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Research Article

EFFECTIVENESS OF CERTAIN BIOLOGICAL AGENTS AND CHEMICAL INDUCERS IN CONTROLLING FUNGI RESPONSIBLE FOR ROOT ROT DISEASE IN EGGPLANT (*SOLANUM MELONGENA* L.)

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ABSTRACT

Eggplant root rot is a serious disease affecting crop production in Babylon Province, prompting this study to investigate the incidence, causal fungi, and potential biological control methods. The results from the surveyed fields revealed that eggplant root rot was present in all regions surveyed, with infection rates ranging from 20% to 100% and infection severity ranging from 5% to 60%. Several fungi were isolated from the roots of eggplants affected by root rot. The majority of isolates belonged to *Fusarium solani*, which was found in 7 areas of the surveyed field with an incidence rate of 74.14%, followed by *Rhizoctonia solani* with an incidence rate of 36.2%. Pathogenicity tests showed that these fungal isolates infected eggplant seeds. The study also showed that *Pseudomonas fluorescens* inhibited the growth of both *R. solani* and *F. solani* on PDA medium, with the inhibition rate reaching 100%. Furthermore, the addition of chitosan to the culture medium at all tested concentrations also inhibited the growth of both fungi. At concentrations of 5%, 10%, and 15%, the inhibition rate was particularly high, and the inhibitory effect of chitosan increased with rising concentration. Results from the greenhouse experiment indicated that all treatments, including *P. fluorescens*, chitosan, and their combination, significantly reduced both the infection rate and the severity of root rot. Moreover, these treatments contributed to improved growth parameters of the eggplant plants. These findings demonstrate that *P. fluorescens* and chitosan, alone or combined, effectively control eggplant root rot and enhance plant growth in Babylon Province.

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INTRODUCTION

Eggplant (*Solanum melongena* L.) belongs to the Solanaceae family and is considered the fifth most popular vegetable crop in the world (Chioti et al., 2022; Ebrahimi et al., 2023). In Iraq, eggplant is regarded as one of the most important crops both economically and nutritionally. The cultivated area under eggplant has increased, especially in greenhouses, to meet the growing market demand. In 2022, the area planted with eggplant in Iraq was approximately 12388 hectares, with a total yield of 183,056 tons. Of this, production in Babylon Governorate alone amounted to 27,540 tons (CSOI, 2022). Eggplant is highly susceptible to a range of biotic stresses that significantly reduce its yield and quality. Soil-borne fungi such as *Fusarium* spp., *Rhizoctonia solani*, and *Macrophomina phaseolina* are major contributors to root rot, seedling damping-off, and vascular wilt, leading to poor plant establishment and stunted growth (Iqbal and Mukhtar, 2014; Iqbal et al., 2014). Root-knot nematodes (*Meloidogyne* spp.), cause gall formation on roots, impairing water and nutrient uptake, ultimately resulting in reduced plant vigor and productivity (Khan et al., 2019). Bacterial wilt caused by *Ralstonia solanacearum* is another devastating disease that infects the vascular system, causing rapid wilting and plant death, especially under warm and moist conditions (Aslam et al., 2019). In addition to these pathogens, insect pests such as the brinjal shoot and fruit borer (*Leucinodes orbonalis*) and stem borer (*Euzophera perticella*) inflict severe damage by boring into shoots and fruits, leading to yield losses and reduced market value (Javed et al., 2017a, b; Kassi et al., 2019; Muhammad et al., 2021a, b).

Among biotic factors, root rot is one of the most serious and widespread soil-borne diseases affecting eggplant. The extent of crop loss caused by this disease is largely influenced by the planting season, the amount of pathogenic fungal inoculum present in the soil, and the interaction with other biological factors (Dar et al., 2018; Matloob, 2019; Al-Baldawy et al., 2021). The fungi *Fusarium solani*, *F. oxysporum*, *R. solani*, and *M. phaseolina* are among the most common soil-borne pathogens responsible for root rot, seed rot, seedling damping-off, and wilt in eggplant (Sadegh et al., 2008; Dar et al., 2018; Mahdi and Jumaah, 2020; Iqbal and Mukhtar, 2020a, b).

