Research Article

Effect of Bio Fumigation Using Broccoli Leaves on Armenian Cucumber Plants Infected with the Fungus *Plectosphaerella cucumerina* and Some Growth Parameters

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Abstract | The study was conducted in the greenhouse of the Department of Plant Protection, College of Agriculture and Forestry, University of Mosul. This study aimed to evaluate the effectiveness of broccoli leaf bio fumigation in managing sudden decline disease caused by *Plectosphaerella cucumerina*, and to assess its impact on selected growth parameters of cucumber plants under greenhouse conditions. The results showed that the highest reduction in the percentage and severity of infection with sudden decline disease was when treating armenian cucumber plants with broccoli leaves at the third concentration (10 g/1 kg soil), as it reached (12.50, 0.06), which differed significantly from the treatment with the pathogenic fungus *Plectosphaerella cucumerina*, as it recorded the highest percentage of infection and its severity, reaching (37.50, 0.22). It also differed significantly from the other concentrations (3, 6) g/1 kg soil in the severity of infection. There was no significant difference between the third and second concentration treatments in the percentage of infection, in addition to that there was a significant difference between green broccoli leaves and dry broccoli leaves used in the study in the severity of infection. The results of bio fumigation with both fresh and dry broccoli leaves showed a positive and effective impact on the growth parameters of armenian cucumber plants (*Cucumis melo var. flexuoses*), as reflected in improvements in both shoot and root traits. The third concentration (10 g/kg soil) of both green and dry broccoli leaves had a significant positive effect on all measured growth parameters of armenian cucumber plants and differed significantly from the lower concentrations and the untreated control. The best overall plant growth was observed in the treatment with green broccoli leaves in the absence of the pathogen. This treatment resulted in the highest values for plant height (76.72 cm), number of leaves (43.33), leaf area (46.87 cm^2), chlorophyll content (37.08 CCI), root length (51.25 cm), shoot fresh weight (90.68 g), root fresh weight (18.41 g), shoot dry weight (4.99 g), and root dry weight (0.57 g).

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Introduction

Cucumis melo var. *flexuoses (L.) Naudin*, commonly known as Armenian cucumber, belongs to the Cucurbitaceae family, also known as the Cord Family. The vegetable crops belonging to it are called Cucurbits. Their plants are similar in their cultivation requirements, growing well in warm climates around the tropics and in temperate regions and not tolerant to frost (Christenhusz and Byng, 2016).

Armenian cucumber *(C. melo var. flexuoses)* is considered one of the important vegetables in Iraq during the summer season, as its fresh fruits are widely consumed either directly or as an ingredient in pickles and salads (Matloob *et al*., 1989). It possesses good nutritional value due to its content of several vitamins, including A, B, and C, in addition to essential minerals such as manganese (Mn), phosphorus (P), iron (Fe), sulfur (S), and calcium (Ca). These components contain alkaline substances that purify the blood, dissolve uric acid and diuretic salts, and are traditionally used in the treatment of freckles and melasma (Hernández *et al*., 2014).

The original homeland of the Armenian cucumber (*C. melo var. flexuosus*) is India. From there, its cultivation spread to China, Italy, Iran, and various countries across Europe and Africa, as well as southeastern Anatolia, Azerbaijan, and Iraq (Hammer and Gladis, 2014; EuroStat, 2019; Hedrick, 1919; Arzanlou *et al*., 2013). Tirawzi (a local name for this variety) contains approximately 1.2% protein, 96% water, 0.7% fat, 2% fiber, and 4.5% carbohydrates. It is also considered an important source of minerals, particularly sodium (25%), magnesium (27%), calcium (33%), phosphorus (37%), and potassium (264%). Additionally, it provides significant levels of vitamins, especially vitamin A (12%) and vitamin C (21.3%), as well as sulfur, iron, oil, amino acids, fiber, protein, and carbohydrates. It is known for its strong, cooling flavor (Ilahy *et al*., 2014; Al-Mathoub *et al*., 1989).

Sudden decline disease is considered one of the most destructive plant diseases affecting Armenian cucumber (*C. melo var. flexuosus*) in particular, and cucurbits in general. Symptoms of the disease become increasingly evident and typically reach their peak toward the end of the growing season. Although it has not yet been diagnosed in Iraq, it has been reported in many countries around the world. The causal agent of this disease is *Plectosphaerella cucumerina*, a destructive fungal pathogen belonging to the class Ascomycota, which causes severe diseases in numerous economically important crops worldwide (Mirtalebi *et al*., 2022).

