



Available Online at EScience Press

Plant Protection

ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

Research Article

Efficacy of Salicylic Acid and *Catharanthus roseus* Leaf Extract in Mitigating Pepper Root Rot Caused by *Fusarium solani*

Lara Basheer Yasir, Nawres Al-Kuwaiti

Plant Protection Department, College of Agricultural Engineering Sciences (CAES), University of Baghdad, Baghdad, Iraq.

ARTICLE INFO

Article history

Received: 22nd February, 2026

Revised: 18th May, 2026

Accepted: 23rd May, 2026

Keywords

Salicylic acid

Catharanthus roseus

Pepper root rot

Fusarium solani

Disease management

ABSTRACT

Fusarium solani is a destructive soil-borne pathogen causing root rot and significant losses in pepper production. The present study evaluated the efficacy of salicylic acid (SA), *Catharanthus roseus* leaf extract, and the fungicide Basten in suppressing *F. solani*, improving plant growth, and modulating the rhizospheric microbiome of pepper plants. Under *in vitro* conditions, all treatments significantly inhibited fungal growth compared with the untreated control. Basten exhibited the highest antifungal activity, reducing colony diameter to 2.1 cm with 75.29% inhibition, followed by SA at 200 ppm (55.29%) and *C. roseus* leaf extract at 200 mg L⁻¹ (50.59%). In pot experiments, Basten, SA (200 ppm), and *C. roseus* extract (200 mg L⁻¹) significantly improved seed germination (93.3%, 88.7%, and 86.0%, respectively) and reduced seedling mortality compared with the infected control. These treatments also enhanced plant height, fresh shoot and root weights, and leaf protein content under pathogen stress. SA at 200 ppm produced growth and physiological responses comparable to those of Basten. Furthermore, all treatments increased rhizospheric microbial populations, with SA (8.5×10^6 cfu g⁻¹ soil) and Basten (8.9×10^6 cfu g⁻¹ soil) showing the highest microbial densities. In conclusion, SA at 200 ppm effectively suppressed *F. solani*, enhanced plant growth and protein accumulation, and promoted beneficial rhizospheric microorganisms, performing similarly to the chemical fungicide. *C. roseus* leaf extract also showed promising bioactivity, highlighting its potential as an eco-friendly component of integrated pepper root rot management.

Corresponding Author: Nawres Al-Kuwaiti

Email: n.alkuwaiti@coagri.uobaghdad.edu.iq

Introduction

Sweet pepper (*Capsicum annuum* L.) is a cash crop grown in Iraq throughout the year both in protected culture and open fields (Al-Hamad et al., 2022). Based on latest statistics, the estimated growing area and fruit production of pepper were 6,385 donum (1,577.8 acres) and 12,239 tons respectively (ASGIS, 2023). Sweet pepper cultivation is limited by many biotic and abiotic constraints including root diseases (El-Kazzaz et al., 2022). Among those, root rot caused by the fungus

Fusarium solani is the most destructive restraint, threatening pepper production (Hussein, 2024). This soil-borne vascular fungus is widely distributed and highly adaptable, as it can survive in poor soil conditions through the production of resistant dormant spores (Engalycheva et al., 2024; Tilahun et al., 2026). The disease symptoms include poor germination, wilting of seedlings and discoloration of root tissues. The pathogen can block the vascular system impairing water and nutrient uptake, causing a significant reduction in plant

growth and yield both quantitatively and qualitatively (Hussein, 2024). Chemical fungicides including Basten, have been applied intensively to control fusarium wilt diseases, due to their fast action (Al-aamel and Al-maliky, 2023; Yasir and Almaliky, 2023;). However, fungicide overuse can result in several disadvantages including development of resistant fungal populations, soil and water pollution, adverse effects on non-target beneficial organisms, and the accumulation of pesticide residues in plant parts (Cucu et al., 2025). In this context, there is a growing interest in finding out naturally sourced non-toxic and sustainable alternatives. Salicylic acid (SA), an inexpensive alternative phenolic compound, is an essential component in the plant immune defense. It can induce systemic acquired resistance (SAR) pathways; triggering pathogenesis related (PR) protein synthesis and activating antioxidant defense enzymes (Peng et al., 2021; Irkitbay et al., 2023). Many investigations have demonstrated the potential of different plant extracts containing bio-active compounds as a bio-control strategy. *Catharanthus roseus* L. (Madagascar periwinkle) is among those species with recognized medicinal potential. It is rich in alkaloids including vincristine and vinblastine along with the azoxy metabolites that have exhibited a strong natural antifungal activity (Zahari et al., 2019). To achieve the best eco-friendly control, this study was designed to test the antifungal activity of salicylic acid, *C. roseus* leaf extract, and the chemical fungicide Basten against *F. solani*, causing root rot disease in pepper plant.

