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## Management of Potato Root Rot - Disease Caused by *Fusarium* Species Using Some Eco-Friendly Controlling Agents

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### Abstract

Potatoes are underground stem- tubers of the plant *Solanum tuberosum*, a perennial in the nightshade family Solanaceae. Potatoes can be infected by several fungi, causing severe losses in potato production. This study was designed for isolation and identification of potato root rot fungal pathogens in Assiut governorate, Egypt. Testing some biocontrol agents like *Bacillus subtilis*, *Saccharomyces cerevisiae*, and *Trichoderma* species, and testing the antifungal properties of zinc and titanium nanoparticles against potato root rot diseases caused by *Fusarium* spp. The assessment was conducted by measuring disease severity and morphological and physiological changes such as total antioxidants, total phenols, total flavonoids and total terpenes in the plant roots. *Fusarium incarnatum*, *F. solani*, and *F. moniliforme* were the dominant pathogens in 30 infected samples, with disease severity range from 0% to 83.3%. The results showed that T3 (*Trichoderma atroviride*), T4 (*B. subtilis*), T8 (ZnNPs 150 ppm), and T11 (TiNPs 150 ppm) effectively reduced disease severity to 0% and enhanced plant morphological and physiological characteristics compared with the infected control plants. The research showed various effective solutions for controlling *Fusarium* pathogens in soil the ability to apply these treatments in controlling potato root rot and wilt diseases.

**Keywords:** *Bacillus subtilis*, Root rot, *Saccharomyces cerevisiae*, *Trichoderma* sp., Zinc nanoparticles.

### Introduction

Potato (*Solanum tuberosum* L.) ranks first as a non-cereal food crop for human consumption and has great potential in ensuring food security in developing nations (Faostat 2019). The diverse distribution pattern and major cultivation as a cash crop in areas with a high level of hunger and malnutrition make it a global crop in sustainable food availability (Haverkort *et al.* 2013; Devaux *et al.* 2020; Lal *et al.* 2020). The food and agriculture organization (FAO) declared 2008 the international year of potato production. Potato is currently growing over 19 million hectares with an annual production of 388 million tons worldwide. Approximately 1.3 billion people consume

fresh potatoes as a staple food (50 kg per person annually) in India and China. The consistent increase in potato production in the developing world, which exceeds that of developed nations, indicates its importance as a source of food, income, and employment, especially in Asia, Africa, and Latin America (Devaux *et al.* 2020). Potato crops are vulnerable to numerous diseases that can impact production both pre- and post-harvest. In particular, fungal pathogens are responsible for substantial economic losses during various stages, such as cultivation, storage, transport, and marketing (Eken *et al.*, 2000). Among these pathogens, the *Fusarium* genus stands out as a major group of plant-pathogenic fungi, leading to potato wilt in the field and tuber dry rot during storage.

*Rhizoctonia solani* causes a variety of symptoms at different growth phases, including damping-off before and after emergence, root rot, wire stem, seed decay, and hypocotyl or tap root with necrotic patches (Gomaa *et al.*, 2025). The most frequent isolates from wilted and root-rotted pepper plants were *F. oxysporum* and *R. solani*. The plants were infected with *F. oxysporum* f. sp. *capsici* and *R. solani*, according to pathogenicity tests conducted on the isolated pathogens from the afflicted pepper plants. Similarly, damping-off and vascular wilt symptoms were observed in plants infected with *F. oxysporum* f.sp. *capsici* (Abd-Elmonsef *et al.*, 2019; El-Kazzaz *et al.*, 2022).

*Fusarium*-induced dry rot and root rot is a global issue, present in all potato cultivated regions (Stevenson *et al.*, 2001). According to research by Cullen *et al.*, (2005). Thirteen different *Fusarium* spp. have been identified as causal agents of this disease in potatoes around the world. However, the diversity of these species is influenced by both geographical factors and seasonal variations (Mahmoud *et al.*, 2021). The use of fungicides for control currently poses risks to human and animal health, highlighting the need for environmentally friendly alternatives (Fatima *et al.*, 2024). This study aimed to evaluate the effectiveness of various bio-control agents as an eco-safe option for controlling potato root rot disease caused by *Fusarium* species.