Prasad *et al*. (2015) indicated that, as a result of scientific advances in agricultural technology, it is necessary to rely on diverse and unconventional alternatives to manage soil-borne pests and diseases (Al-Taae, 2016; Al-Hakeem and Al-Taae, 2020; Al-Ethawi and Al-Taae, 2022), regardless of the various chemical alternatives, which cause increasing consumer concern regarding the effects and residues of pesticides (Compant *et al*., 2005).

The alternatives used in this study include soil bio fumigation, which is an environmentally safe alternative for controlling soil borne pathogens. It is also called green manure and releases isothiocyanates (ITCS), which are chemically similar to methyl isothiocyanate (an active ingredient in artificial fumigants). Members of the Brassicaceae family are inhibitors of pathogens, insect pests, and weeds (Kareem *et al*., 2015; Mawar and Lodha, 2002).

Cucurbit cultivation in Iraq faces several constraints that negatively affect both the quantity and quality of production. Among the most significant challenges are diseases that cause substantial losses, including fungal pathogens such as leaf spot, powdery mildew, charcoal rot, wilt diseases, root rot, and gummy stem blight (Hussein and Juber, 2014; Al-Taae and Al-Taae, 2019; Al-Jaboory, 2020). Viral diseases also pose a major threat (Pscheidt and Ocamb, 2020).

Given the importance of cucumber as an economic crop widely cultivated in Mosul, with its market value and favorable economic returns, it is imperative to use environmentally friendly alternatives such as leaves from the cruciferous family (green and dry broccoli leaves) to combat the pathogen, as well as their impact on some growth parameters of cucumber plants.

Materials and Methods

Isolation and diagnosis

Samples were collected from infected Armenian cucumber (*C. melo var. flexuosus*) plants (roots, stems, and leaves) from each surveyed field. The samples were placed in polyethylene (plastic) bags labeled with the collection site and date, then transported to the Plant Pathology Laboratory, Department of Plant Protection, College of Agriculture and Forestry, University of Mosul, for the purpose of isolation and diagnosis.

The samples were washed thoroughly with water for 25 minutes to remove dust and suspended particles. The leaves were separated from the stems and roots and cut into small pieces (approximately 3-4 cm) long, individually for each sample collected. These pieces were superficially sterilized with a 1% sodium hypochlorite solution for three minutes, then washed with distilled water for one minute to remove the sterilizing substance and dried between folds of sterile filter paper. The pieces were then transferred to Petri dishes with a diameter of 9 cm containing a culture medium of Potato Dextrose Agar sterilized in an autoclave at a temperature of 121°C and a pressure of 1.5 kg/cm2, to which the antibiotic chloramphenicol was added at a rate of 50 mg/L to prevent the growth of bacterial colonies, at a rate of (4-5) pieces per dish. The dishes were incubated at a temperature of 25°C (±2) for (5-7) days.

The examination was conducted to detect the associated fungi, and the percentage frequency of fungal occurrence was calculated using the following formula:
Percentage frequency of fungal occurrence in the sample = (Number of plant fragments in which the fungus appeared on the plates / Total number of fragments used in the sample) × 100

The most frequently occurring fungus was selected for this study.

A portion from the edge of a newly developed colony was taken and mounted on a glass slide for microscopic examination at 40X magnification. Distinctive characteristics of the pathogen *Plectosphaerella* were observed, including the morphology of the fungal mycelium and the structures.

Evaluation of the efficacy of the best concentration of broccoli leaves against the pathogen in the greenhouse

The experiment was conducted under a Shade net house at the Department of Plant Protection, College of Agriculture and Forestry. A loamy soil mixture (1:2 ratio) was prepared, thoroughly mixed, and sterilized using 5% formalin. The treated soil was distributed into 3-kg pots and inoculated with 6–7-days old pathogenic fungal inoculum, carried on millet seeds, at a rate of 5 g/pot. The soil was moistened with water and covered with polyethene sheets for three days to maintain moisture.

Fresh and dried broccoli leaves were chopped into small pieces (2–3 cm in size), and incorporated into the soil at a depth of 3 cm below the surface. Three concentrations were tested: 3, 6, and 10 g per 1 kg of soil. The pots were then tightly covered with polyethylene sheets for 10 days.

