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THE EFFECT OF SILICON APPLICATION AND TYPE OF MEDIUM ON YIELDING AND CHEMICAL COMPOSITION OF TOMATO

Zbigniew Jarosz
University of Life Sciences in Lublin

Abstract. Fertilization of plants with silicon is particularly justified in soilless culture in which the roots of plants cannot use silicon resources in the soil. Silicon is the only element that does not harm plants when taken up in excessive amounts and its use in plant fertilization improves the yielding ability of plants and their resistance to various stress factors. The effectiveness of silicon application in growing plants is strictly dependent on both the source of this element, plant species and cultivars. The aim of this study was to determine the effect of root application of colloidal silicon as well as of three types of growing media of different silica content and varying ability to release orthosilicate monomers (rockwool, sand, straw) on yield and chemical composition of greenhouse tomato. The research was conducted in greenhouse in the period 2008–2009. Tomato was grown in an extended growth cycle (22 clusters) using a drip irrigation and fertilization system with closed nutrient solution circulation. Tomato plants fertigated with the nutrient solution enriched with silicon showed significantly higher total fruit yield (15.98 $\mathrm{kg \cdot plant^{-1}}$) compare to plant grown in control treatments. In the studies not found significant differences in total and marketable yield as well as in mean fruit weight between plants grown in rockwool and straw mediums. The total fruit yield of tomato plants grown in sand was lower compared to rockwool-grown plants. The fruit of tomato grown in sand was shown to have more dry matter (5.52%), total sugars (2.58% FR.W.) and potassium (4.19% DW) compared to rockwool culture as well as significantly the highest amount of silicon. The leaves of tomato fertilized with the silicon-enriched nutrient solution contained more silicon as well as less manganese and zinc compared to control plants.

Key words: soilless culture, rockwool, sand, straw, dry weight, vitamin C, total sugars, nutrients

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Corresponding author: Zbigniew Jarosz, Department of Soil Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin, Leszczyńskiego 58, 20-068 Lublin, Poland, e-mail: zbigniew.jarosz@up.lublin.pl

INTRODUCTION

In spite of proven benefits arising from the application of silicon in plant fertilization [Liang et al. 2006, Epstein 2009, Górecki and Danielski-Busch 2009] the use of this element in soilless culture is still limited [Wolff et al. 2012]. The reason for this is the lack of a sufficiently stable fertilizer product that could be used in fertigation [Datnoff et al. 2001, Voogt and Sonneveld 2001, Jarosz 2013]. Currently offered silicon supplements have a limited ability to mix with other fertilizers and they create, to a smaller or greater degree, the risk of blocking microcapillaries dispensing a liquid nutrient solution [Guevel et al. 2007, Kingston 2011, Wolff et al. 2012].

In soilless culture, a properly chosen growing medium composed of materials that release this element during plant growth can be an important source of silicon for plants [Korndörfer and Pereira 2011, Jarosz 2013]. Ma and Takahashi [2002] propose to use for this purpose compost made of plants with high silicon content. In the opinion of Pereira et al. [2004] report that raw plant waste that accumulates this element in large amounts can be a source of silicon. An example of such material can be cereal straw; depending on cultivar and place of cultivation, it can contain from 1.1 to 3.9% Si in dry weight [Antongiovanni and Sargentini 1991, El Nashaar et al. 2011]. This material is a natural and cheap slow-release silicon fertilizer [Korndörfer and Pereira 2011]. Hodson et al. [2005] and Cornelis et al. [2011] argue that during the biomineralization of organic matter intratissue silicon structures are degraded and released, although the rate of degradation is strictly dependent on the form and shape of secondary silicon structures. Furthermore, these authors stress that a part of silicon in the plant occurs in non-crystalline form and is transferred to the solution already at the initial stages of degradation.

Sand is a cheap and easily available growing medium with high silicon content and its usefulness in soilless tomato culture has been proven in the studies of Nurzyński et al. [2003] and Jarosz [2006]. Although this material, from the chemical point of view, is almost pure silica containing of 95% of SiO_2 in the form of quartz, its solubility is low compared to other silicon-containing materials [Raviv et al. 2002, Crooks and Prentice 2011]. Korndörfer and Pereira [2011] emphasise that a measure of usefulness of material being a potential source of silicon for plants is not its total Si content, but the degree of release of orthosilicate monomers. For this reason rockwool, which consists of silica (SiO_2) in 47%, is not considered to be a material that is a source of orthosilicate monomers [Datnoff et al. 2001, Raviv et al. 2002].

