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Evaluation of the Compatibility of CO_2 with *Streptomyces albidoflavus* and Compost on Vegetative, Productive, and Qualitative Parameters of Pepper Infected With White Mold Disease Caused by *Sclerotinia sclerotiorum*

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Abstract

The present study was conducted at the Department of Plant Protection, College of Agriculture, Tikrit University, with the objective of managing white mold disease caused by *Sclerotinia sclerotiorum* (K-5) on pepper (*Capsicum annuum* L.) and assessing the synergistic effects of CO_2 gas with *Streptomyces albidoflavus* and compost in enhancing plant resistance. Results demonstrated that the combined treatment of Luna fungicide, *S. albidoflavus*, and organic compost exhibited the highest efficiency across all evaluated parameters. Disease severity significantly decreased from 64.85% in the pathogen-inoculated plants to 14.05% under the triple treatment, and further declined to 8.13% in the presence of CO_2. Peroxidase activity increased from 2.105 to 3.63 units/mL, while chlorophyll content reached 45.82 SPAD, compared to 29.85 SPAD in infected plants. Moreover, vegetative dry weight increased from 71.38 g to 176.68 g, root dry weight from 9.83 g to 49.77 g, and fruit yield from 612.15 g to 1280.66 g. Vitamin C concentration also increased markedly from 50.54% to 85.67%. The presence of CO_2 further enhanced plant performance, with improvements ranging between 8–12% across different traits. In vitro experiments evaluated various concentrations of organic compost extract (5, 10, and 15%) and *S. albidoflavus* filtrate in combination with the half-dose of Luna fungicide (0.07) against *S. sclerotiorum*. Treatments combining the fungicide with either compost extract or bacterial filtrate achieved complete inhibition of fungal growth (colony diameter = 0 cm) compared to the control (5.74 cm). These findings highlight the potential of integrating CO_2 enrichment with beneficial microorganisms and organic amendments as an eco-friendly strategy to enhance disease resistance and reduce the reliance on chemical fungicides for sustainable pepper production.

I. Introduction

Pepper (*Capsicum annuum* L.) belongs to the family Solanaceae and is considered one of the most important vegetable crops worldwide (Thang, 2007). It is rich in vitamins such as vitamin C and vitamin E, as well as antioxidant compounds and phenolic substances (Marin et al., 2004). The latest statistics indicated that the total cultivated area of this crop in Iraq in 2023 reached 12,239 dunums, with a total production of 6,385 tons and a yield of 19168 kg/dunum (Central Organization for Statistics, 2023).However, during its growth period, pepper plants are highly susceptible to several pathogenic microorganisms that cause damping-off and various rot diseases, leading to serious quantitative and qualitative yield losses. These pathogens include *Macrophomina phaseolina, Fusarium solani, Fusarium*

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oxysporum, Phytophthora capsici, and *Rhizoctonia solani* (Gupta & Paul, 2002; Gupta & Thind, 2012).Among these pathogens, *Sclerotinia sclerotiorum* (Lib.) De Bary, the causal agent of white mold disease, is one of the most destructive fungi due to its broad host range, which extends to 64 plant families, 225 genera, and about 450 species, collectively known to suffer from white mold (Wei et al., 2023).

The isolates of *S. sclerotiorum* differ genetically and physiologically in their growth rate, production of enzymes and oxalic acid, and in colony morphology, sclerotia number, weight, and distribution pattern, all of which contribute to differences in pathogenicity and virulence (Bhatt & Sharma, 2024).

Although chemical fungicides are effective in controlling many plant diseases, their continuous use is associated with environmental and health hazards and high economic costs. Therefore, recent studies have focused on eco-friendly alternatives, including biological control agents, physical treatments, and plant extracts (Arslan et al., 2009).Among biological agents, Actinomycetes, particularly Streptomyces species, are considered valuable beneficial microorganisms due to their ability to produce enzymes, hormones, and antibiotics with strong biocontrol activity. They also improve soil fertility, enhance plant growth, and suppress phytopathogens through multiple mechanisms, in addition to their tolerance to harsh environmental conditions (Javed et al., 2021; Silva et al., 2022).

Organic compost is another environmentally friendly and inexpensive soil amendment that improves soil physical and chemical properties, increases organic matter and water retention, and enhances plant growth while reducing the severity of diseases. Its suppressive effect may result from physical, chemical, or biological mechanisms, such as altering soil nutrient levels, pH, and moisture, as well as enriching the soil microbiome with beneficial microbes that compete with pathogens, produce antibiotics and hydrolytic enzymes, or induce systemic resistance in the host (Devarajan et al., 2021).