Uniform cucumber (*C. melo* var. *flexuoses*) seedlings were prepared by germinating seeds in seedling trays and transplanted into the treated pots after the incubation period (Kareem *et al*., 2015; Koike and Subbarao, 2000). The experiment followed a factorial design with three factors: (1) broccoli leaf type (fresh and dried), (2) concentrations, and (3) presence or absence of fungal inoculation. The study was conducted using a Completely Randomized Design (CRD) with three replications per treatment:

1. Standard treatment (control)/ without any addition.
2. Soil amended with green broccoli leaves at concentration one (3 g/ 1 kg soil).
3. Soil amended with green broccoli leaves at a concentration two (6 g/ 1 kg soil).
4. Soil amended with green broccoli leaves at a concentration three (10 g/ 1 kg soil).
5. Standard treatment is contaminated with the pathogen.
6. Soil contaminated with the pathogen+ concentration one of green broccoli leaves.
7. Soil contaminated with the pathogen+ concentration two of green broccoli leaves.
8. Soil contaminated with the pathogen+ concentration three of green broccoli leaves

The same treatments were repeated using dry broccoli leaves:

1. Standard treatment (control)/ without any addition.
2. Soil amended with dry broccoli leaves at concentration one (3 g/ 1 kg soil).
3. Soil amended with dry broccoli leaves at concentration two (6 g/ 1 kg soil).
4. Soil amended with dry broccoli leaves at concentration three (10g/ 1 kg soil).
5. Standard treatment contaminated with the pathogen.

6. Soil contaminated with the pathogen+ concentration one of dry broccoli leaves.
7. Soil contaminated with the pathogen+ concentration two of dry broccoli leaves.
8. Soil contaminated with the pathogen+ concentration three of dry broccoli leaves

Two months after the date of inoculation with the pathogen:

A: The percentage of infection and severity of infection were calculated as follows:

$$\text{Percentage of infection} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

Severity of infection = Number of plants in the first category × Their class + Number of plants in the second category × Their class + ... Total number of plants examined × Highest disease index (4) (McKinney, 1923).

B: Plant height (cm): Plant height was calculated using a measuring tape, and the plant's length was measured from the area of contact with the soil to the highest leaf on the plant.

C: Leaf area (cm2): Leaf area was calculated by taking five leaves per plant and piercing five discs from them in the middle with one cm diameter cork borer. The wet weight of each leaf and disc was calculated using a sensitive balance. The leaves were then dried in an electric oven for 72 hours at 75°C until the weight stabilized. The leaf area/plant was calculated using a ratio and proportional method, and measured on five randomly selected plants/experimental unit.

D: Wet and dry weight of the vegetative system (gm): The vegetative system was separated from the root system at the crown area and cleaned of any adhering dust. The wet weight of each plant was measured using a sensitive electric balance (Sartorius /Germany). The leaves were then collected and placed in paper bags and dried in an electric oven for 72 hours at 65°C until the weight stabilized. The dry weight of each experimental unit was then measured using a sensitive balance.

Results and Discussion

Isolation and diagnosis

The results of microscopic examination of samples of cucumber plants (*C. melo var. flexuoses*) obtained from different field survey areas (Shekhan, Salamiyah, Baashqiyah, Al-Fadhiliyah and the Seven Clans) showed various disease symptoms, including yellowing and death of leaves close to the crown area, which appear as if they were sunburned, and brown discoloration of the infected branches. These symptoms reach their severity near the end of the crop by microscopic examination of the growing colonies at magnification (10x and 40x), it was observed that the colony is honey-colored (beige), the fungal hyphae are transparent, branched and divided, the Conidiophore is unbranched, the ascospores are ellipsoidal or oval, single or bicellular, transparent or light brown, their surface is smooth or slightly rough, and the conidia are variable in shape, single or bicellular, transparent or pigmented, arranged in chains or in sticky heads, with a length of (3-) 5.3-6.3 (-9) micrometers and a width of (2-) 3-3.58 (-5) micrometers. It was observed that there are transverse connections between the spores, and these characteristics are favorable for the characteristics of the fungus *P. cucumerina*, according to what was mentioned by Domsch and Gams (1972) and also described by Carlucci *et al*. (2012).

Effect of the most efficient concentration of broccoli leaves against the pathogen in a plastic greenhouse

The results of testing the efficacy of both dried and fresh broccoli leaves showed their ability to reduce infection of snake cucumber (*C.melo* var. *flexuosus*) plants with sudden decline disease caused by the fungus *P. cucumerina*, in addition to their significant positive effect on various growth parameters. According to the statistical analysis results (Figure 1), it was observed that the third concentration of broccoli leaves applied (10 g/ 1 kg soil) significantly reduced both the infection percentage and severity, reaching (12.50% and 0.06), respectively. This concentration differed significantly from the first concentration and the control treatment, while it did not differ significantly from the second concentration in terms of infection percentage. However, it did show a significant difference in reducing disease severity compared to all other treatments. The highest infection percentage and severity were recorded in the control treatment (untreated with broccoli leaves), reaching 37.50% and 0.22, respectively.

While it was clear from Figure 2 that there were no significant differences between green and dry broccoli leaves in the percentage of infection with the pathogen, there was a significant difference between green and dry broccoli leaves in the severity of infection at a rate of (22.71, 27.50) % and (0.16, 0.11) respectively.