Materials and Methods

Experiment location

The experimental work was performed at the College of Agricultural Engineering Sciences (CAES), University of Baghdad (UOB), Iraq during February 2023 to March 2024. Fungal isolation and *in vitro* inhibition assays were conducted under controlled thermal incubators in Plant Pathology Laboratory at the above institution. Greenhouse trials were performed in a protected house about 30 m² located in the CAES research station. Drip irrigation was applied, and environmental conditions including temperature and humidity were monitored to achieve the best plant growth.

Seed material

Seeds of a local variety of sweet pepper (*C. annuum* L.) were provided by the CAES seed unit. Seeds were surface sterilized before planting using 70% ethanol for

10 min and subsequently 1% NaOCl (sodium hypochlorite) for 3 min and then rinsed extensively with sterile distilled water to prevent contamination and keep consistency in fungal assays.

Plant material

Healthy leaves of *C. roseus* L. were obtained from the botanical garden of CAES, UOB. Leaves were washed, shade-dried (at room temperature; ~25°C) for 14 days, ground into fine powder, and stored under a dark, cool conditions to protect bio-active agents (Gizaw et al., 2022).

Preparation of plant extract

Leaf extract was prepared using the cold maceration method at a ratio of 1:10 (w/v). About 10 g of powdered plant material was mixed with sterile distilled water for 24 h on an orbital shaker at 150 rpm. The extract was initially filtered through double-layered muslin cloth and then through Whatman No. 1 filter paper. The final filtrate was stored at 4°C (Ekrim et al., 2025).

Preparation of salicylic acid solution

Salicylic acid with ≥ 99% purity (Sigma-Aldrich), was first dissolved in a small volume of ethanol, then diluted with sterile distilled water to a final volume of 1 L. The solution was sterilized using a 0.22 µm membrane filter and stored in dark glass bottles at 4°C. The solution was prepared freshly prior to each application (Yousif, 2018).

Chemical fungicide, Basten®

The commercial fungicide Basten® 25% SC (active ingredient: Tebuconazole) was prepared at a concentration of 1 mL per liter of water and stored in a dry, dark environment following standard storage guidelines.

The pathogenic fungus source

The fungus isolate *F. solani* (Gen bank acc. No. PP446821) was sub-cultured on a freshly prepared sterilized PDA medium for purification. Morphological identification was confirmed using standard mycology keys (Domsch et al., 2007). The pathogenicity was confirmed via re-inoculation.

In vitro assays

In vitro inhibition tests were conducted on PDA medium using the poisoned food technique (PFT). About a 5 mm diameter disc, sliced from the pathogenic fungus culture was placed in the middle of each tested treatment plate and incubated for 7 days at 25°C. Three replicates of each treatment were used. The percentage inhibition was calculated using the standard formula, following protocols described by Ekrim et al. (2025).

Greenhouse experiment

Plastic pots (10 L capacity) were used in greenhouse trials. Soil was steam-sterilized and artificially infested with *F. solani* inoculum at a rate of 10^6 spores/g soil. Treatments were applied at seed sowing, and germination percentage was assessed after 10 days. Seedling mortality was calculated after the emergence of all seedling in non-infected control treatment (Yasir and Almaliky, 2023) by using the following equations:

$$\% \text{ Germination} = \frac{\text{Number of germinated seeds in treatment}}{\text{Number of germinated seeds in control}} \times 100$$

$$\% \text{ Seedling mortality} = \frac{\text{Number of dead seedlings in treatment}}{\text{Number of seedling in control}} \times 100$$

Growth and protein content measurements

At 21 days post-sowing, plant height and fresh biomass were measured. Total protein content was estimated using the Bradford method by measuring absorbance at 595 nm. This method is based on the binding affinity of Coomassie Brilliant Blue to protein molecules (Bradford, 1976).

Microbial rhizosphere assessment

On the seventh day, plant roots with attached rhizospheric soil were carefully collected. One gram of moist soil was serially diluted (10^{-1} to 10^{-9}). The concentrations 10^{-8} and 10^{-9} were plated on nutrient agar supplemented with salicylic acid, plant extract and chemical fungicide. Plates

of treatment were incubated for 48 h at 30°C, and colony-forming units (CFUs) were counted following the recommended microbiological procedures (Baldani and Dobereiner, 1980; Leben et al., 1987).

