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THE EFFECT OF SILICON APPLICATION AND TYPE OF SUBSTRATE ON YIELD AND CHEMICAL COMPOSITION OF LEAVES AND FRUIT OF CUCUMBER

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Abstract

Silicon fertilization of plants improves yields and increases plant resistance to various stress factors. The use of silicon in plant fertilization is particularly justified in soilless culture. The aim of the present study, conducted in 2009-2010, was to determine the effect of root application of silicon in the form of silica sol and two growing media with a varying silica content on yield and chemical composition of fruit and leaves of the cultivar Unicum of greenhouse cucumber. Plants were grown in 10 dm^3 cylinders filled with sphagnum peat (I) or peat mixed with large-grained river sand at a ratio of 3:1 (v/v) (II). Four rates of silicon were applied in the study: 0, 250, 500 or 750 mg dm^{-3} Si. The study found a significant increase in cucumber fruit yield when plants were fertilized with silicon by root application at the rates of 500 and 750 mg dm^{-3} Si, compared to the control plants. Cucumbers grown in peat with the addition of sand (v/v 3:1) produced significantly fewer fruits compared to the culture in peat alone, but these fruits contained more total soluble solids. Significantly less calcium and more silicon were found in leaves of cucumber root-fertilized with silicon compared to the control plants. Fruits of cucumber plants fed with silicon by root application contained more dry matter, total soluble solids and silicon but less zinc and copper compared to fruits of the control plants.

Key words: peat, peat with sand, dry weight, TSS, nutritional status, macronutrients, micronutrients.

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WPŁYW STOSOWANIA KRZEMU I RODZAJU PODŁOŻA NA PLONOWANIE ORAZ SKŁAD CHEMICZNY LIŚCI I OWOCÓW OGÓRKA

Abstrakt

Żywienie roślin krzemem poprawia plonowanie roślin oraz zwiększa ich odporność na różnorodne czynniki stresowe. Stosowanie krzemu w żywieniu roślin jest szczególnie uzasadnione w uprawach bezglebowych. Celem badań przeprowadzonych w latach 2009-2010 było określenie wpływu dokorzeniowego stosowania krzemu w formie zolu krzemianowego oraz dwu podłoży o zróżnicowanej zawartości krzemionki na plonowanie i skład chemiczny owoców i liści ogórka szklarniowego odmiany Unicum. Rośliny uprawiano w cylindrach o pojemności 10 dm^3 wypełnionych torfem wysokim (I) oraz torfem zmieszanym z gruboziarnistym piaskiem rzecznym w proporcji v/v 3:1 (II). W badaniach zróżnicowano dawki krzemu, stosując: 0; 250; 500 lub 750 mg dm^{-3} Si. W badaniach stwierdzono istotny wzrost plonu owoców ogórka po dokorzeniowym żywieniu roślin krzemem w dawce 500 i 750 mg dm^{-3} Si, w porównaniu z roślinami z obiektu kontrolnego. Ogórek uprawiany w torfie z dodatkiem piasku (v/v 3:1) wydał istotnie mniej owoców w porównaniu z uprawą w torfie, ale owoce te zawierały więcej ekstraktu. W liściach ogórka żywionego dokorzeniowo krzemem odnotowano istotnie mniej wapnia oraz więcej krzemu w porównaniu z roślinami kontrolnymi. Owoce ogórka żywionego dokorzeniowo krzemem zawierały więcej suchej masy, ekstraktu, krzemu oraz mniej cynku i miedzi w porównaniu z owocami roślin kontrolnych

Słowa kluczowe: torf, torf z piaskiem, sucha masa, ekstrakt, stan odżywienia, makroelementy, mikroelementy.

INTRODUCTION

The application of silicon in soilless culture of cucumber increases yield and improves the basic quality parameters of its fruit (Savant et al. 1999, Hogendorp 2008, Górecki, Danielski-Busch 2009). Numerous studies have also proven that silicon fertilization of plants improves plant resistance to stress factors, such as biotic stress (Liang et al. 2005, Kamenidou et al. 2008, Epstein 2009), salt stress (Zhu et al. 2004, Liang et al. 2006, Amirossadat et al. 2012), water stress (Kamenidou et al. 2008, Sacała 2009), and toxic metal excess (Mitani, Ma 2005, Liang et al. 2006).