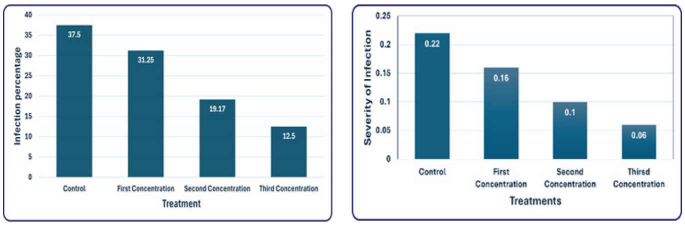

Figure 1: *The effect of different treatments on the infection percentage and severity of infection by the fungus P. cucumerina in cucumber plants.*

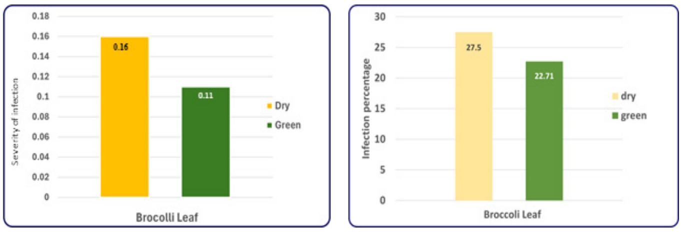

Figure 2: *The percentage of infection and severity of infection by the fungus P. cucumerina in dry and green broccoli leaves.*

There were significant differences between snake cucumber (*C. melo* var. *flexuosus*) plants inoculated with the pathogen and those not inoculated, in both disease incidence and severity of sudden wilt disease at a rate of (50.21%, 0.00%) and (0.28, 0.00), respectively.

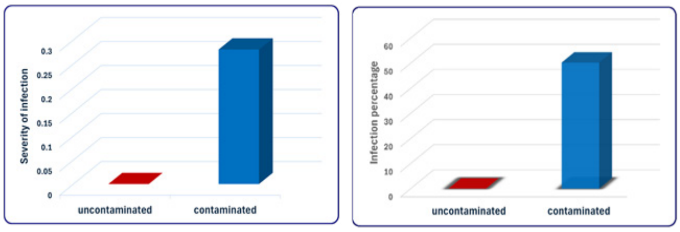

Figure 3: *The percentage of infection and severity of infection with the fungus P. cucumerina in cucumber plants.*

According to the results of the statistical analysis presented in Tables 1 and 2, the two-way interaction between the type of broccoli leaves (dry and fresh) and the treatment (pathogen-contaminated and uncontaminated) revealed that the highest infection rate was recorded in the treatment using dry broccoli leaves contaminated with the pathogen, reaching 55.00%. This was followed by the treatment using fresh broccoli leaves contaminated with the pathogen, which showed an infection rate of 45.42%.

Table 1: *Effect of different treatments and their interactions on the percentage of infection in cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli Leaves Inoculation
		Control	First	Second	Third	
Dry	Non-inoculated	0.00 e	0.00 e	0.00 e	0.00 e	0.00 c
	Inoculated	83.33 a	58.33 bc	43.33 cd	35.00 d	55.00 a
Green	Non-inoculated	0.00 e	0.00 e	0.00 e	0.00 e	0.00 c
	Inoculated	66.67 b	66.67 b	33.33 d	15.00 e	45.42 b
*Leaf type concentrations	Dry	41.67 a	29.17 bc	21.67 cd	17.50 de	
	Green	33.33 ab	30.33 ab	16.67 de	7.50 e	
*Inoculation concentrations	Non-inoculated	0.00 e	0.00 e	0.00 e	0.00 e	
	Inoculated	75.00 a	60.50 b	38.33 c	25.00 d	

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

Table 2: *Effect of different treatments and their interactions on the severity of infection in cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli leaves inoculation
		Control	First	Second	Third	
Dry	Non-inoculated	0.00 g	0.00 g	0.00 g	0.00 g	0.00 c
	Inoculated	0.46 a	0.36 bc	0.28 d	0.21 e	0.33 a
Green	Non-inoculated	0.00 g	0.00 g	0.00 g	0.00 g	0.00 c
	Inoculated	0.42 ab	0.29 cd	0.13 f	0.05 g	0.22 b
*Leaf type concentrations	Dry	0.23 a	0.18 ab	0.14 bc	0.10 cd	
	Green	0.21 a	0.15 bc	0.07 de	0.02 e	
*Inoculation concentrations	Non-inoculated	0.00 c	0.00 c	0.00 c	0.00 c	
	Inoculated	0.44 a	0.33 b	0.21 c	0.13 d	

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

Moreover, the two-way interaction between the type of broccoli leaves (dry and fresh) and their three application rates (3, 6, and 10 g/kg soil) indicated that the highest infection incidence and severity were recorded in the control treatment (without the addition of dry or fresh broccoli leaves), reaching 41.67% and 33.33% incidence, and 0.23 and 0.21 severity, respectively. In contrast, the lowest infection incidence and severity were observed at the highest application rate (10 g/kg soil) of fresh and dry broccoli leaves, recording 7.50% and 17.50% incidence, and 0.02 and 0.10 severity, respectively.