Statistical analysis

A Completely Randomized Design (CRD) was followed to perform the experiment with three replicates. Data were statistically analyzed using SPSS software (IBM, USA). Means were compared using the Least Significant Difference (LSD) test at a 5% significance level. Graphical illustrations and interpretations were performed following standard scientific reporting methods (Steel and Torrie, 1980).

Results and Discussion

Effect of treatments on the inhibition of *F. solani* growth under *in vitro* conditions

Salicylic acid, *C. roseus* leaf extract, and the chemical fungicide Basten treatments inhibited the growth of *F. solani* cultured on PDA medium under laboratory conditions (Figure 1). There were significant differences (LSD = 0.05) among treatments in their activity to inhibit the growth of *F. solani* in the *in vitro* assay. Chemical fungicide Basten induced the maximum inhibition in fungal colony diameter scoring 2.1 ± 0.09 cm and 75.29% inhibition compared to 0% in untreated control.

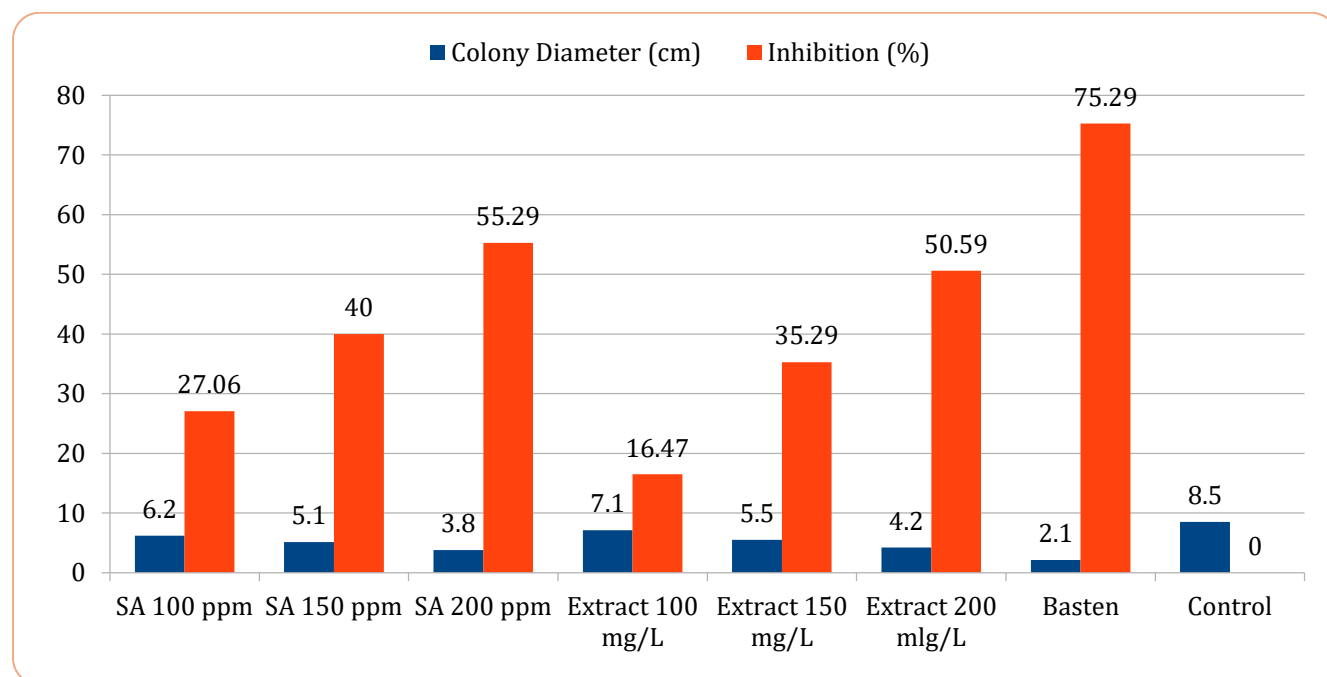


Figure 1. Inhibitory activity of *C. roseus* leaf extract, salicylic acid, and the chemical fungicide Basten on the growth of *F. solani* under *in vitro* conditions.