The application of silicon is particularly justified in a soilless culture system, in which the roots of plants cannot use silicon resources from the soil solution (Kamenidou et al. 2008, Sonneveld, Voogt 2009). The effectiveness of silicon fertilization of plants is strictly dependent on the type of silicon fertilizer used and the applied rate of this element (Kamenidou et al. 2008, Górecki, Danielski-Busch 2009, Mohaghegh et al. 2010). The use of potassium or sodium metasilicates, waterglass oligomeric, as well as colloidal silica solutions is recommended for fertigation of plants grown in a soilless system, although the use of these materials has disadvantages too (Datnoff et al. 2001). Due to the risk of polymerisation in the nutrient solution and in the root environment, researchers continue efforts to find sources of silicon that would eliminate this adverse phenomenon during cultivation (HOGENDORP 2008).

An appropriately selected medium composed of silicon-rich materials, which – under the influence of the conditions in the root environment - release to the rhizosphere plnat-available ortosilic acid, which can be an important source of silicon for soilless grown plants (DATNOFF at al. 2001, CORNELIS et al. 2011). Organic materials rich in this element and easily mineralized, such as rice hull and straw (KAMENIDOU et al. 2008, YU et al. 2008), cereal straw (MA and TAKAHASHI 2002, NURZYŃSKI et al. 2012) and composts (KAMENIDOU et al. 2008, YU et al. 2008, CORNELIS et al. 2011), are most frequently mentioned as a potential source of silicon for plants. Silicon available to plants can also be released from materials that are generally considered to be inert, such as rockwool, glass wool and perlite (DATNOFF et al. 2001). Sand is another potential source of silicon available to plants; it is the material often added to mixed substrates (OLYMPIOS 1999, RAVIW et al. 2002). However, the literature is short of more specific reports on this subject.

The aim of the present study was to determine the effect of different rates of silicon applied as silica sol and two types of substrate on yield and chemical composition of fruit and leaves of cv. Unicum greenhouse cucumber.

MATERIAL AND METHODS

In 2009-2010, a study was conducted in a greenhouse of the Department of Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin. The experimental plant was cv. Unicum cucumber grown in 10 dm^3 cylinders filled with sphagnum peat (I) or peat mixed with large-grained river sand at a ratio of 3:1 (v/v) (II). Cucumber seeds were sown on 15. June 2009 and 11. June 2010 in general purpose peat growing medium. Seedlings were planted in their permanent place on 6. July 2009 and 5. July 2010 in the medium with a pH adjusted to 6.5. The experiment was carried out using a completely randomized design in 8 replications.

The plants were watered automatically by a drip-irrigation system from a deep well containing water with the following chemical composition (in mg dm^{-3}): 0.02 $N\text{-}NH_4$, 5.0 $N\text{-}NO_3$, 4.0 $P\text{-}PO_4$, 1.4 K, 120 Ca, 13.8 Mg, 32.0 $S\text{-}SO_4$, 9.5 Cl, 6.7 Si, 2.7 Na, 0.24 Fe, 0.018 B, 0.026 Mn, 0.038 Zn, 0.001 Cu, pH 7.44 and EC 0.71 mS cm^{-1}. The plants were fertilized regularly, every 8-10 days, with liquid nutrient solution prepared from the fertilizer Nutrifol green (Yara) and additionally with solution of calcium nitrate, potassium nitrate and magnesium sulphate (23% MgO). The amount of nutrients was the same in all treatments, adjusted according to the results of chemical analysis of the growing medium and to the nutritional requirements of cucumber (Sonneveld, Voogt, 2009). The rates of silicon were differentiated, consisting of 0, 250, 500 or 750 mg Si dm^{-3}. Silicon was supplied to the roots as a liquid solution of silica sol prepared in accordance with the recommendations Iler (1979), at five equal doses during the fertilization of the plants.

Fruit picking was carried out three times a week from 3 August to 19 August 2009 and from 4 August to 23 August 2010, each time determining the number and weight of fruits from particular plants. Due to their very good quality parameters, all fruits harvested from the treatments were classified as marketable yield. Plant protection treatments and cultivation were performed in accordance with the relevant recommendations.