The combined impact of these pests and pathogens necessitates integrated management approaches involving host resistance, cultural practices, and biological or ecological controls to ensure sustainable eggplant production. Biological control agents are increasingly being used as alternatives to chemical pesticides. These organisms function as biopesticides, enhancing crop protection and improving yields (Matloob and Al-Baldawy, 2020; Attia et al., 2022; Elnahal et al., 2022). Among the most effective biological agents are Plant Growth-Promoting Rhizobacteria (PGPR) (Shahzaman et al., 2015; Batool et al., 2020; Azeem et al., 2025). Chitosan also plays a significant role in inducing plant resistance against pathogens (Makhlouf et al., 2022; Nedved et al., 2022).

Given the economic significance of seedling damping-off and root rot in eggplant, and the limited studies available on controlling these diseases using biological agents, this study aims to evaluate the effectiveness of PGPR and the chemical elicitor chitosan in controlling major pathogens responsible for root rot in eggplant.

MATERIALS AND METHODS

Field survey

A field survey was conducted at eleven eggplant fields and nurseries located in Babylon Province from March 26 to May 14, 2024 (Table 1). The number of infected plants was recorded, and disease incidence was calculated for each field (Al-Juboory et al., 2016; Al-Shebly et al., 2020) using the following formula:

$$\text{Disease incidence (\%)} = \frac{\text{Number of diseased seedlings}}{\text{Total number of seedlings}} \times 100$$

The severity of root system infection was assessed using a 6-point disease index:

0 = Healthy plant

1 = 0-25% of roots affected with rot and brown discoloration

2 = 26-50% of roots affected

3 = 51-75% of roots affected

4 = 76-100% of roots affected

5 = Plant death

Disease severity was calculated using the formula (McKinney, 1923):

$$\text{Disease Severity (\%)} = \frac{\Sigma\ (\text{Number of plants in each grade} \times \text{grade value})}{\text{Total number of plants} \times 5} \times 100$$

Isolation and identification of fungi associated with diseased eggplant roots

Root samples showing symptoms of root rot (wilting, yellowing, weak growth, and brown rots on main and secondary roots) were collected during the survey. Infected root pieces were surface sterilized and transferred (four pieces per plate) to Petri dishes (9 cm diameter) containing Potato Dextrose Agar (PDA). Plates were incubated at 25 ± 1°C for three days. Fungal colonies were purified and identified to genus level using taxonomic keys (Parmeter and Whitney, 1970; Booth, 1971; Dugan, 2006). The frequency of fungal occurrence was calculated using the formula by Hussein and Juber (2014):

$$\text{Fungal frequency (\%)} = \frac{\text{Number of root pieces with pathogenic fungi}}{\text{Total number of root pieces}} \times 100$$

Pathogenicity test

Using cabbage seeds on PDA

The pathogenicity of 7 isolates of *F. solani*, 7 isolates of *R.solani*, and 6 isolates of *M. phaseolina* was tested (Bolkan and Butler, 1974). A 0.5 cm disk from each fungal isolate was placed at the center of a PDA plate. After three days of incubation at 25 ± 1°C, 10 cabbage seeds were sown in each plate. Germination percentage was recorded once all seeds in the control plates had germinated.

Effects of fungal isolates on eggplant seeds

This experiment was conducted under net shade conditions (Sirran), Department of Biological Control Technologies. Fungal inoculum was prepared by culturing isolates on local millet seeds (*Panicum miliaceum L.*) following Dewan (1989). The fungal inoculum isolates used in the study included *F. solani* (Fs-2, Fs-3, and Fs-4) and *R. solani* (Rs-3, Rs-4, and Rs-5). Ten surface-sterilized local eggplant seeds were planted in pots treated with fungal inoculum. Pots were carefully watered, and germination percentage was recorded once the control treatment had fully germinated.

Determination of effective concentration of *Pseudomonas fluorescens* suspension

A bacterial inoculum of *P. fluorescens* was obtained from the Plant Diseases Laboratory and cultured in Nutrient Broth. Cultures were incubated at 37°C for 48 h (Bakker et al., 1986). Serial dilutions (10^{-1} to 10^{-5}) of the bacterial suspension were prepared, and 1 ml of each dilution was spread on PDA plates.