Elevated CO_2 concentration is one of the key manifestations of climate change caused by human activities and can have positive physiological effects on plants. High CO_2 enhances photosynthesis, primary and secondary metabolism, and increases the C:N ratio, while reducing water loss through partial stomatal closure. Additionally, elevated CO_2 can inhibit the growth of pathogenic fungi and bacteria, including *S. sclerotiorum* and *Botrytis cinerea*, thereby reducing disease severity and promoting beneficial soil microbiota (Zou et al., 2019; Smith & Luna, 2023).

Given the wide host range and economic importance of *S. sclerotiorum*, this study was conducted to evaluate the compatibility of CO_2 with Streptomyces albidoflavus and organic compost in improving vegetative, productive, and qualitative traits of pepper plants under infection with *S. sclerotiorum*.

II. Materials and Methods

Pathogen and Biocontrol Agents

The most virulent isolate of *Sclerotinia sclerotiorum* was used in this study, along with the bacterial isolate *Streptomyces albidoflavus*, as previously identified by Hassan and Rajab (2025). The organic compost was obtained from the College of Agriculture, University of Tikrit.

The fungicide Luna, containing the active ingredients fluopyram and trifloxystrobin, produced by Bayer Company, was also used.

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Laboratory Experiments

1. Effect of Different Concentrations of Compost Extract Combined with Half-Dose Luna Fungicide on the Growth of *S. sclerotiorum*

Compost extract was tested at three concentrations (5, 10, and 15%) in combination with the half concentration of Luna fungicide (0.07 ml/L).The extract was added to PDA medium with or without the fungicide, then inoculated with *S. sclerotiorum*. After the incubation period, colony diameter was measured to determine the degree of fungal growth inhibition.

2. Compatibility of Different Concentrations of *S. albidoflavus* Filtrate with Half-Dose Luna Fungicide Against *S. sclerotiorum*

The bacterial filtrate was tested at 5, 10, and 15% concentrations, combined with the half concentration of Luna fungicide (0.07 ml/L). Plates were inoculated with the fungal pathogen, incubated, and the colony diameter was recorded. These tests were conducted both with and without the fungicide to assess the interactive inhibitory effect of bacterial metabolites and chemical fungicide on fungal growth.

Field Experiment

The field experiment was conducted to evaluate the effects of compost, bacterial filtrate, and their compatibility with the chemical fungicide in controlling white mold disease on pepper under CO_2 enrichment.The experiment was carried out at the Research Station, Department of Plant Protection, College of Agriculture, University of Tikrit, during the 2023–2024 season.The greenhouse was prepared by covering with plastic, irrigating to field capacity, plowing, installing a drip irrigation system, and sterilizing the soil with 4% formaldehyde, sprayed using a 100 L sprayer. The house was tightly closed for 7 days, then ventilated for 3 days before transplanting 25 pepper seedlings per treatment.The greenhouse was divided into two main sections:The first factor included the treatment combinations,The second factor involved CO_2 concentrations (presence and absence).Plants were inoculated with *S. sclerotiorum* and then treated with compost extract, fungicide, and bacterial filtrate seven days after inoculation.

Experimental Factors

Factor 1 – Treatment combinations:

1. control (uninfected plants)

2. Pathogen only

3. Pathogen + Luna fungicide

4. Pathogen + *S. albidoflavus* filtrate

5. Pathogen + compost

6. Pathogen + Luna + *S. albidoflavus* filtrate

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7. Pathogen + Luna + compost

8. Pathogen + Luna + *S. albidoflavus* filtrate + compost

Factor 2 – CO_2 concentration:

Each of the above treatments was tested with and without CO_2 enrichment.

Studied Traits

Effect of *Sclerotinia sclerotiorum* isolates on disease severity (%) in four host plants

This experiment was conducted to evaluate the effect of *Sclerotinia sclerotiorum* isolates on disease severity (%) in four crops — tomato, eggplant, pepper, and squash — at the Research Station, Department of Plant Protection, College of Agriculture, Tikrit University. Plants were mechanically inoculated with sclerotia of the pathogen by making a small incision in the stem area, which was then sealed with parafilm. The severity of infection caused by the fungal isolates on the four crops was monitored weekly for eight weeks, starting from the first appearance of symptoms (Dickson and Petzoldt, 1996; Al-Darraji, 2018).