Fruits were sampled for analysis in the middle of the fruiting period, while leaves were collected at the end of the experiment. Dry weight was determined in fresh fruits by the gravimetric method (PN-90/A-75101/03), while total soluble solids (TSS) were determined refractometrically. After leaves and fruits were dried (temp. 105°C), total nitrogen was determined using Kjeldahl's method. Following mineralization of the material in a mixture of nitric and perchloric acids at a ratio of 3:1 (v/v), phosphorus was determined colourimetrically with ammonium-vanadium-molybdate (Thermo, Evolution 300), while potassium, calcium, magnesium, iron, manganese, zinc and copper were assessed by AAS (Perkin-Elmer, Analyst 300). After ashing the material, the silicon content in leaves and fruits was determined by X-ray fluorescence (XRF) using an Axios spectrometer (Panalitycal).

The results were submitted to analysis of variance, using the mean values and employing Tukey's test to evaluate the significance of differences at α=0.05 level of significance. The presented results are two-year means.

RESULTS AND DISCUSSION

Silicon is an element that has a beneficial effect on plants, but crop plants differ radically in their ability to take up and accumulate this element (Epstein 1994, Savant et al. 1999, Epstein 2009). Numerous studies have proven that the application of silicon in fertilization of cucumber has a positive influence on the growth, development and yield of plants (Hogendorp 2008, Górecki, Danielski-Busch 2009, Mohaghegh et al. 2010).

The statistical analysis of the present results showed a significant increase in cucumber fruit yield in the treatments where silicon was root applied at the rates of 500 and 750 mg dm^{-3} compared to the control, in which plants were not supplied with silicon (Table 1). This increase was 8.60 and 5.89%, respectively. These results support earlier studies, in which silicon fertilization of plants resulted in a significant increase in cucumber yield (Górecki, Danielski-Busch 2009, Mohaghegh et al. 2010). In the research

Table 1

The effect of silicon dose (mg) and type of substrate on the yield of fruits (kg plant $^{-1}$), number of fruit per plant, dry weight (%) and total soluble solid (% fr. w.) in the fruit of cucumber

Substrate (A)	Silicon dose (B)	Year (C)	Yield of fruit	Number of fruit	Dry weight	TSS
Peat	0	2009	1.879	9.875	3.945	3.157
		2010	1.539	7.501	4.295	4.071
	250	2009	1.909	9.125	4.630	3.914
		2010	1.846	8.375	4.470	3.800
	500	2009	2.010	9.130	4.745	2.857
		2010	1.809	8.875	4.545	4.100
	750	2009	1.899	8.503	4.700	3.486
		2010	1.794	8.375	4.475	4.171
Peat + sand	0	2009	1.761	8.505	3.360	2.786
		2010	1.473	7.510	3.955	3.329
	250	2009	1.831	8.375	4.085	3.243
		2010	1.456	7.495	4.215	3.371
	500	2009	1.799	7.750	3.910	3.343
		2010	1.604	8.490	4.320	3.529
	750	2009	1.960	8.250	4.650	3.829
		2010	1.394	6.750	4.320	3.643
Mean A	peat		1.819	8.719	4.501	3.695
	peat + sand		1.660	7.891	4.102	3.834
Mean B	0 mg		1.663	8.344	3.939	3.336
	250 mg		1.727	8.243	4.350	3.582
	500 mg		1.806	8.562	4.380	3.457
	750 mg		1.761	7.969	4.536	3.782
Mean C	2009		1.875	8.687	4.253	3.327
	2010		1.604	7.922	4.349	3.752
$LSD_{0.05}$						
A			0.043	0.407	0.072	0.093
B			0.079	n.s.	0.138	0.173
C			0.152	0.563	0.075	0.090
A x B			0.183	n.s.	0.237	0.290

n.s.- not significant

of GÓRECKI, DANIELSKI-BUSCH (2009), an increase in yield of silicon-fed plants resulted from a significantly higher number of fruits per plant. In the present study, the number of fruits per plant in individual treatments did not differ (Table 1), and the recorded increase in yield should therefore be explained by the higher unit fruit weight.

