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Efficiency of some Silicon Sources for Controlling Damping-off of Coriander (*Coriandrum sativum* L.) in Egypt

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Isolation trials from infected coriander seedlings and plants growing in Qalubiya and Sharkiya governorates, showing symptoms of damping-off, root-rot, stem-rot and/or wilt diseases, yielded *Alternaria alternata, Fusarium oxysporum, F. moniliforme, F. solani, Pythium* sp., *Macrophomina phaseolina*, *Rhizoctonia solani* and *Sclerotinia sclerotiorum.* However, *R. solani* recorded the highest mean of frequency in isolation (19.1%), followed by *S. sclerotiorum* (13.5%) and *F. oxysporum* (13.2%), while *A. alternata* was the least (5.7%). The seven tested fungi were found to be pathogenic to coriander seedlings. *F. oxysporum*, *R. solani*, and *S. sclerotiorum* were the most virulent fungi, causing the highest damping-off incidence. Three silicon (Si) sources, *i.e*. calcium silicate, potassium silicate and sodium silicate with four concentrations (100, 200, 400 and 800 ppm), significantly inhibited mycelial growth of the seven pathogenic fungi to coriander seedlings. Potassium silicate at 400ppm was more effective than the other silicon sources tested, since it completely inhibited mycelial growth of the tested fungi. Under greenhouse conditions, damping-off (pre- and post-emergence) was completely controlled in the case of *F. oxysporum* by using Vitavax/Thiram whereas, post-emergence damping-off caused by any of *F. moniliforme* and *F. solani* was effectively controlled using either Vitavax/Thiram or potassium silicate. Also, applying the three silicon sources as soil drench to the infested soil significantly decreased percentages of damping-off, subsequently increased survival plants as well as improved plant height and fresh weight. Under field conditions, seeds soaking plus soil drenching by calcium silicate (800 ppm), potassium silicate (400 ppm) or sodium silicate (800 ppm) significantly reduced the incidence (%) of damping-off and increased plant height, number of branches and blossoms. Also, seed yield/plant and essential oil seed contents were improved. However, potassium silicate was the most effective treatment in reducing damping-off incidence and in improving plant growth parameters as well as seed yield and seed oil yield.

Keywords: Coriander, damping-off, root-rot, silicon sources and stem-rot.

Coriander (*Coriandrum sativum* L.) is one of the most important medicinal and aromatic plants belonging to Family Apiaceae, grown in Egypt and around the whole world countries. It is native to the Mediterranean Basin region; however, it is grown in Europe and in other parts of the world (Rahman *et al.*, 2000 and Ravi *et al*., 2007). Seeds are used as a spice, whereas seeds and leaves are used in the Egyptian kitchens in food processing. Moreover, coriander is an important plant in medicine, food production as well as in the cosmetics and perfumes industry (Maasda *et al*., 2007). It provides two types of herbal raw materials: fruits and leaves (Wangensteen *et al*., 2004 and Bhuiyan *et al*., 2009). Coriander has been used in traditional medicines as an anti-inflammatory, analgesic and antibacterial agent. Also, it has recently been shown to have antioxidant, antidiabetic, hepatoprotective, antibacterial and antifungal activities (Asgarpanah and Kazemivash, 2012).

Damping-off, root-rot, stem-rot and wilt are among the most destructive diseases attacking coriander plants (Sharma and Chaudhary, 1981; Stakvileviciene, 2003; Koike and Gordon, 2005; Ajit, 2009 and Bhaliya and Jadeja, 2013). These diseases are caused by soil borne fungi which can be also transmitted by seeds (Vaidehi, 1984). Occurrence of these diseases always increased in the absence of control means in field and replanting the crop in the same area for many successive years.

Silicon (Si) is known to play an important role in plant growth and development (Epstein, 1994 and Datnoff *et al*., 2001). Silicon amended to soil or nutrient solution low in soluble silicon, exhibited the improvement of plant growth and yield, increased disease and insect resistance and reduced mineral toxicities (Belanger *et al*., 1995; Savant *et al*., 1999 and Saigusa *et al*., 2000)**.** Soluble silicon has shown potential for the increasing resistance to fungal diseases such as powdery mildew and root-rot (Epstein, 1994 and Belanger *et al*., 1995) which infecting cherry fruit, cucumber, muskmelon, squash and peach (Menzies *et al*., 1992; Biggs *et al*., 1997 and Qin and Tian, 2005). Using of Si was found to be effective in controlling Fusarium wilt on many economic important crops (Datnoff *et al*., 2007). For soil borne pathogens, amendment of Si to the soil or to the nutrient solution led to decrements in the intensities of diseases caused by *Pythium ultimum* and *P. aphanidermatum* on cucumbers, *Phytophthora capsici* on bell peppers, *Fusarium oxysporum* f.sp. *radicis-lycopersici* on tomatoes and *F. oxysporum* f.sp. *cubense* on banana (Belanger *et al*., 1995; Cherif *et al*., 1992a&b; Dannon and Wydra, 2004; French-Monar *et al*., 2010; Huang *et al*., 2011 and Fortunato *et al*., 2012).

The present study was designed to evaluate performance of applying silicon (Si) for controlling coriander damping-off by soaking seeds and drenching soil with the soluble silicon in comparison with the fungicide Vitavax/Thiram under greenhouse and field conditions. Also, improvement of plant shoot and root parameters as well as increase in seeds yield and essential oil content were considered.

