	11.1 ab
T_6	25.8 ab	18.3 ab	6.3 ab	354.7 ab	104.2 ab	43.4 b	10.8 ab
T_7	28.8 a	19.6 a	6.2 ab	363.4 a	106.7 a	50.7 a	12.1 a
T_8	30.8 a	19.8 a	5.99 b	367.4 a	107.2 a	51.6 a	11.7 a

3.2 Harvesting and yield

Tomatoes were harvested at four different times based on their maturity. After harvesting, fruit size and weight were used to grade the tomatoes and compare the different treatments. The total weight of fruits from each treatment was recorded to assess the overall yield. Based on the disease management and total yield, the optimal dose of *TFC* was determined. In general, all treatments in the three experiments resulted in increased tomato yields. The highest yield increase was observed in treatment T8, which used 500 g of wheat grain colonised *TFC* (Figure 7). The yield increased as the amount of Trichoderma-colonized wheat grain mixed with poultry refuse increased.

3.3 Effect of TFC on tomato yield

Fo inoculated field

The largest yield increase (27.27%) was observed in treatment T_8, followed by 21.40% in treatment T_7, and 18.18% in treatment T_6 (Table 5). The yield increases in treatments T_8, T_7, and T_6 were similar, but all were significantly higher compared to controls T_1 and T_2. Treatments T_7, T_6, T_5, T_4, and T_3 showed identical yield increases and were significantly higher than control treatments T_1 and T_2. The smallest yield increase (5.72%) was recorded in treatment T_1 (healthy tomato seedlings without any amendments) (Figure 7). The yield increased with the increasing amount of wheat grain colonised *Trichoderma*-fortified compost. All treatments with amendments resulted in significantly higher yields than Control 2, where only the pathogen was inoculated without any amendments.

Harvesting occurred at four different times, as tomatoes ripened at different rates. The largest quantity of tomatoes was harvested during the third harvest for all treatments. The size, uniformity, and colour of the tomatoes also varied depending on the treatment. Tomatoes grown under treatments T_8, T_7, and T_6 were larger, more uniform, and predominantly red, while those from the untreated control were smaller, with variable sizes and colours ranging from yellowish to reddish.

Table 5. Effect of (TFC) on the yield of tomato for Fusarium field

Treatments	Fruit wt. (kg) per plot				Total yield (kg/plot)	Yield (ton/ha)
	1st harvest	2nd harvest	3rd harvest	4th harvest		
T_1	6.4	11.3	13.2	9.8	40.7	67.83 c
T_2	6.1	12.4	14.2	5.8	38.5	64.16 d
T_3	8.8	14.7	16.1	5.7	43.3	72.16 bc
T_4	7.9	10.2	15.9	8.9	42.9	71.5 bc
T_5	5.2	13.2	15.2	10.3	44.2	73.6 b
T_6	5.3	13.5	16.9	9.1	45.5	75.83 ab
T_7	7.1	13.7	17.8	8	46.6	77.67 ab
T_8	7.8	16.2	16.3	8.7	49	81.67 a

3.4 R. solani inoculated field

The highest tomato yield of 84.33 tons per hectare was observed in treatment T_8, followed by 83.16 tons per hectare in treatment T_7, 75.32 tons per hectare in treatment T_6, and 74.5 tons per hectare in treatment T_5 (Table 6). The yield of tomatoes increased with the amount of *Trichoderma*-fortified compost, although no significant differences in yield were observed among treatments with increasing doses. The lowest yield increase (5.10%) was recorded in treatment T_1, which had no pathogen or amendments (Figure 7). The tomato yield increased with the increasing amount of wheat grain colonized *Trichoderma*-fortified compost. All treatments with amendments resulted in significantly higher yields compared to Control 2, where only the pathogen was inoculated without any amendments. The highest quantity of tomatoes was harvested during the third harvest for all treatments, except for treatments T_7 and T_6. The size, uniformity, and color of the tomatoes also varied depending on the treatment. Tomatoes from treatments T_8, T_7, and T_6 were larger, more uniform, and predominantly red, while tomatoes from the untreated control were smaller and showed greater variation in size and color, ranging from yellowish to reddish, like the other experiments.