## Materials and Methods

### 1. Isolation of pathogens associated with potato root rot

Potato plants with root rot and wilt symptoms were collected from different areas in the Assiut government, Egypt, from September to December 2022. Fungal cultures were isolated from wilted plants and roots showing root rot symptoms. The infected potato roots were washed with tap water to remove all soil particles adhering to the roots. Selected organs (rotten tuber fragments, stems fragments, roots and stem bases) were superficially disinfected for 5 min in a 70 % ethanol solution, rinsed three times with sterile distilled water for 5 min each time, and dried with a sterile filter paper. The disinfected fragments 0.5 cm in diameter were transplanted to a PDA (Potato Dextrose Agar) medium, four pieces per plate, and incubated at 25 °C for 5–7 days. Different types of fungal colonies were seen on the medium, but only typical colonies with *Fusarium* features were selected (Azil *et al.*, 2021). The main characteristics that were evaluated included macroscopic (colony color and appearance, presence of aerial mycelium) and microscopic traits (presence of chlamydospores and micro- and

macroconidia). Subcultures obtained from the colony margin were single-spored by germinating conidia on water agar medium at 25 °C for 4–5 days (Stefańczyk and Sobkowiak 2017; Mahmoud *et al.*, 2025).

## 2. Pathogenicity tests

The pathogenic capabilities of thirty isolates were tested on potato under greenhouse conditions during the 2023 season. The inoculums of the tested isolates were prepared by growing them in a sterilized glass bottle (1 liter) containing barely medium (200 g barely seed and PDA media), autoclaving them for two consecutive days, and incubating them at 28 °C for 15 days. Sterilized pots (30 cm in diameter) were filled with sterilized clay soil and infested with each isolate at a rate of (3%). Each pot was planted with 3 potato tubers. Three pots were used for each treatment as replicates. Untreated pots with pathogens were used as the control (reference). Diseases severity was recorded after 45 days, according to Mohamed (2013).

A numerical scale ranging from 0 to 4 was used to quantify root rot severity based on the type and extent of symptoms observed. The severity scale was as follows:

0: No observed symptoms.

1: Initial symptoms appear on the first leaf of the plant.

2: Symptoms appear above the true leaf, and 25%–50% of the root system is brown.

3: The entire plant shows signs of wilting, and 51%–75% of the root system is dark brown, showing clear root rot symptoms.

4: The plant shows complete wilting, and 76%–100% of the roots are dark brown with extensive root rot.

$$\text{Disease severity \%} = \frac{\sum[(N \times 0) + (N \times 1) + \dots + (N \times 4)]}{4T} \times 100$$

Where: (N) = the number of plants assigned to each numerical grade (0, 1, 2, 3, 4, ).

(4T) = the total number of plants (T) multiplied by the largest numerical grade (4).

## 3. Biocontrol experimental design

Plant growth-promoting *Bacillus subtilis* was grown in nutrient broth medium for 24 hours at  $30 \pm 1$  °C until it reached 1 OD<sub>660</sub> and was then used as a bacterial inoculum (Mahmoud *et al.*, 2023). *Saccharomyces cerevisiae* and *Trichoderma* species (*T. harzianum*, *T. atroviride*, and *T. longibrachiatum*) were grown in Czapek's dextrose broth medium for 3 days at  $30 \pm 1$  °C, and  $10^6$  CFU/ml inoculums were used (Abeed *et al.*, 2022; Mahmoud *et al.*, 2024). Chemically prepared zinc oxide and titanium oxide nanoparticles using Ball milling technique from their metal oxides were utilized with three concentrations (50, 100, and 150 ppm) (Ibrahim and Mahmoud 2021).