As for the two-way interaction between the three concentrations and with the treatments contaminated and uncontaminated with the pathogen, the highest percentage of infection and its severity was with the comparison treatment contaminated with the pathogen (75.00)% and (0.44) and the lowest was with the third concentration of broccoli leaves of both types contaminated with the pathogen (25.00)% and (0.13) respectively, while there were no significant differences for all treatments uncontaminated with the pathogen at a rate of (0.00%) and (0.00), respectively.

It is evident from the same table and through the three-way interaction among cucumber plants (*C. melo* var. *flexuosus*) contaminated and non-contaminated with the pathogen, and the three concentrations of dry and fresh broccoli leaves used in the experiment, that the highest infection percentage and severity were recorded in the control treatment with dry and fresh broccoli leaves under pathogen-contaminated conditions, at (83.33 and 66.67) % and (0.46, 0.42), respectively. In contrast, the lowest infection percentage and severity were observed in the treatment with the third concentration of fresh and dry broccoli leaves under pathogen-contaminated conditions, at (15.00 and 35.00) % and (0.05, 0.21), respectively. The second most effective treatment in reducing infection percentage and severity was the second concentration (6 g/kg soil) of fresh and dry broccoli leaves, recording (33.33 and 43.33) % and (0.13, 0.28), respectively.

The results were consistent with those reported by Kareem *et al.* (2016), who indicated that green cabbage leaves were effective in reducing the severity and incidence percentage of pepper wilt disease caused by *Fusarium oxysporum*, with significant differences compared to the control treatment. The cabbage treatment at a concentration of 10 g/kg soil achieved the highest reduction in disease severity and incidence percentage, reaching 8.75% and 5%, respectively. Brown and Morra (1997) reported that isothiocyanates have a suppressive effect on pests and pathogens, while bio fumigation helps maintain high levels of organic matter in the soil, thereby improving growth parameters and reducing the rate and severity of disease infection (Cohen *et al.*, 2005).

Suzana *et al.* (2025) also reported that the use of arugula (Eruca sativa) in bio fumigation was effective in reducing the mycelial growth of *Fusarium nygamai* in the greenhouse, which in turn reduced disease severity and infection rates during both seasons. It also contributed to decreasing the number of infected spikes. According to the statistical analysis results of Table 3, there was a significant difference in the plant height of *C. melo* var. *flexuosus* between pathogen-contaminated and non-contaminated treatments, with a difference of 17.57 cm.

Table 3: *Effect of different treatments and their interactions on the height of cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli leaves inoculation	Leaf type	Inoculation
		Control	First	Second	Third			
Dry	Non-inoculated	57.40f	58.43 f	68.83 de	72.70 cd	64.34 b		
	Inoculated	41.63 i	41.27 i	47.40 h	49.60 h	44.98 d		
Green	Non-inoculated	70.10 cd	74.57 bc	79.23 ab	82.97 a	76.72 a		
	Inoculated	51.53 gh	54.87 fg	64.97 e	72.43 cd	60.95 c		
*Leaf type concentrations	Dry	49.33 g	52.92 f	57.17 e	59.22 de		54.66 b	
	Green	62.48 cd	63.05 c	72.10 b	77.70 a		68.83 a	
*Inoculation Concentrations	Non-inoculated	63.75 c	68.83 b	73.63 a	75.90 a			70.53 a
	Inoculated	46.58 e	48.07 e	56.18 d	61.02 c			52.96 b
Concentrations			55.91 c	62.51 b	68.46 a			

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

Table 4: *Effect of different treatments and their interactions on leaf area of cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli Leaves Inoculation	Leaf type	Inocula-tion
		Control	First	Second	Third			
Dry	Non-inoculated	39.05 de	39.65 d	41.31 cd	49.40 b	42.35 b		
	Inoculated	24.02 k	26.87 jk	28.57 ij	32.19 gh	27.91 d		
Green	Non-inoculated	41.40 cd	43.50 c	48.20 b	54.35 a	46.86 a		
	Inoculated	26.78 jk	31.38 hi	34.67 fg	36.27 ef	32.28 c		
*Leaf type concentrations	Dry	31.53 e	33.26 de	34.94 d	40.80 b		35.13 b	
	Green	34.09 d	37.44 c	41.44 b	45.31 a		39.57 a	
*Inoculation concentrations	Non-inoculated	40.22 c	41.57 c	44.75 b	51.80 a			44.61 a
	Inoculated	25.40 g	29.13 f	31.62 e	34.23 d			30.09 b
Concentrations			35.35 c	38.19 b	43.05 a			