The aim of the present study is to determine the effect of root application of silicon in the form of colloidal silica solution as well as of three types of growing media of different silica content and variability to release orthosilicate monomers on yield and chemical composition of greenhouse tomato.

MATERIALS AND METHODS

The study was carried out in the period 2008–2009. The experimental object was the tomato cultivar ‘Cunero F_1’ grown in greenhouse. This variety is resistant to heat and suitable for extended growth cycle. Requires elevated levels of potassium and calcium in root zone. The fruits of a weight from 140 to 160 g are resistant to mechanical damage. Tomato plants were grown in three different types of mediums: rockwool, large-grained river sand and triticale straw cut into 2 cm pieces. Sand and straw was placed in plastic containers, corresponding in their shape and volume to a rockwool slab (12 dm^3). The sand in the bottom part of the containers was mixed with bark (v:v 3:1) which allowed the sampling of extracts from the rhizosphere of plants. The experiment was set up as a completely randomized design with seven replicates. A slab (container) in which two plants were grown was one replicate. Tomato plants were planted in their permanent place in the first 10-days period of February (6 February 2008 and 3 February 2009) in the initial phase of blossom first cluster. They were grown in an extended growth cycle (22 clusters) at a density of 2.3 $plant \cdot m^{-2}$ until the middle of October (14 October 2008 and 16 October 2009), using a drip irrigation and fertilization system with closed nutrient solution circulation. The study used a nutrient solution with the following average values of nutrients ($mg \cdot dm^{-3}$): 12.2 $N\text{-}NH_4$, 235.0 $N\text{-}NO_3$, 56.5 $P\text{-}PO_4$, 350.5 K, 256.0 Ca, 94.1 Mg, 185.0 $S\text{-}SO_4$, 26.0 Na, 18.5 Cl, 2.0 Fe, 0.95 Mn, 0.54 B, 0.09 Cu, 0.56 Zn, 0.09 Mo, EC 2.65 $mS \cdot cm^{-1}$, and pH – 5.65. The nutrient solution was prepared with the following chemical composition of water ($mg \cdot dm^{-3}$): 0.02 $N\text{-}NH_4$, 0.5 $N\text{-}NO_3$, 4.0 $P\text{-}PO_4$, 1.4 K, 111.0 Ca, 13.8 Mg, 32.0 $S\text{-}SO_4$, 9.5 Cl, 2.7 Na, 6.7 Si, 0.24 Fe, 0.026 Mn, 0.038 Zn, 0.001 Cu, pH – 7.44, EC – 0.71 $mS \cdot cm^{-1}$. The solution was supplied to all plants in the same amount and with the same composition, except for silicon. The nutrient solution containing 100.0 mg $SiO_2 \cdot dm^{-3}$ in the form of modified colloidal silica solution [Iler 1979] was supplied to one half of plants. The composition and proportions of particular elements in the nutrient solution were changed during plant growth and adjusted to plant development stages in accordance with the latest of recommendations [Nurzyński and Jarosz 2012]. The amount of nutrient solution supplied to plants was determined with an excess of about 25%. The frequency of nutrient solution supply, controlled by a solar timer, depended on solar radiation intensity. Humidity and temperature during the tests were measured at two-hour intervals. Average monthly temperatures ranged from 18.4 to 24.2ºC while the average value the humidity ranged from 45.3 to 84.6%. The flowers were pollinated by the large earth bumblebee (*Bombus terrestris*). Plant protection treatments were carried out using biological agents (*Encarsia formosa*, En-Strip, Koppert). All tending treatments were performed in accordance with the applicable praxis recommendations.

Fruit harvest started on 29 April 2008 and 15 April 2009, respectively, and fruits were picked twice a week in the harvesting maturity stage. They were counted and sorted out; subsequently, total fruit yield, marketable fruit yield and average fruit weight were determined in accordance with EU standards (Commission Regulation (EC) No. 790/2000, 2000).

Fruits were sampled for analysis from the 11th cluster at the harvest maturity stage. Dry weight was determined in fresh material by the gravimetric method [PN-90/A-75101/03], vitamin C by Tillman's method [PN-A-04019 1998], and total sugars by Schoorl-Rogenhausen's method [Rutkowska 1981]. After the material was dried (8 hours at 105°C), total nitrogen was determined using Kjeldahl's method [Ostrowska et al. 1991]. Following mineralization of the material in a mixture of nitric and perchloric acids at a ratio of 3:1 (v:v) [Ostrowska et al. 1991], phosphorus was determined colourimetrically with ammonium-vanadium-molybdate (Thermo, Evolution 300), while potassium, calcium, magnesium, iron, manganese, zinc and copper by AAS (Perkin-Elmer, AAnalyst 300). Leaves were sampled for analysis (the 9th leaf from the tip) twice during the growing season (in the beginning and at the end of plant fruiting).

