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Effectiveness of *Ruta graveolens* and *Syzygium aromaticum* Extracts and the Nanoparticles of ZnO against *Rhizoctonia solani* and *Fusarium incarnatum* Causing the Damping-off Disease on Eggplants

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ABSTRACT

Background: Rhizoctonia and Fusarium are the most prevalent soil-borne fungi that lead to decline in a number of plants. *Rhizoctonia solani* is a pathogenic parasite that causes dangerous diseases on various vegetative crops. To evaluate the impact of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO against damping-off disease caused by *Rhizoctonia solani* and Fusarium *incarnatum*.

Methods: A pot experiment was conducted in the nursery of the Diyala Agriculture Directorate, Diyala Province, Iraq, in the season 2024-2025 to evaluate the effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO against the disease of damping off caused by *Rhizoctonia solani* and *Fusarium incarnatum*.

Result: The treatment of *R. graveolens* extract 4% + nano zinc oxide recorded the lowest infection incidence and disease severity with *F. incarnatum*, which reached 11.11%. The same treatment with the absence of pathogenic fungi achieved the highest chlorophyll at 62.30 SPAD followed by the treatment of *S. aromaticum* extract 4% + nano zinc oxide with *Fusarium incarnatum* at 61.37 SPAD. The treatment of *S. aromaticum* extract 4% + nano zinc oxide with the absence of pathogenic fungi recorded the highest wet and dry vegetative weight, which were 363.8 g and 34.10 g, respectively.

Key words: Nanoparticles of ZnO, *Ruta graveolens*, *Syzygium aromaticum*.

INTRODUCTION

Eggplant is one of the important crops in Iraq, both nutritionally and economically. It is grown in many regions of Iraq. Rhizoctonia and Fusarium are the most prevalent soil-borne fungi that lead to decline in a number of plants. *Rhizoctonia solani* is a pathogenic parasite that causes dangerous diseases on various vegetative crops. It exists spontaneously as vegetative hyphae and sclerotia due to the absence of conidia (Abdelaziz *et al.*, 2022). One of the most potent and destructive soil-borne diseases is Fusarium wilt, which is caused by the Fusarium fungus. By infecting host roots and colonizing xylem vessels, it causes plant wilting and substantial economic losses (Ahmed *et al.*, 2017). Plant extracts are the best alternatives to the hazardous chemicals, where decreasing their use is crucial to reducing the pollution. Therefore, it is necessary to choose friendly manners to promote plant growth (Al-Dhabaan *et al.*, 2017). *Ruta graveolens*, a plant belonging to the Rutaceae family, has the ability to produce furanocoumarins, which are phytoalexins play a role in the activity of antifungal and antimicrobial (Alharbi *et al.*, 2023). Clove (*Syzygium aromaticum* L.) is an important aromatic and medicinal plant belonging to the Myrtaceae family. It is rich in phenolic compounds, primarily eugenol, as well as terpene compounds and volatile esters such as eugenyl acetate, which give clove its unique aromatic and medicinal properties (He *et al.*, 2011).

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ZnO-NPs nanoparticles possess a high capacity to penetrate fungal cell walls and interact with their internal vital components such as proteins, nucleic acids and enzymes, leading to disruption of their basic vital processes, damage to the cellular structure, breakdown of plasma membrane functions and ultimately fungal cell death. Recent studies have confirmed that ZnO-NPs cause cell wall lysis, induce anatomical changes in the internal structure of fungal cells and reduce reproduction and germination rates, making them an effective agent in halting the spread of pathogenic fungi (Hassan and Yousif, 2013). One of the most important aspects of using ZnO-NPs in modern agriculture is the biogenic synthesis of these

nanoparticles using plant extracts as natural reducing agents and stabilizers. This method is an environmentally safe alternative to traditional chemical methods that may leave toxic residues or contribute to soil and water pollution. Studies have shown that using plant extracts such as *Ruta graveolens* and *Syzygium aromaticum* in ZnO-NP synthesis produces stable and effective particles characterized by low toxicity to beneficial organisms and greater sustainability when applied in agricultural environments (He *et al.*, 2011). The aim of this study was to evaluate the impact of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO against damping-off disease caused by *Rhizoctonia solani* and *Fusarium incarnatum*.

MATERIALS AND METHODS

A pot experiment was conducted in the nursery of the Diyala Agriculture Directorate, Diyala Province, Iraq, in the season 2024-2025. The study fungi were acquired from the Directorate of Diyala Agriculture's Plant Pathology Lab. They were molecularly identified using the PCR technique, with accession numbers OQ357844-OQ357845 for *R. solani* and OQ357846-OQ357847 for *F. incarnatum*.