Materials and Methods

Laboratory experiments:

I. Isolation and identification of the associated organisms and their frequency (%):

Coriander seedlings and plants showing damping-off, root-rot and wilt symptoms were collected from different plantations located at Qalubiya and Sharkiya Governorates during 2010/11 & 2011/12 growing seasons. Infected stems and roots were washed several times under tap water, cut into small pieces, surface sterilized by immersing in 3% sodium hypochlorite for 2 min, washed in several changes of sterile water then aseptically transferred into PDA plates and incubated at $25\pm2^{o}C$ for 7 days. The growing fungi were purified and identified according to their morphological and cultural characteristics as described by Nelson *et al.* (1983) for

Fusarium species and Domsch *et al.* (1980) for *Alternaria alternata, Macrophomina phaseolina, Pythium* species, *Rhizoctonia solani* and *Sclerotinia sclerotiorum.* Percentage of frequency of each fungus was also determined.

2. Effect of different sources of silicon on mycelial growth of fungi isolated from diseased coriander plants:

Stock solutions (1000 ppm) were prepared from calcium silicate (Ca_2SiO_4), potassium silicate (K_2SiO_3) and sodium silicate (Na_2SiO_3), produced by (Central Drug House(P) LTD Post Bon No. 7138, New Delhi-110002). Appropriate amount of each Si solution was transferred into conical flasks containing sterilized PDA medium (100 ml) before solidification in order to obtain 100, 200, 400 and 800 ppm. Media amended with Si sources were individually poured in sterile Petri dishes then inoculated after solidification at the centre with 0.5cm fungal disc taken from 7-day-old culture of any of the tested fungi, *i.e. F. oxysporum, F. moniliforme, F. solani, M. phaseolina, Pythium* sp*., R. solani* and *S. sclerotiorum*. PDA medium free from Si sources were kept as control (check). Five plates were used as replicates for each particular treatment. All plates were incubated at 25±2^{o}C until the fungal growth reached the edges of any Petri dish representing a particular treatment and then the growth diameters were recorded and the growth inhibition percentages were calculated according to the following formula:

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

Whereas: C= Growth diam. (cm) of control and T= Growth diam. (cm) of treatment.

Greenhouse experiments:

1. Pathogenicity tests:

Pathogenicity tests were carried out using the most frequently isolated fungi, *i.e. F. oxysporum, F. moniliforme, F. solani, M. phaseolina, Pythium* sp*., R. solani* and *S. sclerotiorum*. Inocula of the tested fungi were prepared by growing their pure cultures on maize meals sand medium and incubated at 25±2^{o}C for two weeks. Formalin-disinfested plastic pots (20-cm-diam.) packed with formalin-disinfested clay and washed sand (1:1: v/v) were infested with the tested fungi at the rate of 1% (w/w), 7 days before planting. Three replicated pots were used for each tested fungal isolate. Ten apparently healthy seeds of coriander were planted in each pot. Disease incidence (%) as pre- and post- emergence damping-off as well as survived plants was determined 30, 45 and 60 days after planting, respectively. Also, growth parameters, *i.e.* plant height (cm) and plant fresh weight (g) were estimated.

2. Effect of three sources of silicon and fungicide (Vitavax/Thiram) on the incidence of damping-off caused by the tested fungi and on some plant growth parameters:

For evaluating the efficiency of silicon sources in controlling damping-off, greenhouse experiment was carried out in pots (20-cm-diam.) filled with soil infested with each tested fungus as mentioned before. One hundred ml. of any of calcium silicate (800ppm), potassium silicate (400ppm) and sodium silicate (800ppm) solutions as well as the fungicide Vitavax/Thiram at the rate of 3g/l water, were added to the pots 7 days after sowing seeds. Three replicated pots were used for each particular treatment. Ten apparently healthy seeds of coriander were planted in each pot. Percentages of pre-and post-emergence damping-off as well as survived plants were determined 30, 45 and 60 days after planting, respectively. Also, plant height (cm) and fresh weight (g) were estimated 60 days after sowing seeds.

Field experiments:

Field experiments were carried out during two successive seasons (2011/12 & 2012/13) in Mashtul El-Sok County at Sharkiya Governorate. Coriander seeds were soaked for 6 hrs in any tested solution of calcium silicate (800ppm), potassium silicate (400ppm) and sodium silicate (800ppm) as well as the fungicide Vitavax/Thiram at the rate of 3g/l water. Treated seeds were sown in plots (3x4m), each with 5 rows and 16 hills/row. Two seeds/hill were sown with total of 160 seeds/plot. Untreated seeds were sown as check. Three replicated plots were used for each treatment. Fifteen days after sowing, 50 ml/hill of tested soluble silicon or fungicide were separately applied, at the previously mentioned rates, to the soil. All recommended agricultural practices were applied. Three months after sowing, disease incidence was expressed as mean percentage of wilted plants due to root- and stem-rot. Also, plant height (cm), number of branches and blossoms per plant, dry fruit weight (g)/plant and essential oil yield (ml)/100g seeds was determined at the end of the growing season. Volatile oil of coriander seeds produced from each treatment was extracted with steam distillation and determined according to Guenther (1961).

Statistical analysis:

Data were statistically analysed using analysis of variance and means were compared using L.S.D. test at 5% probability as described by Gomez and Gomez (1984).