On the other hand, the treatment 200 ppm salicylic acid decreased the colony diameter up to 3.8 cm scoring 55.29% inhibition. Similarly, the aqueous leaf extract of *C. roseus* at 200 mg/L decreased fungal growth to 4.2 cm, scoring 50.59% inhibition. On the other hand, the lower concentrations of both SA 100 ppm and the leaf extract 100 mg/L demonstrated limited efficacy showing lower colony diameters and inhibition (Figure 1). The control treatment exhibited the highest fungal growth with a colony diameter of 8.5 cm. No significant difference between SA and *C. roseus* leaf extract treatments was observed.

Effect of treatments on germination rate and seedling mortality

Data presented in Table 1 revealed significant differences ($p \leq 0.05$) among treatments in terms of seed germination percentage and seedling mortality three days after sowing. The chemical fungicide, Basten recorded the highest germination rate scoring $93.3\% \pm 1.2$, followed by 200 ppm SA and 200 mg/L *C. roseus* leaf extract treatments scoring germination rates of $88.7\% \pm 1.5$ and $86.0\% \pm 1.6$ respectively. In contrast, the infected control treatment (fungus only) scored the lowest germination rate of $43.3\% \pm 2.1$ and the highest seedling mortality of $41.3\% \pm 1.8$ respectively.

Table 1. The activity of different concentrations of *C. roseus* leaf extract, salicylic acid, and Basten fungicide on seed germination rate and seedling mortality of pepper infected with *F. solani*.

Treatment	% Germination	% Seedling Mortality
SA 100 ppm	68.0 ± 1.7^c	21.3 ± 1.2^b
SA 150 ppm	75.3 ± 1.4^b	15.3 ± 1.1^b
SA 200 ppm	88.7 ± 1.5^a	7.3 ± 1.0^c
Extract 100 mg/L	62.0 ± 1.8^c	24.7 ± 1.3^b
Extract 150 mg/L	72.7 ± 1.6^b	16.7 ± 1.1^b
Extract 200 mg/L	86.0 ± 1.6^a	8.7 ± 1.0^c
Basten	93.3 ± 1.2^a	3.3 ± 0.9^c
Infected Control	43.3 ± 2.1^d	41.3 ± 1.8^a

Values sharing common letters in each column show statistical similarity. Values following $\pm$ show standard errors.

Effect of treatments on growth parameters in pepper plants infected with *F. solani*

All treatments improved height, fresh shoot and root weight of pepper plants under *F. solani* infection (Table

2). The data showed highly significant differences ($p \leq 0.01$) among treatments.

Plant height

Salicylic acid at 200 ppm treatment resulted in 25.5 cm plant height, similar to Basten fungicide (26.1 cm) whereas *C. roseus* aqueous extract at 200 mg/L concentration scored an average height 23.9 cm.

Fresh shoot weight

SA 200 ppm and Basten treatments enhanced shoot weight to 6.2 g and 6.4 g, respectively suggesting counteracting the disease impact and enhancement in the biomass accumulation. The *C. roseus* extract was also effective scoring 5.7 g.

Fresh root weight

SA 200 ppm and Basten treatments produced 3.1 g and 3.2 g, respectively. Overall, SA at 200 ppm and the Basten fungicide demonstrated the highest efficacy in improving both vegetative and root development traits under fungal infection. On the other hand, *C. roseus* extract also showed a considerable performance compared to the infected control, indicating their potential use as a complementary or sustainable biological alternative in disease management.

Protein content

The total protein content in the shoot system of pepper plants revealed that each treatment increased the plant's physiological response and metabolic performance under pathogenic stress conditions (Table 2). Hence, the total protein content in leaves of pepper plants can be a key physiological indicator to the plant metabolic performance under biotic stresses. Protein content can be a vital marker for many processes including photosynthesis, amino acid biosynthesis, and enzyme activity. Treatment with SA 200 ppm resulted in a high protein content ($3.6 \pm 0.11\%$), similar to the Basten fungicide treatment ($3.7 \pm 0.14\%$). In contrast, *C. roseus* extract treatment at 200 mg/L scored $3.1 \pm 0.13\%$ protein content compared to infected plants ($p < 0.05$), indicating a high bio-activity.

Effect of treatments on the rhizospheric microbiome of pepper plants infected with *F. solani*

The analysis of data revealed that SA and other treatments enabled modulating the microbial communities within the root zone under the stress of pathogenic fungus. *C. roseus* extract, SA, and Basten increased the microbial density in the rhizospheric soil of pepper plants, compared to those in both infected and uninfected control treatments (Figure 2).

Table 2. The activity of different concentrations of *C. roseus* leaf extract, salicylic acid, and Basten fungicide on growth parameters of pepper infected with *F. solani*.