A significant decrease (by 8.74%) in the fruit yield of cucumber plants grown in peat with the addition of sand (v/v 3:1) compared to those grown in peat alone is an interesting finding. This result should be related to the nutritional status of the examined plants (Table 2). Significantly less potassium (40.06 g kg^{-1} DW), calcium (79.02 g kg^{-1} DW) and magnesium (12.35 g kg^{-1} DW) occurred in leaves of cucumber grown in peat with the addition of sand compared to plants grown in peat alone. Poorer nutrition of plants grown in peat with sand could have been the reason for the poorer yield of plants growing in these treatments. Similar results were also obtained in an experiment on tomato grown in sand, compared to peat and rockwool (JAROSZ 2006). The poorer yield of cucumber grown in peat with sand could also have resulted from an increase in the medium density and the consequent change in air and water conditions (OLYMPIOS 1999, RAVIW et al. 2002).

The analysis of the results obtained in the present study showed a significantly higher content of dry matter and total soluble solids (TSS) in fruits of silicon-fertilized plants by root application compared to control plants (Table 1). These results corroborate earlier reports that proved the beneficial effect of the application of silicon in plant cultivation on the main quality parameters of fruits, including the content of dry matter and total soluble solids (AZIZ et al. 2002, HOGENDORP 2008). Significantly less dry matter (4.102%) and more TSS (3.834 % fr. w.) were recorded in fruits of cucumber grown in peat with the addition of sand compared to cucumber plants grown in peat alone.

Silicon is taken up by plants mainly as uncharged orthosilicic acid monomers (MA, TAKAHASHI 2002, EPSTEIN 2009, SACAŁA 2009), with ion forms being less important in plant nutrition (MA, TAKAHASHI 2002, MATICHENKOV, CALVERT 1999). Nevertheless, root fertilization with silicon significantly affects the uptake and distribution of nutrients in the plant (EPSTEIN 1994, AZIZ et al. 2002, MA, TAKAHASHI 2002, EPSTEIN 2009). This is also confirmed by the results reported herein (Tables 2-3). It should be stressed that there was no significant effect of root-applied silicon on the phosphorus content in leaves and fruits of the analyzed plants. These results are contradictory to many reports, which demonstrate a beneficial effect of silicon fertilization on improved phosphorus nutrition of plants (EPSTEIN 1994, AZIZ et al. 2002). According to MATICHENKOV, AMMOSOVA (1996), orthosilicic acid has the ability to release phosphorus from calcium, aluminium and iron phosphates, which are unavailable to plants, and it adsorbs aluminium hydroxides reducing their mobility; thereby, the chemical sorption of phosphates is reduced by 40-70% (JUNIOR et al. 2010). However, all these relationships were observed

Table 2

The effect of silicon dose (mg) and type of substrate on the content of selected nutrients and silicon in leaves of cucumber (2009-2010)

Substrate (A)	Silicon dose (B)	N total	P	K	Ca	Mg	Si	Fe	Zn	Mn	Cu
		(g kg^{-1} d.w.)						(mg kg^{-1} d.w.)			
Peat	0	45.82	4.465	45.12	103.9	12.30	2.340	89.95	86.85	241.14	5.475
	250	46.15	3.543	45.10	87.05	14.35	5.530	113.41	98.87	318.21	5.820
	500	45.70	4.438	41.05	91.18	13.85	5.457	210.73	94.47	262.67	5.997
	750	44.62	3.920	38.97	78.37	12.65	6.887	95.24	91.70	263.14	5.577
Peat + sand	0	46.30	4.045	41.62	86.92	12.15	4.527	90.62	101.61	375.73	5.607
	250	45.87	4.990	40.61	79.75	12.45	4.850	97.07	103.84	339.67	5.955
	500	45.82	5.135	39.75	77.45	11.77	5.905	90.69	98.77	366.01	5.982
	750	46.30	4.495	38.25	71.97	13.02	6.690	102.70	89.12	375.54	5.702
Mean A	peat	45.57	4.091	42.56	90.29	13.29	5.054	127.39	92.97	271.18	5.717
	peat + sand	46.07	4.666	40.06	79.02	12.35	5.493	95.26	98.32	364.24	5.812
Mean B	0	46.06	4.255	43.37	95.42	12.22	3.434	90.29	94.24	308.42	5.541
	250	46.01	4.266	42.85	83.40	13.40	5.190	105.22	101.33	329.13	5.887
	500	45.76	4.786	40.41	84.62	12.81	5.681	150.68	96.62	314.31	5.990
	750	45.46	4.208	38.61	75.17	12.84	6.789	98.96	90.41	319.19	5.640
$LSD_{0.05}$											
A		0.310	0.466	0.771	2.736	0.687	n.s.	n.s.	4.315	9.738	n.s.
B		n.s.	n.s.	1.471	5.224	n.s.	1.601	n.s.	n.s.	15.59	n.s.
A x B		1.018	n.s.	2.518	8.938	n.s.	n.s.	n.s.	n.s.	31.82	n.s.

