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Research Article

Effects of Silicon on the growth, ion distribution and physiological mechanisms that alleviate oxidative stress induced by powdery mildew infection in pumpkin (*Cucurbita pepo*, var. Styriac)

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Abstract: Silicon (Si) is considered as one of the beneficial elements for plants that play important roles in plant resistance to stresses. In this experiment, the effects of three levels of silicon (0, 0.85 and 1.7 mM) on the growth and physiological processes of pumpkin were studied in plants inoculated with *Sphaerotheca fuliginea* (250000 conidia ml^{-1}) and non-inoculated plants under hydroponic condition. Applying silicon increased the Si concentration in plant tissues. Application of Si in plants inoculated with *S. fuliginea* decreased significantly severity of disease symptom (30%) and also the shoot membrane permeability was decreased. Addition of Si significantly increased the reactive sulfhydryl group content whereas disease decreased sulfhydryl group which was significantly lower in Si-free medium. The infected plants that were treatedwith 1.7 mM Si levels grew and yielded similar to non -infected pumpkins. Using Si nutrition decreased Fe and Mn and increased Zn concentration in the roots and shoots of plants. Alleviation of disease severity in the silicon treatments may be due to enhancing of plant tolerance to disease by decreasing of shoot membrane permeability, increasing the reactive sulfhydryl group content, and also due to effect of silicon on the uptake and distribution of some ions. This study revealed that Silicon at 1.7 mM used in hydroponic system effectively reduced powdery mildew and improved pumpkin growth.

Keywords: Silicon, growth, oxidative stress, powdery mildew infection

Introduction

Despite abundance of silicon in most soils, it is not considered as an essential nutrient because most plants can complete their life cycle without it. Absorption of silicon by plant tissues depends greatly on plant species and Si uptake and transfer mechanisms (Epstein, 1994; Hasanuzzaman *et al.*, 2014). Si content in many plants ranges between 0.1 to 10% dry matter (Epstein, 1999). Si has many effects on plants, such as enhancement of growth and yield, improvement of mechanical properties (stature, soil penetration by roots, exposure of leaves to light, resistance to lodging), reduction of transpiration, tolerance to drought stress, salinity and metal toxicities, the effects on enzyme activities and increased resistance to pathogens (Ma and Takahashi, 2002; Ma, 2004; Epstein, 1999; Wu *et al*., 2013; Haghighi and Pessarakli, 2013). In addition, silicon reduces

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the imbalances between minerals in plants due to biotic and abiotic stresses. (Epstein, 1994). While, some positive roles of silicon are related to the bioactivity of monosilicic acid, the others are likely due to the deposition of amorphous silica ($SiO_2.nH_2O$) in the leaves, stems, and hulls by the polymerization of monomeric monosilicic acid (H_4SiO_4) (Ma, 2004; Miyake and Takahashi, 1983; Sangster and Hodson, 1986).

Pumpkin *Cucurbita pepo,* var. Styriaca is one of the important cucurbits in the Middle East (Gemrot *et al.,* 2006). More than 250000 hectares of irrigated land, in Iran are cultivated for cantaloupes, melons and pumpkins where Powdery mildew (*Sphaerotheca fuliginea*) is the most important disease in these fields. Cucurbits powdery mildew is one of the most destructive foliar diseases in both temperate and subtropical climates (Sitterly, 1978). Mycelia, conidiophores and conidia appear on leaves, petioles and stems as a white, powdery mass. The resulting decrease in photosynthesis may cause significant reductions in the quality and yield of fruit. Although fruits are not directly attacked by powdery mildew fungi; they may be malformed or sunburned due to loss of foliage cover, and are reduce both in size and number (Hansen, 2002; Mercure, 1998). Most farmers use repeated applications of fungicides for managing powdery mildew. However, alternative methods for disease management are expected by the public due to increasing concernsthatfungicide may have negative impact onenvironment and human health (Mercure, 1998). Silicon (Si) has been reported as a beneficial element that may enhance plant growth and development while protecting plants against diseases and abiotic stress. Some researches have been done on possible mechanisms by which Si affects susceptibility of cucurbits to diseases. For example Cherif and Belanger (1992) and Samuels (1993) found that soluble Si in cucumber infected with powdery mildew can activate defense mechanisms against *pythium* by increased activity of chitinases, peroxidases and polyphenol oxidases, Fawe *et al*. (1998) also suggested the increasing of flavonoid phytoalexins in Si-treated plants are effective onto diseases. Some researchers have shown that soluble Si absorbed by plants tends to accumulate in the apoplast, particularly in epidermal cell walls, and prevents fungal disease by physically inhibiting fungal germ tube penetration into the epidermis. (Belanger *et al*., 1995; Epstein, 1994; Samuels *et al*., 1993). Si treated plants have also shown a higher percentage of accumulated phenolic compounds in infected cells that are fungitoxic (Cherif and Belanger., 1992; Menzies *et al*., 1991). Si also binds to Hydroxyl groups of proteins involved in signal transduction; or it can interfere with cationic co-factors of enzymes influencing pathogenesis-related events (Belanger, 1995).

