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(Original Article)

Induction of Resistance in Basil Plants to Root-rot and Wilt Diseases by Biochar, Silica, and Sodium Silicate

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Abstract

Basil plants (*Ocimum basilicum* L.) are affected by several soil-borne diseases leading to significant reductions in crop productivity. Root-rot and wilt diseases are prevalent in basil cultivation in the Assiut governorate.The fungi isolated from diseased basil plants included *Fusarium oxysporum, Rhizoctonia solani, Fusarium moniliforme, Fusarium semitectum, Macrophomina phaseolina,* and *Alternaria alternata*. The results confirmed that *F. oxysporum* and *R. solani* exhibited the highest incidence and frequency during isolation. Moreover, *F. oxysporum* was a highly pathogenic isolate, causing wilt in basil plants when compared to uninfected control plants. Silica gel (6 g/L) was the most effective treatment, followed by sodium silicate and biochar, in reducing the linear mycelial growth of the six tested fungi compared with untreated control. Under greenhouse conditions, silica gel significantly decreased disease severity, followed by sodium silicate, whereas biochar provided moderate disease suppression during both the 2023 and 2024 growing seasons.

Keywords: *Induction of resistance, Basil, Biochar, Sodium silicate, Silica gel.*

Introduction

Basil (*Ocimum basilicum* L.) is a medicinal and aromatic plant that is used for various purposes. In the food industry, it is used as fresh leaves or as an extract oil, and it is also employed in medical and cosmetic fields (Sakkas and Papadopoulou, 2017). Basil is commercially produced in Egypt and other countries (Zahedi *et al*., 2011). The Assiut governorate is one of the most prominent areas in Egypt for growing basil, especially in Abnoub county. The area in Assiut was approximately 1,174 Feddan (Anonymous, 2024). *R. solani, F. solani, F. oxysporum,* and *M. phaseolina* infect basil plants, causing root rot and wilt. These pests remain a major threat to basil cultivation in Egypt and other parts of the world (Garibaldi *et al*., 1997; Toussaint *et al*., 2008; Al-Sohaibani *et al*., 2011). Basil fusarium wilt is a destructive disease that causes significant loss of basil production (Lori *et al*., 2014). Reuveni *et al*. (2002) identified *F. oxysporum* f. sp. *basilicum* as one of the main causative pathogens of wilt symptoms. Yanashkov and Vatchev (2021) reported that *Rhizoctonia solani* Kühn AG 4 caused root and basal rot of sweet basil (*Ocimum basilicum* L.) in Bulgaria. Fungal pathogens cause multiple symptoms such as rots and wilts (Jaiswal *et al*., 2017). Biochar is a solid

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carbon-containing material synthesized through the thermal treatment of biomass wastes in a limited oxygen supply (Hossain *et al*., 2020). Recently, biochar has been utilized as a soil amendment. It enhances soil fertility and plant productivity (Kalus, 2019 and Nath *et al*., 2022) and helps justify climate change by sequestering carbon and reducing greenhouse gas emissions (Kumar *et al*., 2022 and Lyu *et al*., 2022). Additionally, it is used against soil-borne fungal pathogens and interacts with soil microbes and plants (Bonanomi *et al*., 2015 and Frenkel, 2017). In plants, it can induce both systemic acquired resistance and systemic resistance (Harel *et al*., 2012). Silicon (Si) plays an important role in mitigating numerous environmental stresses and enhancing plant resistance to pathogens (Wang *et al*., 2017).

Potassium silicate is the main source of soluble potassium and silicon. Plants require silica to counteract biotic and abiotic stress (Ma, 2004). This study amid to control basil root-rot and wilt using biochar, silica, and sodium silicate.