The degree of infection was determined according to the disease index proposed by Dickson and Petzoldt (1996) for *S. sclerotiorum*, as shown in Table (1).

Table (1). Pathological scale of infection caused by *Sclerotinia sclerotiorum*

Scale	Symptom description (mm)
0	No infection
1	Lesion < 2 mm from wound
2	Lesion 2–4 mm from wound
3	Lesion 4–6 mm from wound
4	Lesion 6–8 mm from wound, stem not girdled
5	Lesion > 8 mm from wound with stem girdling

Disease Severity Assessment

Disease severity (%) was calculated according to the formula of McKinney (1923) as follows:

$$\text{Disease Severity (\%)} = \frac{Sum\ of\ all\ disease\ ratings}{Total\ number\ observations \times Maximum\ disease\ rating} \times 100$$

Determination of Peroxidase Enzyme Activity

Peroxidase activity was determined according to the method described by Hammerschmidt et al. (1982). The reaction mixture consisted of 2.5 mL of guaiacol solution and hydrogen peroxide solution, to which 0.1 mL of crude enzyme extract from each treatment was added separately.The absorbance of the reaction mixture was measured using a

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spectrophotometer at a wavelength of 470 nm. One unit of peroxidase activity was defined as the change in absorbance of 0.01 per minute.

$$\frac{\Delta \mathbf{A} \times \mathbf{3}}{\Delta \mathbf{T} \times \mathbf{0.01}}$$

Vegetative Parameters

Determination of Chlorophyll Content (SPAD units)

The relative chlorophyll content of leaves was measured in the morning using a chlorophyll meter (SPAD). The average readings were taken from three plants in each replicate (Jemison and Williams, 2006). The device automatically punctured the leaf to prevent re-measurement of the same area in subsequent readings.

Determination of Dry Shoot and Root Weights

The dry weights of both shoot and root systems were determined at the end of the growing season. Plants were carefully uprooted, and roots were thoroughly washed with water to remove any adhering soil. Shoots were separated from roots at the crown region and left for sun-drying until a constant weight was achieved. The average dry weights of the shoot and root systems (g) were then recorded.

Determination of Yield Weight

The total fruit yield per treatment was determined through four successive harvests using a mechanical balance.

Determination of Vitamin C Content

Vitamin C (ascorbic acid) content in pepper fruits was determined using a ready-made Ascorbic Acid Assay Kit (ab65656) supplied by Abcam, Japan. The method is based on the reduction of ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) in the reaction mixture. The reaction was stopped in the presence of ascorbate oxidase, and absorbance was measured at 593 nm using a spectrophotometer.

Vitamin C was then calculated according to the standard calibration curve shown below

Statistical Analysis

The obtained data were statistically analyzed using analysis of variance (ANOVA) with the SPSS software.A Completely Randomized Design (CRD) was applied for laboratory experiments, while a Randomized Complete Block Design (RCBD) was used for the field experiment.Treatment means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05 (Al-Rawi and Khalaf Allah, 1980).

III. Results and Discussion

Compatibility of Different Concentrations of Compost Extract with Half Concentration of Luna Fungicide on the Growth of *Sclerotinia sclerotiorum*

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Figure (2) illustrates the compatibility between different concentrations of compost extract and the half concentration of Luna fungicide on the growth of *Sclerotinia sclerotiorum.*The results showed that both the full concentration of the fungicide and the combination of the half concentration of Luna with compost extract were the most effective in reducing the colony diameter of the pathogen, achieving complete inhibition compared to the control treatment (without compost extract), which recorded a colony diameter of 5.74 cm. These findings are consistent with previous studies that tested compost extracts against several fungi, including *S. sclerotiorum*. The results indicated that some compost extracts were highly effective in suppressing fungal growth, suggesting that beneficial microorganisms present in compost play a major role in this antifungal effect. When the fungal growth on PDA medium was compared to that on compost extract medium, a significant reduction in colony diameter was observed, ranging from 20% to more than 80%, and in some cases, complete inhibition occurred at higher extract concentrations. Additionally, the number and formation of sclerotia were delayed or completely suppressed, reducing the survival of the fungus in the soil (Kerkeni et al., 2007; Prajapati et al., 2022). Luna fungicide combines two active ingredients effective against a wide range of fungal diseases. The first, fluopyram (SDHI), inhibits the succinate dehydrogenase enzyme in fungal mitochondria, which is essential for the electron transport chain. Inhibiting this enzyme disrupts ATP production, leading to fungal death or growth inhibition.

