



Isolation of Some Pathogenic Fungi Causing Eggplant Wilt and Their Control Using *Trichoderma Harzianum* and The Effect on Production Indicators

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Abstract

In this study, four local isolates of *Trichoderma harzianum* from the fields in Hama governorate were isolated from the eggplant (*Solanum melongena* L.) in 2022. Treatments with the pathogenic fungi *R. solani* and *F. oxysporum* resulted in a sharp, significant decrease in all studied growth and production indicators. In contrast, the application of *T. harzianum* isolates resulted in a marked increase in the studied indicators, including plant dry weight, fresh and dry weight of the vegetative mass, and plant yield, compared with the untreated control. The isolate I25 achieved the most significant increase in production indicators. Treatments involving the addition of *T. harzianum* isolates in association with the pathogens *R. solani* and *F. oxysporum* showed a significant increase in the studied production indicators compared to treatments with the pathogens alone. The research results also demonstrated the effectiveness of the four local isolates in reducing fungal infection rates in the field. The isolate I25 outperformed the others in both biofertilizer and biocontrol applications.

Keywords: Biological control, Antagonism, biofertilizer, *Rhizoctonia solani*

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Introduction

Soil-borne fungi are a major cause of various plant diseases, including damping off, root rot, crown rot, vascular wilt, and others. The eggplant (*Solanum melongena* L.), an important vegetable crop, is susceptible to numerous diseases, often caused by fungi and bacteria, leading to significant yield losses. Among fungal diseases, wilt caused by *Fusarium oxysporum* and *Rhizoctonia solani* is a major constraint on eggplant production in greenhouses and fields (14, 21, 23). Soil-borne fungi are extremely difficult to control using traditional methods such as chemical pesticides, as they can survive for many years in the soil. Consequently, research efforts have increasingly shifted toward developing new biocontrol methods for safe and effective management of plant diseases (33, 4). The use

of microorganisms as biocontrol agents is important because they maintain soil microbial biodiversity. *T. harzianum* is one of the most important biocontrol agents and biofertilizers for many plants (1, 45). The induction of systemic resistance, competition with pathogens, mycoparasitism, and the production of antibiotics and fungal cell wall-degrading enzymes are among its most important mechanisms of action in biocontrol (11, 30, 45). In addition, it stimulates plant growth by facilitating the solubilization and increased availability of various nutrients in the soil (35).

Fungi of the genus *Trichoderma* produce cytokine-like molecules, such as zeatin and gibberellins (GA3) or related compounds. Controlled production of these compounds can enhance plant biofertilization and stimulate the synthesis or production of plant hormones. Most strains of *T. harzianum* alter their environment by

secreting organic acids, such as gluconic, citric, or fumaric acids (34). These acids are produced by the metabolism of other carbon sources, especially glucose, and are, in turn, capable of solubilizing phosphate, micronutrients, and metal cations, including iron, manganese, and magnesium (39). Therefore, adding *T. harzianum* to soils where these cations are scarce increases crop productivity; the poorer the soil, the greater the subsequent yield increases. *T. harzianum* also increases the sugar and phenolic content, photosynthesis and transpiration rates, and water content in plants, and primarily produces auxins that promote root growth (24).

This study aimed to enhance disease management methods and increase eggplant production by evaluating the efficacy of local isolates of *T. harzianum* in controlling eggplant wilt caused by *F. oxysporum* and *R. solani* and assessing their impact on various growth and production indicators.

Materials and Methods

The study was conducted in the laboratories of the Hama Biological Control Center, affiliated with the Syrian Ministry of Agriculture, and its associated fields during the 2022-2023 period. Field samples were collected from the soil surrounding the rhizosphere and adjacent to the roots of eggplant plants grown in a field near the city of Hama According to Table 1. The samples were placed in polyethylene bags labeled with the necessary information (date and place of collection, and the cultivated plant). They were then transported to the laboratory and dried in a shaded, well-ventilated room. After complete drying, the soil layer surrounding the roots was gently scraped off using a metal scalpel inside a plastic jar. The resulting soil was smoothed using a mortar and pestle, sieved, numbered, and stored in the refrigerator.

Table 1. Sampling Locations Coordinates in Hama Governorate.

Location Name	Sampling Site Description	Field Type	Cultivated Crop	Latitude (°N)	Longitude (°E)
Hama - Kafr Buhum Road	Agricultural lands at Al-Farra Farms, located within the first third of the main road.	Open Field	Eggplant	35.102658	36.744113
Kafr Qadah - Aqrah Road	Midpoint agricultural fields situated along the main public road between both towns.	Open Field	Eggplant	34.960200	36.481500
Al-Majdal Plains (Near Mahardah)	Agricultural fields overlooking the Hama - Mahardah highway, 4 km south of Mahardah.	Open Field	Eggplant	35.201400	36.596200

Obtaining Fungal Isolates

The *T. harzianum* isolates used in this research were previously obtained through a survey in eggplant fields in Hama (43).