Treatment	Plant height (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Total leaf protein (%)
SA 100 ppm	15.3 ± 0.6 ^c	4.2 ± 0.3 ^c	2.5 ± 0.2 ^c	2.6 ± 0.1 ^b
SA 150 ppm	18.0 ± 0.5 ^b	5.3 ± 0.2 ^b	3.0 ± 0.2 ^b	2.9 ± 0.1 ^b
SA 200 ppm	20.7 ± 0.4 ^a	5.8 ± 0.3 ^a	3.5 ± 0.2 ^a	3.2 ± 0.1 ^a
Extract 100 ml/L	14.7 ± 0.5 ^c	3.8 ± 0.2 ^c	2.2 ± 0.2 ^c	2.4 ± 0.1 ^b
Extract 150 ml/L	17.7 ± 0.4 ^b	5.0 ± 0.3 ^b	2.8 ± 0.2 ^b	2.8 ± 0.1 ^b
Extract 200 ml/L	20.0 ± 0.5 ^a	5.6 ± 0.3 ^a	3.4 ± 0.2 ^a	3.1 ± 0.1 ^a
Basten	21.7 ± 0.7 ^a	6.2 ± 0.3 ^a	3.8 ± 0.2 ^a	3.4 ± 0.1 ^a
Infected Control	10.3 ± 0.6 ^d	2.3 ± 0.2 ^d	1.3 ± 0.2 ^d	1.7 ± 0.1 ^c

Values sharing common letters in each column show statistical similarity. Values following ± show standard errors.

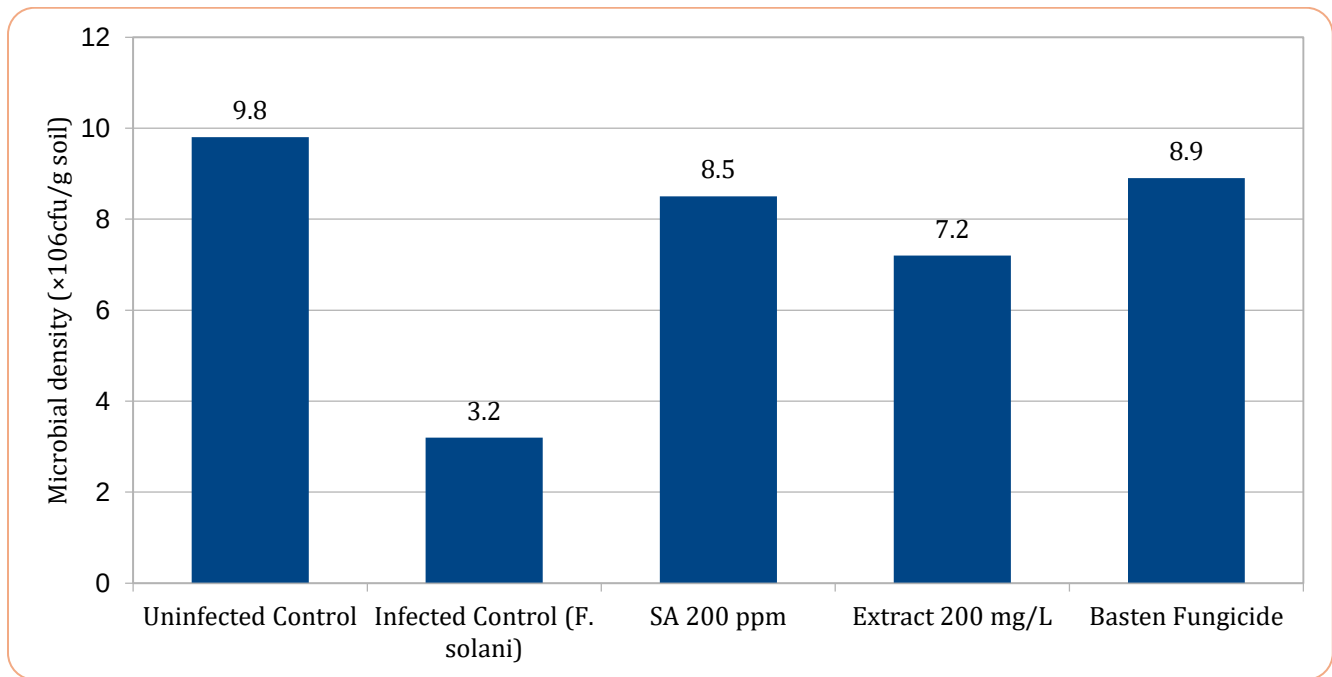


Figure 2. Microbial density in the rhizospheric soil of pepper plants treated with *C. roseus* leaf extract, salicylic acid, and the chemical fungicide Basten under the infection of *F. solani*.