Results

1. Laboratory experiments:

1.1. Isolation and identification of the associated organisms and their frequency percentages:

Isolation trails from infected stem and root tissue of coriander seedlings and plants, collected from Qalubiya and Sharkiya Governorates, on PDA medium yielded eight fungi (Table1). Isolated fungi were identified as: *Alternaria alternate* (Fr.) Keissl, *Fusarium oxysporum* Schlecht., *F. moniliforme* J. Sheld., *F. solani* (Mart.) Appel & Wollenw, *Pythium* sp., *Macrophomina phaseolina* (Tassi) Goid., *Rhizoctonia solani* Kuhn. and *Sclerotinia sclerotiorum* (Lib.) de Bary. Results in Table (1) indicate that *R. solani* recorded the highest frequency (19.1%), followed by *S. sclerotiorum* (13.5%), *F. oxysporum* (13.2 %) and *Pythium* sp. (13.1%). Only *F. oxysporum* was isolated from wilted and/or root rotted plants. On the other hand, frequency percentages ranged between 5.9% (*A. alternata*) to 18.9% (*R.solani*) and from 5.5% (*A. alternata*) to 19.3% (*R. solani*) for fungi isolated from the infected plant samples collected from Qalubiya and Sharkiya Governorates, respectively.

Table 1. Mean frequency (%) of fungi isolated from diseased coriander seedlings and plants, collected from Qalubiya and Sharkiya Governorates during 2010/11 and 2011/12 growing seasons

Isolated fungus	Mean frequency (%) of two seasons*		General mean	Symptoms
	Qalubiya	Sharkiya		
A. alternata	5.9	5.5	5.7	Root & stem-rot
F. oxysporum	13.5	12.8	13.2	Wilt & root-rot
F. moniliforme	13.0	12.8	12.9	Root & stem-rot
F. solani	9.7	9.2	9.4	Root & stem-rot
M. phaseolina	14.6	11.5	13.0	Root & stem-rot
Pythium sp.	12.4	13.8	13.1	Root & stem-rot
R. solani	18.9	19.3	19.1	Root & stem-rot
S. sclerotiorum	11.9	15.1	13.5	Stem-rot
Total	100	100	100	--------

$$* \text{ Frequency (\%)} = \frac{\text{No. of fungal colonies for each fungus}}{\text{Total No. of fungal colonies for all fungi}} \times 100$$

1.*2. Effect of three silicon sources on mycelial growth of fungi isolated from diseased coriander plants:*

Data in Table (2) show that the isolated fungi varied in their sensitivity against the tested soluble silicon sources, *i.e.* calcium silicate, potassium silicate and sodium silicate. In general, toxicity was more evident when the concentration of the Si sources was increased. Fungi-toxic effect was observed at 100 ppm for the three tested Si sources. On the other hand, complete mycelial growth inhibition was depended on the tested fungus and the Si source. However, potassium silicate at 400 ppm caused 100% growth inhibition in all tested fungi, while calcium silicate and sodium silicate at 800 ppm caused complete growth inhibition of all tested fungi, except *F. oxysporum* and *F. moniliforme*. Generally, potassium silicate recorded the best results in this concern followed by calcium silicate, while sodium silicate was the least effective one.

2. Greenhouse experiments:

2.1. Pathogenicity tests:

All tested fungi (Table 3) were found to be pathogenic, to different degrees, to coriander seedlings, since they significantly increased percentages of pre- and post-emergence damping-off in comparison with the check treatments. The highest percentage (36.67%) of pre-emergence damping-off was caused by *R. solani*. Meanwhile, both of *F. oxysporum* and *S. sclerotiorum* recorded the highest percentage (40%) of post-emergence damping-off in the growing coriander seedlings. Among the tested fungi, *F. moniliforme* appeared to be the least pathogenic one. Moreover, all fungi significantly reduced plant height (cm) and plant fresh weight (g) in comparison with those of the check treatments. Moreover, *S. sclerotiorum*, *F. solani* and *F. oxysporum* recorded the highest reduction in the height and weight of seedlings, respectively, followed by *R. solani* and *M. phaseolina*. On the contrary, *Pythium* sp. caused the least reduction in the tested growth parameters.

Table 2. Effect of five concentrations of three silicon sources on the linear growth of seven fungi isolated from diseased coriander plants

Fungus	Conc. (ppm)	Calcium silicate		Potassium silicate		Sodium silicate		Mean
		Colony diam.(cm)	Inhibition (%)	Colony diam.(cm)	Inhibition (%)	Colony diam.(cm)	Inhibition (%)	
F. oxysporum	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	8.5	5.6	6.1	32.2	7.1	21.1	7.2
	200	7.1	21.1	3.0	66.7	6.2	31.1	5.4
	400	4.0	55.6	0.0	100.0	4.2	53.3	2.7
	800	1.2	86.7	0.0	100.0	1.3	85.6	0.8
	Mean	6.0	33.8	3.6	59.8	5.6	38.2	5.1
F. moniliforme	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	7.8	13.3	6.0	33.3	7.2	20.0	7.0
	200	6.3	30.0	3.1	65.6	5.5	28.9	5.0
	400	4.9	45.6	0.0	100.0	3.0	66.7	2.6
	800	2.7	70.0	0.0	100.0	1.7	81.1	1.46
	Mean	6.1	31.8	3.6	59.8	5.3	39.3	5.0
F. solani	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	7.9	12.2	6.5	27.8	8.0	11.1	7.5
	200	6.1	32.2	4.1	54.4	5.7	36.7	5.3
	400	3.4	62.2	0.0	100.0	4.2	53.3	2.5
	800	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	Mean	5.3	41.3	3.9	56.4	5.4	40.2	4.9
M. phaseolina	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	8.4	6.7	6.5	27.8	6.3	30.0	7.1
	200	7.8	13.3	2.4	73.3	5.0	44.4	5.1
	400	2.0	77.8	0.0	100.0	3.4	62.2	1.8
	800	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	Mean	5.4	39.6	3.6	60.2	4.7	47.3	4.6
Pythium sp.	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	7.1	21.1	6.5	27.8	7.1	21.1	7.0
	200	3.3	63.3	2.1	76.7	3.6	60.0	3.0
	400	1.1	87.8	0.0	100.0	1.3	85.6	0.8
	800	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	Mean	4.1	54.4	3.5	60.9	4.2	53.3	3.9
R. solani	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	6.7	25.6	4.9	45.6	5.9	34.4	5.8
	200	3.8	57.8	2.0	77.8	4.2	53.3	3.3
	400	1.8	80.0	0.0	100.0	1.6	82.2	1.1
	800	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	Mean	4.3	52.7	3.2	64.7	4.1	54.0	3.9
S. sclerotiorum	0.0	9.0	0.0	9.0	0.0	9.0	0.0	9.0
	100	7.7	14.4	6.2	31.1	6.3	30.0	6.7
	200	4.8	46.7	3.4	62.2	3.7	58.9	4.0
	400	1.3	85.6	0.0	100.0	1.8	80.0	1.0
	800	0.0	100.0	0.0	100.0	0.0	100.0	0.0
	Mean	4.6	49.3	3.7	58.7	4.2	53.8	4.2
Mean		5.1		3.6		4.8		----
Concentration mean	0.0	12.6		12.6		12.6		-----
	100	7.7		6.1		9.6		-----
	200	5.6		2.9		6.8		----
	400	2.6		0.0		3.9		----
	800	0.6		0.0		0.6		----
	Mean	5.9		4.3		6.7		----