Isolation of *F. oxysporum* and *R. solani* from roots

The roots of eggplants showing symptoms of infection were taken, washed with running water to remove all suspended particles and dirt on their surfaces, cut into small pieces of 1 cm length, and superficially sterilized by immersing them in a 3% sodium hypochlorite solution for two minutes. After that, they were washed twice with sterile distilled water, and the water was removed by placing them on Watman No. 1 sterile filter paper. The pieces were transferred using sterile forceps to Petri dishes containing sterile potato dextrose agar (PDA) at 130 °C for 20 minutes in an autoclave, with 4 pieces placed in each dish in three replicates.

After adding the antibiotic amoxicillin at 500 mg/L to the medium to prevent bacterial growth, the dishes were incubated at 25 ± 2 °C for 7 days (16). The isolates grown on the nutrient medium were purified using the tip hypha technique. The fungus was grown on water agar, and the tips of the fungal hyphae were captured from the medium. The isolates were cultured on PDA and identified based on their cultural characteristics and morphology, as well as by using their taxonomic keys (42).

Preparation of inoculum isolates of the pathogenic fungi *R. solani* and *F. oxysporum*

Millet seeds (*Panicum miliaceum*) were used as a medium for growing *F. oxysporum*. The seeds were soaked in water for 6 hours, filtered through a cloth to remove excess water, and transferred to 250 ml glass flasks at a rate of 50 g / flask. The flasks were autoclaved twice at 121 °C for 20 minutes. After cooling, they were inoculated with a pure colony of *F. oxysporum*

previously grown on PDA medium at 7 days of age. The flasks were incubated at 25 ± 2 °C in the dark for 10 days, with shaking every 2 days to ensure ventilation and even distribution of the inoculum (10).

A similar method was used for growing *R. solani*. The millet seeds containing the fungus were stored at 4 °C for later use in field infection. *F. oxysporum* biomass was harvested from the flasks using 100 ml of sterile deionized water containing Tween 80 (0.01% v/v). The flasks were placed on a 300-rpm shaker for 30 minutes, and the resulting product was transferred to a sterile flask by passing it through two layers of muslin to trap the remaining mycelium (5). A spore suspension of the pathogenic *F. oxysporum* was prepared at a concentration of 1×10^6 spores/ml (7) and stored at 2 °C for subsequent use in field infection. The pathogen was re-isolated from the stem-root junction, and it was confirmed that the causative agent of the infection symptoms was the same fungus.

Preparation of spore suspension of *T. harzianum* isolates

The fungal isolates were propagated by using a previously prepared and sterilized PDA nutrient medium at 121 °C for 30 minutes in an autoclave. The nutrient medium was poured into glass Petri dishes and inoculated with a 1-cm disc of pure *T. harzianum* colony. The dishes were incubated at 25 °C for 7 days. The spore suspension of the fungus was prepared by adding previously sterilized Tween 80 (0.01%, v/v) to the

surface of the fungal culture. The plate was rotated and carefully scraped with a glass pen. The product was poured into a 10 ml test tube by passing it through two layers of muslin cloth to retain mycelial remnants and separate the spores. The necessary dilutions were carried out, and the concentration of the spore suspension was adjusted to 2×10^7 spores/mL using a Neubauer chamber (25). Solid-state fermentation was carried out on a wheat grain medium in 500 mL glass flasks containing 200 g of wheat grains, which were covered with a cotton plug (Fig. 1).

The substrate moisture was adjusted to 55% by adding deionized water and sterilizing at 121°C for 30 min. After cooling, the substrate was inoculated with 25 mL of a *T. harzianum* spore suspension containing 2×10^7 CFU/mL (36). The pH was adjusted to 5.5 with 1N HCl, and the sample was incubated at 25 °C and $70 \pm 5\%$ humidity for 15 days. After the incubation period, conidia were harvested from the flasks using 50 mL of sterile deionized water containing 0.01% (v/v) Tween 80. The flasks were placed in a 300-rpm shaker for 30 mins, and the product was transferred to a sterile flask by passing it through two layers of muslin to trap mycelial remnants (5). Then, 1% carboxymethyl cellulose (CMC), 1% tween 80, and 1% gum Arabic were added to the spore suspension as spreading and adhesive agents to lower surface tensions. The concentration of the spore suspension was adjusted to 1×10^6 spores/ml using a Neubauer chamber (Figure 1) and refrigerated until use.