The second component, trifloxystrobin (QoI), blocks electron transfer at the cytochrome bc1 complex, preventing ATP synthesis necessary for fungal metabolism. The dual action of these compounds targets two different sites in the respiratory pathway, providing both protective (preventive) and curative (post-infection) effects while minimizing the risk of resistance development (Gleason et al., 2021).

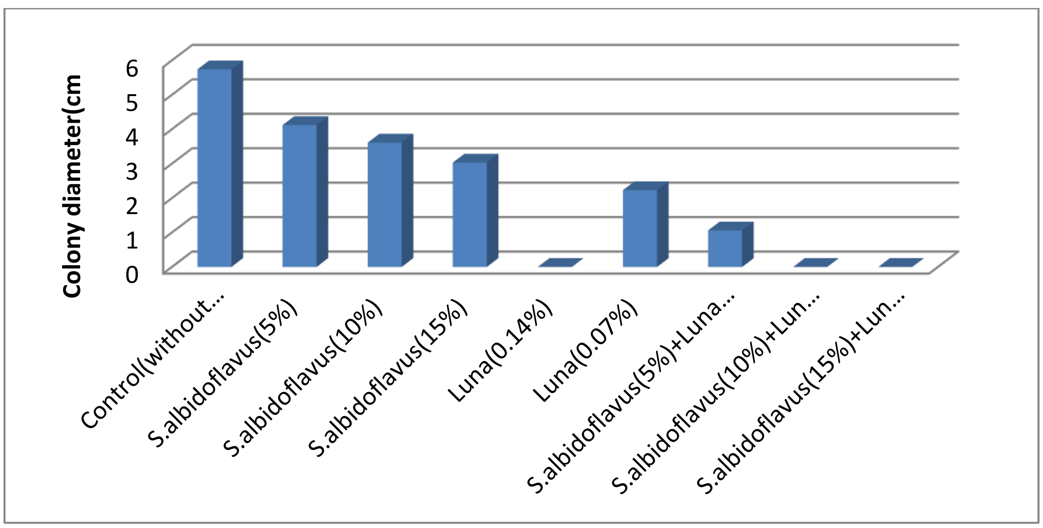

Figure (2). Compatibility of different concentrations of organic fertilizer extract with the half concentration of the fungicide Luna on the growth of the pathogenic fungus *S. sclerotiorum* ($LSD_{0.05}$ = 0.92).

Compatibility of Different Concentrations of *Streptomyces albidoflavus* Filtrate with Half Concentration of Luna Fungicide on the Growth of *Sclerotinia sclerotiorum*

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Figure (3) shows the compatibility between different concentrations of *S. albidoflavus* filtrate and the half concentration of Luna fungicide on the growth of *S. sclerotiorum*.The results indicate that both the full concentration of the fungicide and its half concentration combined with the bacterial filtrate at 10% and 15% concentrations were the most effective treatments, achieving complete inhibition of fungal colony growth compared with the control (without bacterial filtrate), which recorded a colony diameter of 5.74 cm.

Actinomycetes play a significant role in controlling various fungal diseases due to their ability to produce secondary metabolites such as enzymes, volatile compounds, and diffusible antifungal substances.This agrees with the findings of Lahmyed et al. (2021), who tested 15 actinomycete isolates in vitro using the dual culture method on PDA medium against Botrytis cinerea (the causal agent of tomato gray mold). The isolates showed strong antagonistic activity, with inhibition rates ranging from 50% to 72%.Similarly, actinomycete strains have been reported to effectively suppress gray mold disease caused by *B. cinerea* (Boukaew et al., 2017).The present findings are also consistent with Patel et al. (2021), who isolated 40 actinomycete strains from agricultural soils and found that Streptomyces sp. strain AAUBCI 14 exhibited the highest inhibition (50%) against *Macrophomina phaseolina,* followed by *S. asenjonii* (48%) and *S. cavourensis* (44%).The antagonistic potential of Streptomyces species against phytopathogenic fungi is attributed to multiple mechanisms, including the production of antibiotics and secondary metabolites (Olanrewaju and Babalola, 2019).

Luna fungicide, as previously described, contains two active ingredients — fluopyram (SDHI) and trifloxystrobin (QoI) — that act through distinct mechanisms to inhibit fungal respiration.

This dual action provides both preventive and curative protection and reduces the risk of resistance development (Gleason et al., 2021).