The experiment was performed in a greenhouse as a randomized complete design in a split-plot with three replications. Potato tubers were cultivated in pots during the 2023 growing season at the Faculty of Agriculture, Assiut University, Egypt. Five days after infecting the soil with *Fusarium solani* pathogen, the treatments were added (*Trichoderma* treatments T1 to T3 (*T. harzianum*, *T. longibrachitum*, and *T.*

atroviride), T4 (*B. subtilis*), T5 (*S. cerevisiae*), T6 to T8 (ZnNPs), and T9 to T11 (TiNPs)). The pots were kept for 3 days before being inoculated with potato tubers kara type. After 45 days of inoculation, the development of *Fusarium* root rot and wilt symptoms developed. Three replicates (pots) were used for each treatment tested and compared with positive and negative controls.

Disease severity was estimated; the plant was morphologically and physiologically analyzed. The traits of the stem length (cm), root length (cm), number of roots, number of branches, plant fresh weight and dry weight (g), and root dry weight (g) were measured. The chlorophyll contents of the leaves were also measured. Plant responses to pathogens, including total antioxidants, total phenols, total flavonoids, and total terpenes were detected in the plant roots (Fan and He 2006; Mahmoud *et al.*, 2021; Ibrahim *et al.*, 2022).

#### 4. Statistical analysis

The data were analyzed using analysis of variance (ANOVA), and significant differences between means were determined by the least significant difference (L.S.D.) test at the 5% probability level, following the method described by Gomez and Gomez (1984).

### Results and Discussion

#### 1. Isolation and identification of causal pathogens of root rot potato

Potato plants showing symptoms of root rot were collected during the 2022 growing season. Symptoms of pathogens on the leaves of potato in the pot that appeared yellow and wilting. Figure (2) showed the symptoms of disease on root 0 refer to health root and (1&4) appear pathogenicity. *Fusarium* spp., particularly *F. solani*, infect potato roots causing root rot characterized by dark brown to black discoloration and tissue necrosis. Infected roots become soft, often emitting a foul odor, and lesion development may extend into cortical and vascular tissues, sometimes forming concentric rings. Above-ground symptoms include chlorotic, yellow leaves and stunted growth, indicating compromised root function. These symptoms are consistent with *Fusarium-induced* root rot in potatoes (NC State Extension, 2025).



**Fig 1. The differentiation between health leaves [A] and pathogenic leaves in potato [B and C] showed symptoms of yellowing and wilting of leaves and stunting.**



Fig 2. [0] refers to healthy root, [1 to 4] shows rot at the pivot, roots, and collar in infected potato root.

## 2. Frequency % of *Fusarium* spp. isolated from infected potato

The isolated fungi were identified as *F. incarnatum*, *F. solani*, *F. oxysporium*, *F. sambucinum*, *F. nygamai*, *F. fujikuroi*, *F. graminearum*, *F. moniliforme* and *F. chlamydosporum*. based on the morphological characteristics of the mycelia and conidia. Table (1) displayed the frequency percentage of *Fusarium* spp. identified from various isolates. *F. incarnatum* had the highest presence, recorded at a rate of (43.3%), while *F. solani* and *F. moniliforme* were present in 13.3% of the samples and *F. fujikuroi* was present in 10%. *F. sambucinum*, *F. nygamai*, *F. graminearum*, and *F. chlamydosporum* were the lowest, at a rate of (3.3%) among the original samples. This percentage is quite like the findings of Stefańczyk *et al.* (2016), who reported that *F. solani* comprised 10.7% of the samples, while *F. oxysporum* accounted for 45% of the isolates, which is significantly lower in comparison to this study.

Table 1. Percentage of *Fusarium* spp. causing potato root rot

| Samples                  | No. of samples | Frequency (%) |
|--------------------------|----------------|---------------|
| <i>F. incarnatum</i>     | 13             | 43.3          |
| <i>F. fujikuroi</i>      | 3              | 10            |
| <i>F. solani</i>         | 4              | 13.3          |
| <i>F. oxysporium</i>     | 2              | 6.6           |
| <i>F. sambucinum</i>     | 1              | 3.3           |
| <i>F. nygamai</i>        | 1              | 3.3           |
| <i>F. graminearum</i>    | 1              | 3.3           |
| <i>F. moniliforme</i>    | 4              | 13.3          |
| <i>F. chlamydosporum</i> | 1              | 3.3           |
| Total                    | 30             | 100           |