The importance of silicon has been well recognized and the beneficial effects of Si in enhancing the tolerance of plants to biotic and abiotic stresses in several crops, and its relevance to agriculture, have been widely described (Epstein, 1999; Ma, 2004; Liang *et al*., 2007). However, the mechanisms by which Si provides protection against fungal plant pathogens are still unclear (Epstein, 1999; Liang *et al*., 2003). A limited number of investigations have been carried out with Si supplied to growing plants and some of the mechanisms that Si increased the tolerance of plants. Thus, this study aimed to investigate the influence of Si on the growth, uptake and distribution of some ions such as Zn, Mn and Fe, and also studying of some physiological process such as reactive sulfhydryl groups and shoot membranes permeability in Pumpkin under disease stress by powdery mildew (*Sphaerotheca fuliginea*) infection.

Materials and Methods

Plant growth and pathogen inoculation

The moist chamber in an incubator (28 $^{\circ}$C) was used for germination of pumpkin seeds (*Cucurbita pepo,* var. Styriaca). The germinated seeds were sown in sterilized quartz sand in the greenhouse of Shahrekord University. Each pot had four plants and was continuously irrigated

with Johnson nutrient solution. Composition of the nutrient solution is given in Table 1. Treatments for this study included three levels (0, 0.85, 1.7mM) of silicate in the form of sodium silicate and two powdery mildew (syn. *Sphaerotheca fuliginea*) infection levels (inoculated with *Sphaerotheca fuliginea* and mock inoculation).

Table 1 Composition of the nutrient solution used in this experiment (Menzies *et al.,* 1991).

Macronutrients	Concentration (mM)	Micronutrients	Concentration (µM)
KNO_3	1	KCl	50
$Ca(NO_3)_2$	1	Fe EDTA	50
$MgSO_4$	1	H_3BO_3	25
$NH_4 H_2PO_4$	1	$ZnS0_4$	2
		$MnSO_4$	2
		$CuSO_4$	0.5
		$H_2Mo_7O_4$	0.5

Plants were grown for 40 days then seedlings were inoculated with *S. fuliginea*. Conidia of powdery mildew were collected from naturally infected pumpkin leaves, and the fungus was identified as *S. fuliginea* by the presence of fibrosin bodies inside cylindrical conidia (Stadnik *et al.,* 2003) Source leaves were shaken 48 h before conidial harvest to dislodge old conidia and ensure a high level of inoculum. Conidial suspension was prepared by rinsing the source leaves with distilled water. For inoculation, the suspension was inoculated onto the fully expanded third leaf of each plant (0.15 ml suspension per leaf, containing 250 000 conidia ml $^{-1}$) with a micropipette. The inoculated leaf was covered with a polyethylene bag for 48 h to prevent moisture from evaporating. Disease development was checked 25 days after challenge inoculation. Infected leaves were scored with a rating (*r*) of 0, 1, 3, 5, 7 or 9, denoting proportions of disease over the whole leaf area of 0, < 1, 2–5, 6–20, 21–40 and > 40%, respectively (Hansen, 2002). Disease index was calculated according to the equation:

Disease index (%) = $[\Sigma (r\ m_r) / 9\ N_t] \times 100$, where r = rating value, m_r = number of diseased leaves with a rating of r, and N_t= total number of leaves tested.