Table 6. Effect of (TFC) on the yield of tomato for Rhizoctonia field

Treatments	Fruit wt. (g) per plot				Total yield (kg/plot)	Yield (ton/ha)
	1st harvest	2nd harvest	3rd harvest	4th harvest		
T_1	6.7	9.2	18.2	7.8	41.9	69.83 c
T_2	3.4	14.3	15.8	5.7	39.2	65.33 d
T_3	5.3	14.9	15.62	8.2	44.02	73.36 bc
T_4	7.7	14.3	16.2	6.1	44.3	73.83 bc
T_5	6.1	16.9	17.2	4.5	44.7	74.5 ab
T_6	8.2	17.6	13.79	5.6	45.19	75.32 ab
T_7	8.7	17.2	16.8	7.2	49.9	83.16 a
T_8	7.9	15.4	18.2	9.1	50.6	84.33 a

3.5 Sr inoculated field

The highest yield increase (29.57%) was observed in treatment T_8, followed by 26.10% in treatment T_7 and 18.40% in treatment T_6. However, the yield increases in the top three treatments were similar (Table 7). The lowest yield increase (5.35%) was recorded in control treatment T_1, although this was still significantly higher than Control 2 (treatment T_2), where only the pathogen was inoculated without any amendments (Figure 7). Tomato yield increased with the increasing dose of wheat grain colonised *TFC* though no significant differences were found among the top

three doses. In the *S. rolfsii* inoculated field, the highest yield was harvested during the third harvest for all treatments. The size, colour, and uniformity of tomatoes were like those observed in the *Fo* inoculated field.

Table 7. Effect of (TFC) on the yield of tomato for Sclerotium field

Treatments	Fruit wt. (kg) per plot				Total yield (kg/plot)	Yield (ton/ha)
	1st harvest	2nd harvest	3rd harvest	4th harvest		
T_1	7.2	8.65	18.4	6.1	40.35	67.25 c
T_2	6.2	9.2	15.4	7.5	38.3	63.83 d
T_3	5.4	14.06	15.5	7.9	42.86	71.43 bc
T_4	6.9	11.37	17.3	7.1	43.27	72.12 b
T_5	7.7	12.3	18.1	5.6	43.7	72.83 b
T_6	4.3	17.4	18.55	5.4	45.65	76.08 ab
T_7	5.1	19.1	19.8	4.3	48.3	80.5 a
T_8	7.1	17.4	18.2	6.9	49.6	82.67 a

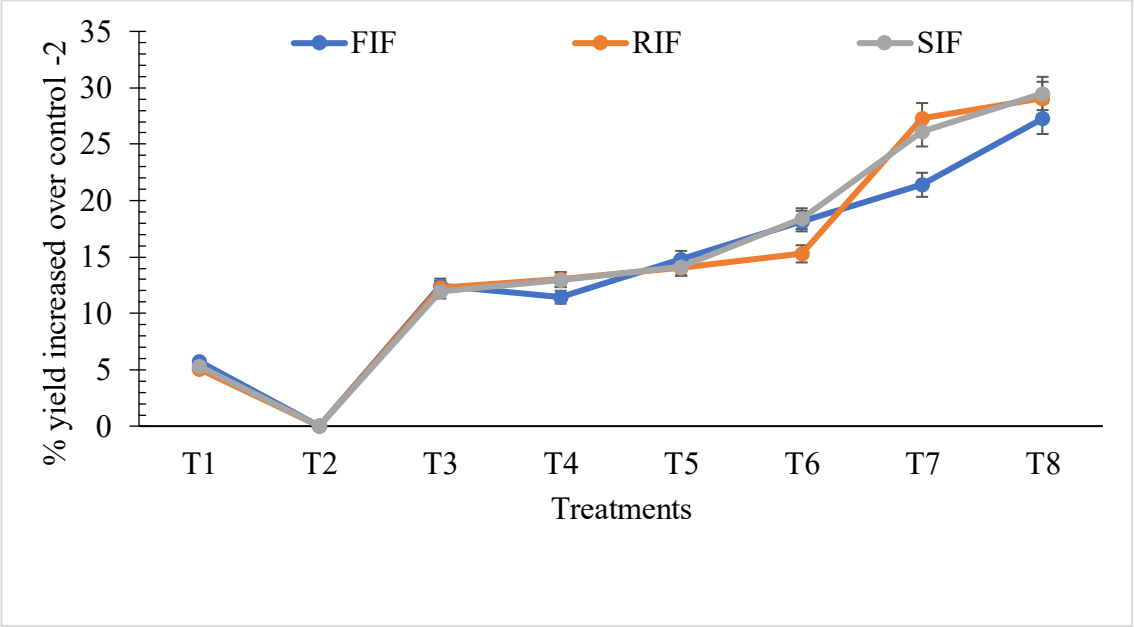


Figure 7. Impact of TFC on percent yield increased over control -2 in the test pathogens (FIF= Fusarium inoculated field, RIF= Rhizoctonia inoculated field, and SIF= Sclerotium inoculated field) inoculated fields

3.6 Discussion

The higher doses of *TFC* proved to be effective in reducing three major tomato diseases (collar rot, southern blight, Rhizoctonia dry root rot, and Fusarium wilt) in both naturally infected and artificially inoculated field conditions.