The content of macro- and micronutrients in leaves was determined following the same methods as those used for fruit analysis. After the material was ashed (in a muffle furnace at a temperature of 550°C), leaf and fruit silicon content was determined by X-ray fluorescence (XRF) using an Axios spectrometer (Panalitycal).

The results were statistically analysed by analysis of variance using the mean values and employing Tukey's test to evaluate the significance of differences at the $\alpha = 0.05$ level of significance. For the statistical analysis all percentages were transformed according to Bliss's formula [Büchse et al. 2007]. The presented results are two-year means.

RESULTS AND DISCUSSION

The effectiveness of silicon application in growing plants is strictly dependent on both the source of this element, plant species and cultivar. In the opinion of Ma and Takahashi [2002], the ability of plants to take up and bioaccumulate this element can also be a varietal character. Tomato is included in species of low silicon uptake ability. The silicon uptake mechanism in tomato has not been fully explained and the reports of the authors attempting to explain this phenomenon are contradictory. Datnoff and Rodrigues [2005] think that the roots of this species take up silicon passively as a result of simple diffusion and transpiration-induced mass flow. Some authors prove that this species belongs to plants that avoid silicon uptake (the so-called rejective uptake), which is caused by the differences in the anatomical structure of the roots compared to typical bioaccumulators of Si [Raven and Edwards 2001, Mitani and Ma 2005, Hogendorp 2008]. In spite of this, numerous studies show a beneficial effect of silicon application in the cultivation of this species [Datnoff et al. 2001, Ma and Takahashi 2002, Stamatakis et al. 2003].

The analysis of the results obtained in the present study showed a significant increase in total fruit yield of plants fertilized with the silicon-enriched nutrient solution (15.98 $\text{kg}\cdot\text{plant}^{-1}$) compared to plants in the control treatments (tab. 1). These results are in agreement with the literature reports proving the beneficial influence of feeding tomato plants with silicon on yield [Datnoff et al. 2001, Stamatakis et al. 2003, Sanchez et al. 2012]. A similar trend can be observed in the case of marketable yield, though in this case it was not statistically confirmed. Taking into account the absence of significant differences in fruit size between the investigated treatments (tab. 1), the increase in yield should be explained by better flowering and better fruit set in silicon-fed plants. These results are consistent with the reports of Sanchez et al. [2012]. Usage of silicon alleviating abiotic stress (thermal, light, salt stress) can improve flowering and fruit set. In the studies not found significant differences in total and marketable yield as well as in mean fruit weight between plants grown in rockwool and straw mediums (tab. 1). These results are consistent with previous studies in which there was no difference in yielding tomato grown in rockwool and straw [Nurzyński et al. 2012]. It needs to be stressed that plants grown in sand showed total fruit yield lower by 2.45% compared to rockwool-grown plants. Given the significantly highest nitrogen (4.15% FW) and phosphorus (0.39% FW) content in the leaves of tomato plants grown in sand and the absence of significant differences in leaf potassium, calcium and magnesium content in the studied plants (tab. 5), the reason for the decrease in yield should be sought in the worse physical parameters of this growing medium, mainly as regards aeration [Raviv et al. 2002]. This is corroborated by an earlier study of Nurzyński et al. [2003] which found a decline in yield for tomato grown in sand with worse air and water properties. As shown by Raviv et al. [2002], oxygen diffusion into fine-grained sand is from 10 to 100 times lower compared to other materials (among others, peat, bark, and perlite). Lower yield of tomato fruits grown in sand may also result from inferior water holding capacity in this medium as compared to the rockwool [Gruda et al. 2013].