Materials and Methods

1. Isolation and identification of the causal pathogens of basil root rot and wilt, along with their frequencies

Ten plants showing natural symptoms of root rot and wilt were collected from four commercial fields (Abnoub, Arab-El-Awamer, El-Wasta, and El-Fath) in the major basil-growing Assiut governorate during the 2022 and 2023 seasons. The affected parts of the plants were divided into small pieces (2-5 mm), washed, surface sterilized using 2% sodium hypochlorite for 2 min, rinsed and dried with sterilized filter paper. The pieces were placed in Petri dishes containing Potato Dextrose Agar (PDA) and incubated at 25°C for 7 days with daily observation. Isolated fungi were purified using single spore and hyphal tip techniques (Dhingra and Sinclair, 1995). The fungal colonies were microscopically examined, counted, and identified according to their morphological and microscopic characteristics, as described by Domsch *et al.* (1980), and Leslie and Summerell (2006). The identification was confirmed by the Assiut University Moubasher Mycological Center (AUMMC). Pure cultures were kept on PDA slants at 5°C for further analyses. The frequency of fungi was calculated using the following formula (Ahmed *et al*., 2017):

$$\text{Frequency}\ \% = (\text{No. of colonies for each fungus}/\text{No. of all isolates})\ 100$$

2. Pathogenicity tests

The pathogenic capability of the isolated fungi was assessed under greenhouse conditions using the Balady cultivar of basil seeds at the Plant Pathology Department, Faculty of Agriculture, Assiut University. Inocula of *F. oxysporum, F. moniliforme, F. semitectum, Macrophomina phaseolina, Alternaria alternata, and R. solani* were prepared by growing the fungi on a maize-meal-sand medium (50% sand + 50% loam) for 20 days at 25°C. Pots were sterilized in a 5% formalin water solution and covered with polyethylene sheets for 7 days. The sterilized soil was left for another 7 days to allow formalin evaporation. Sterilized pots (20 cm in diameter) were filled with a mixture of sterilized clay and soil (1:1 w/w) and inoculated with the fungus at a rate of 1%. Each pot was sown with five basil seeds, and three replicates were used for each fungus. All treated pots and inoculated plants were maintained under greenhouse conditions with periodic irrigation. Disease severity percentage (DS%) was recorded 90 days after planting for both root rot and wilt, using the arbitrary disease index scale (0-5) described by Grünwald *et al.* (2003). was used to measure the DS% of root-rot, where: 0 = No observable symptoms, 1 = Slight hypocotyl lesions, 2 = Lesions merging around epicotyls and hypocotyls, 3 = Lesions spreading into the root system with root tips starting to be infected, 4 = Epicotyl, hypocotyls, and root system almost completely infected, and 5 = Completely infected root. The disease severity of Fusarium wilt and Rhizoctonia root rot was measured using the arbitrary (0-5) disease index scale described by Abdel-Razik *et al.* (2012), where 0 = no observable symptoms; 1 = light vein-clearing and chlorosis of the leaves; 2 = yellowing and wilting of lower leaves extending to upper leaves; 3 = brown discoloration of the vascular systems of taproot and stem; 4 = necrotic streaks on the stem base spreading toward the stem apex; and 5 = premature plant death. To measure the severity of Rhizoctonia root rot: 0 = No visible symptoms; 1 = A few small soft lesions on part of the root system and hypocotyls; 2 = Elongated, discolored lesions spread over the entire root system and hypocotyls; 3 = Deep brown necrosis around the stem, partial root disintegration, yellowing of leaves; 4 = Stem canker, root disintegration, yellowing of leaves, stunting; and 5 = Collapse and death of plants. Disease Severity % (DS) was recorded 90 days after sowing using the following formula

$$\text{DS \%} = [\Sigma\ (\text{n v})\ /\ 5\text{N}]\ 100$$

Where: n = Number of roots in each category, v = Numerical value of each category, and N = Total number of roots in the samples.

The Control Efficiency % (CE %) was calculated according to Yang *et al.* (2022) using the following formula:

$$\text{Control Efficiency \%} = [(\text{DS in control-DS in treated})\ /\ \text{DS in control}]\ 100$$

3. Effects of biochar, sodium silicate, and silica gel on mycelial linear growth *in vitro*

Biochar was prepared by slow pyrolysis in a kiln with a retention time of 2 h and obtained from the Soil and Water Dept., Assiut University. After overnight cooling, the biochar is gently crushed and ground with a 0.5-mm sieve before use.