Fungal disks (0.5 cm diameter) from *R. solani* (Rs-3) and *F. solani* (Fs-2) were placed on the plates. Plates were incubated at 28 ± 2°C. Fungal growth inhibition was calculated using the formula by Montealegre et al. (2003):

$$\text{Inhibition (\%)} = \frac{C - c}{C} \times 100$$

Where:

C = Fungal radius in the control and

c = Fungal radius in presence of the bacterial isolate

The most effective bacterial isolate was selected for further experiments.

Antifungal activity of chitosan against *F. solani* and *R. solani*

Chitosan (HI Media, India) was prepared by dissolving 20 g of chitosan in 50 ml acetic acid and making up the volume to 1000 ml with distilled water. This stock solution was used to prepare 5%, 10%, and 15% concentrations by adding the required volume to 100 ml of PDA medium. The media were poured into Petri dishes and inoculated with 0.5 cm disks from 7-day-old pure cultures of *F. solani* (Fs-2) and *R. solani* (Rs-3). Plates were incubated, and inhibition percentage was calculated as previously described.

Evaluation of *P. fluorescens*, chitosan, and beltanol fungicide against root rot pathogens under greenhouse conditions

This experiment was carried out in a plastic greenhouse at the Department of Biological Control Technologies, Al-Mussaib Technical College, during the autumn season of 2024-2025.

A soil-peat moss mix (1:2) was sterilized using 40% commercial formalin at 20 ml/L. The treated soil was covered with transparent nylon and left in the sun for seven days, followed by three days of ventilation (Al-Karawi, 2021). The soil was then filled into 4-kg plastic pots.

Four 30-day-old seedlings (cv. Barcellona) were planted in each pot. The experimental design was a Completely Randomized Design (CRD) with three replications. Fungal inoculum (*F. solani* Fs-2 and *R. solani* Rs-3) was applied five days before planting using millet seeds as the carrier.

P. fluorescens suspension (10 mL) was applied to each planting hole. Chitosan (10%) was sprayed at planting and again one month later on the foliage. Beltanol fungicide (1%) was applied as a soil drench one day after fungal inoculation.

Three months post-planting, disease incidence and severity of root rot were evaluated. Growth parameters, including plant height, root length, root volume, and fresh and dry weights of shoots and roots, were recorded. Root volume was determined by water displacement using a graduated cylinder.

RESULTS AND DISCUSSION

Field survey of eggplant root rot disease

According to Table 1, the results of the field survey revealed the occurrence of eggplant root rot in all zones, with infection rates ranging from 20% to 100% and infection severity ranging from 5% to 60%. The highest infection rates were recorded in the fields of Al-Akir, Al-Imam district, and Muwailiha, each reaching 100%, followed by the Al-Tali'ah area with an infection rate of 90%. The spread of the disease in these areas may be attributed to the repeated cultivation of eggplant or the cultivation of other crops from the Solanaceae family in the same fields. This likely led to the accumulation of pathogenic fungal inoculum, mainly sclerotia, along with favorable environmental conditions (El-Mougy et al., 2011; Al-Shebly, 2022).

Table 1. Incidence of eggplant root rot infection in Babylon province.

Sr. No.	Site-Babylon	Diseases incidence (%)	Disease severity (%)
1	District/Kutha/Akir area	100	60
2	Centre of Hillah city/Rashidiya	20	5
3	Al-Mahawil District/Imam area	100	51
4	Al-Musayyab Project/Al-Azzawiya	100	52
5	Al-Mahawil/Muwailha	70	50
6	Al-Qasim District/Al-Tali'ah area	90	54
7	Kutha District/Rashid area	35	10
8	Kutha District/Zubaidi area	20	8
9	Al-Nil District/Kish	60	28
10	Kutha District/Al-Sumoud area	60	48
11	Kutha District/Abu Sha'ir area	40	16

Isolation of fungi associated with eggplant roots affected by root rot disease

The diagnostic results revealed the presence of several fungal genera isolated from the roots of eggplant plants exhibiting root rot symptoms. These symptoms included brown discoloration, partial or complete root decay, and yellowing and wilting of the leaves. *Fusarium solani* was the most frequently isolated pathogenic fungus, found in samples from seven surveyed areas, with an overall incidence rate of 74.14% and a maximum incidence of 95%. It was followed by *Rhizoctonia solani*, also isolated from seven areas, with an overall incidence rate of 36.2% and a maximum incidence of 81% (Table 2, Figure 1). These findings align with previous studies that have confirmed the involvement of these fungi in root rot diseases affecting various crops.