Silicon determination

Twenty five days after inoculation the seedlings were harvested and separated into roots and shoots. Plant materials were washed with distilled water and dried at 70 °C for 48 h. To determine Si concentration in plants autoclave-induced digestion and colorimetry were used. In this method organic matter was oxidized and Si was solubilized (Elliot and Snyder, 1991). Samples of plant tissue weighing 500 mg were wetted with 2 ml of 50% H_2O_2 in 100- ml polyethylene tubes previously rinsed with 0.1 M NaOH and demineralized water (DM). To each tube was added 4.5 g of 50% NaOH at ambient temperature, and each tube was gently vortexed. The tubes were individually covered with loose fitting plastic caps. The rack of tubes was placed in an autoclave at 138 kPa for 1 h. After atmospheric pressure was reached, the tubes were removed and the contents brought to 50 ml with DM. Si concentration in these extracts was determined by the colorimetric molybdate-blue method (Kilmer, 1965).

Reactive sulfhydryl group assay

Shoots of intact pumpkin seedling were analyzed by the method described by Norvell and Welch (1993) using sulfhydryl-reactive reagent DTNB. DTNB reacts with sulfhydryl groups to form the nitromercaptobenzoic acid anion, which has an intense yellow color. Five grams of Seedling shoots were immersed in 100 ml of sulfhydryl reaction buffer including 0.2 M Tris-HCl plus 0.02 M Na-EDTA that was adjusted to pH 8.2 with NaOH. A 1.0- ml of 10 mM DTNB dissolved in absolute methanol was added to the reaction buffer at time zero. After 15 min, the shoots were removed from the reaction buffer and Supernatant was used for Reactive sulfhydryl group assays by spectrophotometer at 412 nm. Sulfhydryl concentrations were calculated from standard curves prepared from Cys standards made immediately before the assay.

Shoot membrane permeability

Shoot cell-membrane permeability was assessed by modified method described by Yan *et al*. (1996). The 1-cm washed shoot segments were placed in a beaker containing 10 ml deionized water. The shoot samples were immersed in water for 3 h at 30 °C, and then the conductivity of the solution was measured. The samples were boiled for 2 min, cooled to room temperature (25 °C) and then, their EC was measured. The electrolyte leakage was calculated as follows:

$EC\ (\%) = (C_1 / C_2) \times 100$

Where C_1 and C_2 are the electrolyte conductivities measured before and after boiling, respectively.

Fe, Mn and Zn analysis methods

Dried shoot and root materials were ground, ashed at 550 ºC for 8 h, and the ash dissolved in 2 M HCl (Chapman and Pratt, 1961). Concentrations of Zn, Fe and Mn in the digest solutions were determined by atomic absorption spectrometry (AAS) (PerkinElmer 3400, PerkinElmer, Wellesley, MA).

Statistical analysis

The experiment was set up in a completely randomized factorial design; each treatment contained four replicates. All data were subjected to analysis of variance and means were compared using Duncan's multiple range tests ($P < 0.05$) (SAS Institute 2000).

Results

Disease severity and plant growth

Our results showed that disease index was significantly ($P < 0.05$) reduced with Si application. However disease index was 41.5, 37.5 and 29.3% for 0, 0.85 and 1.7 mM Si treatments, respectively and it seems that silicon applied at 1.7 mM could significantly decrease powdery mildew.

Root and shoot dry weight of pumpkins increased significantly ($P < 0.05$) by Si treatments (Table 2). There was significant difference between the 0.85 mM and 1.7 mM Si levels in the shoot and root dry weights. Inoculation of pumpkins with *S. fuliginea* resulted in significant ($P < 0.05$) decrease in the root and shoot dry weight of plants that were grown in the Si-free media and also in 0.85 mM Si level but disease had no significant effect on the root and shoot dry weight of 1.7 mM Si treatment (Table 2).