Table 1. The characteristics of biochar (source: Soil and Water Dept. Assiut University)

Content (Meq /100 g soil)						Ec (1:20)	pH (1:20)
Bicarbonate	chloride	Potassium	Sodium	Magnesium	Calcium		
8.00	10.00	9.230	4.872	20.00	8.00	1.155	8.28

The biochar was transferred to glass bottles after sterilizing by autoclaving at 121°C for 2 h, and another treatment was left unsterilized. Biochar was added at three concentrations (0.5, 1.0, and 2.0 g/L) to Petri dishes with sterilized PDA to study its effect on mycelial linear growth (Weggler *et al*., 2008). Three concentrations of biochar (0.5, 1.0, and 2.0 g/L), sodium silicate (0.025, 0.050, and 0.0100 g/L), and silica gel (2.0, 4.0, and 6.0 g/L) were tested on the linear growth of pathogenic fungi *in vitro*, along with the untreated control (only water). These concentrations were individually added to sterilized PDA before solidification and then poured into sterile 9-cm-diameter Petri plates. After solidification, the plates were inoculated with 5-mm fungal discs placed at the center of the Petri dishes and incubated at 25°C for 7 days with daily observations. Three plates per concentration of each fungus were used as replicates; three plates served as controls. Linear growth was recorded, and the reduction in linear growth was estimated, with averages recorded. The mean diameter of the pathogenic fungi was measured for each treatment when the fungal growth completely covered any surface of the control treatment. The percentage of radial growth inhibition was calculated using the following equation

$$\text{Growth inhibition } \% = [C - T) / T]\ 100$$

Where: C=Radial growth of control, T=Radial growth of treatment.

4. ffect of biochar, sodium silicate, and silica gel on the severity of basil root-rot and wilt disease under greenhouse conditions

This study was conducted in the Faculty of Agricultural, Assiut University under greenhouse conditions during the seasons of 2023 and 2024. In addition to evaluating the effectiveness of these previously mentioned treatments on the disease incidence and disease severity of basil plants (cv. Balady) compared with the untreated control. Biochar, Sodium silicate, and Silica gel were prepared as previously mentioned. Pots (20 cm in diameter) were filled with approximately 2.0 kg soil (sand+ peat moss 2:1w/w) and artificially infested with the tested fungi and mixed with sterilized potted soil. Each pot was planted with five seeds. Biochar, sodium silicate, and silica gel were mixed with potted soil. Three replicates were used for each treatment. Disease incidence and severity were recorded as percentages, as mentioned in previous pathogenicity tests.

5. Statistical analysis

All experiments were conducted using a randomized complete block design. Data were analyzed using MSTAT C. Means were compared using the least significant difference (L.S.D., p = 0.05) as described by Gomez and Gomez (1984).

Results

1. The isolation and identification of the causal pathogens of basil root-rot and wilt, along with their frequencies

We obtained 124 fungal isolates from diseased basil plants collected from four locations in Assiut governorate. These fungi were purified and identified based on morphological and physiological traits verified by the Assiut University Moubasher Mycological Center (AUMMC). The results showed that the most dominant fungi belonged to six genera, with Fusarium oxysporum being the most frequent,: *Fusarium oxysporum* Schechtendal was isolated 37 times with a 29.84% frequency, *Rhizoctonia solani* Kühn was isolated 30 times with a 24.19% frequency, *Fusarium moniliforme* Sheldon was isolated 22 times with a 17.74% frequency, *Fusarium semitectum* Berk was isolated 18 times with a 14.52% frequency, and *Macrophomina phaseolina* (Tassi) Goidanch was isolated 14 times with a 11.29% frequency. *Alternaria alternata* (Fries) Keissler came in last place, being isolated 3 times with a 2.42% frequency.