In addition, several other fungal species were identified at lower frequencies in association with diseased eggplant roots. These included *Trichoderma* spp. (12%), *Fusarium oxysporum* (8%), *Aspergillus niger* (6%), *Penicillium* spp. (25%), *Sclerotinia sclerotiorum* (30%), *Alternaria alternata* (22%), and *Mucor* spp. (14%). These results are consistent with the findings of Al-Janabi (2022), who reported that *F. solani* and *R. solani* are among the primary pathogens causing root rot and seedling damping-off in eggplants.

Table 2. Percentage of fungi associated with eggplant roots affected by root rot disease in Babylon province.

Names of fungi	Rashidiya	Akir	Imam	Muwailha	Al-Azzawiya	Tali'ah	Rashid	Zubaidi	Kish	Abu Sha'ir	Sumoud	Rate (%)	Highest (%) presence rate
F. solalni	60	95	93	93	-	-	-	50	66	-	62	74.14	95
R. solani	25	30	25	-	81	37	25	-	-	31	-	36.2	81
M. phaseolina	30	25	-	68	31	38	-	10	-	-	-	33.66	68
Trichoderma spp.	8	8	-	-	-	12	-	-	-	-	-	10	12
F. oxysporum	10	8	-	-	10	-	-	-	-	6	-	8.5	10
A.nigeria	4	4	-	-	6	-	-	6	1	6	-	4.5	6
Pencillium spp.	8	13	-	-	-	-	-	-	25	6	6	11.6	25
S. sclerotium	-	30	-	-	-	-	-	-	-	-	-	30	30
A.alternata	10		22	-	-	-	-	12	-	-	--	14.67	22
Mucor spp.	-	14	12	-	-	-	-			11	-	12.33	14

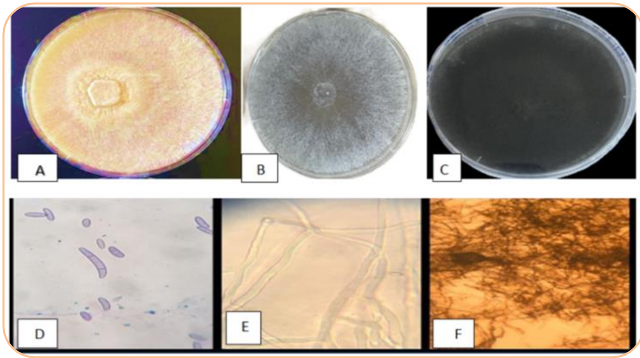

Figure 1. Most frequently isolated fungi from eggplant roots affected by root rot disease. A = F.solani; B = R. solani; C = M. phaseolina; D = Large and small conidia of F. solani under a microscope (40×); E = Sclerotia of R. solani (40×); F = Sclerotia of M. phaseolina (40×).

Pathogenicity test

Pathogenicity test of pathogenic fungal isolates using cabbage seeds on PDA media

All tested pathogenic isolates caused a decrease in the percentage of seed germination, as shown in Table 3, when compared with the control treatment. The germination percentage in the control reached 100%, while the *F. solani* isolate (Fs2) (Akir isolate) caused germination to drop to 0.00% (Figure 2). The Table also showed that all tested *R. solani* isolates caused a significant reduction in seed germination compared to the control. Moreover, the *M. phaseolina* isolates caused a noticeable reduction in germination percentage.