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

The Table 4 shows significant differences in the plant height of *C. melo* var. *flexuosus* when treated with dry and fresh broccoli leaves, with the greatest height recorded in the treatment with fresh broccoli leaves, reaching 68.83 cm. Regarding the effect of different concentrations of broccoli leaves (3, 6, and 10 g/kg soil) on plant height when added to sterilized potting soil, significant differences were observed among the three concentrations. The highest plant height was recorded at the third concentration (10 g/kg soil), reaching 68.46 cm, while no significant differences were observed between the control and the second concentration, which recorded 60.11 cm and 62.51 cm, respectively.

From the two-way interaction between the type of broccoli leaves (dry and fresh) and the pathogen-contaminated and non-contaminated soil, the highest plant height was observed in the treatment with fresh broccoli leaves in non-contaminated soil, reaching 76.72 cm, which differed significantly from the other treatments. The shortest plant height was recorded in the treatment with dry broccoli leaves in pathogen-contaminated soil, with a value of 44.98 cm.

Additionally, the two-way interaction between the type of broccoli leaves (dry and fresh) and their three concentrations (3, 6, and 10 g/kg soil) showed that the highest plant height of *C. melo var. flexuosus* was observed at the third concentration of fresh broccoli leaves (10 g/kg soil), reaching 77.70 cm, which differed significantly from the other treatments. In contrast, the lowest plant height was recorded in the control treatment (untreated), at 49.33 cm. The second-best results were recorded at the second concentration for both fresh and dry broccoli leaves, with plant heights of 72.10 cm and 57.17 cm, respectively.

From the same table, the two-way interaction between the concentrations of dry and fresh broccoli leaves contaminated and non-contaminated with the fungus showed a significant superiority of the second and third concentrations of broccoli leaves in increasing the plant height of *C. melo var. flexuosus* in the non-contaminated treatments. These two concentrations differed significantly from all other treatments. The shortest plant height was recorded in the fungus-contaminated treatments under the control and first concentration treatments, with values of 46.58 cm and 48.07 cm, respectively.

The statistical analysis results in Table 5 revealed a significant difference in leaf area between *C. melo* var. *flexuosus* plants contaminated with the pathogen and those non-contaminated, with a significant difference of 14.51 cm^2.

The Table 5 shows a significant superiority in leaf area for plants treated with fresh broccoli leaves compared to those treated with dry broccoli leaves, with a difference of 4.44 cm^2.

Regarding the effect of the broccoli leaf concentrations and the control treatment, the best leaf area was achieved by plants treated with the third concentration (10 g/kg soil) of broccoli leaves, reaching 43.05 cm^2, which was significantly different from all other treatments. The lowest leaf area was recorded in the control treatment, measuring 32.81 cm^2.

Table 5: *Effect of different treatments and their interactions on the fresh weight of the shoot system in cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli leaves inoculation	Leaf type	Inoculation
		Control	First	Second	Third			
Dry	Non-inoculated	49.70 gh	57.53 ef	64.70 de	74.57 c	61.63 b		
	Inoculated	31.17 j	36.40 ij	42.67 hi	59.00 de	42.31 d		
Green	Non-inoculated	74.17 c	80.80 c	97.47 b	110.27 a	90.68 a		
	Inoculated	34.93 ij	39.90 i	50.40 fg	66.53 d	47.94 c		
*Leaf type concentrations	Dry	43.05 e	50.10 d	52.87 d	61.85 c		51.97 b	
	Green	54.55 d	60.35 c	73.93 d	88.40 a		69.31 a	
*Inoculation concentrations	Non-inoculated	65.25 c	74.37 b	77.50 b	87.48 a			76.15 a
	Inoculated	33.05 f	38.15 e	46.53 d	62.77 c			45.13 b
Concentrations			51.70 c	62.02 b	75.13 a			

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

From the two-way interaction between dry and fresh broccoli leaves, contaminated and non-contaminated with the pathogen, Table 5 shows significant differences among treatments. The highest leaf area was recorded for plants treated with fresh broccoli leaves in the non-contaminated treatment, measuring 46.86 cm^2, which differed significantly from all other treatments. The lowest leaf area was with the treatment of dry broccoli leaves contaminated with the pathogen, at 27.91 cm^2.