Silicon nutrition led to significant ($P < 0.05$) increase in the root and shoot Si concentration. Infection of *S. fuliginea* significantly decreased the root Si concentration of 0.85 mM Si level but fungal infection had no significant effect on the shoot Si concentration of either 0.85 or 1.7 mM Si levels (Table 3).

Reactive sulfhrdryl group concentration

Application of Silicon significantly ($P < 0.05$) increased the reactive SH group concentration (Table 4). There was significant difference in the reactive SH group concentration between the 0.85 mM and 1.7 mM Si treatments. In each Si treatment, no significant difference was observed between the reactive SH group concentration of the plant infected with *S. fuliginea* and the non-infected plants (Table 4).

Shoot membrane permeability

In presence of Si, shoot membrane permeability was decreased but it was sharper at 1.7 mM Si (Table 4). *S. fuliginea* infection significantly ($P < 0.05$) increased the shoot membrane permeability of pumpkins grown in Si free media but this parameter has no significant alternation in 0.85 and 1.7 mM Si treatments (Table 4).

Root and shoot Fe, Mn and Zn concentration(s)

The Si application in nutrient solution significantly ($P < 0.05$) decreased amount of Fe concentration in roots and shoots. Also Fe concentration significantly differed between 0.85 and 1.7 mM Si treatments (Table 3). Inoculation of plants with powdery mildew led to increase in root and shoot Fe concentration (Table 3). The uptake of Fe with Si application significantly increased and also in the presence of fungal disease was enhanced in pumpkins but was not significant (Table 3).

Table 2 Shoot and root dry weight of pumpkin as affected by Si and powdery mildew treatments[1].

Silicon levels (mM)	Root dry weight (g pot^{-1})			Shoot dry weight (g pot^{-1})		
	(+) powdery mildew	(-) powdery mildew	Mean	(+) powdery mildew	(-) powdery mildew	Mean
0	7.6	13.3	10.5 c	11.5	18.9	15.2 c
0.85	21.5	28.6	25.1 b	33.8	42.3	38.0 b
1.7	30.9	35.4	33.2 a	47.8	52.2	50.0 a
Mean	20 B	25.7 A		31.0 B	38.1 A	

1. Values with the same letter within each column are not significantly different (Duncan's multiple range tests, $P < 0.05$). Small letters refer to comparison of Si levels and capital letters refer to comparisons between powdery mildew infection and control (no mildew).

Table 3 Total uptake (roots and shoots) and concentration of Si, Mn, Zn and Fe in root and shoot of pumpkins as affected by Si and powdery mildew treatments.

SL (mM)	(+) PM	(-) PM	Mean	(+) PM	(-) PM	Mean	(+) PM	(-) PM	Mean	(+) PM	(-) PM	Mean
	Si uptake (%pot^{-1})			Fe uptake			Mn uptake			Zn uptake		
0	0.026	0.057	0.04c	19.12	14.17	16.65b	4.33	2.71	3.52b	2.21	1.66	1.93c
0.85	0.179	0.457	0.32b	33.61	32.74	33.17a	6.65	6.61	6.63a	7.48	8.02	7.75b
1.7	0.508	0.915	0.71a	34.34	32.58	33.46a	7.23	6.49	6.86a	11.35	14.32	12.83a
Mean	0.238B	0.476A		29.02A	26.49A		6.07A	5.27A		7.02A	8.00A	
	RSC (%)			RFC (mg Kg^{-1}, dw)			RMC (mg Kg^{-1}, dw)			RZC (mg Kg^{-1}, dw)		
0	0.47	0.72	0.59c	533	439	486a	88.3	76.5	82.4a	44.9	37.5	41.2b
0.85	1.35	2.81	2.08b	428	335	381b	65.6	53.3	59.4b	90.5	58.9	74.7a
1.7	3.93	4.09	4.04a	295	283	289c	49.5	48.3	48.9b	105.4	70.1	87.7a
Mean	1.93A	2.54A		418A	352B		71A	59B		80A	55B	
	SSC (%)			SFC (mg Kg^{-1}, dw)			SMC (mg Kg^{-1}, dw)			SZC (mg Kg^{-1}, dw)		
0	0.93	1.05	0.99c	209	155	182a	53.9	58.1	56a	42.3	31	36.6b
0.85	3.25	3.64	3.45b	164	139	151b	44.1	40.5	42.3b	54.5	46.7	50.5a
1.7	6.45	6.36	6.41a	119	109	114c	33	34.3	33.6c	76.6	59.5	68.1a
Mean	3.54A	3.58A		164A	134B		44.3A	44.3A		57.8A	45.7A	