The variation in the effect of these isolates on cabbage seed germination may be due to genetic differences among isolates collected from different regions or differences in their ability to produce toxins or enzymes that degrade pectin and cellulose during the early stages of infection. These enzymes, including phosphatase, pectinase, cellulase, and pectin lyase, are crucial for the fungi to infect plants by penetrating their hosts. This was supported by Wrather et al. (1997). These findings also agree with those of Matloob et al. (2019) and Khudier and Abdalmoohsin (2023), who identified these fungi as major causes of root rot disease and among the most important pathogens affecting many plant families.

Pathogenicity test of *F. solani* and *R. solani* on eggplant seed germination in plastic pots

As shown in Table 4, the pathogenicity test revealed that the fungal isolates were able to infect eggplant seeds. The germination percentage dropped to 0.00% for the Fs2 isolate, while the control treatment recorded 100% germination. The germination percentages for the isolates Fs3 and Fs4 were 23.3% and 36.7%, respectively. Similarly, the germination percentage dropped to 0.00% for the Rs3 isolate compared to 100% germination in the control (untreated) seeds.

These results are consistent with previous studies documenting the emergence and spread of pathogenic soil fungi on eggplants, causing root rot in eggplants and other crops, with *Fusarium* sp. and *R. solani* being the most notable pathogens (Mwaniki et al., 2015; Mishra, 2017).

Table 3. Identification of fungal isolates associated with diseased eggplant roots using cabbage seeds.

Sr. No.	Isolate	Site	No. of seed germinated	% Germination
1	Control	-	10.00	100.00
2	Fs1	Rashidiya	5.00	50.00
3	Fs2	Akir	0.00	0.00
4	Fs3	Imam	1.00	10.00
5	Fs4	Muwailha	1.33	13.33
6	Fs5	Zubaidi	4.00	40.00
7	Fs6	Kish	2.33	23.33
8	Fs7	Sumoud	2.00	20.00
9	Rs1	Rashidiya	3.66	36.67
10	Rs2	Akir	2.66	26.67
11	Rs3	Imam	0.00	0.00
12	Rs4	Al-Azzawiya	1.00	10.00
13	Rs5	Tali'ah	1.33	13.33
14	Rs6	Rashid	3.33	33.33
15	Rs7	Abu Sha'ir	2.66	26.67
16	Mp1	Rashidiya	3.66	36.67
17	Mp2	Akir	3.00	30.00
18	Mp3	Muwailha	4.33	43.33
19	Mp4	Al-Azzawiya	5.33	53.33
20	Mp5	Tali'ah	2.66	26.67
21	Mp6	Zubaidi	3.33	33.33
		LSD=0.05	1.0170	10.170

Each number represents the average of three replicates. Rs represents the fungus *R. solani*, Fs stands for *F. solani*, and Mp denotes *M. phaseolina*. The numbers following each symbol indicate the number of isolates.

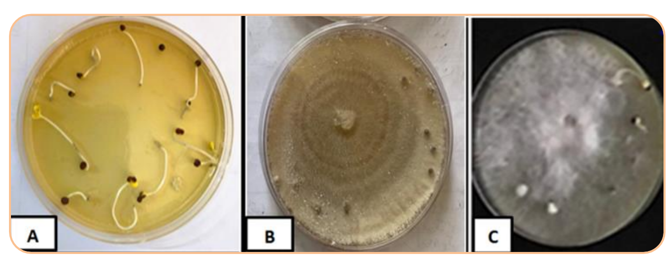

Figure 2. Pathogenicity of fungi isolated from eggplant roots infected with root rot disease. A = Comparison using lettuce seeds; B = Pathogenicity of *R. solani*; C = Pathogenicity of *F. solani*.

Table 4. Pathogenicity test of *F. solani* and *R. solani* on the growth of eggplant seedlings in plastic pots.

Sr. No.	Isolate	No. of seed germinated	Percent Germination
1	Control	10.00	100.00
2	Fs2	0.00	0.00
3	Fs3	1.00	23.3
4	Fs4	1.33	36.7
5	Rs3	0.00	0.00
6	Rs4	1.00	36.7
7	Rs5	1.33	40.00
0.05=LSD		1.146	11.46

Fs = *F. solani*, and Rs = *R. solani*.