The Table 5 also shows the two-way interaction between the types of broccoli leaves (dry and fresh), their three concentrations, and the control treatment. The third concentration (10 g/kg soil) of fresh broccoli leaves significantly increased the leaf area of *C. melo var. flexuosus* plants to 45.31 cm^2, which was significantly higher than other treatments. The second highest was the third concentration of dry broccoli leaves at 40.80 cm^2, which did not differ significantly from the second concentration (6 g/kg soil) of fresh broccoli leaves.

Furthermore, the interaction between the pathogen contamination treatments and broccoli leaf concentrations had a significant effect on the leaf area of *C. melo var. flexuosus* plants. The third concentration in the non-contaminated treatment achieved the highest leaf area of 51.80 cm^2, differing significantly from other treatments, while the lowest leaf area was recorded in the contaminated control treatment, at 25.40 cm^2.

From the same table, the three-way interaction between types of broccoli leaves (dry and fresh), contamination status (contaminated and non-contaminated), and concentrations showed significant differences among treatments. The highest leaf area was recorded in the treatment with the third concentration of fresh broccoli leaves in the non-contaminated (healthy) plants, reaching 54.35 cm^2. The second highest was the third concentration of dry broccoli leaves in the non-contaminated treatment, at 49.40 cm^2, which did not differ significantly from the second concentration of fresh broccoli leaves in the non-contaminated treatment

Through the results of the statistical analysis in Table 6, significant differences were observed between the contamination treatments, with the non-contaminated treatment showing a significant superiority for cucumber plants in the fresh weight of the shoot system by 76.15 g.

Also, from the Table 6, the significant superiority of cucumber plants treated with green broccoli leaves was evident at 69.31 g.

Using the three concentrations of broccoli leaves added to the potting soil planted with cucumber plants, the third concentration (10 g/1 kg soil) showed a significant superiority in the fresh weight of the shoot system at 75.13 g, which differed significantly from the other treatments. However, no significant differences were found between the first concentration treatment and the control treatment (53.71 and 51.70 g, respectively).

Table 6: *Effect of different treatments and their interactions on the dry weight of the shoot system in cucumber plants infected with P. cucumerina.*

Broccoli leaf type	Inoculation	Concentrations				*Broccoli leaves inoculation	Leaf type	Inoculation
		Control	First	Second	Third			
Dry	Non-inoculated	11.97 cd	14.20 c	14.63 c	18.30 b	14.78 b		
	Inoculated	6.40 g	7.33 fg	7.93 efg	10.60 de	8.07 c		
Green	Non-inoculated	13.67 c	17.40 b	19.80 b	22.77 a	18.41 a		
	Inoculated	6.30 g	7.10 fg	9.53 efg	13.73 c	9.17 c		
*Leaf type concentrations	Dry	9.65 d	9.98 d	11.28 cd	14.45 b		11.42 b	
	Green	10.30 d	12.25 c	14.67 b	18.25 a		13.79 a	
*Inoculation concentrations	Non-inoculated	13.93 cd	14.68 c	17.22 b	20.53 a			16.59 a
	Inoculated	6.35 f	7.22 ef	8.73 e	12.17 d			8.62 b
Concentrations		10.14 c	10.95 c	12.98 b	16.35 a			

**Means with the same letters within each column are not significantly different according to Duncan's multiple range test at the 5% probability level.*

From the two-way interaction between broccoli leaves in their dry and green forms and the contamination treatments (non-contaminated and contaminated with the pathogen), the highest fresh weight of the shoot system was recorded in cucumber plants treated with green broccoli leaves in the non-contaminated treatment with the pathogen (90.68 g), which differed significantly from the other treatments. The second highest was cucumber plants treated with dry broccoli leaves in the non-contaminated treatment (61.63 g).

Regarding the two-way interaction between broccoli leaves at the concentrations used in the experiment, the highest fresh weight was with green broccoli leaves at the highest concentration (88.40 g), which differed significantly from the other treatments, while the lowest fresh weight was for cucumber plants grown in pots without broccoli leaf treatment (43.05 g).

For the two-way interaction between contamination treatments (contaminated and non-contaminated with the pathogen) and the three concentrations of broccoli leaves in their dry and green forms, the highest fresh weight of the shoot system of cucumber plants was observed with the third concentration (87.48 g), which differed significantly from other treatments. The second highest fresh weight was with the second and first concentrations of non-contaminated green broccoli leaves (77.50 and 74.37 g, respectively).

Through the three-way interaction between dry and green broccoli leaves at the concentrations used in the experiment, either contaminated or non-contaminated with the pathogen, the third concentration of non-contaminated green broccoli leaves showed significant superiority with a fresh shoot system weight of 110.27 g. The second highest fresh weight was with the second concentration of non-contaminated green broccoli leaves at 97.47 g, which differed significantly from the other treatments. The lowest weights were recorded with the control treatments contaminated and non-contaminated with the pathogen (31.17 and 34.93 g, respectively).