SA 200 ppm treatment scored a relatively high microbial density ($8.5 \times 10^6 \pm 0.28$ cfu/g soil), similar to the fungicide Basten ($8.9 \times 10^6 \pm 0.30$ cfu/g soil). This suggests that SA not only inhibited the fungal pathogen but enhanced the proliferation of beneficial microorganisms as well. Microbiotic increase might possibly occur through stimulating roots to release exudates containing certain nutrients and organic compounds that enhance microbial growth (Cucu et al., 2025). Although, *C. roseus* leaf extract at 200 mg/L scored a microbial density around $7.2 \times 10^6 \pm 0.24$ cfu/g soil, lower than SA and Basten treatments, it was significantly

higher than the infected control. Leaf extract activity of *C. roseus* could be related to the secondary metabolites in the extract, including phenolics and alkaloids, which enabled the pathogen suppression while maintaining the balance in the microbial rhizosphere (Zahari et al., 2019). The rhizosphere zone showed a clear dynamic and biological activity in plant roots when act as an interface between root exudates and beneficial or harmful soil microbiota. Within this zone, microbial density (cfu/g soil) can be a useful sensitive indicator of soil health and biological activity. Sustainability along with eco-friendly approaches in plant disease control can be major

challenges in agriculture and crop production. Based on data obtained in this study, *C. roseus* leaf extract and SA may act as potential fungicides against *F. solani*. This pathogen can cause significant losses in pepper through damaging seeds and seedling at early growth stages. The virulence of *F. solani* can be explained by its ability to produce cell wall-degrading enzymes such as β -glucosidase, xylanase, pectinase, cellulase and lipase. These compounds can damage the delicate meristematic tissues of young roots, resulting in seedling collapse and early death before establishing in the soil (Perincherry et al., 2021). The potent fungitoxicity of Basten against *F. solani* can be related to the presence of Tebuconazole. This active ingredient is a triazole compound targeting the 14 α -demethylase enzyme involved in the synthesis of ergosterol, an essential component of fungal cell membranes. The activity of such a triazol can disrupt the integrity of the fungal cell wall (Zhou et al., 2024). On the other hand, the antifungal activity of SA might be related to triggering the SAR pathway in plants, through induction of defense compounds like phytoalexins (Mishra et al., 2024). Likewise, the antifungal potential of *C. roseus* leaf extract is thought to be related to the bio-active alkaloids (vincristine and ajmalicine), through their activity to disrupt the fungal plasma membrane integrity (Zahari et al., 2019; Tonk et al., 2023; Mishra et al., 2024). Notably, the two botanical treatments showed an antifungal activity close to that of the chemical fungicide, despite scoring a lower inhibitory effectiveness. These two natural alternatives can be potentially used as complementary or partial replacements for synthetic fungicides, to minimize chemical inputs in sustainable agricultural systems. Through including eco-friendly compounds within integrated pest management (IPM), such a strategy can lead to promoting environmental safety and sustainable agriculture. Data obtained suggested a dose-dependent relationship, where higher concentrations enhance the antifungal efficiency of bio-active compounds, a phenomenon previously documented in studies on various plant extracts (Cárdenas-Laverde et al., 2021).

The use of low dose-dependent trend has also been documented in several studies evaluating the antifungal properties of various plant extracts (Jeyaprabha et al., 2024). The protective effects of SA and *C. roseus* extracts could enhance germination performance and promote seedling along with plant growth development (Peng et al., 2021; Fang et al., 2025). The improvement in

germination rates, observed in the SA and *C. roseus* treatments can be attributed to their ability to stimulate the production of antioxidant enzymes including peroxidases and catalases, which minimize oxidative damage caused by free radicals and fungal toxins in seed tissues (Zahari et al., 2019; Cárdenas-Laverde et al., 2021). In addition, they can effectively eliminate fungal spores and prevent from invading seed tissues (Kiran and Bunker, 2020).

However, more investigations are required to confirm whether such compounds are involved in triggering SAR and PR pathways against *F. solani* in plants using molecular approaches including quantitative polymerase chain reaction qPCR and High throughput sequencing (HTS) (Zahari et al., 2019; Tonk et al., 2023).