Testing the antagonistic ability of *P. fluorescens* against the pathogenic fungi *R. solani* and *F. solani*

According to Table 5 and Figure 3, the results demonstrated the ability of *P. fluorescens* to inhibit the growth of *F. solani* (Fs2) and *R. solani* (Rs3) isolates on PDA. *P. fluorescens* exhibited its maximum inhibitory effect at a concentration of 10^{-1}, completely suppressing the growth of both pathogenic fungi, resulting in 100.00% inhibition.

These findings are in agreement with previous studies that have confirmed the antagonistic potential of *P. fluorescens* against *F. solani* and *R. solani* (Al-Fadhal et al., 2019; Alsudani, 2020; El-Sharkawy and Abdelrazik, 2022). Similarly, Singh et al. (2021) reported that *P. fluorescens* inhibited the growth of *R. solani* and *F. oxysporum* on PDA medium by 80% and 40%, respectively. These results are also consistent with the findings of Nain et al. (2023), who observed that *P. fluorescens* inhibited *F. solani* growth by 70.29% compared to the control treatment, which showed no inhibition (0.00%). The test results reported by Suma et al. (2023) also demonstrated the effectiveness of *P. fluorescens* in inhibiting the growth of the pathogenic fungus *R. solani* on King's B medium, showing an inhibition rate of 65.93% compared to 0.00% in the control treatment with the pathogen alone.

Evaluation of the efficiency of chitosan in inhibiting the growth of *F. solani* and *R. solani*

The results presented in Table 6 and Figure 4 demonstrated that the addition of chitosan to the culture medium at all tested concentrations effectively inhibited the growth of *F. solani* and *R. solani* on PDA. Specifically, chitosan treatment against the pathogenic *F. solani* isolate Fs2 at concentrations of 5%, 10%, and 15% resulted in high inhibition rates, 94.4% at 5% and 100% at both 10% and 15%, compared to the untreated control, which showed 0.00% inhibition.

Table 5. Effect of *P. fluorescens* on the pathogenic fungi *F. solani* and *R. solani* on PDA.

Treatment	Concentration	Colony diameter	Percent Inhibition
P. f+Fs2	Control	9.00	0.00
	10^{-1}	0.00	100.00
	10^{-2}	1.33	85.33
	10^{-3}	2.50	73.00
	10^{-4}	3.00	67.00
	10^{-5}	3.50	62.00
Rs3+P.f	Control	9.00	0.00
	10^{-1}	0.00	100.00
	10^{-2}	1.00	89.00
	10^{-3}	2.00	78.00
	10^{-4}	2.50	73.00
	10^{-5}	3.00	67.00
0.05= L.S. D		0.2809	3.089

Fs = *F. solani*, Rs = *R. solani*, and Pf = *P. fluorescens*.

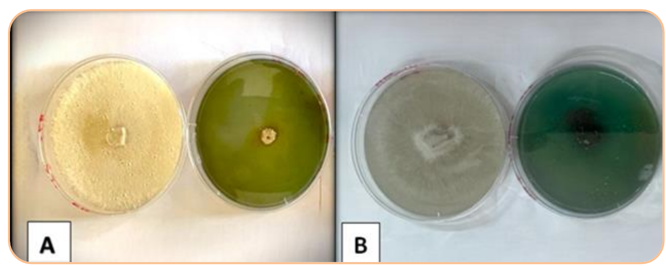

Figure 3. Antagonistic activity of *P. fluorescens* against two pathogenic fungi on PDA culture medium: A = in interaction with the pathogenic fungus *F. solani*; B = in interaction with the pathogenic fungus *R. solani*.

Similarly, the inhibition rates of *R. solani* growth were 96.66% at 5% chitosan concentration and 100% at 10% and 15%. These findings indicate that the inhibitory effect of chitosan increases with its concentration, possibly due to its action on fungal DNA, leading to the inactivation of enzymes and proteins essential for fungal growth.

Supporting this, Iqbal et al. (2024) reported that chitosan's antifungal mechanism involves increasing fungal cell membrane permeability through the interaction of positively charged chitosan with negatively charged fungal membranes. This interaction disrupts DNA, inhibiting the synthesis of essential enzymes and proteins. These results are consistent with those of Ghule et al. (2021), who found that the inhibitory effect of chitosan against *F. solani*, the causal agent of tomato root rot, also increased with concentration. At 1% chitosan, the inhibition rate reached 89.6%, whereas it was only 20% at 0.2%.