Preparation and sterilization of soil

Soil from one of the fields in Diyala Governorate was used. It was cleaned and sifted to remove plant and weed residues. The soil was moistened and sterilized with formalin at a concentration of 3% of the commercial solution (37%). It was covered with nylon for 7 days and then ventilated for 7 days to get rid of the formalin vapors (He *et al.*, 2011).

Soil analysis

The soil was analyzed to identify some of its physical and chemical properties, as shown in Table 1, at the Soil and Water Laboratory-Diyala Agriculture Directorate and the Agricultural Research Department laboratories.

Preparing the fungal inoculum

An inoculum of *R. solani* and *F. incarnatum* was prepared, each individually, by growing on local millet seeds (*Panicum miliaceum* L.) after sterilizing the millet seeds inside 250 ml glass flasks using an autoclave (at a temperature of 121°C for 20 minutes) twice consecutively. Then, they were inoculated with 5 discs with a diameter of 0.5 cm, taken from the edges of fungal cultures grown on PDA medium at 7 days old. Then, the flasks were incubated at a temperature of 25±1°C for 10 days, taking care to shake continuously from time to time to ensure aeration and uniform distribution of the inoculum on all seeds (Milesi *et al.*, 2001).

Preparation of *R. graveolens* and *S. aromaticum* extracts

150 millilitres of deionised water (DW) and 350 millilitres of ethanol were mixed with ten grams of powdered *R. graveolens* and *S. aromaticum*. After that, the mixture was heated to 70°C for three hours while being stirred magnetically. Aluminium foil needed to be used to seal the glass flask. The extract was then stored in the refrigerator after the precipitation was separated using filter sheets (Whitman No. 1, pore size 25 µm).

Biosynthesis of zinc oxide nanoparticles from *R. graveolens* and *S. aromaticum* extracts

According to Otunola (2022), ZnO NPs were prepared by dissolving 10 g of $Zn(NO_3)_2 \cdot 6H_2O$ in 150 ml of D.W. while stirring for 30 minutes. Next, add 45 ml of either *R. graveolens* or *S. aromaticum* and stir for 60 minutes. After that, 20 ml of D.W. was mixed with 2.5 g of sodium hydroxide (NaOH) drop by drop. The mixture was then agitated for ten minutes until a milky precipitate formed. To get rid of any contaminants, the precipitate was cleaned four times using D.W. and ethanol before being dried for an hour at 150°C in an oven. Lastly, the white powder was calcined for three hours at 550°C.

Preparation of zinc oxide nanoparticles loaded on extracts of *R. graveolens* and *S. aromaticum*

Ten g of the previously prepared powder for each extract was weighed and dissolved in 100 ml of deionized distilled water; then 100 ml of each extract was added with continuous stirring on a hot plate magnetic stirrer and then precipitated with NaOH solution.

Addition of *R. solani* and *F. incarnatum* inoculum to the pots

Five g of the pathogenic fungi inoculum carried on millet seeds was added to the soil distributed in plastic pots with a capacity of 9 kg of soil/pot. After three days, the eggplant seedlings were planted at 4-5 weeks old with three replicates for each treatment, as three seedlings were planted in each pot and then thinned to two seedlings. Three replicates were also left for the control treatment (the eggplant seedlings were planted without adding the fungal inoculum).

Field experiment

A factorial experiment was designed in a randomized complete block design (RCBD) and included two factors; the first factor involved extracts of *R. graveolens* and

Table 1: Physical and chemical properties of soil.

Measurement	Value	Unit
pH	7.2	
Electrical conductivity EC	2.32	dS·m
Organic matter	0.2	g/kg·m
Available nitrogen	67	mg/kg·m
Potassium	46	mg/kg·m
Phosphorus	4.4	mg/kg·m
Clay	5.12	g/kg·m
Silver	2.16	g/kg·m
Sand	92.72	g/kg·m

S. aromaticum at three concentrations (0%, 2% and 4%) along with zinc oxide nanoparticles loaded and unloaded onto the plant extracts against *R. solani* and *F. incarnatum* and the second factor included the presence and the absence of the pathogenic fungi. Plants were sprayed with the extracts concentrations when infection appeared after 10 days until saturated, followed by a second spray after 20 days.