Table 1. The effect of silicon application and type of medium on the yield (kg plant^{-1}) and mean fruit weight (g) of tomato (mean from the years 2008–2009)

Medium	Total yield			Marketable yield			Mean fruit weight		
	nutrient solution								
	Si +	Si -	$\bar{x}$	Si+	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$
Rockwool	15.75	16.07	15.92	14.59	14.99	14.79	132.4	154.4	143.4
Sand	16.05	15.01	15.53	14.77	13.97	14.37	158.3	152.7	155.5
Straw	16.15	15.54	15.84	14.92	14.40	14.66	154.7	152.9	143.8
$\bar{x}$	15.98	15.54		14.76	14.45		148.5	153.3	
LSD$_{0.05}$									
Silicon		0.28			ns.			ns.	
Medium		0.37			ns.			ns.	
A × B		0.74			1.05			ns.	

ns. – not significant

The fruits of plants fertilized with the silicon-enriched nutrient solution were characterized by significantly higher dry matter content (5.47%) compared to control plants (5.34%). These results confirm other reports evidencing that silicon application in plant nutrition increases dry matter content in plants [Junior et al. 2010, Jarosz 2013]. The fruit of sand-grown tomato contained significantly higher dry matter (5.52%) and total sugars (2.58% FW) compared to the fruits collected from rockwool-grown plants (respectively, by 5.23% and 2.26% FW).

The analysis of the results concerning the chemical composition of the fruit (tabs 3 and 4) showed that the use of fertigation with the silicon-enriched nutrient solution did not have a significant influence on the content of elements in question, except for manganese. The fruits of plants fertigated with the silicon-enriched solution were found to have significantly less manganese (43.9 mg·kg^{-1} FW) compared to control plants (51.5 mg·kg^{-1} FW). A similar relationship was shown for the leaves of the studied plants (tab. 6). These results are consistent with other authors' studies which investigated the effect of silicon on the mitigation of stress induced by excess manganese [Dragišić Maksimović et al. 2007, Li et al. 2012]. Rogalla and Römheld [2002] showed that in cucumber silicon intensely bound manganese in the cell walls, reducing the concentrations of this element in the apoplast. In the opinion of Junior et al. [2010], it is also probable that there is a mechanism consisting in binding manganese by orthosilicic acid in the nutrient solution and in the root environment, which significantly reduces the uptake of this micronutrient by plants.

Table 2. The effect of silicon application and type of medium on the composition of tomato fruit (mean from the years 2008–2009)

Medium	Dry matter (%)			Vitamin C (mg·100 g^{1} FW)			Total sugars (% FW)		
	nutrient solution								
	Si +	Si –	$\bar{x}$	Si +	Si –	$\bar{x}$	Si +	Si –	$\bar{x}$
Rockwool	5.37	5.20	5.23	21.46	21.89	21.67	2.29	2.22	2.26
Sand	5.58	5.47	5.52	21.50	21.07	21.28	2.73	2.43	2.58
Straw	5.45	5.35	5.40	23.38	23.49	23.44	2.40	2.42	2.41
$\bar{x}$	5.47	5.34		22.11	22.15		2.48	2.36	
LSD$_{0.05}$									
Silicon		0.12			ns.			ns.	
Medium		0.16			ns.			0.21	
A × B		ns.			ns.			ns.	

ns. – not significant

The differences in silicon content in tomato fruits depending on the studied factors are interesting (tab. 4). The content of this element in products intended for consumption is an important parameter of the nutritional value. Many reports show that in human organism silicon plays an important role, among others, reducing the bioavailability of aluminium [Jugdaohsingh et al. 2000, Martin 2007]. The use of the silicon-enriched nutrient solution in tomato cultivation did not cause a statistically confirmed increase in silicon content in the fruit, whereas such an increase was found in the leaves (tab. 6). The factor differentiating the fruit and leaf silicon content in the studied plants was the type of growing medium (tabs 4 and 6). The highest amount of silicon was found in the fruit (149.5 mg·kg^{-1} DW) and leaves (425.6 mg·kg^{-1} DW) of tomato grown in sand. The relatively high fruit and leaf silicon content in tomato plants fertigated with the nutrient solution not enriched with silicon needs to be explained. The original content of this nutrient in the water used for fertigation was the source of silicon for all plants examined. It is generally thought that in water silicon occurs in the form of silicic acid monomers ($Si(OH)^{0}{}_{4}$) available to plants [Datnoff et al. 2001, Ma and Takahashi 2002,

Table 3. The effect of silicon application and type of medium on the chemical composition of tomato fruits (mean from the years 2008–2009)