Figure 1. Propagation of *T. harzianum* on wheat grain (1) and adjusting the concentration of the spore suspension (2).

Evaluation of the effectiveness of *T. harzianum* isolates in controlling pathogenic fungi in the field

The experiment used the Hammoussi eggplant variety, a local variety cultivated in the central region under open-field conditions. The seeds were planted in cork seedling trays filled with humidified peat moss and incubated after planting at 25 ± 2 °C and $65 \pm 5\%$ relative humidity. After germination, they were transferred to a shaded, well-ventilated plastic house, and the necessary plant care was carried out until the fourth true leaf was formed, at which point they were ready for transfer to the permanent land. The land was prepared for planting by conducting two perpendicular plowings, followed by scattering 10000 kg/ hectare of fermented organic fertilizer (compost) and adding 5 kg of NPK mineral fertilizer. This was followed by leveling and planning the land, and installing a drip irrigation system spaced 1 meter between the lines. An empty line was left between the replicates, and two spots were left without planting within each line, as well as between the replicates. The experimental treatments were randomly assigned, with three replicates per treatment. Each replicate comprised eight plants, planted in two lines of four plants each, spaced 40 cm apart and 100 cm between lines.

Experimental Design

The experiment was designed as a completely randomized block design with 15 treatments, each replicated 3 times, and an average of 8 plants per experimental plot (**Figure 2**). The statistical program Statistix10 was used to analyze the data and calculate the least significant difference (LSD) at the 5% significance level.

The experimental treatments involved the following:

- T1: Control (no treatment)
- T2: *R. solani* inoculum applied to millet grains at a 2 g/liter of water per plant
- T3: *F. oxysporum* inoculum prepared as a spore suspension at a concentration of 1×10^6 and a rate of 25 ml/liter of water per plant.
- T4: Inoculum of *T. harzianum* isolate I25 (1×10^6 spore suspension at 25 ml/liter of water per plant)
- T5: Inoculum of *T. harzianum* isolate I26 (1×10^6 spore suspension at 25 ml/liter of water per plant)
- T6: Inoculum of *T. harzianum* isolate I39 (1×10^6 spore suspension at 25 ml/liter of water per plant)
- T7: Inoculum of *T. harzianum* isolate I57 (1×10^6 spore suspension at 25 ml/liter of water per plant)
- T8: Inoculum of the pathogenic fungus *R. solani* with isolate I25
- T9: Inoculum of the pathogenic fungus *F. oxysporum* with isolate I25
- T10: Inoculum of the pathogenic fungus *R. solani* with isolate I26
- T11: *F. oxysporum* inoculum with isolate I26
- T12: *R. solani* inoculum with isolate I39
- T13: *F. oxysporum* inoculum with isolate I39
- T14: *R. solani* inoculum with isolate I57
- T15: *F. oxysporum* inoculum with isolate I57

The pathogenic fungi were added 7 days before planting to allow them to grow and reproduce, thereby providing *T. harzianum*. **Figure 2**: Coefficients and location of the experimental field for eggplant, showing the size of one replicate.



Figure 2. Coefficients and location of the experimental field for eggplant, showing the size of one replicate.

Indicators studied

1. Infection rate 40 days after planting using the equation:

$$\text{Infection rate} = \frac{\text{number of infected plants}}{\text{total number of plants}} * 100$$

2. Infection severity using the infection severity index shown in **Table 2**.

Table 2. Index of severity of wilt disease infection on eggplant plants according to (27).

Degree	Symptoms
0	The root system is white, and the plant is healthy.
1	1-25% has slight discoloration of the root system and base of the stem, and yellowing of the lower leaves
2	25-50% of the plant is slightly stunted with brown discoloration of the roots and base of the stem.
3	50-75% of the plant is stunted with brown discoloration of the roots and base of the stem, and yellowing and dying of the outer leaves.
4	75-100% of the plant is severely stunted with dark brown discoloration of the base of the stem and roots, with yellowing and wilting of the outer leaves.
5	Complete plant death.

The infection severity rate was calculated according to the equation:

$$\text{Percentage of infection severity} = (\text{Number of plants in grade 0} * 0 + \text{Number of plants in grade 1} * 1 + \dots + \text{Number of plants in grade 5} * 5) / (\text{Total number of plants} * \text{Highest infection degree}) * 100$$

The disease reduction percentage was calculated according to the equation:

$$\text{Percentage of disease reduction} = (\text{Infection degree of control} - \text{Infection degree of treatment}) / \text{Infection degree of control} * 100$$

3. Plant height: Measured from the soil surface to the highest growing tip using a yardstick 90 days after planting the seedlings.
4. Fresh weight of the vegetative system: Measured at the end of the production season, 150 days after planting.
5. Dry weight of the plant branches.
6. Fresh weight of the root system.
7. Dry weight of the root system.
8. Production per plant.