Infection incidence of eggplant seedlings (%)

The infection incidence was calculated using the following equation:

$$\text{Infection incidence \%} = \frac{\text{Number of infected plants}}{\text{Total nuber of plants}} \times 100$$

Percentage of infection severity (%)

The percentage of infection severity was estimated 30 days after planting according to the 5-point disease index described by Otunola (2022).

0 = Healthy plants, no disease symptoms.
1 = 1-10% show symptoms of wilting of the lower leaves.
2 = More than 11-25% show symptoms with slight stunting.
3 = More than 26-50% show brown discoloration with moderate stunting of the vegetative parts.
4 = More than 50% show dark discoloration with severe stunting of the vegetative parts.

$$\text{Infection sevirity \%} = \frac{\text{Number of plant in each grade} \times \text{Diease grade}}{\text{Total number of plants} \times \text{Highest infection grade}} \times 100$$

The findings of infection incidence, infection severity, wet and dry vegetative weight and chlorophyll were taken 30 days after planting.

Statistical analysis

The statistical data were analyzed using a randomized complete block design (RCBD) with a factorial experiment using the statistical program SPSS to analyze according to Duncan's multinomial test at a probability level of 0.05.

RESULTS AND DISCUSSION

Effect of *R. graveolens* and *S. aromaticum* extracts and the nanoparticles of ZnO on infection incidence of *R. solani* and *F. incarnatum* in the eggplant

The results in Table 2 indicate that there were significant differences among treatments in infection incidence as compared to the control, as treatment of *R. graveolens* extract 4% + nano zinc oxide achieved the lowest infection incidence, reaching 7.41%, followed by other treatments, while the control treatment recorded the highest infection incidence at 66.67%. In spite of no significant differences being observed in infection incidence between the pathogenic fungi *R. solani* and *F. incarnatum*, but it outperformed the treatment without fungi. Regarding the interaction between the treatments and the presence or absence of the pathogenic fungi. *R. graveolens* extract 4% + nano zinc oxide achieved the lowest infection incidence at 11.11% against *R. solani* and *F. incarnatum*, besides the treatment of *S. aromaticum* extract 4% + nano zinc oxide at 11.11% against *F. incarnatum* as compared with the control at 100% to each fungus.

Effect of *R. graveolens* and *S. aromaticum* extracts and the nanoparticles of ZnO on infection severity of *R. solani* and *F. incarnatum* in the eggplant

The results in Table 3 showed that there were significant differences among treatments in infection severity as compared to the control, as treatment of *R. graveolens* extract 4% + nano zinc oxide recorded the lowest infection severity, reaching 8.33 %, followed by *R. graveolens* extract 2% + nano zinc oxide and *S. aromaticum* extract 2% + nano

Table 2: Effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO on infection incidence of *Rhizoctonia solani* and *Fusarium incarnatum* in the eggplant.

Treatments	Without pathogenic fungi	With the presence of pathogenic fungi		Mean
		R. solani	*F. incarnatum*	
Control	0.0 d	100.00a	100.00a	66.67A
R. graveolens extract 2%	0.0 d	44.44b	44.44b	29.63B
R. graveolens extract 4%	0.0 d	33.33bc	33.33bc	22.22BC
Nano zinc oxide from *R. graveolens* extract 2%	0.0 d	33.33bc	33.33bc	22.22BC
Nano zinc oxide from *R. graveolens* extract 4%	0.0 d	33.33bc	33.33bc	22.22BC
R. graveolens extract 2% + nano zinc oxide	0.0 d	22.22cd	22.22cd	14.81CD
R. graveolens extract 4% + nano zinc oxide	0.0 d	11.11de	11.11de	7.41D
S. aromaticum extract 2%	0.0 d	55.55b	44.44b	33.33B
S. aromaticum extract 4%	0.0 d	44.44b	34.44bc	26.29BC
Nano zinc oxide from *S. aromaticum* extract 2%	0.0 d	33.33bc	22.22cd	18.52BC
Nano zinc oxide from *S. aromaticum* extract 4%	0.0 d	22.22cd	22.22cd	14.81CD
S. aromaticum extract 2% + nano zinc oxide	0.0 d	22.22cd	22.22cd	14.81CD
S. aromaticum extract 4% + nano zinc oxide	0.0 d	22.22cd	11.11de	11.11D
Mean	0.0 B	36.75A	33.42A	

zinc oxide, which amounted to 10.18%, while the control treatment recorded the highest infection severity at 54.63%. The infection severity achieved the lowest value in *F. incarnatum* at 27.77% with significant differences from *R. solani* at -29.70% and the absence of fungi at 0%. The treatment of *R. graveolens* extract 4% + nano zinc oxide recorded the lowest infection severity with *F. incarnatum* at 11.11%, whereas the control with *R. solani* recorded the highest infection severity at 83.33%, when the interaction between the treatments and the presence or absence of the pathogenic fungi.