Similarly, findings by Balodi et al. (2023) and Al-Khafaji (2024) support the inhibitory effect of chitosan on various fungal pathogens, including *F. solani*, *R. solani*, *Botrytis cinerea*, and *Aspergillus flavus*.

Table 6. Effect of different concentrations of chitosan on the inhibition of *F. solani* and *R. solani* on PDA.

Treatment	Concentration	Colony diameter	Percent Inhibition
Chitosan + *F.solani*2	5%	0.50	94.44
	10%	0.00	100.00
	15%	0.00	100.00
	Control	9.00	0.00
Chitosan + *R.solani*3	5%	0.30	96.66
	10%	0.00	100.00
	15%	0.00	100.00
	Control	9.00	0.00
LSD= 0.05		0.0865	0.961

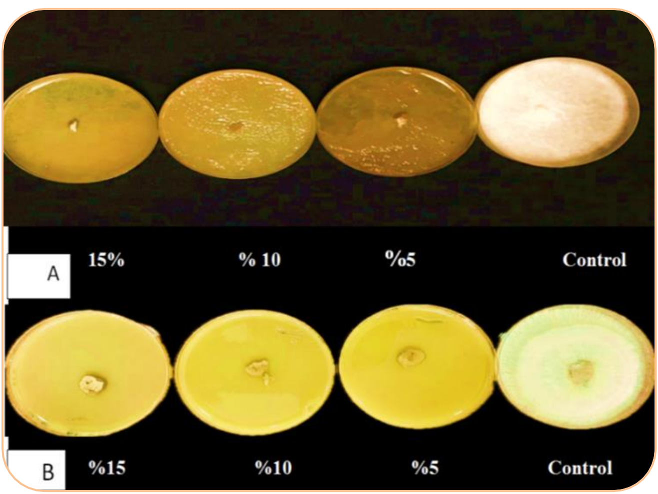

Figure 4. Effects of chitosan at concentrations of 5%, 10%, and 15% against (A) *F. solani* and (B) *R. solani* on PDA.

Evaluation of *P. fluorescens*, chitosan, and beltanol for managing eggplant root rot (*F. solani* and *R. solani*) and enhancing growth under greenhouse conditions

The results (Table 7) showed that all treatments, whether applied individually or in combination, significantly reduced the incidence and severity of eggplant root rot compared to the control treatments inoculated only with the pathogens *R. solani* and *F. solani*, which showed infection rates of 100%, 75%, and 80%, respectively. The combined treatment of *P. fluorescens* and chitosan in the presence of the pathogens showed the highest efficacy, reducing infection rates to 16.67% for both *R. solani* and *F. solani*, with corresponding disease severity of 5% and 8.33%, respectively.

All treatments also led to improvements in various growth parameters of eggplants, including plant height, root length, root volume, and the fresh and dry weights of both shoots and roots, compared to the pathogen-only controls. In contrast, the *R. solani* and *F. solani* treatments alone caused significant reductions in these growth metrics, with values recorded as follows: plant height, 18.53 cm and 17.17 cm; root length, 21.66 cm and 20.33 cm; root volume, 3.10 ml and 3.00 ml; fresh shoot weight, 11.20 g and 10.03 g; dry shoot weight, 2.50 g and 2.00 g; fresh root weight, 3.53 g and 3.36 g; and dry root weight, 0.33 g and 0.21 g, respectively.

Among all treatments, the combination of *P. fluorescens* and chitosan in pathogen-infested soil was significantly superior, with enhanced growth parameters: plant height, 35.87 cm and 34.03 cm; root length, 44.10 cm and 44.00 cm; root volume, 8.00 ml for both pathogens; fresh shoot weight, 35.00 g and 34.00 g; dry shoot weight, 6.40 g and 6.00 g; fresh root weight, 8.53 g and 8.11 g; and dry root weight, 1.70 g and 1.67 g, respectively, compared to the pathogen-only treatments. These results are in agreement with those of Ding et al. (2024), who reported that *P. fluorescens* significantly inhibited black mold and root rot in tobacco caused by *F. solani*. Similarly, Sultana et al. (2017) demonstrated the effectiveness of chitosan in protecting plants from pathogenic fungi and enhancing growth through foliar application in the early stages of tomato and eggplant cultivation. Furthermore, these findings align with those of Cheng et al. (2025), who confirmed the efficacy of chitosan in protecting plants against fungal infections.