Table 2. Isolation sources and frequency (%) of fungi associated with basil root-rot and wilt disease

Isolate name	Isolate source								Total No. of isolates	Mean of frequency (%)
	Abnoub		Arab-El-Awamer		El-Wasta		El-Fath			
	No. of isolates	Frequency (%)	No. of isolates	Frequency (%)	No. of isolates	Frequency (%)	No. of isolates	Frequency (%)		
F. oxysporum	9	32.14	6	30.00	10	30.30	12	27.91	37	29.84
R. solani	7	25.00	5	25.00	8	24.24	10	23.26	30	24.19
F. moniliforme	5	17.86	4	20.00	5	15.15	8	18.60	22	17.74
F. semitectum	4	14.29	3	15.00	5	15.15	6	13.95	18	14.52
M. phaseolina	3	10.71	2	10.00	4	12.12	5	11.63	14	11.29
A. alternate	0.0	0.0	0.0	0.0	1	3.03	2	4.75	3	2.42
Total	28	100.00	20	100.00	33	100.00	43	100.00	124	100.00

2. Pathogenicity tests

Pathogenicity tests conducted in the greenhouse showed that the isolated fungi were capable of infecting basil plants (cv. Balady), causing root rot and wilt. The pathogens responsible for root rot included *Rhizoctonia solani, Fusarium moniliforme*, and others, while *Fusarium oxysporum* caused wilt. The highest severity of root rot was caused by *Rhizoctonia solani* (54.40%), followed by *Fusarium moniliforme* (47.63%) and *Fusarium semitectum* (38.03%), while *Fusarium oxysporum* isolate No. I caused the highest wilt severity (59.93%).

Table 3. Pathogenicity of fungi isolated from basil plants (cv. Balady) under greenhouse conditions

No. of isolates	Isolate name	Disease	Severity (%)
1	*Fusarium oxysporum* No. I	Wilt	59.93
2	*F. oxysporum* No. II	Wilt	56.63
3	*F. oxysporum* No. III	Wilt	44.40
4	*F. oxysporum* No. IV	Wilt	37.76
5	*Rhizoctonia solani* No. I	Root-rot	54.40
6	*R. solani* No. II	Root-rot	46.60
7	*R. solani* No. III	Root-rot	38.03
8	*R. solani* No. IV	Root-rot	33.30
9	*Fusarium moniliforme* No. I	Root-rot	47.63
10	*F. moniliforme* No. II	Root-rot	43.86
11	*F. moniliforme* No. III	Root-rot	36.11
12	*F. moniliforme* No. IV	Root-rot	31.26
13	*F. moniliforme* No. V	Root-rot	38.03
14	*F. semitectum* No. I	Root-rot	33.83
15	*F. semitectum* No. II	Root-rot	32.50
16	*F. semitectum* No. III	Root-rot	27.76
17	*Macrophomina phaseolina* No. I	Root and Crown rot	33.84
18	*M. phaseolina* No. II	Root and Crown rot	31.66
19	*M. phaseolina* No. III	Root and Crown rot	25.00
20	*M. phaseolina* (4)	Root and Crown rot	22.50
21	*Alternaria alternata* No. I	Root and Crown rot	26.66
22	*A. alternata* No. II	Root and Crown rot	20.83
23	*A. alternata* No. III	Root and Crown rot	13.30
24	*A. alternata* No. IV	Root and Crown rot	11.06
25	Control	--	0.00
L.S.D 0.05			**7.15**

3. Effects of biochar, sodium silicate, and silica gel on the mycelial linear growth of fungal pathogens *in vitro*

Results in Table 4 show that the three applied biochar (0.5, 1.0, and 2.0 g/L), silica gel (2.0, 4.0, and 6.0 g/L), and sodium silicate (0.025, 0.050, and 0.100 g/L) significantly suppressed the mycelial linear growth of pathogens. The isolates produced an inhibition zone of growth that increased with increasing concentration. Results indicated that Silica gel (6.0 g/L) reduced mycelial linear growth by 4.87%, 6.48%, 6.10%, 5.76%, 5.47%, and 5.31% for the six tested fungi compared to other treatments and the untreated control.