L.S.D. at 5%: Fungi (F)= 0.4; Treatment (T)= 0.4; Concentration (C)= 0.2; FxC= 1.1; TxC= 0.5; FxTxC= 1.8 & FxT= 1.3

Table 3. Pathogenicity of the fungi isolated from coriander and their effectiveness on seedling growth parameters under greenhouse conditions

Fungus	Damping-off		Survival plants (%)	Reduction* (%)	Plant height (cm)	Reduction (%)	Fresh weight /plant (g)	Reduction (%)
	Pre-emergence (%)	Post-emergence (%)						
F. oxysporum	26.7	40.0	33.3	66.7	21.3	37.7	8.3	43.2
F. moniliforme	20.0	20.0	60.0	40.0	25.7	24.8	9.6	34.2
F. solani	26.7	30.0	43.3	56.7	20.5	40.1	7.5	48.6
M. phaseolina	30.0	26.7	43.3	56.7	22.5	34.2	8.7	40.4
Pythium sp.	20.0	26.7	53.3	46.3	24.6	28.1	11.4	23.0
R. solani	36.7	30.0	33.3	66.7	21.8	36.3	8.2	43.8
S. sclerotiorum	26.7	40.0	33.3	66.7	18.4	46.2	6.4	56.2
Control (Fungus free)	00.0	00.0	100.0	------	34.2	-----	14.6	-----
L.S.D. 5%	6.0	8.6	7.2	------	3.1	-----	0.9	-----

* Reduction relative to control treatment (fungus free).
Reduction (%) = [(Control-treatment) / Control] X 100.

2.2. Effect of three silicon sources and the fungicide (Vitavax/Thiram) on the incidence of damping-off caused by the tested fungi:

The effect of three silicon sources and the fungicide (Vitavax/Thiram) applied as soil drench on infection of coriander plants grown in artificially infested soil by the fungi tested was investigated (Table 4). All the three silicon sources tested as well as the fungicide (Vitavax/Thiram) significantly decreased percentages of pre- and post-emergence damping-off as well as increased percentages of survived plants compared with the control treatment. Recorded increases in percentages of survived plants ranged between 31.6-56.7% in case of *F. oxysporum*; 9.5-34.5% for *F. moniliforme;* 26.1-39.3% for *F. solani*; 15.8-38.5% for *M. phaseolina*; 14.3-28.0% for *Pythium* sp.; 41.7-50.0% for *R. solani* and 40.9-53.6% for *S. sclerotiorum*. Tested soluble silicon varied in their efficacy according to the tested fungal pathogen. Potassium silicate followed by calcium silicate recorded the most effective results in controlling pre- and post-emergence damping-off, in comparison with the other treatments.

Sodium silicate was the least effective treatment in this respect. Generally, fungicide (Vitavax/Thiram) was found to be the best effective treatment in increasing percentages of survived plants, followed by potassium silicate with all tested fungi. Damping-off (pre- and post-emergence) was completely controlled in the case of *F. oxysporum* by using Vitavax/Thiram whereas, post-emergence damping-off caused by any of *F. moniliforme* and *F. solani* was effectively controlled using either Vitavax/Thiram or potassium silicate.

Table 4. Effect of 3 silicon sources and Vitavax/Thiram on incidence of damping-off caused by 7 pathogenic fungi under greenhouse conditions