CONCLUSIONS

The current study concludes that eggplant root rot disease is prevalent across all areas surveyed in Babylon Governorate. *Rhizoctonia solani* and *Fusarium solani* were the most frequently isolated pathogens from diseased and infected eggplant plants. Plant Growth-Promoting Rhizobacteria were isolated from the rhizosphere of healthy eggplant plants, with one isolate identified as *Pseudomonas fluorescens*. This bacterium was effective in inhibiting the growth of both fungal pathogens on potato dextrose agar medium.

Moreover, chitosan at all tested concentrations was capable of inhibiting fungal growth on PDA, with the inhibitory effect increasing at higher concentrations. Both *P. fluorescens* and chitosan, when applied individually or in combination, significantly reduced disease incidence and severity, enhanced plant protection against pathogens, and improved the growth parameters of eggplant under greenhouse conditions.

Table 7. Evaluation of the efficacy of *P. fluorescens* and chitosan against the pathogenic fungi *R. solani* and *F. solani*, and their effects on the growth parameters of eggplant under greenhouse conditions.

Sr. No.	Treatment	Disease Incidence %	Severity %	Shoot Length (cm)	Shoot Weight (g)		Root Length (cm)	Root Volume (ml)	Root Weight (g)	
					Fresh	Dry			Fresh	Dry
1	Rs3	100	75.00	18.53	11.20	2.50	21.66	3.10	3.53	0.33
2	Rs3 + Pf	25.00	15.00	35.06	32.36	5.80	40.00	7.10	6.94	1.32
3	Rs3 +Ch	50.00	20.00	33.25	31.33	5.23	37.20	6.80	6.25	1.21
4	Rs3 + Pf +Ch	16.67	5.00	35.87	35.00	6.40	44.10	8.00	8.53	1.70
5	Rs3 + Bel	0.00	0.00	30.21	30.00	4.00	35.00	5.15	6.00	1.21
6	Fs2	100	80.00	17.17	10.03	2.00	20.33	3.00	3.36	0.21
7	Fs2 + Pf	25.00	16.66	33.93	31.50	5.60	39.00	7.00	6.70	1.31
8	Fs2 + ch	50.00	21.66	33.03	31.03	5.00	37.00	6.20	5.15	1.18
9	Fs2 + Pf + Ch	16.67	8.33	34.03	34.00	6.00	44.00	8.00	8.11	1.67
10	Fs2 + Bel	0.00	0.00	30.20	30.00	4.00	34.00	5.00	6.00	1.21
11	Pf	0.00	0.00	40.50	37.00	8.00	46.00	10.33	10.50	2.96
12	Ch	0.00	0.00	35.07	35.46	7.00	45.00	9.00	9.00	2.16
13	Pf+ Ch	0.00	0.00	43.07	39.86	9.00	49.00	12.00	10.7	3.34
14	Control	0.00	0.00	32.20	30.50	4.37	35.40	5.20	6.50	1.51
LSD=0.05		9.124	4.470	0.894	0.9466	0.8010	0.999	0.894	1.315	0.132

Each number represents the average of three replicates. Fs = *F. solani*, Rs = *R. solani*, Pf = *P. fluorescens*, Ch = Chitosan, Bel = Beltanol.

AUTHORS' CONTRIBUTIONS

RAAA and AAAHM conceptualized the idea and designed the study; RAAA collected the samples and conducted the experiments; AAAHM isolated, purified, and identified the fungi, performed statistical analysis, and supervised the research; RAAA wrote the first draft; AAAHM proofread the manuscript; Both authors approved the final version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUSTAINABLE DEVELOPMENT GOALS TARGETED

SDG 2: Zero Hunger

SDG 12: Responsible Consumption and Production

SDG 13: Climate Action

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