The results of this study align with Rahman et al. (2024), who found that *Trichoderma harzianum* fortified with poultry refuse significantly increased tomato yield and reduced disease incidence. In the present study, the application of wheat grain alone in the pathogen-inoculated fields, without any compost or *Trichoderma*, also contributed to a notable reduction in disease incidence and increased tomato yield. This could be attributed to improved soil structure and fertility, as wheat grain decomposition acts as an organic amendment, like other organic inputs, which can

reduce the incidence of soil-borne diseases. The application of composts, particularly poultry manure, has been well established as an effective organic amendment to improve soil health and suppress diseases caused by soil-borne pathogens. *Trichoderma* thrives in such composts, enhancing microbial activity and providing a sustainable means for biocontrol. Hoitink and Boehm (2009) emphasized that compost serves as an ideal feeding medium for biocontrol agents, helping them establish and thrive in the soil, which supports long-term disease control. Salam (2017) explored the use of various composts, including poultry refuse, to suppress soil-borne diseases in tomatoes, finding that poultry refuse was particularly effective when combined with *Trichoderma harzianum*. The present study extends these findings by optimizing the dose of *Trichoderma* and developing a poultry refuse-based compost that was more effective in controlling major soil-borne tomato diseases. This study is unique in its integrated approach, as prior research mainly used composts and antagonists separately, with limited integration (Akter et al., 2016; Salam, 2017). In this study, several doses of *Trichoderma*-fortified poultry refuse compost (200, 300, 400, and 500 g per 6 m^2 plot, equivalent to 333, 500, 667, and 833 kg per hectare) were tested. The highest dose showed the most significant reduction in disease incidence and promoted better growth and yield, aligning with Rahman et al. (2024) findings, where 667 kg/ha of *Trichoderma*-fortified poultry refuse compost was most effective in reducing disease incidence. Beneficial microorganisms like *Trichoderma* produce antibiotic compounds that help control various fungal pathogens, such as *R. solani* and *S. rolfsii* (Hoitink & Boehm, 2009). However, the biocontrol mechanisms of *(TFC)* were not explored in this study, which could be a potential area for future research. The improvement in tomato growth and yield through the application of *(TFC)* supports findings from Hoitink and Keener (2013), and Salam (2017), who reported similar benefits in various vegetables after applying *Trichoderma*-enhanced compost. Additionally, composts produced from bio-solids are widely used as peat substitutes in horticulture, reducing production costs, and this approach could be applicable for sustainable crop production in Bangladesh. *Trichoderma* is commonly found in soil, making it readily available and easy to cultivate. It can be mixed with compost and marketed in a packaged form or formulated as a liquid spray for foliar diseases (Arefin et al., 2019). *Trichoderma* has a proven ability to control both seed and soil-borne fungal pathogens during crop cultivation. Recent research has also highlighted that the effectiveness of *Trichoderma* in the field depends not only on the strain and dose, but also on the mode of application and the resulting shifts in the rhizosphere microbiome. Bandara and Kang (2024) reported that while post-transplant application of *T. virens* resulted in the highest rhizosphere colonisation, at-transplant application most effectively promoted tomato growth and enhanced soil suppressiveness against *F. oxysporum* pathogens. They further demonstrated that volatile compounds produced by rhizosphere microbes and metabolites extracted from soils after at-transplant treatments significantly suppressed pathogen growth and spore germination. These findings suggest that microbiome-mediated mechanisms contribute to the disease-suppressive effects of *Trichoderma* and that application timing can be critical for maximising benefits. Our results, which confirm that an optimised dose of *T. harzianum*–fortified compost (*TFC*) suppressed multiple pathogens and improved yield, complement these insights by demonstrating that dose standardisation also plays a decisive role. Together, these studies underscore that both the application method and the dose of *Trichoderma*-based formulations should be considered when designing reliable, farmer-friendly strategies for sustainable tomato production.

4. Conclusions

This study demonstrated that Trichoderma-fortified compost (*TFC*) is an effective and eco-friendly strategy for managing soil-borne diseases in tomato while enhancing plant growth and yield. The optimised dose of 500 g per 6 m^2 plot (≈833 kg ha^{-1}) of *T. harzianum* isolate PABT-22 consistently reduced disease incidence to 12.5–14.0% and increased yield by 27–30% compared with pathogen-only controls. These findings provide a standardised, residue-free alternative to

chemical fungicides, supporting sustainable and organic tomato production. From a practical standpoint, the adoption of *TFC* at the recommended dose offers farmers a low-cost, farmer-friendly solution for integrated disease management. Future research should focus on validating these results under multi-location and multi-season field conditions, across different tomato varieties and soil types, and with attention to rhizosphere microbiome dynamics to ensure broad applicability and long-term sustainability.

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