Conclusions

The study demonstrated that salicylic acid at 200 ppm and *C. roseus* leaf extract at 200 mg/L can be highly effective against *F. solani* root rot pathogen in pepper under both laboratory and greenhouse conditions. These two naturally occurring active ingredients could improve seed germination, reduce seedling mortality, and enhance plant growth parameters. Moreover, they could promote the population of beneficial microorganisms in the rhizosphere, indicating their dual impact on disease suppression and plant health enhancement. Our data suggested the potential uses of SA and *C. roseus* extract as safe, eco-friendly alternatives to synthetic fungicides within integrated disease management strategies. These findings can be useful for further investigates to identify more effective alternatives to traditional chemical fungicides. Such compounds may enable the advancement of integrated and sustainable management practices along with achieving environmental safety and high-quality agricultural production.

Author Contributions

LBY conceptualized and designed the experiment, conducted the field investigations, executed the experimental work, and provided overall supervision to ensure methodological and analytical consistency throughout the study. NA served as supervisor, offering critical guidance on experimental design, data interpretation, and refinement of the research at various stages. LBY and NA prepared the initial manuscript draft, including structuring the content, compiling results, and integrating preliminary interpretations. All authors

critically reviewed the manuscript, contributed to intellectual refinement, verified the data and analyses, and approved the final version for submission.

Research Funding

This research did not receive any grant from funding agencies.

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 15: Life on Land

Policy Addressed

This study supports sustainable agriculture and integrated pest management (IPM) policies by demonstrating the potential of salicylic acid and *Catharanthus roseus* leaf extract as eco-friendly alternatives to conventional fungicides for managing pepper root rot. The findings further align with policies promoting soil health, biodiversity conservation, pesticide risk reduction, and enhanced agricultural productivity for food security.

References

- Al-aamel, A.N.A., Al-maliky, B.S., 2023. Control pepper *Fusarium* wilting by biocontrol agent *Trichoderma harzianum* and chelated iron Fe-EDDHA. *Baghdad Science Journal* 20, 2411–2141.
- Al-Hamad, S.J., Khazal, J., Al-Kuwaiti, N., 2022. First molecular confirmation of the fungus *Leveillula taurica* causing powdery mildew disease on sweet pepper in Iraq. *Archives of Phytopathology and Plant Protection* 55, 1588-1591.
- ASGIS, 2023. Agricultural Statistics, part 3. Iraqi Commission of statistics and GIS, Baghdad.
- Baldani, V.L.D., Döbereiner, J., 1980. Host-plant specificity in the infection of cereals with *Azospirillum* spp. *Soil Biology and Biochemistry* 12, 433-439.
- Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry* 72, 248-254.
- Cárdenas-Laverde, D., Barbosa-Cornelio, R., Coy-Barrera, E., 2021. Antifungal activity against *Fusarium oxysporum* of botanical end-products: An integration of chemical composition and antifungal activity datasets to identify antifungal bioactives. *Plants* 10, 2563.
- Cucu, M.A., Choudhary, R., Trkulja, V., Garg, S., Matić, S., 2025. Utilizing environmentally friendly techniques for the sustainable control of plant pathogens: A review. *Agronomy* 15, 1551.
- Domsch, K.H., Gams, W., Anderson, T.-H., 2007. *Compendium of Soil Fungi*, 2nd ed. HW-Verlag, Eching.
- Ekrim, M.N., Abouharrou, H.A., Al-Sadek, M.G., 2025. Evaluation of the antifungal activity of aqueous plant extracts against *Fusarium oxysporum* f. sp. *lycopersici*. *Sirte University Scientific Journal* 15, 69-73.
- El-Kazzaz, M.K., Ghoneim, K.E., Agha, M.K.M., Helmy, A., Behiry, S.I., Abdelkhalek, A., Saleem, M.H., Al-Askar, A.A., Arishi, A.A., Elsharkawy, M.M., 2022. Suppression of pepper root rot and wilt diseases caused by *Rhizoctonia solani* and *Fusarium oxysporum*. *Life* 12, 587.
- Engalycheva, I., Kozar, E., Frolova, S., Vetrova, S., Tikhonova, T., Dzhos, E., Engalychev, M., Chizhik, V., Martynov, V., Shingaliev, A., Dudnikova, K., Dudnikov, M., Kostanchuk, Y., 2024. *Fusarium* species causing pepper wilt in Russia: Molecular identification and pathogenicity. *Microorganisms* 12, 343.
- Fang, X., Xie, Y., Yuan, Y., Long, Q., Zhang, L., Abid, G., Zhang, W., 2025. The role of salicylic acid in plant defense responses against biotic stresses. *Plant Hormones* 1, e004.
- Gizaw, A., Marami, L.M., Teshome, I., Sarba, E.J., Admasu, P., Babele, D.A., Dilba, G.M., Bune, W.M., Bayu, M.D., Tadesse, M., Abdisa, K., 2022. Phytochemical screening and in vitro antifungal activity of selected medicinal plants against *Candida albicans* and *Aspergillus niger* in West Shewa Zone, Ethiopia. *Advances in Pharmacological and Pharmaceutical Sciences* 2022, 3299146.
- Hussein, S.N., 2024. Some chemical and biological methods to control pepper root rot disease in Iraq. *Indian Journal of Agricultural Research* 58, 706-712.
- Irkitbay, A., Madenova, A., Sapakhova, Z., 2023. The role of salicylic acid in the plant defense mechanism.