n.s.- not significant

Table 3

The effect of silicon dose (mg) and type of substrate on the content of selected nutrients and silicon in fruits of cucumber (2009-2010)

Substrate (A)	Silicon dose (B)	N total	P	K	Ca	Mg	Si	Fe	Zn	Mn	Cu
		($g\ kg^{-1}$ d.w.)						($mg\ kg^{-1}$ d.w.)			
Peat	0	37.75	5.541	31.60	5.495	2.218	0.723	48.52	33.55	34.72	9.300
	250	37.95	5.737	31.05	4.243	1.821	0.983	47.97	32.27	32.40	7.210
	500	37.01	5.958	31.42	5.398	2.164	1.115	44.07	29.90	32.85	7.460
	750	33.92	5.759	33.82	5.310	2.216	1.324	49.25	28.37	34.67	6.775
Peat + sand	0	40.02	6.320	30.55	4.400	2.020	0.907	50.42	40.45	40.55	9.437
	250	36.52	6.492	22.05	4.470	2.254	1.138	45.57	34.77	39.42	7.705
	500	38.01	6.331	23.90	4.795	2.238	1.130	44.22	34.62	39.30	7.447
	750	34.85	7.051	32.15	4.160	2.206	1.368	44.15	30.68	40.60	6.367
Mean A	peat	36.66	5.749	31.97	5.111	2.105	1.037	47.45	31.02	33.62	7.687
	peat + sand	37.35	6.549	27.16	4.456	2.179	1.135	46.09	35.13	39.97	7.739
Mean B	0	38.89	6.040	31.07	4.948	2.119	0.815	49.47	37.00	37.64	9.369
	250	37.24	6.114	26.55	4.356	2.037	1.058	46.77	33.52	35.91	7.457
	500	37.50	6.145	27.66	5.096	2.201	1.125	44.15	32.26	36.07	7.454
	750	34.39	6.296	32.99	4.735	2.221	1.346	46.70	29.52	37.64	6.572
$LSD_{0.05}$											
A		0.307	0.171	1.355	0.332	n.s.	n.s.	n.s.	1.415	1.226	n.s.
B		0.588	n.s.	2.588	0.634	n.s.	0.191	2.877	2.701	n.s.	0.398
A x B		1.005	0.558	4.428	1.085	0.357	n.s.	n.s.	n.s.	n.s.	n.s.

n.s.- not significant

under field conditions and seem related to the soil environment. In soilless culture, the effectiveness of silicic acid is of lesser importance, since the root environment of plants grown in growing media is free from excessive mobile forms of aluminium, iron and manganese, while phosphorus is regularly supplied in small doses throughout the whole growing period. It is also worth remembering that the effect of silicates used in plant fertilization on the uptake and allocation of nutrients in the plant is not fully explained and the conclusions are often contradictory. An example is the study of MA, TAKAHASHI (2002), who showed a decrease in the phosphate ion content in aerial parts of plants fertilized with orthosilicic anions, explaining this phenomenon by the competition in the uptake of these anions by plants. In turn, EPSTEIN (1994) thinks that the benefits resulting from silicon fertilization of plants, compared to phosphorus fertilization, primarily consist in regulating the uptake and allocation of phosphorus and zinc in plants by silicon.