Table 4. Effects of biochar, sodium silicate, and silica gel on mycelial linear growth *in vitro*

Treatments	Concentration (g/l)	Pathogen linear growth diameter (mm)					
		F. oxysporum	*R. solani*	*F. moniliforme*	*F. semitectum*	*M. phaseolina*	*A. alternata*
Biochar	0.5	76	61	61	54	50	45
	1.0	71	60	50	43	41	40
	2.0	63	60	50	44	44	41
	0.0	90	90	90	90	90	90
Silica gel	2.0	62	61	56	51	46	41
	4 .0	60	50	51	43	41	37
	6 .0	53	51	43	40	31	31
	0.0	90	90	90	90	90	90
Sodium silicate	0.025	81	80	71	70	61	60
	0.050	80	71	63	61	55	51
	0.100	73	66	61	61	51	55
	0.0	90	90	90	90	90	90
L.S.D 0.05		**4.86**	**5.35**	**3.86**	**3.01**	**4.99**	**5.89**

4. Effects of some inducers on basil wilt caused by *Fusarium oxysporum* under greenhouse conditions during the 2023 and 2024 growing seasons

Data in Table 5 indicates that in the two tested seasons (2023, 2024), silica gel treatments resulted in the highest control efficiency, reaching 26.9% and 32.8% in 2023 and 2024, respectively. Meanwhile, biochar exhibited the lowest efficiency, reducing disease severity by only 13.3% and 5.5% in the two seasons. However, treatment with sodium silicate showed moderate effectiveness, with control efficiency values of 15.9% and 14.6% in 2023 and 2024, respectively. The highest disease severity was recorded in control (untreated) at 41.66% in 2023 and 36.33% in 2024, confirming the lack of protection in untreated conditions. In contrast, control (uninfected) maintained 0.00% severity and 100% efficiency, demonstrating complete resistance.

Overall, the data suggests that silica gel is the most effective treatment, whereas biochar shows minimal disease suppression. Sodium silicate provides intermediate protection, but it is not as effective as silica gel.

Table 5. Effects of some inducers on basil wilt caused by *Fusarium oxysporum* under greenhouse conditions during the 2023 and 2024 seasons

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	36.1	13,3	34.33	5.5
Silica gel	30.42	26,9	24.40	32.8
Sodium silicate	35.00	15,9	31.0	14.6
Control1 (untreated)	41.66	0.00	36.33	0.00
Control 2 (uninfected)	0.00	100	0.00	100
LSD 0.05	**5.12**		**8.91**	

5. Effects of some inducers on basil root-rot caused by *Rhizoctonia solani* under greenhouse conditions during the 2023 and 2024 growing seasons

Data in Table (6) indicates that in both seasons (2023 and 2024), treatments with sodium silicate achieved the greatest control efficiency, reaching 72.1% in 2023 and 59.9% in 2024. Similarly, Silica gel demonstrated high-efficiency values of 71.3% and 66.6% in the four seasons. On the other hand, among the tested treatments, biochar exhibited the lowest control efficiency, reducing disease severity by 54.0% in 2023 and 35.9% in 2024. Meanwhile, the highest disease severity was recorded in control 1 (untreated) at 54.40% in 2023 and 52.0% in 2024, confirming the lack of protection in untreated conditions. In contrast, control 2 (uninfected) consistently maintained 0.00% severity and 100% efficiency, lighting its complete resistance. Overall, the results suggest that sodium silicate and Silica gel were the most effective treatments, significantly reducing disease severity. Biochar provides some level of disease suppression, but there are notably fewer treatments.