Fungus	Treatment	Damping-off (%)		Survived plants (%)	Increase* (%)
		Pre-emergence	Post-emergence		
F. oxysporum	Calcium silicate	16.7	10.0	73.3	69.28
	Potassium silicate	10.0	6.7	83.3	92.37
	Sodium silicate	20.0	16.7	63.3	46.18
	Vitavax/Thiram	00.0	00.0	100.0	130.94
	Control	26.7	30.0	43.3	-----
	Mean	14.7	12.7	72.7	67.75
F. moniliforme	Calcium silicate	20.0	6.7	73.3	15.79
	Potassium silicate	16.7	00.0	83.3	31.59
	Sodium silicate	16.7	13.3	70.0	10.58
	Vitavax/Thiram	3.3	00.0	96.7	52.76
	Control	20.0	16.7	63.3	-----
	Mean	15.3	7.3	77.3	22.14
F. solani	Calcium silicate	6.7	10.0	83.3	47.17
	Potassium silicate	3.3	3.3	93.3	64.84
	Sodium silicate	16.7	6.7	76.6	35.33
	Vitavax/Thiram	6.7	00.0	93.3	64.84
	Control	26.7	16.7	56.6	------
	Mean	12.0	7.3	80.6	42.43
M. phaseolina	Calcium silicate	20.0	13.3	66.7	25.14
	Potassium silicate	6.7	6.7	86.6	62.47
	Sodium silicate	23.3	13.3	63.3	18.76
	Vitavax/Thiram	10.0	6.7	83.3	56.28
	Control	30.0	16.7	53.3	------
	Mean	18.0	11.3	70.7	32.53
Pythium sp.	Calcium silicate	16.7	3.3	80.0	33.33
	Potassium silicate	10.0	6.7	83.3	38.83
	Sodium silicate	16.7	13.3	70.0	16.66
	Vitavax/Thiram	10.0	13.3	76.7	27.83
	Control	16.7	23.3	60.0	------
	Mean	14.0	12.0	74.0	23.33
R. solani	Calcium silicate	6.7	6.7	86.7	85.65
	Potassium silicate	3.3	3.3	93.3	99.78
	Sodium silicate	6.7	13.3	80.0	71.30
	Vitavax/Thiram	3.3	10.0	86.7	85.65
	Control	23.3	30.0	46.7	------
	Mean	8.7	12.7	78.7	68.47
S. sclerotiorum	Calcium silicate	13.3	6.7	80.0	84.75
	Potassium silicate	6.7	3.3	90.0	107.85
	Sodium silicate	16.7	10.0	73.3	69.28
	Vitavax/Thiram	6.7	10.0	93.3	115.47
	Control	26.7	30.0	43.3	------
	Mean	14.0	12.0	76.0	75.47
L.S.D.at 5% for:	Fungi=	2.0	1.4	4.0	
	Treatment=	1.7	1.4	1.9	
	(F) x (T)=	3.6	3.8	4.9	

* Increase relative to the control (without treatment).
Increase (%)= [(Treatment – control) / Control] X 100.

2.3. Effect of three silicon sources and Vitavax/Thiram on coriander seedling height and fresh weight under greenhouse conditions:

Data in Table (5) reveal that all tested soluble sources of silicon and the fungicide Vitavax/Thiram significantly increased plant height and plant fresh weight in comparison with the controls. Efficiency of each treatment varied according to the causal pathogen. Potassium silicate followed by calcium silicate were the best treatments in increasing percentages of height and fresh weight of plants grown in soil infested with the tested fungi, except *F. moniliforme* in case of plant height whereas, sodium silicate was the least effective treatment. Increasing percentages in plant height and fresh weight ranged between 15.9-132.1% and 25.3-148.7% to control, respectively. Potassium silicate, the superior treatment in increasing plant height and fresh weight, recorded increases ranged between 56.0-132.1% and 105.3-148.7% to control, respectively.

3. Field experiments:

Effect of three silicon sources and the fungicide Vitavax/Thiram as seed soaking plus soil drenching treatments on disease incidence (%) and survived plants during growing seasons of 2011/12 & 2012/13 was carried out under field conditions (Table 6). Soaking coriander seeds in either of the three silicon sources tested or the fungicide (Vitavax/Thiram) before sowing plus soil drenching significantly decreased percentages of disease incidence as well as increased percentages of healthy survived plants in the two experimental seasons (2011/12 & 2012/13) compared to their control (without treatment). Seed soaking plus soil drenching with potassium silicate followed by calcium silicate were the most effective treatments. They recorded the highest reduction percentages (73.4-82.0%) & (55.7–65.3%) in disease incidence during the two growing seasons. Meanwhile, soluble sodium silicate was the least efficient treatment used since it recorded reduction percentages in disease incidence by 42.7 and 61.7% in the two seasons, compared to their control treatments. Results of healthy survived plants indicated that potassium silicate was the best treatment in increasing percentage of survived plants (21.9 & 25.5%) followed by calcium silicate (16.6 & 20.6%) in the two tested seasons, respectively. Generally, efficacy of treating seeds plus soil drench with potassium silicate was approximately equal to that of Vitavax/Thiram during the two successive seasons, *i.e*. 2011/12 and 2012/13 (Table 6).

Effect of three silicon sources and Vitavax/Thiram as seed soaking plus soil drenching on number of branches and blossoms/ plant during growing seasons of 2011/12 & 2012/13 under field conditions was determined (Table 7). Soaking coriander seeds and soil drenching with any of the three silicon sources tested gave significant increase in number of branches and blossoms per plant in the two experimental seasons compared to the control treatments. In this respect, increases occurred in mean numbers of branches and blossoms reached (5.3-63.2%) & (16.7-78.3%) and (33.3-96.1%) & (28.6-89.6%) in both seasons, respectively. Generally, potassium silicate followed by calcium silicate were the superior treatments, since they yielded the highest increases (%) in numbers of branches and blossoms (63.2% & 45.6%) & (41.7% & 35.6%) and (96.1% & 76.1%) & (89.6% & 61.8%) in both seasons, respectively. Whereas, sodium silicate treatment was the least effective in increasing numbers of branches and blossoms during the two tested seasons.