Results and Discussion

As shown in **Table 3**, inoculation with the pathogenic fungi *R. solani* and *F. oxysporum* caused a sharp and significant decrease in all studied growth and production indicators, including vegetative and root growth, plant length, and yield per plant, compared to the control treatment. Specifically, *R. solani* infection resulted in 46.1% and 41.1% reductions in vegetative weight and yield per plant, respectively, relative to the control. Similarly, *F. oxysporum* infection led to reductions of 37.0% and 33.7% in vegetative mass and yield per plant, respectively. *R. solani* had a more severe impact than *F. oxysporum* in reducing the fresh weight (0.48 g vs. 0.56 g) and dry weight (100 g vs. 110 g) of the vegetative mass, and yield per plant (1.43 kg vs. 1.61 kg). In contrast, no significant differences were observed between the two pathogens in their effects on root system fresh/dry weight or plant length.

Conversely, all treatments involving *T. harzianum* isolates resulted in a significant increase in the studied indicators compared to both the control and the pathogen-only treatments. These isolates significantly outperformed the control in terms of plant dry weight, vegetative mass fresh and dry weight, and yield per plant. Among the isolates, I25 was the most effective, achieving the highest values for vegetative system fresh weight (0.94 g), dry weight (170 g), plant length (87.93 cm), and yield per plant (2.7 kg). Its performance was significantly different from that of I26 in some metrics and was significantly superior to I39 and I57 in both fresh and dry weight. Notably, isolate I26 exhibited the highest vegetative system dry weight, surpassing all other treatments.

Furthermore, the data in **Table 3** indicate that combining *T. harzianum* isolates with *R. solani* significantly improved all indicators compared with the *R. solani* only treatment. The combined treatment *R. solani* × I25 was non-significantly superior to *R. solani* × I26 and markedly outperformed all other *R. solani* with other isolates. Compared to the pathogen-only treatment, the *R. solani* × I25 treatment increased vegetative system fresh and dry weight by 21.3% and 16.6%, respectively. It also increased root system fresh and dry weight by 19.7%, plant height by 22.3%, and yield per plant by 17.3%. A similar positive trend was observed when *T. harzianum* isolates were applied in combination with *F. oxysporum*, with all combined treatments showing a significant increase in the indicators studied compared to the *F. oxysporum*-only treatment.

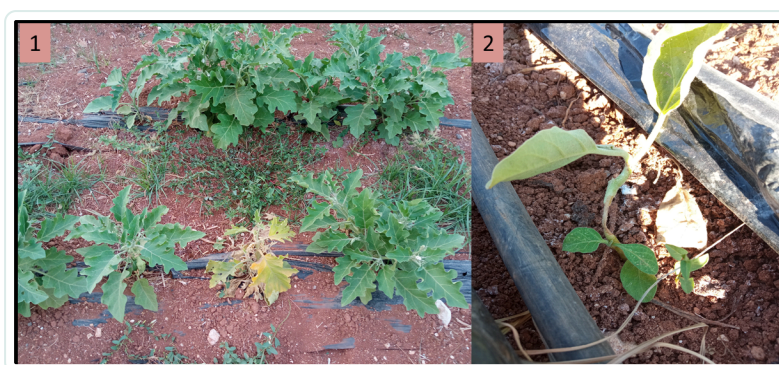


Figure 3. Infection of eggplant by *Fusarium oxysporum* (1) and *Rhizoctonia solani* (2)

Table 3. Effect of experimental treatments of *T. harzianum* fungus isolates on some production indicators of the eggplant.