Effect of *R. graveolens* and *S. aromaticum* extracts and the nanoparticles of ZnO on chlorophyll content of eggplants that are infected with *R. solani* and *F. incarnatum*

The result in Table 4 revealed that the chlorophyll content in the leaves is significantly different among treatments as compared to the control. The treatments of *S. aromaticum* extract 4% + nano zinc oxide, *R. graveolens* extract 4% + nano zinc oxide and nano zinc oxide from *S. aromaticum* extract 4% have the highest chlorophyll content, reaching 60.48, 59.46 and 59.01 SPAD, respectively, compared to

Table 3: Effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and their nanoparticles of ZnO on infection severity of *Rhizoctonia solani* and *Fusarium incarnatum* in the eggplant.

Treatments	Without pathogenic fungi	With the presence of pathogenic fungi		Mean
		R. solani	*F. incarnatum*	
Control	0.0 h	83.33a	80.55a	54.63A
R. graveolens extract 2%	0.0 h	33.33c	30.55cd	21.29B
R. graveolens extract 4%	0.0 h	27.78d	27.78d	18.52BC
Nano zinc oxide from *R. graveolens* extract 2%	0.0 h	30.55cd	30.55cd	20.37BC
Nano zinc oxide from *R. graveolens* extract 4%	0.0 h	27.78d	25.00de	17.59C
R. graveolens extract 2% + nano zinc oxide	0.0 h	16.66f	13.88f	10.18E
R. graveolens extract 4% + nano zinc oxide	0.0 h	13.88fg	11.11g	8.33E
S. aromaticum extract 2%	0.0 h	33.33c	33.33c	22.22B
S. aromaticum extract 4%	0.0 h	30.55cd	27.78d	19.44BC
Nano zinc oxide from *S. aromaticum* extract 2%	0.0 h	33.33c	27.78d	20.37BC
Nano zinc oxide from *S. aromaticum* extract 4%	0.0 h	25.00de	25.00de	16.67CD
S. aromaticum extract 2% + nano zinc oxide	0.0 h	16.66f	13.88fg	10.18E
S. aromaticum extract 4% + nano zinc oxide	0.0 h	13.88fg	13.88fg	9.26E
Mean	0.0 C	29.70A	27.77B	

Table 4: Effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO on chlorophyll content of eggplants that are infected with *Rhizoctonia solani* and *Fusarium incarnatum.*

Treatments	Without pathogenic fungi	With the presence of pathogenic fungi		Mean
		R. solani	*F.incarnatum*	
Control	62.30a	25.30d	26.97d	38.19E
R. graveolens extract 2%	58.17b	47.83c	51.17bc	52.39C
R. graveolens extract 4%	59.03ab	51.70bc	55.70bc	55.48BC
Nano zinc oxide from *R. graveolens* extract 2%	58.27ab	51.17bc	51.17bc	53.53C
Nano zinc oxide from *R. graveolens* extract 4%	60.03a	53.37bc	57.37ab	56.92B
R. graveolens extract 2% + nano zinc oxide	61.63a	54.17bc	58.17ab	57.99AB
R. graveolens extract 4% + nano zinc oxide	62.30a	57.03ab	59.03ab	59.46A
S. aromaticum extract 2%	60.03a	49.27c	51.83c	53.71C
S. aromaticum extract 4%	61.63a	50.77c	56.03bc	56.14B
Nano zinc oxide from *S. aromaticum* extract 2%	60.37a	53.50bc	52.83c	55.57B
Nano zinc oxide from *S. aromaticum* extract 4%	61.63a	55.70bc	59.70ab	59.01A
S. aromaticum extract 2% + nano zinc oxide	60.03a	56.17bc	58.50ab	58.23AB
S. aromaticum extract 4% + nano zinc oxide	61.70a	58.37ab	61.37a	60.48A
Mean	60.55A	51.10C	53.83B	

the control, which recorded 38.19 SPAD. The plants with the absence of the pathogenic fungi achieved the highest content of chlorophyll at 60.55 SPAD, followed by plants with *F. incarnatum* at 53.83 SPAD and with *R. solani* at 51.10 SPAD. The interaction between the treatments and the presence or absence of the pathogenic fungi showed that the treatments of *R. graveolens* extract 4% + nano zinc oxide and the control with the absence of the pathogenic fungi have the highest content of chlorophyll, reaching 62.30 SPAD, while the plants with *R. solani* and *F. incarnatum* recorded the lowest content of chlorophyll at 25.30 and 26.97 SPAD respectively.