Table 5. Effect of three silicon sources and Vitavax/Thiram fungicide on coriander seedling height and fresh weight under greenhouse conditions

Fungus	Treatment	Plant height (cm)	Increase * (%)	Plant fresh weight (g)	Increase (%)
F. oxysporum	Calcium silicate	32.2	66.0	12.7	67.1
	Potassium silicate	39.3	102.6	15.6	105.3
	Sodium silicate	29.5	52.1	12.4	63.2
	Vitavax/Thiram	25.7	32.5	10.8	42.1
	Control	19.4	-----	7.6	-----
	Mean	29.2	63.3	11.8	69.4
F. moniliforme	Calcium silicate	30.3	32.9	15.2	74.7
	Potassium silicate	36.0	57.9	17.6	102.3
	Sodium silicate	31.2	36.8	13.2	51.7
	Vitavax/Thiram	27.8	22.0	10.9	25.3
	Control	22.8	-----	8.7	-----
	Mean	29.6	37.4	13.1	40.5
F. solani	Calcium silicate	32.9	78.8	15.1	112.7
	Potassium silicate	39.0	111.9	17.6	147.9
	Sodium silicate	29.3	59.2	14.2	100.0
	Vitavax/Thiram	24.3	32.1	12.0	69.0
	Control	18.4	-----	7.1	-----
	Mean	28.8	70.5	13.2	114.1
M. phaseolina	Calcium silicate	33.3	54.2	16.4	110.3
	Potassium silicate	37.7	74.5	19.4	148.7
	Sodium silicate	29.1	34.7	13.6	74.4
	Vitavax/Thiram	25.9	19.9	11.2	43.6
	Control	21.6	-----	7.8	-----
	Mean	29.5	45.8	13.7	94.2
Pythium sp.	Calcium silicate	31.8	26.2	15.3	64.5
	Potassium silicate	39.3	56.0	19.2	106.5
	Sodium silicate	30.2	19.8	13.6	46.2
	Vitavax/Thiram	29.2	15.9	12.0	29.0
	Control	25.2	-----	9.3	-----
	Mean	31.1	29.5	13.9	61.5
R. solani	Calcium silicate	31.6	62.9	15.8	97.5
	Potassium silicate	38.5	98.5	19.1	138.8
	Sodium silicate	27.4	41.2	12.0	50.0
	Vitavax/Thiram	24.6	26.8	10.6	32.5
	Control	19.4	-----	8.0	-----
	Mean	28.3	57.3	13.1	79.7
S. sclerotiorum	Calcium silicate	30.9	94.3	10.8	77.1
	Potassium silicate	36.9	132.1	13.0	113.1
	Sodium silicate	26.9	69.2	9.1	49.2
	Vitavax/Thiram	19.6	23.3	8.5	39.3
	Control	15.9	-----	6.1	-----
	Mean	26.0	79.7	9.5	69.7
L.S.D. at 5%:	Fungi(F) =	1.5	-----	0.9	-----
	Treatment (T) =	1.1		0.6	
	(F) x (T) =	2.3		0.9	

* Increase relative to the control as described in footnote of Table (4).

Table 6. Effect of three silicon sources and Vitavax/Thiram used as seed soaking plus soil drenching on the incidence of damping-off during the growing seasons (2011/12 & 2012/13) under field conditions

Treatment	Season of 2011/12				Season of 2012/13			
	Disease incidence (%)	Reduction* (%)	Survived plants (%)	Increase (%)*	Disease incidence (%)	Reduction (%)	Survived plants (%)	Increase (%)
Calcium silicate	10.2	55.7	89.8	16.6	8.2	65.3	92.0	20.6
Potassium silicate	6.1	73.4	93.9	21.9	4.3	82.0	95.7	25.5
Sodium silicate	13.1	42.7	86.8	12.7	9.1	61.7	90.9	19.2
Vitavax/Thiram	8.0	65.3	92.0	19.5	4.8	79.7	95.2	24.8
Control (untreated)	23.0	-----	77.0	-----	23.7	-----	76.3	-----
L.S.D. at 5%	2.8	-----	5.6	-----	2.9	-----	5.4	-----

* Reduction (%) or increase (%) relative to the control (without treatment) as described in footnote of Tables (3 & 4)

Table 7. Effect of three silicon sources and Vitavax/Thiram as seed soaking plus soil drenching on number of branches and blossoms/plant during 2011/12 & 2012/13 seasons under field conditions

Treatment	Season of 2011/12				Season of 2012/13			
	No. of branches/plant	Increase * (%)	No. of blossoms/plant	Increase * (%)	No. of branches/plant	Increase (%)	No. of blossoms/plant	Increase (%)
Calcium silicate	8.3	45.6	31.7	76.1	9.0	50.0	35.6	61.8
Potassium silicate	9.3	63.2	35.3	96.1	10.7	78.3	41.7	89.6
Sodium silicate	6.7	17.5	28.3	57.2	8.0	33.3	33.0	50.0
Vitavax/Thiram	6.0	5.3	24.0	33.3	7.0	16.7	28.3	28.6
Control (untreated)	5.7	-----	18.0	-----	6.0	-----	22.0	-----
L.S.D. at 5%	2.3	-----	4.2	-----	1.8	-----	5.1	-----

* Increase relative to the control as described in footnote of Table (4).

Effect of the three silicon sources and Vitavax/Thiram as mentioned before on plant height (cm) and root length (cm)/plant during growing seasons of 2011/12 & 2012/13, under field conditions was determined (Table 8). All the treatments tested resulted in significant increases in plant height and root length per plant in the two experimental seasons. Treating seeds plus soil drench with potassium silicate was found to be the superior treatment in improving plant height and root length in both seasons. On the contrary, Vitavax/Thiram was the least effective treatment since it recorded the lowest increases in this respect (Table 8).