Production per plant/kg	Plant height/cm	Dry weight of root system/g	Fresh weight of root system/g	Dry weight of plant branches/kg	Fresh weight of the shoot system /kg	Treatment
2.43bc	85.23 abc	29.30 cde	65.63 cdef	0.15c	0.89 a	Control
1.43i	63.57g	21.63g	49.67 h	0.10 i	0.48f	<i>R. solani</i>
1.61 ghi	65.00g	21.93g	50.3 h	0.11 fgh	0.56e	<i>F. oxysporum</i>
2.70a	87.93a	33.07b	76.03ab	0.17 ^a	0.94a	I25
2.61ab	85.60abc	35.61a	81.87a	0.16a	0.91a	I26
2.54ab	85.37abc	32.77b	75.23b	0.16abc	0.93a	I39
2.71a	86.80ab	29.84cd	68.53cd	0.16 ^{ab}	0.94a	I57
1.73 efg	81.87 bcdef	26.97ef	61.90efg	0.12 ^{fg}	0.61de	I25*R
2.33c	83.43 abcd	31.16 bc	71.7 bc	0.15bc	0.82b	I25*F
1.65gh	78.27 def	27.08ef	62.33efg	0.11ghi	0.58e	I26*R
1.87ef	76.47f	29.87cd	68.73cd	0.12ef	0.67cd	I26*F
1.68fgh	81.13 cdef	26.57f	61.07fg	0.11fgh	0.59e	I39*R
2.08d	82.77 abcde	29.06 cde	67.47 cde	0.14d	0.73c	I39*F
1.52hi	77.53ef	25.88f	58.77g	0.10hi	0.54ef	I57*R
1.93de	78.70 def	27.67 def	64.43 defg	0.13de	0.69c	I57*F
0.20	5.41	2.34	6.08	0.01	0.07	LSD 0.05

*Different letters indicate significant differences between treatments within the same column according to the LSD test ($P \leq 0.05$).

The treatment with isolate I25 was significantly superior to the other isolates supplemented with *F. oxysporum*, as indicated by the percentage increase in the fresh and dry weight of the vegetative system compared to the pathogen-alone treatment, reaching 31.7% and 26.6%, respectively. The increase in the fresh and dry weight indicators of the root system reached 29.8% and 29.6%, respectively. Additionally, the plant height indicator increased by 22%, and the production indicator per plant increased by 30.9%. The results indicated that

T. harzianum isolates, in the presence of *F. oxysporum*, increased the studied indicators more than they did in the presence of the pathogen *R. solani*.

The I25×F treatment outperformed the I25×R treatment significantly in increasing the values of the fresh (0.82 g and 0.61 g) and dry (150 g and 120 g) weights of the vegetative group, fresh (71.7 g and 61.9 g) and dry (31.16 and 26.97 g) weights of the root group, and production per plant (2.33 kg and 1.73 kg). Superiority was also apparent in the plant length. Similarly, the I26×F treatment significantly outperformed the I26×R treatment in increasing the

values of the aforementioned indicators, whereas the I57×F treatment apparently outperformed the I57×R treatment in increasing the values of the indicators for fresh and dry root mass weight and plant height.

These results suggest that plant nutrients undergo transformations in the soil from soluble to insoluble forms, thereby affecting their accessibility and root uptake. These transformations may be influenced by microorganisms (38). In the laboratory, a strain of *T. harzianum* can produce a large number of chemicals to dissolve phosphate, zinc, manganese, iron, and copper, increasing iron availability and enhancing its absorption (38, 40). *Trichoderma* applications increase tomato yields by up to 40% and enhance fruit sugar-acid ratios, improving marketable quality (46). Adding *Trichoderma* fungi with organic matter to the potato crop increased the absorption capacity of major nutrients. A combination of *T. harzianum* and *Pseudomonas* sp with potatoes increased fertilizer decomposition and productivity (28). *Trichoderma* fungi also have the ability to dissolve iron and make it available to plants (18, 40), thereby enhancing plant growth and increasing production.

This explains the positive effect of the tested *T. harzianum* isolates on all growth and production indicators of eggplant. Enzymes such as chitinase and gluconase produced by *Trichoderma* fungi are responsible for inhibiting the pathogen. These enzymes work by breaking down polysaccharides, chitin, and beta-glucan, which are responsible for the rigidity of fungal cell walls, thereby destroying the cell walls (31, 37, 47). This also impacts plant health, safety, and productivity. It was found by (12) that *T. harzianum* produces protease enzymes capable of degrading the cell walls of pathogenic fungi, thereby reducing the

pathogen's ability to infect the plant. It was also demonstrated that proteases can directly inhibit the pathogen's growth and inactivate its enzymes.

Root colonization with *T. harzianum* strains often enhances root growth and development, crop productivity, resistance to abiotic stresses, and nutrient absorption and utilization (3), which explains the increased eggplant root weight observed in *T. harzianum*-treated plants compared to the control. *T. harzianum* significantly inhibited the growth of *F. oxysporum* and enhanced the growth of eggplant. This can be attributed to the fact that *Trichoderma* species produce extracellular cellulase and pectinase enzymes capable of degrading the cell walls of pathogenic fungi (26). This finding is consistent with our previous research on the positive effect of *T. harzianum* isolates on reducing the incidence and severity of *F. oxysporum* infection. The use of *T. harzianum* with a diluted carbendazim dose on eggplant plants resulted in the lowest infection rate by *F. oxysporum*. It also produced the highest values for fresh and dry weight indicators in the vegetative group, as well as for single-plant length and productivity, compared with the infected control without treatment (22).