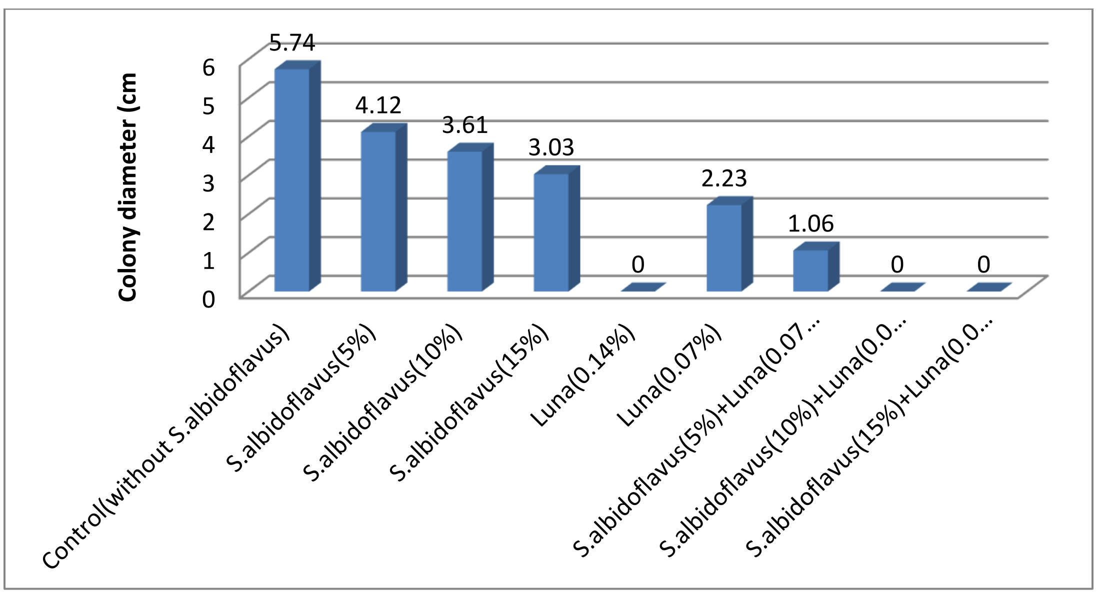

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Figure (3). Compatibility of different concentrations of the bacterial filtrate *S. albidoflavus* with the half concentration of the fungicide Luna on the growth of the pathogenic fungus *S. sclerotiorum* ($LSD_{0.05}$ = 0.86).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Disease Severity (%) of Pepper Infected with the Pathogenic Fungus *Sclerotinia sclerotiorum*

Table (2) shows the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the disease severity (%) of pepper plants infected with the pathogenic fungus *S. sclerotiorum*. The results indicated that the treatment consisting of (*S. sclerotiorum* + Luna fungicide + *S. albidoflavus* + compost) exhibited the greatest reduction in disease severity, which reached 14.05%, compared with 64.85% in the pathogen-only treatment.A general decrease in disease severity was observed across all treatments (with and without CO_2 gas). The triple treatment (*S. sclerotiorum* + Luna + *S. albidoflavus* + compost) showed the lowest disease severity under CO_2-enriched conditions (8.13%) compared with 53.93% in the pathogen-only treatment under CO_2. Without CO_2 enrichment, the triple treatment recorded 19.97%, while the pathogen-only treatment reached 75.77%.

Application of organic compost (10–15 tons/ha) reduced Fusarium wilt severity by 40–55%, while compost tea spray decreased powdery mildew severity in vegetable crops by 20–45%. Compost not only serves as a nutrient source but also acts as an inducer of plant immunity because it contains organic acids and beneficial microorganisms such as *Trichoderma, Bacillus*, and Actinomycetes, which can attack pathogens or trigger induced systemic resistance (ISR) (Aminifard et al., 2013; Zaccardelli et al., 2018).

These findings agree with Gebily et al. (2021), who reported that the filtrate of actinomycetes inhibited *Fusarium oxysporum* FU3 growth by 41.7% on solid medium and by 81.8% in liquid culture. Moreover, Streptomyces strains reduced disease symptoms in bean plants. The Luna Sensation fungicide was shown to be highly effective, reducing powdery mildew severity in pepper to 8% compared to 67% in the control, while also decreasing secondary infections such as mold (Gabrekiristos et al., 2018).