Table 8. Effect of three silicon sources and Vitavax/Thiram as seed soaking plus soil drenching on plant height (cm) and root length (cm)/plant during 2011/12 & 2012/13 seasons under field conditions

Treatment	Season of 2011/12				Season of 2012/13			
	Plant height/plant (cm)	Increase * (%)	Root length/plant (cm)	Increase (%)	Plant height/plant (cm)	Increase (%)	Root length/plant (cm)	Increase (%)
Calcium silicate	93.8	34.4	16.2	43.4	97.6	25.8	19.8	66.4
Potassium silicate	104.9	50.3	18.6	64.6	108.3	39.6	22.7	90.8
Sodium silicate	86.7	24.2	15.3	35.4	90.7	16.9	16.8	41.2
Vitavax/Thiram	78.5	12.5	13.6	20.4	81.4	4.9	14.2	19.3
Control (untreated)	69.8	-----	11.3	-----	77.6	-----	11.9	-----
L.S.D. at 5%	5.0	-----	3.8	-----	5.9	-----	3.4	-----

* Increase relative to the control as described in footnote of Table (4).

Regarding to the effect of three silicon sources and Vitavax/Thiram on seed yield (g)/plant and the essential oil (ml)/100g dry seeds, during seasons of 2011/12 & 2012/13, under field conditions, data in Table (9) indicate that all the tested treatment significantly increased dry seeds yield per plant and oil yield/100g of dry seeds at different degrees, than the control treatments in the two experimental seasons (Table, 9). The increases, however ranged between (24.8-80.1 %) and (26.1-74.8 %), respectively, in the 1st season, while they figured (28.2-88.7 %) and (25.2-78.9 %), respectively, in the 2nd season. Potassium silicate was the most effective treatment, since it yielded increases by 80.1-88.7% and 74.8-78.9% in seeds weight and oil yields, respectively, during the two experimental seasons. In contrast, the fungicide Vitavax/Thiram was the least effective treatment in this respect.

Table 9. Effect of three silicon sources and Vitavax/Thiram as seed soaking plus soil drenching on seed yield (g)/plant and essential oil (ml)/100g seeds during seasons of 2011/12 & 2012/13 under field conditions

Treatment	Season of 2011/12				Season of 2012/13			
	Seeds yield/plant (g)	Increase * (%)	Oil yield ml/100g seeds	Increase * (%)	Seeds yield/plant (g)	Increase * (%)	Oil yield ml/100g seeds	Increase * (%)
Calcium silicate	34.5	52.7	1.7	57.7	35.6	49.6	1.9	54.5
Potassium silicate	40.7	80.1	1.9	74.8	44.9	88.7	2.2	78.9
Sodium silicate	31.2	30.1	1.6	44.1	32.7	37.4	1.7	39.8
Vitavax/Thiram	28.2	24.8	1.4	26.1	30.5	28.2	1.5	25.2
Control (untreated)	22.6	-----	1.11	-----	23.8	-----	1.2	-----
L.S.D. at 5%	4.6	-----	0.25	-----	4.2	-----	0.33	-----

* Increase relative to the control as described in footnote of Table (4).

Discussion

Diseased samples of coriander seedlings and plants showing typical symptoms of damping-off, root-rots and /or wilt diseases, collected from fields of Qalubiya and Sharkiya governorates, yielded *A. alternata, F. oxysporum, F. moniliforme, F. solani, M. phaseolina, Pythium* sp., *R. solani* and *S. sclerotiorum* in isolation trials from roots and basal stems. *Rhizoctonia solani* followed by *S. sclerotiorum, F. oxysporum* and *M. phaseolina* were the most frequent isolated fungi. *F. oxysporum, R. solani* and *S. sclerotiorum* caused the highest percentages of damping-off (pre- and post-emergence). While, both of *F. moniliforme* and *Pythium* sp. were the least pathogenic fungi. These results are, to somewhat, similar to those recorded by many investigators (Sharma and Chaudhary, 1981; Mahor *et al*., 1982; Zaky, 1998; Stakvileviciene, 2003; Koike and Gordon, 2005; Rodeva *et al.*, 2010; Ajit, 2009; Al-Askar, 2012 and Bhaliya and Jadeja, 2013). On the other hand**,** plant growth parameters (plant height and fresh weight) were significantly decreased, to different degrees, as a result of infection by all tested pathogenic fungi. Meanwhile, *R. solani, M. phaseolina, F. oxysporum* and *S. sclerotiorum* recorded the highest decrements in this respect. These results are in accordance with those obtained by many researchers (Zaky, 1998; Koike and Gordon, 2005 and Ajit, 2009 and Bhaliya and Jadeja, 2013). In this concern, plant growth parameters, *i.e.* plant height and fresh weight, were greatly declined in chamomile (Abdel-Wahed, 2007), safflower (Hilal and Zaky, 2008) and spearmint (Nada and Hilal, 2008) as a result of infection by soil borne fungi including most of the coriander pathogenic ones.