The results in Figure 4 show that the control and *T. harzianum* isolate treatments alone did not result in *R. solani* infection. In contrast, the infection rate and severity with *R. solani* alone reached 58.3% and 32.5%, respectively. The treatment of *T. harzianum* isolates with *R. solani* significantly reduced infection rate and severity compared with *R. solani* treatment alone. The I25×R outperformed the I26×R - I57×R in significantly reducing the infection rate to 8.3% over the I26×R - I57×R treatments, which reduced the infection rate to 33.3% and 29.2%, respectively, compared to the *R. solani* treatment alone (58.3%).

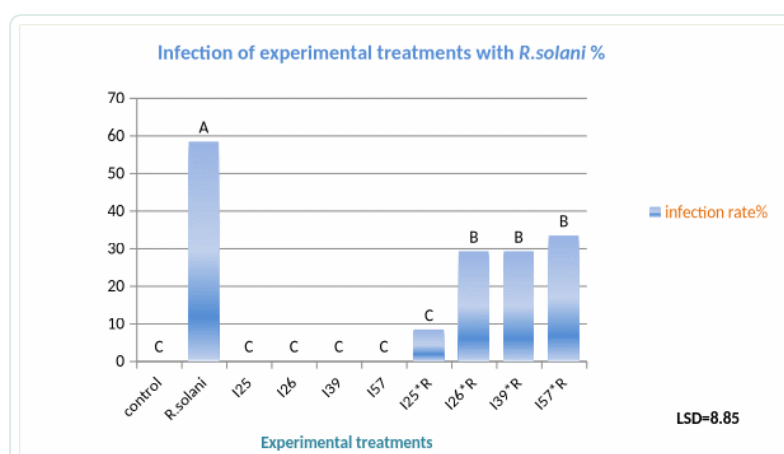


Figure 4. Infection rate of the experimental treatments with the *R. solani* fungus.

*Different letters indicate significant differences between treatments within the same column according to the LSD test ($P \leq 0.05$).

The I25×R and I26×R treatments also significantly reduced infection severity to 3.3% and 5%, respectively, compared to the *R. solani* treatment alone, which was

32.5% (Figure 5).

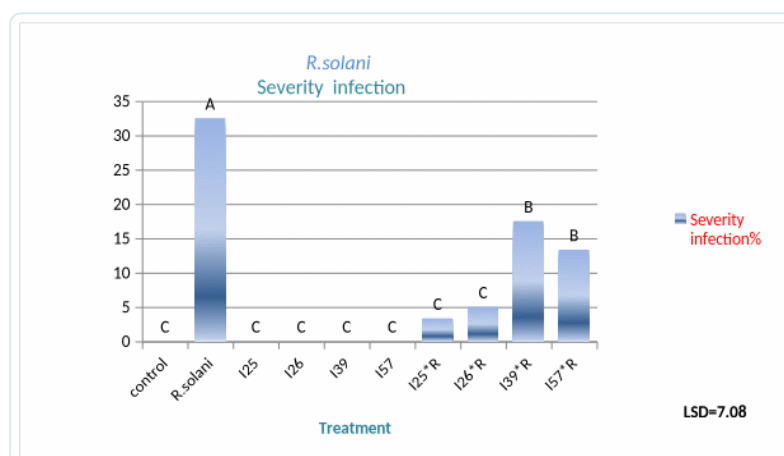


Figure 5. Infection severity in experimental treatments with the fungus *R. solani*.

*Different letters indicate significant differences between treatments within the same column according to the LSD test ($P \leq 0.05$).

The results in Figure 6 on the infection rate of the treatments with the *F. oxysporum* fungus indicate that the control and the *T. harzianum* isolates treatments alone were not exposed to any infection with the pathogen. In contrast, the infection rate in the *F. oxysporum* treatment reached 54.2%. The results also indicate that all *T. harzianum* isolates can significantly reduce infection rates, with the I25×F treatment being the most effective in providing complete protection (100%) against the

appearance of infection symptoms. The infection rates for the I26×F, I39×F, and I57×F treatments were 25%, 20.8%, and 16.7%, respectively. Meanwhile, infection reduction rates for these treatments reached 53.8%, 61.6%, and 69.1%, respectively. The results indicate no significant difference in infection reduction between the I26×F and I39×F treatments, and that the I57×F treatment significantly outperformed the I26×F treatment.