Elevated CO_2 enhances plant chemical defenses by increasing the synthesis of phenolic compounds, phytoalexins, and defense-related enzymes (POD and PPO), as well as the C:N ratio. These changes suppress the growth of certain pathogens such as *S. sclerotiorum* and *Botrytis cinerea*, due to alterations in pH, oxygen levels, or the rhizosphere microbiome (Eastburn et al., 2011; Meena et al., 2020; Ng et al., 2024).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Disease Severity (%) of Pepper Infected with the Pathogenic Fungus *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	0	0	0
Pathogen	75.77	53.93	64.85
Pathogen + Luna fungicide	27.07	15.23	21.15
Pathogen + *S. albidoflavus* filtrate	29.52	17.68	23.6
Pathogen + compost	31.39	19.55	25.47
Pathogen + Luna + *S. albidoflavus* filtrate	24.35	12.51	18.43
Pathogen + Luna + compost	25.91	14.07	19.99

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Pathogen + Luna + *S. albidoflavus* filtrate + compost	19.97	8.13	14.05
Mean of Co_2	29.2475	17.6375	
LSD $_{0.05}$	Treatments: 1.79 ، Gas: ،2.93 Interaction: 3.58		

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Peroxidase Activity (U/mL) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Table (3) illustrates the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the peroxidase activity (U/mL) of pepper plants under infection with the pathogenic fungus *S. sclerotiorum*. The results indicate that the highest peroxidase activity at the treatment level was observed in the triple treatment (*S. sclerotiorum* + Luna fungicide + *S. albidoflavus* + compost), which reached 3.63 U/mL, while the lowest activity was recorded in the control treatment (healthy plants) at 2.105 U/mL. At the interaction level, the same triple treatment recorded the highest peroxidase activity both with and without CO_2, at 4.39 and 2.87 U/mL, respectively. In contrast, the control treatment (healthy plants) exhibited the lowest values under both conditions (2.92 and 1.29 U/mL, respectively).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Peroxidase Activity (U/mL) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	1.29	2.92	2.105
Pathogen	1.63	3.15	2.39
Pathogen + Luna fungicide	1.46	2.98	2.22
Pathogen + *S. albidoflavus* filtrate	1.7	3.22	2.46
Pathogen + compost	1.82	3.34	2.58
Pathogen + Luna + *S. albidoflavus* filtrate	2.56	4.08	3.32
Pathogen + Luna + compost	2.21	3.83	3.02
Pathogen + Luna + *S. albidoflavus* filtrate + compost	2.87	4.39	3.63
Mean of Co_2	1.9425	3.48875	
LSD $_{0.05}$	Treatments: 0.055 ، Gas: 0.061 ، Interaction: 0.072		

Vegetative Growth Parameters

Effect of CO_2 on the Treatments of Bacterial and Okra Compost Extracts and the Fungicide Luna on Chlorophyll Content (SPAD) of Pepper Plants under Infection Conditions with the Pathogenic Fungus *S. sclerotiorum*

Table (6) illustrates the effect of CO_2 on the treatments of bacterial and okra compost extracts and the fungicide Luna on chlorophyll content (SPAD) of pepper plants under infection conditions with the pathogenic fungus *S. sclerotiorum*.

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The results indicate that the highest chlorophyll content was recorded in the treatment (pathogenic fungus + Luna fungicide + *S. albidoflavus* + compost), reaching 45.82 SPAD, whereas the lowest chlorophyll content was observed in the pathogenic fungus treatment, with 29.85 SPAD. At the interaction level, the treatment (pathogenic fungus + Luna fungicide + *S. albidoflavus* + compost) recorded the highest chlorophyll content both in the presence and absence of CO_2 gas, reaching 47.67 and 43.96 SPAD, respectively. In contrast, the pathogenic fungus treatment recorded the lowest chlorophyll content under both CO_2 conditions, with 31.7 and 27.99 SPAD, respectively.

Table (6). Effect of CO_2 on the treatments of bacterial and compost extracts and the fungicide Luna on chlorophyll content (SPAD) of pepper plants under infection conditions with the pathogenic fungus *S. sclerotiorum*.