Abbreviations: SL: Silicon level, PM: Powdery mildew, RSC: Root Si concentration, RFC: Root Fe concentration, RMC: Root Mn concentration, RZC: Root Zn concentration, SSC: Shoot Si concentration, SFC: Shoot Fe concentration, SMC: Shoot Mn concentration, SZC: Shoot Zn concentration.
1Values with the same letter within each column are not significantly different (Duncan's multiple range tests, $P < 0.05$). Small letters refer to comparison of Si levels and capital letters refer to comparisons between powdery mildew infection and control.

Table 4 Electrolyte leakage percentage, reactive sulfhydryl group concentration in the shoot of pumpkins as affected by Si addition and powdery mildew infection[1].

SL (mM)	Electrolyte leakage percentage (%)			Sulfhydryl group concentration (µmol g^{-1})		
	(+) PM	(-) PM	Mean	(+) PM	(-) PM	Mean
0	40.8	29.8	35.3 a	155	227	191 c
0.85	31.9	22.8	27.4 a	217	246	231 b
1.7	15.7	11.9	13.8 b	352	321	336 a
Mean	29.5A	21.5A		241A	265 A	

Abbreviations: SL: Silicon level, PM: Powdery mildew.
[1.] Means with the same letter within each column are not significantly different at $P < 0.05$. Small letters refer to comparison of Si levels and capital letters refer to comparisons between powdery mildew infection and control.

The root Mn concentration decreased by Si supplement and this variable did not significantly differ between 0.85 and 1.7 mM Si treatments (Table 3). Root Mn concentration increased in presence of mildew infection but shoot manganese concentration was not affected (Table 3). The uptake of Mn in presence of disease slightly increased but was significantly increased with application of silicon nutrition solution (Table 3). Application of Si significantly increased concentration of Zn in root and shoot and also difference was observed between 0.85 and 1.7 mM Si treatments (Table 3). Root Zn concentration increased in presence of mildew infection but shoot manganese concentration was not significant affected (Table 3). Zn uptake increased significantly with enhancing of Si levels (Table 3) and the presence of infection with *S. fuliginea* didn't have any effect on the overall Zn uptake in pumpkins (Table 3).

Discussion

Application of Silicon increased the shoot and root growth of pumpkin and this was more pronounced in 1.7 mM Si level. The beneficial effect of Si nutrition on growth of several plant species has been reported (Lewin and Reimann, 1969; Ma *et al.,* 2002; Liang *et al.,* 2007; Haghighi *et al.,* 2013). Voshida *et al*. (1969) reported that Si improved plant growth by increasing the mechanical stability of stems and leaves and also by enhancement of their light interception and photosynthetic capacity. Silicon can also increase growth by enhancement of chlorophyll content per unit area of leaf tissue (Adtina and Besford, 1986; Shetty *et al.,* 2012; Haghighi *et al.,* 2013).