Growth of *F. oxysporum, F. moniliforme, F. solani, M. phaseolina, Pythium* sp., *R. solani* and *S. sclerotiorum* was inhibited on PDA medium amended with calcium, potassium or sodium silicate at the rates of 800, 400 and 800ppm, respectively. These results are similar to those of Bekker *et al*. (2009) who mentioned that silicon suppressed the growth of several phytopathogenic fungi. Also, the growth of *P. aphanidermatum, R. solani* and *F. oxysporum* was inhibited on PDA medium amended with potassium silicate (Rachniyom and Jaenaksorn, 2008; Bekker *et al.*, 2009 and Shen *et al*., 2010). Moreover, Li *et al*. (2009) found that sodium silicate at the rate of 100 and 200 Mm inhibited *F. sulphureum* growth by 52% and 90%, respectively. Results of this study show also that the growth of *F. oxysporum, F .moniliforme, F. solani, M. phaseolina, Pythium* sp., *R. solani* and *S. sclerotiorum* was completely inhibited when PDA medium was amended with calcium silicate, potassium silicate or sodium silicate at the rates of 800, 400 and 800 ppm, respectively. The inhibitory effect of potassium silicate to all tested fungi was greater than those of calcium silicate or sodium silicate. Potassium silicate, however, has fungicidal effect on mycelial growth of phytopathogenic fungi as reported by many researchers (Cherif *et al.*, 1994; Rachniyom and Jaenaksorn, 2008; Bekker *et al.,* 2009 and Shen *et al*., 2010).

All tested silicon treatments significantly improved the height and weight of seedling grown in soil infested with any of the tested pathogenic fungi, and reduced the incidence of fungal diseases as well as increased plant growth parameters under field conditions. Many researchers studied the ability of silicon in enhancing the growth of various crops and the control of root-rot diseases caused by many pathogenic fungi, *i.e. P. aphanidermatum* and *P. ultimum*, Fusarium crown and root-rot and Fusarium wilt (Cherif and Belanger, 1992; Cherif *et al*., 1994; Belanger *et al*., 1995; Rachniyom and Jaenaksorn, 2008; Huang *et al*., 2011 and Fortunato *et al*., 2012). Liang *et al*. (2005) reported that silicon could prevent pathogen penetration into host tissues**.** Reduction in disease incidence in plants treated with silicon sources under field conditions is probably not due to the fungistatic effects of silicon, but rather other mechanisms such as silicon acting as physical barrier against pathogen penetration or silicon induced defence response in plant (Shen *et al*., 2010). On the other hand, Cherif *et al*. (1992a&b) found that treating cucumber roots with soluble silicon resulted in an increase in peroxidase and polyphenoloxidase activities and the silicon stimulated accumulation of polymerized phenolic. Improving in coriander plant growth and increasing in yield production (seeds & oil), which were usually found in the field experiments, might be due to the biochemical changes induced by silicon.

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فعالية بعض مصادر السيلكون في مقاومة موت البادرات في الكزبرة فى مصر

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تم إجراء عمليات العزل من شتلات ونباتات الكزيرة المصابة والتي جمعت من محافظتى القليوبية والشرقية والتى ظهر عليها أعراض الأصابة بأمراض موت البادرات وأعفان الجذور وأعفان السوق والذبول. وكانت الفطريات المعزولة هى: *Alternaria alternata, Fusarium oxysporum, F. moniliforme, F. solani, Pythium* sp., *Macrophomina phaseolina, Rhizoctonia solani* and *Sclerotinia sclerotiorum*. وقد سجل الفطر *R. solani* أعلى تكرارا فى العزل (١٩.١%) يليه *S. sclerotiorum* (١٣.٥%) ثم *F. oxysporum* (١٣.٢%) فى حين كان الفطر *A. alternata* (٥.٧%) الأقل فى هذا المجال.

أظهرت السبع فطريات المختبرة قدرتها على إصابة بادرات الكزبرة. كانت الفطريات *F. oxysporum* و *R. solani* و *S. sclerotiorum* أشد العزلات الفطرية التى سببت مرض موت البادرات. تم اختبار تأثير ثلاثة من مصادر السيلكون وهى سليكات الكالسيوم وسليكات البوتاسيوم وسليكات الصوديوم بتركيزات ١٠٠ ،٢٠٠ ، ٤٠٠ ، ٨٠٠ جزء فى المليون على نمو الفطريات فى المعمل حيث ثبطت معنوياً النمو الميسليومي للفطريات السبعة الممرضة لبادرات الكزبرة. وكانت سليكات البوتاسيوم بتركيز ٤٠٠ جزء فى المليون هى الأكثر تأثيراً، حيث ثيطت النمو الميسليومي كلية لجميع الفطريات المختبرة بالمقارنة بباقى مصادر السيلكون الأخرى. وفى تجارب الصوبة تحت ظروف العدوى الصناعية أدى استخدام المبيد الفطرى فيتافاكس /ثيرام الذى أحدث منع كلى لحدوث موت البادرات قبل الظهور فوق سطح التربة كما فى حالة الفطر *F. oxysporum* ، فى حين كان الفيتافاكس/ثيرام وسليكات البوتاسيوم الأكثر تأثير فى خفض نسبة موت البادرات بعد الإنبات. أدى استخدام المصادر الثلاثة للسيلكون فى غمر التربة الملوثة بالفطريات المعدية إلى خفض معنوي فى النسبة المئوية لحدوث مرض موت البادرات مع زيادة معنوية أيضاً فى النباتات المتبقية حية ، كما حسنت من ارتفاع النبات والوزن الطازج. وفى تجارب الحقل- تحت ظروف العدوى الطبيعية أدى نقع بذور الكزبرة فى محاليل أي من سليكات الكالسيوم (٨٠٠ جزء فى المليون)، سليكات االبوتاسيوم (٤٠٠ جزء فى المليون) وسليكات الصوديوم (٨٠٠ جزء فى المليون) مع معاملة التربة بنفس التركيز إلى خفض معنوي فى نسبة حدوث الإصابة بمرض موت البادرات مع تحسين بعض مقاييس نمو النبات (إرتفاع النبات ، عدد الأفرع وعدد النورات) وكذلك زيادة المحصول الناتج من البذور والزيت المنتج منها.