The analysis of the results obtained in the present study showed a significantly lower calcium content, which ranged from 75.15 to 84.62 g kg^{-1} DW, in leaves of cucumber grown in the silicon-fertilized treatments (Table 2). Leaves of cucumber grown in peat with the addition of sand also contained significantly less calcium (79.02 g kg^{-1} DW) compared to plants grown in peat alone (90.29 g kg^{-1} DW). These results are in agreement with the findings of other authors who showed a reduction in the calcium content in plants fed with silicon (EPSTEIN 1994, CHEN et al. 2011). A decrease in the calcium content in silicon-fed plants can be caused by the fixation of this element by silicates in the root environment of plants as well as in the plant structures (MA, TAKAHASHI 2002). AZIZ et al. (2002) present a different view. These authors quote the results indicating that the application of silicon in rice growing caused a decrease in the content of nitrogen, potassium, iron and manganese as well as an increase in the content of calcium and magnesium in plants. The present study found a significant reduction in the leaf potassium content compared to the control treatments only in the treatments where plants were fertilized with silicon at the rates of 500 and 750 mg Si dm^{-3} (by 6.82 and 10.97%, respectively).

Cucumber is a species characterized by a moderate affinity for the uptake of silicon, accumulating from 0.5 to 1.5% Si in dry matter (HOGENDORP 2008). In this study, an amount from 4.850 to 6.690 g kg^{-1} DW of silicon was found in leaves of plants fertilized with silicon by root application, while the silicon content in fruits was 0.983 do 1.368 g Si kg^{-1} DW. A lower content of silicon in cucumber leaves and fruit was found by GÓRECKI, DANIELSKI-BUSCH (2009), who investigated the effectiveness of calcium and ammonium silicate as slow silicon release fertilizers in container cultivation. In turn, studying the effect of different silicon concentrations together with fertigation in rockwool-grown cucumber, SONNEVELD, VOOGT (2009) found from 350 to 1400 mmol Si kg^{-1} DW in leaves and from 25 to 100 mmol Si kg^{-1} DW in fruits.

A relatively high Si content in leaves and fruits of plants in the control treatments, in which this element was not used for root fertilization, needs to be stressed (Tables 2, 3). As reported by MA, TAKAHASHI (2002), water used for watering plants can be a source of available silicon for plants grown in a soilless system. Orthosilicic acid can also be released from a growing medium. LIU et al. (2011) showed the release of silicon forms available to plants from sand at an amount of 8-13 mg kg^{-1}, whereas RAVIW et al. (2002) reported an analogous value within the range of 8-10 mg kg^{-1}, depending on the plant growing conditions. In turn, DATNOFF et al. (2001) reports that sphagnum peat, which contains from 15 to 220 mmol kg^{-1} Si and releases this element during plant cultivation at an amount of *ca* 0.2 mmol dm^{-3}, can also be a source of silicon available to plants. However, the present study did not show significant differences in the silicon content in leaves and fruits of plants depending on the type of medium.

The statistical analysis of the results obtained in the present study showed significantly less zinc (29.52-33.52 mg kg^{-1} DW) and copper (6.572-7.457 mg kg^{-1} DW) in fruits of plants fertilized with silicon by root application compared to fruits picked from control plants. Similar results are presented in other reports, which confirms that silicon fertilization of plants significantly modifies the chemical composition of marketable plant organs (EPSTEIN 1994, SAVANT et al. 1999, MA, TAKAHASHI, 2002, EPSTEIN 2009).

CONCLUSIONS

1. The study demonstrated a significant increase in cucumber fruit yield when plants were fertilized by root application with silicon at the rates of 500 and 750 mg dm^{-3} Si, compared to control plants.

2. Cucumber grown in peat with the addition of sand (v/v 3:1) produced significantly fewer fruits compared to plants grown in peat alone, but these fruits contained more total soluble solids.

3. Significantly more silicon and less calcium were found in leaves of cucumber plants fertilized by root application with silicon, compared to control plants.

4. Fruits of cucumber plants fed with silicon by root application contained more dry matter, total soluble solids and silicon but less zinc and copper compared to fruits of control plants.

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