It is evident from Table 6 that there is a significant difference between the contamination treatments (non-contaminated and contaminated with the pathogen). According to the statistical analysis results in the same table, the green broccoli leaves showed a significant superiority in the dry weight of the shoot system by 13.79 g when added to the potting soil planted with cucumber plants. The three concentrations had a positive and effective impact, especially the third concentration on the dry weight of the shoot system, averaging 16.35 g, which differed significantly from the other treatments. The lowest dry weight was recorded in the control treatment (without addition) and the first concentration (10.14 and 10.95 g, respectively).

Regarding the two-way interaction between broccoli leaves and the contamination treatments, the table shows that the highest dry weight of the shoot system was recorded with the non-contaminated treatment of green broccoli leaves (18.41 g). No significant difference was found between the dry and green broccoli leaves in the non-contaminated treatments (8.07 and 9.17 g, respectively).

For the two-way interaction between broccoli leaves (dry and green) at the concentrations used in the experiment, the third concentration of green broccoli leaves showed significant superiority with 18.25 g, differing significantly from other treatments. The second highest values were recorded with the second concentration of green broccoli leaves and the third concentration of dry leaves (14.67 and 14.45 g, respectively).

Regarding the two-way interaction between contamination treatments and the concentrations used in the experiment, the highest dry weight of the shoot system was with the third concentration in the non-contaminated treatment at 20.53 g, which differed significantly from other treatments. The lowest dry weights were recorded with the control and first concentration treatments contaminated with the pathogen (6.35 and 7.22 g, respectively), with no significant difference between the latter and the second concentration treatment in the contaminated group.

The three-way interaction between the studied factors in the experiment also revealed the highest dry weight of the shoot system at the third concentration, reaching 22.77 g, with a significant difference from the other treatments. The lowest dry weights were recorded in the control treatments of green and dry broccoli leaves contaminated with the pathogen (6.30 and 6.40 g, respectively), with no significant differences compared to the first concentrations of green and dry leaves contaminated with the pathogen and the second concentration of dry leaves (7.10, 7.33, and 7.93 g, respectively).

The effect of bio fumigation by cauliflower residues had a significant impact on the growth parameters of pepper plants treated with cauliflower residues. The use of cruciferous plant residues as green manure is considered effective because they contain a group of natural chemical compounds known as isothiocyanates, which are released into the soil after their aqueous decomposition by the enzyme myrosinase into glucosinolates (Kirkegaard and Matthiessen, 2004).

The results confirmed the findings of Kareem et al. 2016, where treating pepper plants with different concentrations, especially (10 g/1 kg soil), had a significant effect on improving growth parameters represented by leaf length and width, as well as fresh and dry weight of the plants. These results differed significantly from the untreated control. Similarly, the use of arugula leaves added to soil planted with cucumber, both contaminated and non-contaminated with the fungus *Rhizoctonia solani*, showed a positive effect on some growth parameters (Abdul-Karim, 2015).

Worldwide results have been promising, and a meta-analysis incorporating data from 934 bio fumigation experiments using cruciferous residues demonstrated a reduction in disease incidence and an increase in crop productivity by approximately 30% (Morris *et al*., 2020).

Conclusions

This study summarizes that one of the successful alternative methods for controlling soil-borne pathogens is green manure (bio fumigation), represented by the use of broccoli leaves (a cruciferous plant) at three concentrations (3, 6, and 10 g/1 kg soil), in addition to the control treatment. These treatments had a significant positive effect in reducing the percentage and severity of sudden decline disease caused by the fungus *Plectosphaerella cucumerina*, with varying degrees of effectiveness, especially at the highest concentration compared to the standard treatment (control).

Furthermore, they played an effective positive role in some of the studied growth parameters, contributing to the improvement of the productive traits of cucumber plants (*C. melo var. flexuosus*).

Novelty Statement

This study is the first to investigate the role of broccoli leaves as a bio-fumigant in controlling *Plectosphaerella cucumerina* on Armenian cucumber plants, demonstrating their effectiveness as an environmentally friendly alternative to chemical pesticides.

Author's Contribution

Hiba Ibrahim Hussien: Technical Input at every step, Overall Management of the article, Data collection, Data entry in SPSS and analysis, Result and discussion, introduction, References

Dr. Huda Hazim Al-Taae Prof.: Conceived the idea, wrote abstract, Methodology, Did SPSS analysis, Conclusion, Technical Input at every step, Overall Management of the article, Result and discussion, introduction, References

Conflict of interest

The authors have declared no conflict of interest.

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