Presence of mildew infection significantly reduced the root dry weight in treatments of 0 and 0.85 mM Si but the shoot dry weight of plants that treated by 0.85 and 1.7 mM Si was not affected in presence of disease. This experiment showed that growth of pumpkins infected with powdery mildew was significantly improved especially with the application of 1.7 mM Si. Similar results on improvement of yield in cucumber by Si supplement under biotic stress have been reported for diseases caused by pathogens such as *Pythium ultimum* (Cherif and Belanger, 1992), *Pythium aphanidermatum* (Cherif *et al*., 1994), *Fusarium* sp. (Belanger *et al,*. 1995), *Didymella bryoniae* (O'Neill, 1991) and *Botrytis cineria* (O'Neill, 1991). Adtina and Besford (1986) illustrated that optimization of Si nutrition resulted in enhancement of mass and volume of roots that increased total absorbing or adsorbing surface. Some authors state that Si acts as a physical barrier in cell walls, preventing the penetration of fungal hyphae into host tissues (voshida *et al*., 1969; Samuels *et al*., 1993), while others believe Si is related to specific plant defense reactions (Cherif *et al*., 1994; Fawe *et al*., 1998; Rodrigues *et al*., 2003). Silicon increased

resistance of cucumber to *Sphaerotheca fuliginea* by enhancing antifungal activity within the plant, and this was attributed to the presence of a phytoalexin identified as flavonol aglycone rhamnetin (Fawe *et al*., 1998). Cherif *et al*. (1994) also reported that Si enhances resistance to pathogens after deposition of phenolic materials that are conclusively fungitoxic. Since silicon has a role in the resistance of plants to fungus attack, it would be difficult to decide whether the effects of silicon on plant growth were direct or indirect.

In this experiment, Si application in nutrient solution significantly increased the uptake and concentration of Si in root and shoot of plants. Pumpkin is an intermediate plant in Si uptake and the rate of Si uptake by plant is similar to water uptake, thus, with increasing of Si concentration in the root sphere, pumpkin can absorb large amounts of Si as high as gramineous plants (Liang *et al*., 2003). Root Si concentration decreased in presence of mildew infection but this decrease was not significant in 1.7 mM Si level. It is possible that disease resulted in leakage of Silicon out of plant. the environmental stresses can enhance damage of plasma membranes by the oxidation of biomolecules such as lipids and proteins thus these damage at last can lead to ion leakage from roots (Shalata and Tal, 1998). Also Si uptake by pumpkin is a passive process which is greatly inhibited by biotic and abiotic stresses, metabolic inhibitors, and low temperature (Liang *et al*., 2005).

Our results showed that even in the presence of infection, Si nutrient significantly decreased the electrolyte leakage percentage thus; Si application can conserve the membrane integrity of pumpkin under disease stress. In this experiment, application of 1.7 mM Si was more decreased destructive effects of disease than 0.85 mM Si level. Liang *et al*. (1999) also reported Si application decreased the permeability of leaf cells plasma membrane and declined lipid peroxidation in barely. Probably, in this experiment another evidence for the positive role of Si in maintaining the root membrane integrity is a significant increase observed in the reactive sulfhydryl group of proteins in the pumpkin plants grown in presence of Si compared to those in the Si-free medium. Lewin and Reimann (1969) also illustrated that addition of Si might enhance sulfhydryl protein contents at the cell surface and impair the action of respiratory enzymes within cells. It seems that Si application can alleviate disease stress in this study by preventing structural and functional deterioration of cell membrane via deposition in cell walls and increasing of component stability in plasma membranes.

In our experiment, addition of Si decreased root and shoot Fe concentration. Okuda and Takahashi (1965) showed Si supplement decreased uptake of iron by oxidation of Fe and its precipitation on the surface of the root.

Addition of Si significantly decreased the Mn concentration in the roots and shoots and we cannot explain that dilution effect has occurred because Mn uptake also increased in root when the growth of plants in the presence of Silicon was enhanced. Decreasing of Mn concentration with application of Si maybe created by alternation of the cation binding properties of cell wall or by enhancement of Mn oxidation. Horst *et al*. (1999) illustrated that Si due to a lower appoplast Mn concentration in cowpea by modifies the cation binding properties of cell wall and also decreas in uptake of Mn by the plants. Okuda and Takahashi (1965) also reported that Silicon affects the alleviation of Mn toxicity in rice plants with decrease of Mn uptake and the enhancement of Mn oxidation power and increasing of Manganese oxides deposition on the root surface (Okuda and Takahashi, 1965).