Effect of CO_2 on the Treatments of Bacterial and Okra Compost Extracts and the Fungicide Luna on Chlorophyll Content (SPAD) of Pepper Plants under Infection Conditions with the Pathogenic Fungus *S. sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	42.1	45.81	43.96
Pathogen	27.99	31.7	29.85
Pathogen + Luna fungicide	33.73	37.44	35.59
Pathogen + *S. albidoflavus* filtrate	36.8	40.51	38.66
Pathogen + compost	36.79	40.5	38.65
Pathogen + Luna + *S. albidoflavus* filtrate	41.35	45.06	43.21
Pathogen + Luna + compost	38.62	42.33	40.48
Pathogen + Luna + *S. albidoflavus* filtrate + compost	43.96	47.67	45.82
Mean of Co_2	37.6675	41.3775	
LSD $_{0.05}$	Treatments: 1.04 ، Gas: 1.62 Interaction: 2.13		

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Vegetative Dry Weight (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Table (7) shows the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the vegetative dry weight (g) of pepper plants infected with *S. sclerotiorum*.The results revealed that the lowest vegetative dry weight was recorded in the pathogen-only treatment (71.38 g), whereas the highest value was observed in the triple treatment (*S. sclerotiorum* + Luna fungicide + *S. albidoflavus* + compost), which reached 176.68 g. At the interaction level, the same triple treatment recorded the highest vegetative dry weight both with and without CO_2, reaching 183.11 g and 170.24 g, respectively. In contrast, the pathogen-only treatment recorded the lowest weights under the two conditions (77.81 g with CO_2 and 64.94 g without CO_2).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Vegetative Dry Weight (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	157.16	170.03	163.60
Pathogen	64.94	77.81	71.38

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Pathogen + Luna fungicide	135.91	148.78	142.35
Pathogen + *S. albidoflavus* filtrate	151.11	163.98	157.55
Pathogen + compost	149.15	162.02	155.59
Pathogen + Luna + *S. albidoflavus* filtrate	164.53	177.4	170.97
Pathogen + Luna + compost	157.36	170.23	163.80
Pathogen + Luna + *S. albidoflavus* filtrate + compost	170.24	183.11	176.68
Mean of Co_2	143.8	156.67	
LSD $_{0.05}$	Treatments: 2.76 ، Gas: 3.64 Interaction: 4.32		

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Root Dry Weight (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Table (8) shows the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the root dry weight (g) of pepper plants infected with *S. sclerotiorum*.The results indicate that the highest root dry weight at the treatment level was obtained from the triple treatment(*S. sclerotiorum* + Luna fungicide + *S. albidoflavus* + compost), which reached 49.77 g, whereas the lowest value was recorded in the pathogen-only treatment (9.83 g). At the interaction level, the same triple treatment exhibited the highest root dry weights under both CO_2 and non-CO_2 conditions, recording 51.7 g and 47.83 g, respectively. Conversely, the pathogen-only treatment showed the lowest root weights under the same conditions (11.76 g with CO_2 and 7.89 g without CO_2).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Root Dry Weight (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	35.15	39.02	37.09
Pathogen	7.89	11.76	9.83
Pathogen + Luna fungicide	34.07	37.94	36.01
Pathogen + *S. albidoflavus* filtrate	38.46	42.33	40.39
Pathogen + compost	36.19	40.06	38.13
Pathogen + Luna + *S. albidoflavus* filtrate	44.04	47.91	45.98
Pathogen + Luna + compost	42.35	46.22	44.29
Pathogen + Luna + *S. albidoflavus* filtrate + compost	47.83	51.7	49.77
Mean of Co_2	35.7475	39.6175	
LSD $_{0.05}$	Treatments: 1.31 ، Gas: 2.04 Interaction: 2.55		

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Yield (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

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Table (9) shows the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the yield (g) of pepper plants infected with *S. sclerotiorum*. The results revealed that the highest yield at the treatment level was obtained from the triple treatment (*S. sclerotiorum* + Luna fungicide + *S. albidoflavus* + compost), reaching 1280.66 g, while the lowest yield was recorded in the pathogen-only treatment (612.15 g). At the interaction level, the same triple treatment recorded the highest yield under both CO_2 and non-CO_2 conditions, with 1331.67 g and 1229.64 g, respectively. In contrast, the pathogen-only treatment exhibited the lowest yields under both conditions (663.16 g with CO_2 and 561.13 g without CO_2).

In a study by Zaccardelli et al. (2018), spraying compost tea on vegetable crops increased total yield by 21.9% in the first year and 16.3% in the second year compared to the control. Similarly, Imran et al. (2022) reported that the use of improved organic compost increased pepper and tomato yields by up to 75% compared to untreated plants.

Actinomycetes are known to act as plant growth-promoting rhizobacteria (PGPR), improving plant health, enhancing stress tolerance, and increasing nutrient uptake—all factors that ultimately contribute to yield improvement. Numerous studies have demonstrated that Streptomyces strains can enhance vegetable yields by stimulating root growth, nitrogen fixation, phosphate solubilization, and phytohormone production (Silva et al., 2022).