- Bulletin of the L.N. Gumilyov Eurasian National University. Bioscience Series 140, 83-96.
- Jeyaprabha, J., Surega, R., Mudhalvan, S., Sathiskumar, M., Sindhu, S., 2024. *In vitro* evaluation of medicinal plant extracts against Fusarium yellows of French bean (*Phaseolus vulgaris* L.) caused by *Fusarium oxysporum* f. sp. *phaseoli*. International Journal of Research in Agronomy 7, 867-869.
- Kiran, L., Bunker, R.N., 2020. Efficacy of fungicides, biocontrol agents and neem cake to suppress the wilt of cluster bean caused by *Fusarium solani* (Mart.) Sacc. International Journal of Current Microbiology and Applied Sciences 9, 1339-1350.
- Leben, S.D., Wadi, J.A., Easton, G.D., 1987. Effects of *Pseudomonas fluorescens* CHAO on potato plant growth and control of *Verticillium dahliae*. Phytopathology 77, 1592-1595.
- Mishra, S., Roychowdhury, R., Ray, S., Hada, A., Kumar, A., Sarker, U., Aftab, T., Das, R., 2024. Salicylic acid (SA)-mediated plant immunity against biotic stresses: An insight on molecular components and signaling mechanism. Plant Stress 11, 100427.
- Peng, Y., Yang, J., Li, X., Zhang, Y., 2021. Salicylic acid: Biosynthesis and signaling. Annual Review of Plant Biology 72, 761-791.
- Perincherry, L., Urbaniak, M., Pawłowicz, I., Kotowska, K., Waśkiewicz, A., Stępień, Ł., 2021. Dynamics of *Fusarium* mycotoxins and lytic enzymes during pea plants' infection. International Journal of Molecular Sciences 22, 9888.
- Steel, R.G.D., Torrie, J.H., 1980. Principles and Procedures of Statistics: A Biometrical Approach, 2nd ed. McGraw-Hill Book Company, New York.
- Tilahun, T., Abate, S., Andualem, S., Taye, M., 2026. Fusarium wilt in hot pepper: Biology, diagnostics, pathogenicity and sustainable management strategies. Journal of Phytopathology 174, e70230.
- Tonk, D., Mujib, A., Maqsood, M., Khusrau, M., Alsughayyir, A., Dewir, Y.H., 2023. Fungal elicitation enhances vincristine and vinblastine yield in the embryogenic tissues of *Catharanthus roseus*. Plants 12, 3373.
- Yasir, L.B., Almaliky, B.S.A., 2023. Integrated control of root rot and wilt disease on *Catharanthus roseus* using biological and chemical control. Iraqi Journal of Market Research and Consumer Protection 15, 132-146.
- Yousif, Y.M., 2018. Effects sprayed solution of salicylic acid to prevent wilt disease caused by *Fusarium oxysporum*. Journal of Physics: Conference Series 1003, 012001.
- Zahari, R., Terhem, R., Halimoon, N., Rusmadi, S.Z., Ahmad, M.F., Abdullah, N., 2019. *Catharanthus roseus* extract as bio-fungicide for controlling *Fusarium oxysporum* on selected vegetable seedlings. Asian Journal of Pharmaceutical Research 3, 14-22.
- Zhou, F., Zhou, X., Jiao, Y., Han, A., Zhou, H., Chen, Z., Li, W., Liu, R., 2024. Baseline tebuconazole sensitivity and potential resistant risk in *Fusarium graminearum*. BMC Plant Biology 24, 789.

Publisher's note: EScience Press remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access: This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.