Effect of *R. graveolens* and *S. aromaticum* extracts and the nanoparticles of ZnO on wet vegetative weight of eggplants that are infected with *R. solani* and *F. incarnatum*

The results in Table 5 indicate that -the wet vegetative weight is significantly different among treatments as compared to the control. The treatment of *S. aromaticum* extract 4% + nano zinc oxide recorded the highest wet vegetative weight, reaching 333.8 g, while the control recorded the lowest wet vegetative weight, 173.0 g. The plants with the absence of the pathogenic fungi achieved the highest wet vegetative weight at 357.8 g, followed by plants with *F. incarnatum* at 269.8 g and with *R. solani* at 240.7 g. The interaction between the treatments and the presence or absence of the pathogenic fungi showed that the control with the absence of the pathogenic fungi has the highest wet vegetative weight, amounting to 370.0 g, followed by the treatments of *S. aromaticum* extract 4% + nano zinc oxide with the absence of the pathogenic fungi and with *R. solani*, reaching 363.8 g, while the plants with *R. solani* and *F. incarnatum* recorded the lowest wet vegetative weight at 68.7 g and 80.4 g, respectively.

Effect of *R. graveolens* and *S. aromaticum* extracts and the nanoparticles of ZnO on dry vegetative weight of eggplants that are infected with *R. solani* and *F. incarnatum*

The results in Table 6 showed that the dry vegetative weight is significantly different among treatments as compared to the control. The treatments of *S. aromaticum* extract 4% + nano zinc oxide and *R. graveolens* extract 4% + nano zinc oxide recorded the highest dry vegetative weight, reaching 30.77 g and 30.54 g, respectively, while the control recorded the lowest dry vegetative weight, 21.0 g. The plants with the absence of the pathogenic fungi achieved the highest dry vegetative weight at 31.16 g, followed by plants with *F. incarnatum* at 26.43 g and with *R. solani* at 24.99 g. The interaction between the treatments and the presence or absence of the pathogenic fungi showed that the treatment of *S. aromaticum* extract 4% + nano zinc oxide in the absence of the pathogenic fungi has the highest dry vegetative weight, amounting to 34.10 g, while the plants with *R. solani* and *F. incarnatum* recorded the lowest dry vegetative weight at 14.13 g and 14.87 g, respectively.

Ethyl acetate extract from *R. graveolens* leaves shows strong antifungal activity against *Botrytis cinerea, Fusarium oxysporum* and *Colletotrichum* spp. The extract of *R. graveolens* exhibits fungicidal properties against key agricultural pathogens including *Colletotrichum fragariae*, *C. gloeosporioides*, *C. acutatum*, *Botrytis cinerea* and *Fusarium oxysporum* (Otunola, 2022; Yadav and Ghasolia, 2022).

In addition to preventing the mycelial growth of pathogenic fungus, zinc nanoparticles can either kill or stop germs from germinating (Pandey *et al.*, 2011). The survival of cotton seedlings was developed when ZnONPs was used against *R. solani*. In the pots study, foliar ZnONP spray outperformed seed covering in increasing plant dry

Table 5: Effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO on wet vegetative weight of eggplants that are infected with *Rhizoctonia solani* and *Fusarium incarnatum.*

Treatments	Without pathogenic fungi	With the presence of pathogenic fungi		Mean
		R. solani	*F. incarnatum*	
Control	370.0a	68.7d	80.4d	173.0D
R. graveolens extract 2%	347.1a	217.1c	257.1bc	273.7B
R. graveolens extract 4%	350.4a	233.8c	260.4b	281.5B
Nano zinc oxide from *R. graveolens* extract 2%	360.0a	226.9c	263.3b	283.4B
Nano zinc oxide from *R. graveolens* extract 4%	360.2a	250.2bc	280.2b	296.8AB
R. graveolens extract 2% + nano zinc oxide	360.2a	273.7b	326.9a	320.3C
R. graveolens extract 4% + nano zinc oxide	360.4a	360.4a	327.2a	332.7C
S. aromaticum extract 2%	347.2a	347.2a	260.5b	278.2B
S. aromaticum extract 4%	350.5a	350.5ac	260.5b	281.6B
Nano zinc oxide from *S. aromaticum* extract 2%	356.7a	356.7ac	263.3b	284.6B
Nano zinc oxide from *S. aromaticum* extract 4%	360.2a	360.2a	276.8b	299.1AB
S. aromaticum extract 2% + nano zinc oxide	364.2a	364.2a	323.6a	323.9A
S. aromaticum extract 4% + nano zinc oxide	363.8a	363.8a	327.1a	333.8A
Mean	357.8A	240.7C	269.8B	