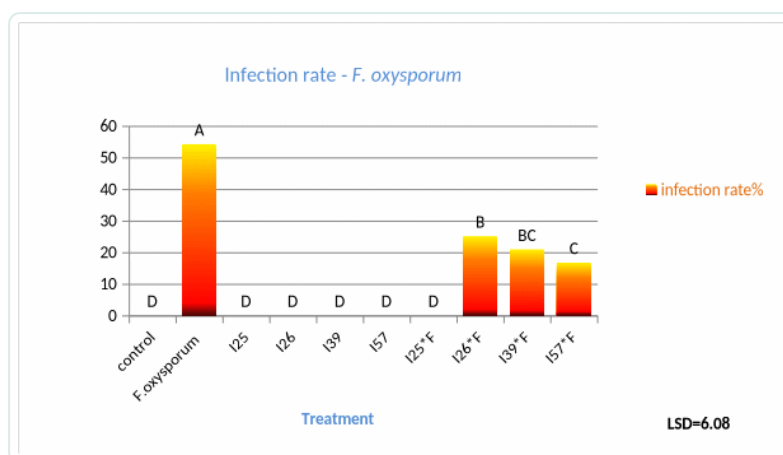


Figure 6. Infection rate of the experimental treatments with *F. oxysporum*.

*Different letters indicate significant differences between treatments within the same column according to the LSD test ($P \leq 0.05$).

Figure 7 shows that the I26×F, I39×F, and I57×F treatments reduced infection severity by 48.3%, 45.45%, and 63.63%, respectively, compared to the *F. oxysporum* treatment, without significant differences among them. The results of this study demonstrate the effectiveness of the four local isolates in reducing the field infection rate of the tested fungal pathogens. Isolate I25 exhibited the greatest efficacy, functioning effectively as both a

biofertilizer and a biocontrol agent. Its exceptional efficacy results from the natural variation in biocontrol potential among *T. harzianum* isolates. This variation is multifaceted, depending on an isolate's specific capacity to secrete inhibitory antibiotics, produce hydrolytic enzymes like chitinases and glucanases that degrade pathogen cell walls, and effectively compete for available nutrients in the rhizosphere.

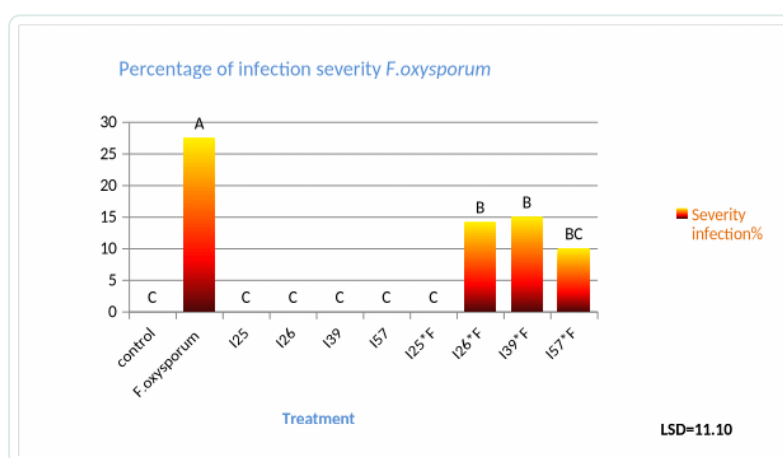


Figure 7. Infection severity in experimental treatments with *F. oxysporum*.

*Different letters indicate significant differences between treatments within the same column according to the LSD test ($P \leq 0.05$).

The success of any biocontrol agent, however, is not solely dependent on its own mechanisms, but also on the target pathogen's inherent ability to grow, compete, and establish itself in the same environment (13, 34). The beneficial effects of the tested *T. harzianum* isolates are attributed to several factors, including antagonism, mycoparasitism, production of secondary metabolites, and enhancement of plant growth and resistance (2, 19, 46). This wide range of effects is very promising for the production of commercial biopesticides. It is also

explained by the induction of resistance in eggplant plants by treatment with *T. harzianum*, one of the biocontrol mechanisms (20). *T. harzianum* strains colonize and penetrate the plant's root tissues, causing a series of morphological and biochemical changes in the plant, which is considered part of the plant's defense response, ultimately leading to the induction of systemic resistance (ISR) throughout the entire plant (9).