### - Pathogenicity tests

Results of the pathogenicity tests in Table (2) showed that nine *Fusarium* species, namely *F. incarnatum*, *F. solani*, *F. oxysporum*, *F. sambucinum*, *F. nygamai*, *F. graminearum*, *F. fujikuroi*, *F. moniliforme*, and *F. chlamydosporum*, were isolated

from diseased potato roots. These isolates were found to handle root rot and exhibited typical symptoms associated with these diseases. The data presented in Table.2 show that all tested *Fusarium* isolates significantly increased root rot compared with the control treatment. Among the pathogens, *F. incarnatum* caused the highest percentage of seedling root rot, with root rot severity reaching 83.5%, followed by *F. solani* (3), which caused 75% root rot severity. *F. oxysporium* (1) exhibited the lowest pathogenicity, with 16% root rot severity. Some species from *F. incarnatum* and *F. solani* did not cause any pathogenicity to potatoes. *F. solani* (sexual morph *Nectria haematococca*) is a significant filamentous fungus.

**Table 2. Pathogenicity tests of *Fusarium* spp. isolated from 30 infected potato plants**

| Isolate name             | Disease severity (%) |
|--------------------------|----------------------|
| <i>F. incarnatum</i> 1   | 8.3                  |
| <i>F. incarnatum</i> 2   | 83.3                 |
| <i>F. incarnatum</i> 3   | 58.3                 |
| <i>F. incarnatum</i> 4   | 33.3                 |
| <i>F. incarnatum</i> 5   | 25.0                 |
| <i>F. incarnatum</i> 6   | 25.0                 |
| <i>F. incarnatum</i> 7   | 16.0                 |
| <i>F. incarnatum</i> 8   | 16.0                 |
| <i>F. incarnatum</i> 9   | 25.0                 |
| <i>F. incarnatum</i> 10  | 25.0                 |
| <i>F. incarnatum</i> 11  | 33.3                 |
| <i>F. incarnatum</i> 12  | 16.0                 |
| <i>F. incarnatum</i> 13  | 8.3                  |
| <i>F. fujikuroi</i> 1    | 0.0                  |
| <i>F. fujikuroi</i> 2    | 0.0                  |
| <i>F. fujikuroi</i> 3    | 0.0                  |
| <i>F. solani</i> 1       | 25.0                 |
| <i>F. solani</i> 2       | 33.0                 |
| <i>F. solani</i> 3       | 75.0                 |
| <i>F. solani</i> 4       | 8.3                  |
| <i>F. moniliforme</i> 1  | 66.7                 |
| <i>F. moniliforme</i> 2  | 0.0                  |
| <i>F. moniliforme</i> 3  | 25.0                 |
| <i>F. moniliforme</i> 4  | 8.3                  |
| <i>F. oxysporium</i> 1   | 16.0                 |
| <i>F. oxysporium</i> 2   | 16.0                 |
| <i>F. sambucinum</i>     | 25.0                 |
| <i>F. nygamai</i>        | 25.0                 |
| <i>F. graminearum</i>    | 33.3                 |
| <i>F. chlamydosporum</i> | 50.0                 |
| Control                  | 0.0                  |
| LSD 0.05                 | 1.34                 |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA.

Phytopathogenic members of the *Fusarium solani* species complex (FSSC) include some of the most economically significant plant pathogens, particularly those

associated with root rots and vascular wilts in over 100 crop species. Infected host plants typically show foot or root rot, with the extent of necrosis correlated with disease severity. Above-ground symptoms may include wilting, stunting, chlorosis, or the appearance of lesions on stems and leaves. These symptoms vary depending on the specific FSSC pathogen and the host plant. Similar symptoms, including root rot, wilting, and yellowing of leaves, have been observed on potato plants, consistent with those previously described for FSSC infections. Other *Fusarium* spp. of lesser economic impact also causes root rots, such as *F. chlamydosporum*, which infects coleus and other ornamental plants, and *F. oxysporum*, which infects members of the *Cactaceae* family and causes stem and root rot in Milon (Williamson-Benavides *et al.*, 2021).