Table 6: Effect of *Ruta graveolens* and *Syzygium aromaticum* extracts and the nanoparticles of ZnO on dry vegetative weight of eggplants that are infected with *Rhizoctonia solani* and *Fusarium incarnatum*.

Treatments	Without pathogenic fungi	With the presence of pathogenic fungi		Mean
		R. solani	*F. incarnatum*	
Control	34.07a	14.13f	14.87f	21.02D
R. graveolens extract 2%	28.43bc	24.10e	23.77e	25.43C
R. graveolens extract 4%	29.00bc	24.00e	25.33de	26.11BC
Nano zinc oxide from *R. graveolens* extract 2%	29.93bc	25.47de	27.27cd	27.56BC
Nano zinc oxide from *R. graveolens* extract 4%	30.37b	26.03de	27.37cd	27.92BC
R. graveolens extract 2% + nano zinc oxide	32.00ab	28.00bc	29.33bc	29.78AB
R. graveolens extract 4% + nano zinc oxide	33.10a	28.43bc	30.10b	30.54A
S. aromaticum extract 2%	28.77bc	23.77e	24.10e	25.54C
S. aromaticum extract 4%	30.00b	25.00de	25.67de	26.89BC
Nano zinc oxide from *S. aromaticum* extract 2%	30.93b	25.13de	27.93cd	28.00AB
Nano zinc oxide from *S. aromaticum* extract 4%	31.70ab	25.70de	28.03bc	28.48AB
S. aromaticum extract 2% + nano zinc oxide	32.67ab	27.00cd	29.67bc	29.78AB
S. aromaticum extract 4% + nano zinc oxide	34.10a	28.10bc	30.10b	30.77A
Mean	31.16A	24.99C	26.43B	

weight and managing the complex disease in beetroot roots, *Beta Vulgaris* L., which is caused by *Pectobacterium betavasculorum*, *Meloidogyne incognita* and *R. solani* (Salim *et al.*, 2016; Bashyal *et al.*, 2022). One primary mechanism of ZnONP toxicity against *R. solani* is mechanical encapsulation, which is believed to be how ZnONPs interact with pathogens) Aye and Matsumoto, 2011). This effect was evidenced by electron microscopy, which revealed clear deformations in the fungal hyphae of *F. oxysporum* treated with ZnO nanoparticles (Sivasankarapillai *et al.*, 2023). In their study of the antifungal activity of zinc nanoparticles (ZnONPs) against *F. oxysporum* on tomato plants, (Suresh *et al.*, 2015; Hong *et al.*, 2022) found that ZnONPs at concentrations of 1500-3000 g/ml produced the lowest disease severity and the disease incidence rate.

The use of zinc nanoparticles (ZnONPs) has greatly improved the survival rate of cotton plants affected by seedling damping off disease, leading to increased height and dry weight. They may create an antifungal layer around seeds, providing protection against fungi (Yehia and Ahmed, 2013). The application of zinc oxide nanoparticles (ZnO-NPs) as foliar sprays on tomato plants showed effective control of *Botrytis cinerea* infection, leading to reduced disease severity and increased plant biomass, indicating ZnO-NPs' growth-promoting capabilities. Treated plants exhibited elevated catalase and peroxidase activities, suggesting that ZnO-NPs may enhance resistance against *B. cinerea*, thereby providing an alternative to traditional fungicides for managing gray mold disease in tomatoes (Zaki *et al.*, 2021).

CONCLUSION

The study's results demonstrated that the treatment of *R. graveolens* extract 4% + nano zinc oxide was superior in reducing the incidence and disease severity and increasing chlorophyll, whereas the treatment of *S. aromaticum* extract 4% + nano zinc oxide was outperformed in increasing wet and dry vegetative weight. It can be concluded that *Ruta graveolens* and *Syzygium aromaticum* extracts, along with ZnO nanoparticles, could protect eggplant seedlings from damping-off disease and improve their growth characteristics.

Conflict of interest

The authors declare that no conflict of interest.

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