The results of biological control with *T. harzianum* against *F. oxysporum* also showed a significant decrease in *F. oxysporum* wilt infection rate in eggplant compared to pathogen treatments (41). In another study, plants infected with *F. oxysporum* and treated with *T. harzianum* showed the lowest infection rates and severity at 43.7% and 17.6%, respectively, compared to 80.6% and 57.7%, respectively, for the infected control without treatment (44). This is close to the results obtained here. The potential of *T. harzianum* was also reported by (29), who indicated a significant reduction in the severity of infection by *F. oxysporum*, with the infection reduction rate reaching 41%. A team of researchers also reported that *T. harzianum*, as a soil-borne antifungal, exhibits different modes of action that inhibit the development of diseases caused by soil-borne pathogens, especially *F. oxysporum* and *R. solani*, in host plants (15). The modes of action of *T. harzianum* include the ability to parasitize plant pathogens. It can also detect the presence of *Fusarium* wilt in the soil-root zone, move toward it, and directly attack it by wrapping around its fungal hyphae (6, 15), as documented in this laboratory study.

The reduced disease severity observed in this study can be attributed to *T. harzianum*'s production of cell wall-degrading enzymes, such as chitinase and 1,3- and 1,6-glucanases, which act on the pathogen's cell wall, leading to loss of cell wall integrity (6, 37). The biological activity of *T. harzianum* against *Fusarium* wilt in eggplant reduced the disease incidence under field conditions by deterring *Fusarium oxysporum* f. sp. *melongenae* populations in the soil (8). The growth and productivity of eggplant plants increased when *T. harzianum* was used (32), as confirmed by this study. The reduced disease incidence and increased plant growth are attributed to *T. harzianum* inhibiting the growth and activity of soil-borne pathogens by producing antibiotics, chitinase, and cellulase that degrade pathogen cell walls and deprive them of nutrients (17). *Trichoderma* also induces systemic defense responses in host plants, preparing them to respond more quickly and to a greater extent in the event of a pathogen invasion (47).

Conclusion

The effect of *R. solani* was significantly greater than that of *F. oxysporum* in reducing all field production indicators. All treatments of *T. harzianum* isolates showed a significant increase in the values of the studied indicators compared to the control and the remaining

treatments. Furthermore, the results indicated that *T. harzianum* isolates were more effective at enhancing the studied indicators when challenged with *F. oxysporum* than *R. solani*. The research results demonstrated the effectiveness of the four local isolates in reducing the field infection rate caused by the tested fungal pathogens. Notably, isolate I25 outperformed the others, exhibiting the strongest effects both as a biofertilizer and a biocontrol agent. The wide range of positive effects shown by the local *T. harzianum* isolates is highly promising for the development of commercial biopesticides, reinforcing the concept of biological control using indigenous *Trichoderma* species as a sustainable alternative strategy for managing soil-borne fungal pathogens. The study recommends further investigation into a consortium of the four *T. harzianum* isolates as a single bioproduct, which could simultaneously harness their collective benefits. Such a product should be tested for its efficacy against other fungal diseases and on different crop species. There is also a need to conduct molecular characterization of these isolates and formulate them into a commercial biopesticide.

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عزل بعض الفطريات الممرضة المسببة لذبول الباذنجان ومكافحتها باستخدام فطر *Trichoderma harzianum* وتأثير ذلك على مؤشرات الإنتاج

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الخلاصة

استخدمت في هذا البحث أربع عزلات محلية من فطر *Trichoderma harzianum* معزولة من حقول مزرعة نبات الباذنجان في محافظة حماة خلال العام 2022. أدت المعاملات بعدوى الفطريات الممرضة *R.solani* و *F.oxysporum* إلى انخفاض حاد ومعنوي في كافة قيم مؤشرات النمو والإنتاج المدروسة، كما تفوق تأثير فطر *R.solani* معنوياً على تأثير فطر *F.oxysporum* في تخفيض مؤشرات الإنتاج. بالمقابل أظهرت معاملات عزلات فطر *T. harzianum* زيادة في قيم المؤشرات المدروسة بشكل ملحوظ بالمقارنة مع الشاهد ومع باقي المعاملات، حيث تفوقت معنوياً على الشاهد في مؤشرات الوزن الجاف للنبات والوزن الطري والجاف للمجموع الخضري وإنتاج النبات الواحد. وحققت العزلة I25 أكبر زيادة في مؤشرات الإنتاج، أبدت معاملات إضافة عزلات فطر *T. harzianum* مع كلا العاملين الممرضين *R.solani* و *F.oxysporum* زيادة معنوية في مؤشرات الإنتاج المدروسة مقارنة بمعاملة العامل الممرض لوحده، كما أثبتت نتائج البحث فعالية العزلات المحلية الأربعة في تخفيض نسبة الإصابة الحقلية بالآفات الفطرية المختبرة وتفوقت العزلة I25 على بقية العزلات المختبرة في تأثيرها كمخصب حيوي من جهة وكعامل مكافحة حيوية من جهة أخرى

الكلمات المفتاحية: المكافحة الحيوية، التطفل الفطري، مخصب حيوي