Table 6. Effect of some inducers on basil root-rot caused by *Rhizoctonia solani* under greenhouse conditions during the 2023 and 2024 growing seasons

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	25	54.0	33.29	35.9
Silica gel	15.58	71.3	17.35	66.6
Sodium silicate	15.15	72.1	20.83	59.9
Control1 (untreated)	54.40	0.00	52.0	0.00
Control 2 (uninfected)	0.00	100	0.00	100
LSD 0.05	**9.45**		**11.52**	

6. Effects of some inducers on basil rot caused by *Fusarium moniliforme* under greenhouse conditions during the 2023 and 2024 growing seasons

Data in Table 7 indicates that in the two seasons (2023 and 2024), treatments with silica gel resulted in the highest control efficiency, reaching 82.6% in 2023 and 59.2% in 2024. Similarly, sodium silicate showed significant effectiveness, with control efficiency values of 74.3% and 50.6%, respectively. In contrast, biochar exhibited the lowest control efficiency among the tested treatments, reducing disease severity by 56.7% in 2023 and 38.6% in 2024. The highest disease severity was recorded in control 1 (untreated) at 47.93% in 2023 and 45.0% in 2024, confirming the lack of protection in untreated conditions. Meanwhile, control 2 (uninfected) consistently maintained 0.00% severity and 100% efficiency, demonstrating complete resistance.

Table 7. Effects of some inducers on basil rot caused by *Fusarium moniliforme* under greenhouse conditions during the 2023 and 2024 growing seasons

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	20.80	56.6	27.16	38.6
Silica gel	8.30	82.6	18.33	59.2
Sodium silicate	12.31	74.3	22.21	50.6
Control1 (untreated)	47.93	0.00	45.0	0.00
Control 2 (uninfected)	0.00	100.0	0.00	100.0
LSD 0.05	**5.43**		**12.73**	

7. Effects of some inducers on basil rot caused by *Fusarium semitectum* under greenhouse conditions during the 2023 and 2024 growing seasons

Data in Table 8 indicates that treatments with Silica gel resulted in the highest control efficiency, reaching 78.1% in 2023 and 59.8% in 2024. Similarly, Sodium silicate showed significant effectiveness, with control efficiency values of 67.1% and 53.1%, respectively. In contrast, among the tasted treatments, Biochar exhibited the lowest control efficiency, reducing disease severity by 56.3% in 2023 and 36.9% in 2024. The highest disease severity was recorded in control 1 (untreated) at 38.03% in 2023 and 37.0% in 2024, confirming the lack of protection in untreated conditions. Meanwhile, control 2 (uninfected) consistently maintained 100% efficiency, demonstrating complete resistance. Overall, silica gel was the most effective treatment, significantly reducing disease severity, followed by sodium silicate, whereas biochar provided moderate disease suppression.

Table 8. Effects of some inducers on basil rot caused by *Fusarium semitectum* under greenhouse conditions during the 2023 and 2024 growing seasons

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	16.61	56.3	23.33	36.9
Silica gel	8.30	78.1	14.86	59.8
Sodium silicate	12.50	67.1	17.33	53.1
Control1 (untreated)	38.03	0.00	37.0	0.00
Control 2 (uninfected)	0.00	100.0	00.0	100.0
LSD 0.05	**7.00**		**9.08**	

8. Effects of some induced materials on basil rot caused by *Macrophomina phaseolina* under greenhouse conditions during the 2022 and 2023 growing seasons.

Data in Table 9 indicates that treatments with silica gel resulted in the highest control efficiency, reaching 77.5% in 2023 and 68.4% in 2024. Similarly, sodium silicate showed significant effectiveness, with control efficiency values of 75.4% and 49.5%, respectively. In contrast, among the tested treatments, biochar exhibited the lowest control efficiency, reducing disease severity by 62% in 2023 and 39.3% in 2024. The highest disease severity was recorded in control 1 (untreated) at 33.83% in 2023 and 33.0% in 2024, confirming the lack of protection in untreated conditions. Meanwhile, control 2 (uninfected) consistently maintained 0.0% severity and 100%

efficiency, demonstrating complete resistance. Overall, silica gel was the most effective treatment, significantly reducing disease severity, followed by sodium silicate, whereas biochar provided moderate disease suppression.

Table 9. Effects of some induced materials on basil rot caused by *Macrophomina phaseolina* under greenhouse conditions during the 2022 and 2023 growing seasons

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	12.83	62	20.0	39.3
Silica gel	7.61	77.5	10.41	68.4
Sodium silicate	8.30	75.4	16.66	49.5
Control1 (untreated)	33.83	0.00	33.0	0.00
Control 2 (uninfected)	0.00	100	0.00	100
LSD 0.05	**3.87**		**6.76**	

9. Effects of some induced materials against basil root rot caused by *Alternaria alternata* under greenhouse conditions during 2023/2024 growing season.