Addition of Si increased the concentration of Zn in roots and shoots while disease stress also increased the Zn content of the roots. However, Epstein (1994) illustrated that Si alleviated a detrimental nutrient imbalance between Zinc and Phosphorus in conditions of stress. Enhancement of Zn with application of Si, itself can also improve physiology and biochemistry of higher plants including the stabilization of sulfhydryl groups in membrane proteins

involved in ion transport processes (Cakmak and Marschner, 1992; Norvell and Welch, 1993) and maintenance of structural stability of plant organelles, thus; Si through its effect on distribution of elements may decrease destructive effects of disease in pumpkin plants.

In this study, disease decreased plant growth but with application of Si growth and yield of shoot and root of pumpkins infected with powdery mildew *(S. fuliginea*) was increased significantly. Based on our results it seems that tolerance to disease in pumpkin was induced by alleviation of oxidative damage of functional molecules and conservation of many physiological and biological processes, such as decreasing shoot membrane permeability, increasing concentration of the reactive sulfhydryl group and also by detrimental nutrient imbalance that this coincides with decrease in Fe and Mn concentration and increase in the concentration of Zn in the roots and shoots. Thus, it is suggested that Si may act to ameliorate the stress caused by powdery mildew (*S. fuliginea*) in pumpkin via decreasing destructive activities of fungus on the roots and shoots and increasing of physiological resistance and also by affecting on the uptake, transport and distribution of some ions in the plants under disease stress.

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اثر سیلیسیم بر رشد، توزیع یون‌ها و سازوکارهای فیزیولوژیکی کاهنده تنش اکسیداتیو ناشی از سفیدک سطحی در کدوی پوست‌کاغذی

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چکیده: سیلیسیم (Si) به‌عنوان عنصری مفید برای برخی گیاهان معرفی شده است. پژوهش‌های جدید نشان می‌دهد این عنصر در افزایش مقاومت گیاهان در برابر تنش، نقش مؤثری ایفا می‌کند. در این آزمایش، اثرات سه سطح (صفر، ۰/۸۵ و ۱/۷ میلی‌مولار) سیلیسیم بر رشد و فرآیندهای فیزیولوژیکی کدوی پوست کاغذی تحت تنش ایجاد شده بوسیله‌ی *Sphaerotheca fuliginea* (در سیستم هیدروپونیک، مورد بررسی قرار گرفت. نتایج نشان داد، کاربرد سیلیسیم منجر به افزایش غلظت این عنصر در بافت‌های گیاهی شده است. کاربرد سیلیسیم در گیاهان آلوده به*S. fuliginea* به‌طور معنی‌داری شدت و نشانه‌های بیماری را تا ۳۰ درصد و هم‌چنین نفوذپذیری غشاء سلول‌های اندام هوایی را کاهش داد. افزایش سیلیسیم در محلول غذایی منجر به افزایش معنی‌دار غلظت گروه‌های فعال سولفیدریل شد. بیماری باعث کاهش گروه‌های سولفیدریل غشاء گیاهان شد که این کاهش در گیاهان رشد کرده در محلول‌های فاقد سیلیسیم معنی‌دار بود. استفاده از سیلیسیم منجر به کاهش غلظت آهن و منگنز و افزایش غلظت روی در ریشه و اندام هوایی گیاهان شد. در این آزمایش، کاهش عوارض ناشی از بیماری قارچی در حضور تیمارهای سیلیسیم ممکن است ناشی از کاهش نفوذپذیری غشاء اندام هوایی، افزایش غلظت گروه‌های سولفیدریل فعال و هم‌چنین اثر سیلیسیم بر جذب و توزیع برخی عناصر باشد. براساس این آزمایش سطح ۱/۷ میلی‌مولار سیلیسیم اثر بیشتری بر کاهش بیماری سفیدک سطحی و بهبود شاخص‌های رشد کدو داشته است.

واژگان کلیدی: سیلیسیم، رشد، تنش اکسیداتیو، آلودگی سفیدک سطحی