### 3. Effect of *F. solani* control treatments on the morphological characteristics of healthy and infected potato plants

Table (3) illustrates the impact of biological control shown by certain microorganisms and nanomaterials on various sections of the infected plant, including branches and roots, alongside a comparison to both a healthy control sample and an infected sample. All treatments showed a beneficial impact on enhancing the number of branches, aligning them more closely with the healthy control group. Treatment T3 for *Trichoderma atroviride* demonstrated a significant increase in the number of branches compared with the health control. Conversely, the treatments did not yield uniform results on root count. The treatments did not demonstrate any significant impact on the root count, with certain treatments resulting in a reduction in the root count compared with the control group. The most effective treatment was T1 (*Trichoderma harzianum*), which increased the number of roots in certain afflicted plants after treatment.

**Table 3. Effect of controlling treatments on the potato number of branches and number of roots in healthy and infected plants.**

| Treatments                        | <i>Fusarium solani</i> (pathogen) |                 |
|-----------------------------------|-----------------------------------|-----------------|
|                                   | Number of branches                | Number of roots |
| Negative control (Healthy plant)  | 7.23                              | 9.77            |
| Positive control (Infected plant) | 5.77                              | 7.77            |
| T1 ( <i>T. harzianum</i> )        | 6.40                              | 9.87            |
| T2 ( <i>T. longibrachiatum</i> )  | 6.60                              | 7.63            |
| T3 ( <i>T. atroviride</i> )       | 8.83                              | 8.43            |
| T4 ( <i>B. subtilis</i> )         | 8.53                              | 6.97            |
| T5 ( <i>S. cerevisiae</i> )       | 7.53                              | 7.77            |
| T6 (ZnNPs 50ppm)                  | 7.20                              | 5.97            |
| T7 (ZnNPs 100ppm)                 | 7.77                              | 9.33            |
| T8 (ZnNPs 150ppm)                 | 8.63                              | 5.87            |
| T9 (TiNPs 50ppm)                  | 7.40                              | 6.93            |
| T10 (TiNPs 100ppm)                | 8.63                              | 7.83            |
| T11 (TiNPs 150ppm)                | 7.10                              | 7.97            |
| Mean                              | 7.51                              | 7.85            |
| LSD0.05 (Treatment)               | 1.53                              | 1.67            |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA

### - Effect of *F. solani* control treatments on potato root and stem length

All treatments in Table (4) had a favorable influence on root and stem length, with ZnNPs (50 ppm) and TiNPs (100 ppm) having the greatest effect on root length when compared to the healthy control. Additionally, T1 (*T. harzianum*) had the greatest impact on stem length. While some treatments exhibited less effects such as T4 (*B. subtilis*) and T2 (*T. longibrachiatum*).

**Table 4. Effect of controlling treatments on the potato stem and roots length (cm) in healthy and infected plants.**

| Treatments                        | <i>Fusarium solani</i> (pathogen) |                          |
|-----------------------------------|-----------------------------------|--------------------------|
|                                   | Length of the roots (cm)          | Length of the stems (cm) |
| Negative control (Healthy plant)  | 24.47                             | 17.37                    |
| Positive control (Infected plant) | 19.57                             | 13.87                    |
| T1 ( <i>T. harzianum</i> )        | 27.07                             | 27.70                    |
| T2 ( <i>T. longibrachiatum</i> )  | 21.53                             | 22.30                    |
| T3 ( <i>T. atroviride</i> )       | 25.00                             | 26.63                    |
| T4 ( <i>B. subtilis</i> )         | 21.10                             | 25.43                    |
| T5 ( <i>S. cerevisiae</i> )       | 27.63                             | 23.57                    |
| T6 (ZnNPs 50ppm)                  | 32.00                             | 27.00                    |
| T7 (ZnNPs 100ppm)                 | 23.13                             | 15.37                    |
| T8 (ZnNPs 150ppm)                 | 23.73                             | 23.33                    |
| T9 (TiNPs 50ppm)                  | 27.27                             | 17.97                    |
| T10 (TiNPs 100ppm)                | 29.00                             | 18.23                    |
| T11 (TiNPs 150ppm)                | 22.00                             | 20.80                    |
| Mean                              | 24.88                             | 21.51                    |
| LSD0.05 (Treatment)               | 3.29                              | 2.88                     |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA

### -Effect of *F. solani* control treatments on potato roots fresh weight, plant fresh weight, plant dry weight and Chlorophyll

*Bacillus subtilis* T4 had the highest fresh root weight (6.20 g), followed by T3 (*T. atroviride*) at 5.93 g and T1 (*T. harzianum*) at 5.83 g. T6 (ZnNPs 50ppm) had the greatest fresh weight of the whole plant, measuring 16.10 g, followed by T4 (*B. subtilis*) at 15.73 g and T8 (ZnNPs 150ppm) at 15.33 g. The infected control had the lowest root weight (3.53 g), followed by T8 (ZnNPs 150ppm) at 3.70 g and Control at 4.43 g. The lowest total plant weights were infected control (4.77 g), healthy control (6.00 g), and T5 (*S. cerevisiae*) at 8.63 g. T4 (*B. subtilis*) and T8 (Zn150) were the most efficient treatments in boosting the plant's dry weight, both with 5.33 g, whereas T1 and T7 each had 5.00 g. The highest chlorophyll content values were obtained in the healthy control (105.80), T8 (ZnNPs 150ppm) (91.03), and T7 (ZnNPs 100ppm) (83.00). The lowest dry weights were observed in I. Control (1.33 g), Control (1.70 g), and T11 (2.67 g). T2 (*T. longibrachitum*) had the lowest chlorophyll levels (43.90 mg/g fw) (43.90), followed by T4 (*B. subtilis*) at 46.87 and T1 at 47.13.

**Table 5. Effect of controlling treatments on the fresh weight of potato roots, fresh weight of plants, dry weight of plants, and chlorophyll content of leaves in healthy and infected plants**

| Treatments                        | <i>Fusarium solani</i> (pathogen) |                        |                      |                       |
|-----------------------------------|-----------------------------------|------------------------|----------------------|-----------------------|
|                                   | Fresh weight of the roots (g)     | Plant fresh weight (g) | Plant dry weight (g) | Chlorophyll (mg/g fw) |
| Negative control (Healthy plant)  | 4.43                              | 6.00                   | 1.70                 | 105.80                |
| Positive control (Infected plant) | 3.53                              | 4.77                   | 1.33                 | 84.63                 |
| T1 ( <i>T. harzianum</i> )        | 5.83                              | 10.30                  | 5.00                 | 47.13                 |
| T2 ( <i>T. longibrachiatum</i> )  | 5.30                              | 11.10                  | 4.00                 | 43.90                 |
| T3 ( <i>T. atroviride</i> )       | 5.93                              | 14.07                  | 4.33                 | 49.43                 |
| T4 ( <i>B. subtilis</i> )         | 6.20                              | 15.73                  | 5.33                 | 46.87                 |
| T5 ( <i>S. cerevisiae</i> )       | 4.53                              | 8.63                   | 3.67                 | 48.13                 |
| T6 (ZnNPs 50ppm)                  | 4.60                              | 16.10                  | 4.33                 | 48.53                 |
| T7 (ZnNPs 100ppm)                 | 5.50                              | 15.10                  | 5.00                 | 83.00                 |
| T8 (ZnNPs 150ppm)                 | 3.70                              | 15.33                  | 5.33                 | 91.03                 |
| T9 (TiNPs 50ppm)                  | 4.93                              | 12.20                  | 4.33                 | 45.37                 |
| T10 (TiNPs 100ppm)                | 5.07                              | 9.33                   | 3.67                 | 45.80                 |
| T11 (TiNPs 150ppm)                | 5.20                              | 9.87                   | 2.67                 | 74.63                 |
| Mean                              | 4.98                              | 11.43                  | 3.90                 | 62.64                 |
| LSD0.05 (Treatment)               | 1.38                              | 1.80                   | 1.70                 | 3.93                  |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA.**Table 6. Effect of *F. solani* treatment control on potato disease severity**