In a field study conducted in Ethiopia, the fungicide Luna Sensation effectively reduced powdery mildew (Leveillula taurica) in pepper, improving fruit quality and yield attributes (fresh weight, fruit number, and marketable yield) compared with untreated control plants (Gabrekiristos et al., 2018).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Yield (g) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	1111.48	1213.51	1162.50
Pathogen	561.13	663.16	612.15
Pathogen + Luna fungicide	987.04	1089.07	1038.06
Pathogen + *S. albidoflavus* filtrate	1085.48	1187.51	1136.50
Pathogen + compost	1074.56	1176.59	1125.8
Pathogen + Luna + *S. albidoflavus* filtrate	1174.09	1276.12	1225.11
Pathogen + Luna + compost	1112.57	1214.6	1163.59
Pathogen + Luna + *S. albidoflavus* filtrate + compost	1229.64	1331.67	1280.66
Mean of Co_2	1041.999	1144.029	
LSD $_{0.05}$	Treatments: 11.31 ، Gas: 16.74 Interaction: 21.66		

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Vitamin C Content (%) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Table (11) presents the effect of CO_2 in the treatments involving bacterial filtrate, organic compost, and the fungicide Luna on the vitamin C content (%) of pepper plants infected with the pathogenic fungus *S. sclerotiorum*. The results showed that the highest vitamin C concentration at the treatment level was recorded in the triple treatment (*S.*

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sclerotiorum + Luna fungicide + *S. albidoflavus* + compost), reaching 85.67%, whereas the lowest concentration was observed in the pathogen-only treatment (50.54%). At the interaction level, the triple treatment exhibited the highest vitamin C content under both CO_2 and non-CO_2 conditions, recording 87.68% and 83.65%, respectively. In contrast, the pathogen-only treatment showed the lowest values under the same conditions (52.57% with CO_2 and 48.51% without CO_2).

Organic compost has been reported to increase vitamin C (ascorbic acid) content in pepper fruits. Several field and laboratory studies have shown significant increases in ascorbate levels following compost application (Tortosa et al., 2018).

Actinomycetes are beneficial soil microorganisms that produce a wide range of secondary metabolites such as antibiotics and enzymes, which contribute to microbial balance, plant health, and improved fruit quality (Orouji et al., 2023). According to Chaiya et al. (2021), actinomycetes promote plant health and enhance disease resistance, thereby indirectly improving fruit quality.

The Luna fungicide also contributes to better fruit quality and storability by effectively controlling diseases. Its influence on vitamin C content is likely indirect, resulting from reduced disease pressure and improved overall plant health (Gabrekiristos et al., 2018).

Effect of CO_2 in the Treatments of Bacterial Filtrate, Organic Compost, and Luna Fungicide on the Vitamin C Content (%) of Pepper Plants Infected with *Sclerotinia sclerotiorum*

Treatments	Co_2 treatments		Mean of treatments
	Without Co_2	With Co_2	
control (uninfected plants)	80.33	85.38	82.86
Pathogen	48.51	52.57	50.54
Pathogen + Luna fungicide	69.76	73.84	71.8
Pathogen + *S. albidoflavus* filtrate	74.79	78.82	76.81
Pathogen + compost	71.62	75.69	73.66
Pathogen + Luna + *S. albidoflavus* filtrate	77.86	81.9	79.88
Pathogen + Luna + compost	73.15	77.22	75.19
Pathogen + Luna + *S. albidoflavus* filtrate + compost	83.65	87.68	85.67
Mean of Co_2	72.45875	76.6375	
LSD $_{0.05}$	Treatments:1.32 ، Gas: 1.40 Interaction: 1.75		

IV. Conclusions

The results of this study demonstrated that the combined application of Luna fungicide, *Streptomyces albidoflavus*, and organic compost achieved the most effective performance in reducing the incidence of white mold disease caused by *Sclerotinia sclerotiorum* in pepper plants. This integrated treatment not only suppressed the pathogen efficiently but also improved vegetative growth, yield, and fruit quality traits, including higher chlorophyll content, dry biomass, and vitamin C concentration. The enrichment with CO_2 gas further enhanced plant resistance and photosynthetic

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efficiency, leading to greater carbohydrate accumulation and improved physiological vigor. The synergistic interaction among the organic, biological, and chemical components contributed to strengthening plant defense mechanisms and optimizing productivity under pathogen stress. Overall, these findings highlight the importance of combining biological and organic management strategies with selective chemical control under elevated CO_2 conditions to achieve sustainable and healthy pepper production.

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