Table 10 indicates that in the tested seasons (2023, 2024), treatments with silica gel resulted in the highest control efficiency, reaching 76.5% in 2023 and 54.8% in 2024. Similarly, sodium silicate showed significant effectiveness, with control efficiency values of 68.8% and 27.6%, respectively. In contrast, biochar exhibited the lowest control efficiency among the tasted treatments, reducing disease severity by 63.6% in 2023 and 17.7% in 2024. The highest disease severity was recorded in control 1 (untreated) at 26.66% in 2023 and 27.66% in 2024, confirming the lack of protection in untreated conditions. Meanwhile, control 2 (uninfected) consistently maintained 0.0% severity and 100% efficiency, demonstrating complete resistance. Overall, silica gel proved to be the most effective treatment, reducing disease severity, followed by sodium silicate, whereas biochar provided moderate disease suppression.

Table 10. Effects of some induced materials against basil rot caused by *Alternaria alternata* under greenhouse conditions during the 2023 and 2024 growing seasons.

Treatments	Season 2023		Season 2024	
	Severity (%)	Control efficiency (%)	Severity (%)	Control efficiency (%)
Biochar	9.68	63.6	22.91	17.1
Silica gel	6.25	76.5	12.50	54.8
Sodium silicate	8.30	68.8	20.0	27.6
Control1 (untreated)	26.66	0.00	27.66	0.00
Control 2 (uninfected)	0.00	100	0.00	100
LSD 0.05	**3.05**		**6.26**	

Discussion

Basil is one of the most important medicinal and aromatic plants due to its various applications. It is utilized in the food industry in many forms, such as fresh leaves or oil extracted from it. Additionally, it plays a vital role in the medical and cosmetic industries. Assiut governorate, especially in Abnoub county, is one of the most prominent areas in Egypt for basil cultivation. Aromatic plants are grown both in summer and winter, with basil cultivated in summer and fennel in winter (Sakkas and Papadopoulou, 2017).

In this study, basil was found to be affected by numerous diseases, with fungal pathogens being the most significant cause, particularly those that result in root rot and wilt. These diseases are common in Assiut governorate. Six fungal isolates were obtained from infected basil samples collected from commercial fields in Abnoub, Arab-El-Awamer, El-Wasta, and El-Fath. These regions are major basil-growing areas in Assiut governorate, surveyed during the 2022 and 2023 seasons. *Fusarium oxysporum* was the most frequently isolated fungus, followed by *Rhizoctonia solani*, *Fusarium moniliforme*, *Fusarium semitectum*, and *Macrophomina phaseolina*. *Alternaria alternata* was the least frequent isolation. These findings align with those of Jaiswal *et al.* (2017) and Yanashkov and Vatchev (2021).

The pathogenicity test showed that *F. oxysporum* and *R. solani* were the most virulent fungi, causing wilt and/or root rot in the Balady basil cultivar. *F. moniliforme*, *F. semitectum*, and *M. phaseolina* caused moderate effects, while *A. alternata* produced the mildest symptoms. These results are consistent with those of Gamliel *et al.* (1996) and Lori *et al.* (2014), who observed that all isolates of *F. oxysporum* were virulent on sweet basil seedlings grown in greenhouses.

Moreover, the study evaluated the effectiveness of biochar, sodium silicate, and silica gel in controlling mycelial growth both in vitro and under greenhouse conditions. These treatments significantly reduced disease severity to varying degrees. These results are consistent with those of Weggler *et al.* (2008), who also reported the effectiveness of these treatments in managing plant diseases.