| Treat                             | <i>Fusarium solani</i> (pathogen) |
|-----------------------------------|-----------------------------------|
|                                   | D.S (%)                           |
| Negative control (Healthy plant)  | 0                                 |
| Positive control (Infected plant) | 100                               |
| T1 ( <i>T. harzianum</i> )        | 16.6                              |
| T2 ( <i>T. longibrachiatum</i> )  | 25                                |
| T3 ( <i>T. atroviride</i> )       | 0                                 |
| T4 ( <i>B. subtilis</i> )         | 0                                 |
| T5 ( <i>S. cerevisiae</i> )       | 58.3                              |
| T6 (ZnNPs 50ppm)                  | 50                                |
| T7 (ZnNPs 100ppm)                 | 25                                |
| T8 (ZnNPs 150ppm)                 | 0                                 |
| T9 (TiNPs 50ppm)                  | 33.3                              |
| T10 (TiNPs 100ppm)                | 16.6                              |
| T11 (TiNPs 150ppm)                | 0                                 |
| LSD0.05 (Treatment)               | 1.47                              |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA.

#### 4. Effect of *F. solani* treatment control on potato disease severity

As shown in Table 6, all treatments, including *Trichoderma* treatments T1 to T3 (*T.harzianum*, *T.longibrachitum*, and *T.atroviride*), T4 (*B. subtilis*), T5 (*S. cerevisiae*), T6 to T8 (ZnNPs), and T9 to T11 (TiNPs), significantly reduced root rot of potatoes caused by *F. subtilis. Solani* compared with the control. Treatments T3 (*Trichoderma atroviride*), T4 (*B. subtilis*), T8 (ZnNPs 150 ppm), and T11 (TiNPs 150 ppm) showed a significant decrease in root rot (0% disease severity), whereas the rest of the treatments reduced the severity of the infection to varying degrees, ranging from 16.6% to 53.3%. Earlier researches showed that biocontrol agents can effectively inhibit *F. oxysporum* and *F. solani* compared with the untreated control using a dual method (Khedher *et al.*, 2021). Interaction of *Trichoderma* and *F. solani* indicated good disease control by 0% disease incidence (Ommati *et al.*, 2012). Nanoparticles are considered a good alternative to control phytopathogenic fungi in agriculture. Different shapes and sizes have shown outstanding antifungal activity (Sehsahb *et al.*, 2023)

**Table 7. Effect of *F. solani*-controlling treatments on total antioxidants (TA), total phenols (TP), total flavonoids (TF) and total terpenes (TT) in healthy and infected potato plants**

| Treatments                        | <i>Fusarium solani</i> (pathogen) |       |       |       |
|-----------------------------------|-----------------------------------|-------|-------|-------|
|                                   | TF                                | TT    | TA    | TP    |
| Negative control (Healthy plant)  | 2.08                              | 2.79  | 3.75  | 2.31  |
| Positive control (Infected plant) | 7.71                              | 12.21 | 23.64 | 12.69 |
| T1 ( <i>T. harzianum</i> )        | 6.05                              | 9.03  | 6.74  | 2.69  |
| T2 ( <i>T. longibrachiatum</i> )  | 3.17                              | 3.85  | 12.15 | 12.44 |
| T3 ( <i>T. atroviride</i> )       | 6.38                              | 9.67  | 13.14 | 10.23 |
| T4 ( <i>B. subtilis</i> )         | 4.86                              | 6.76  | 15.98 | 7.35  |
| T5 ( <i>S. cerevisiae</i> )       | 5.11                              | 7.24  | 8.05  | 5.68  |
| T6 (ZnNPs 50ppm)                  | 5.40                              | 5.97  | 4.67  | 4.21  |
| T7 (ZnNPs 100ppm)                 | 5.43                              | 8.15  | 8.47  | 5.34  |
| T8 (ZnNPs 150ppm)                 | 5.76                              | 9.39  | 10.50 | 7.46  |
| T9 (TiNPs 50ppm)                  | 4.16                              | 5.42  | 6.82  | 5.90  |
| T10 (TiNPs 100ppm)                | 5.75                              | 8.45  | 8.89  | 6.94  |
| T11 (TiNPs 150ppm)                | 6.19                              | 10.21 | 11.53 | 9.54  |
| Mean                              | 5.23                              | 7.63  | 10.33 | 7.14  |
| LSD0.05 (Treatment)               | 0.31                              | 0.72  | 0.97  | 0.51  |

L.S.D least significant difference at  $P \leq 0.05$  by ANOVA.

#### 5. Effect of *F. solani* control treatments on total antioxidants (TA), total phenols (TP), total flavonoids (TF), and total terpenes (TT) in potato plants

Flavonoids, terpenes, antioxidants, and phenols are phytochemical substances with important antifungal properties. After infection with *F. solani*, secretion of these substances increased to resist the fungus, demonstrating increased levels of these chemicals in the infected control. After treatment, some materials can prevent *F. solani* growth and restore the levels of phytochemical compounds to near-natural levels. Treatment T2 (*T. longibrachiatum*) had the best treatment impact on flavonoids and terpenes (3.17 and 3.85 mg/g) respectively, and it was virtually at the level of

health control (2.08 and 2.79). Zinc nanoparticles at 50 ppm, on the other hand, had the greatest effect on both antioxidant and phenol levels because it was able to inhibit fungal development and thus lower their levels until they reached the normal level found in the uninfected control sample.

## Conclusion

This study highlights the significant role of *Fusarium* species, particularly *F. incarnatum*, *F. solani*, and *F. moniliforme*, in causing root rot and wilt in potato crops grown in Assiut governorate, Egypt. The different treatments applied to *Fusarium* showed significant antifungal activity, resulting in a considerable reduction in infection levels. In some cases, the treatments eliminated the root rot disease. Zinc oxide nanoparticles (ZnO NPs) and titanium dioxide nanoparticles (TiO<sub>2</sub> NPs) showed superior efficacy in controlling the pathogen. *Trichoderma* showed strong biocontrol potential. In contrast, other treatments showed comparatively lower effectiveness.

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## مكافحة مرض عفن جذور البطاطس المتسبب عن فطر الفيوزاريوم باستخدام بعض عوامل مكافحة الصديقة للبيئة

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### الملخص

نبات البطاطس هو نبات عشبي يكون درنات تحت سطح التربة *Solanum tuberosum*، وهو نبات من العائلة الباذنجانية. تصاب البطاطس بالعديد من الفطريات التي تسبب خسائر فادحة في الإنتاج صُممت هذه الدراسة لعزل وتحديد مسببات الأمراض الفطرية لتعفن جذور البطاطس في محافظة أسيوط، مصر. تم اختبار بعض عوامل مكافحة الحبيوية مثل *Bacillus subtilis*، *Saccharomyces cerevisiae*، وكذلك اختبار الخصائص المضادة للفطريات لجسيمات الزنك والتيتانيوم النانوية ضد أمراض تعفن جذور البطاطس التي يسببها *Fusarium spp*. تم إجراء التقييم من خلال قياس شدة المرض والتغيرات المورفولوجية والفسولوجية مثل مضادات الأكسدة الكلية والفينولات الكلية والفلافونويدات الكلية والتربينات الكلية في جذور النبات. كانت *F. incarnatum*، *F. moniliforme* هي الممرضات السائدة في 30 عينة مصابة بمدى شدة المرض من 0 إلى 83.3%. أظهرت النتائج أن المعاملات T3 (*Trichoderma atroviride*)، T4 (*B. subtilis*)، T8 (ZnNPs 150 ppm)، T11 (TiNPs 150 ppm) قللت من شدة المرض لتتخفص إلى 0%، وحسنت الخصائص المورفولوجية والفسولوجية للنبات مقارنةً بنباتات الكنترول المصابة. وأظهر البحث حلولاً فعالة متعددة لمكافحة مسببات مرض الفيوزاريوم في التربة، وإمكانية تطبيق هذه المعاملات في مكافحة تعفن جذور البطاطس وأمراض ذبولها

**الكلمات المفتاحية:** *Bacillus subtilis*، *Trichoderma sp.*، جزيئات نانومترية من الزنك، *Saccharomyces cerevisiae*، عفن الجذور.