Biochar improves soil properties such as pH, organic matter, nutrient retention, cation exchange capacity, surface area, porosity, microbial community diversity, and water-holding capacity (Singh *et al*., 2022). Biochar's application in soil remediation is beneficial due to its unique physicochemical properties, such as its high carbon content and metal fixation abilities. Additionally, biochar can reduce environmental stress injuries in plants (Agarwal *et al*., 2022). Asif *et al*. (2023) proposed a multi-mechanism model to explain the impact of biochar on plant health and productivity. This model considers the complex interactions among various physical, chemical, and physiological components in the soil-plant-pathogen system.

Graber *et al.* (2014) found that biochar amendments affect disease progression caused by soilborne plant pathogens in various pathosystems. The alteration of plant disease intensity by biochar may result from its varied influences on the soil-rhizosphere-pathogen-plant system. These influences include biochar's effects on nutrient content, water-holding capacity, redox activity, adsorption ability, pH, and the presence of toxic or hormone-like compounds. The direct and indirect effects of biochar on the soil environment, the host plant, the pathogen, and the rhizosphere microbiome can lead to complex changes in plant development and disease progression.

In the present study, the growth of *F. oxysporum*, *R. solani*, *F. moniliforme*, *F. semitectum*, *M. phaseolina*, and *A. alternata* were inhibited when the PDA medium was amended with biochar, sodium silicate, and silica gel. Among these treatments, silica gel had the greatest inhibitory effect on all tested fungi, followed by sodium silicate and biochar. These results are in line with those of Rachniyom and Jaenaksorn (2008), who also observed significant inhibitory effects of chemical inducers on pathogenic fungi. Other researchers (Bekker *et al*., 2009; Shen *et al*., 2010) have reported similar findings regarding the effects of chemical inducers on fungal growth. This study emphasizes the potential of biochar, sodium silicate, and silica gel as effective treatments for managing fungal diseases in basil. The results suggest that these treatments could offer sustainable alternatives for disease control in basil cultivation. Further research is needed to optimize these treatments and understand their long-term effects on plant health and yield.

Conclusion

Silica gel (6 g/L) was the most effective treatment for reducing the linear mycelial growth of the six tested fungi, followed by sodium silicate and biochar, when compared with the untreated control. Under greenhouse conditions, silica gel significantly decreased the severity of basil root-rot and wilt, followed by sodium silicate. Biochar provided moderate disease suppression during both the 2023 and 2024 growing seasons.

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استحثاث المقاومة في نباتات الريحان ضد أمراض أعفان الجذور والذبول بواسطة الفحم الحيوي والسليكا

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الملخص

تصاب نباتات الريحان (*Ocimum basilicum* L.) بالعديد من الأمراض التي تنقلها التربة والتي تسبب خسائر كبيرة في الإنتاجية أهمها أمراض أعفان الجذور والذبول والسائدة في زراعات الريحان في محافظة أسيوط. تم عزل وتعريف الفطريات المعزولة من نباتات الريحان المصابة طبيعيا على أنها *Fusarium oxysporum, Rhizoctonia solani, Fusarium moniliforme, Fusarium semitectum, Macrophomina phaseolina,* and *Alternaria alternata.* أكدت النتائج أن *F. oxysporum*، *R. solani* أظهرت أعلى نسبة الإصابة وتكرارا أثناء العزل علاوة على ذلك، كان *F. oxysporum*أكثر ضراوة من الفطريات الأخرى التي تسبب اعفان الجذور والذبول مقارنة مع معاملة الكنترول غير المصابة. كان السيليكا جل بمعدل 6 جم/لتر هي المعاملة الأكثر فعالية، يليه سيليكات الصوديوم والفحم الحيوي في تقليل النمو الفطري الشعاعي على الأطباق في المعمل للفطريات الستة المختبرة مقارنة بمعاملة الكونترول غير المعالج. تحت ظروف الصوبة تبين ان السيليكا جل هو العلاج الأكثر فعالية حيث قلل بشكل كبير من شدة المرض، تليها سيليكات الصوديوم ثم الفحم الحيوي خلال كل من موسمي الزراعة2024،2023

الكلمات المفتاحية: *استحثاث المقاومة، الريحان، الفحم الحيوي، السيليكا جل، سيليكات الصوديوم*