Medium	N Total (% DW)			P (% DW)			K (% DW)			Ca (mg·kg^{-1}DW)			Mg (mg·kg^{-1} DW)		
	nutrient solution														
	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$
Rockwool	2.33	2.30	2.32	0.32	0.30	0.31	3.91	3.66	3.79	916.0	956.5	936.2	1024.7	1098.7	1061.7
Sand	2.23	2.21	2.22	0.25	0.23	0.24	4.32	4.07	4.19	886.2	904.2	895.2	997.5	999.7	998.6
Straw	2.31	2.22	2.26	0.32	0.30	0.31	4.13	3.99	4.06	894.0	1005.5	949.7	1127.7	1167.0	1147.4
$\bar{x}$	2.29	2.24		0.30	0.28		4.12	3.91		898.7	955.4		1050.0	1088.5	
$LSD_{0.05}$															
Silicon		ns.			ns.			ns.			ns.			ns.	
Medium		ns.			ns.			0.32			ns.			62.6	
A × B		ns.			ns.			ns.			ns.			ns.	

ns. – not significant

Table 4. The effect of silicon application and type of medium on the contents of silicon and selected micronutrients (mg·kg^{-1} DW) in tomato fruits (mean from the years 2008–2009)

Medium	Si			Fe			Mn			Zn			Cu		
	nutrient solution														
	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$
Rockwool	85.9	73.1	79.5	39.9	46.9	43.4	41.8	51.5	46.7	27.2	30.1	28.7	4.12	4.70	4.41
Sand	146.5	152.5	149.5	39.5	40.4	39.9	40.5	44.8	42.6	24.3	25.1	24.6	3.10	3.39	3.24
Straw	127.2	113.7	120.4	56.8	48.1	52.5	49.2	58.2	53.7	32.2	32.8	32.5	3.87	4.35	4.11
$\bar{x}$	119.7	113.1		45.4	45.1		43.9	51.5		27.9	29.3		3.70	4.15	
$LSD_{0.05}$															
Silicon		ns.			ns.			6.48			ns.			ns.	
Medium		14.2			ns.			8.17			5.95			ns.	
A × B		ns.			ns.			ns.			ns.			ns.	

ns. – not significant

Table 5. The effect of silicon application and type of medium on the chemical composition (% DW) of tomato leaves (mean from the years 2008–2009)

Medium	N Total			P			K			Ca			Mg		
	nutrient solution														
	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$
Rockwool	3.96	4.03	3.99	0.33	0.29	0.31	4.77	4.59	4.68	2.33	2.60	2.46	0.25	0.23	0.24
Sand	4.16	4.24	4.15	0.40	0.38	0.39	4.92	4.63	4.78	2.30	2.42	2.36	0.26	0.26	0.26
Straw	4.07	3.98	4.02	0.35	0.32	0.34	4.62	4.56	4.59	2.46	2.72	2.59	0.27	0.27	0.27
$\bar{x}$	4.06	4.05		0.36	0.33		4.77	4.59		2.34	2.58		0.26	0.25	
$LSD_{0.05}$															
Silicon		ns.			ns.			ns.			ns.			ns.	
Medium		0.11			0.04			ns.			ns.			ns.	
A × B		ns.			ns.			ns.			ns.			ns.	

ns. – not significant

Table 6. The effect of silicon application and type of medium on the contents of silicon and selected micronutrients ($mg \cdot kg^{-1}$ DW) in tomato leaves (mean from the years 2008–2009)

Medium	Si			Fe			Mn			Zn			Cu		
	nutrient solution														
	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$	Si +	Si -	$\bar{x}$
Rockwool	285.6	257.3	271.4	127.3	121.4	124.3	443.9	458.4	451.1	68.4	81.0	74.7	7.98	8.64	8.31
Sand	495.9	355.3	425.6	131.3	148.7	140.1	424.1	435.4	429.7	54.1	60.9	57.5	7.40	7.21	7.30
Straw	364.9	343.7	354.3	101.6	93.5	97.5	458.5	474.8	466.6	66.0	72.1	69.1	6.79	7.05	6.92
$\bar{x}$	382.1	318.8		120.1	121.2		442.1	456.2		62.8	71.3		7.39	7.63	
$LSD_{0.05}$															
Silicon		19.5			ns			6.93			5.73			ns.	
Medium		38.9			14.4			9.74			7.97			0.54	
A × B		ns.			ns.			ns.			ns.			ns.	

ns. – not significant

Sacała 2009, Sonneveld and Voogt 2009]. The significant differences in the content of this element in the fruit and leaves depending on the type of medium investigated are also evidence that growing medium material is a source of silicon. In the opinion of Nurzyński et al. [2012], straw used as a growing medium in soilless tomato culture is mineralized in about 70% during all-year-round cultivation of tomato. In the present study straw used as a growing medium was mineralized in 55–60%. Orthosilicate monomers, easily available to plants, are released to the root environment throughout this process [Hodson et al. 2005, Cornelis et al. 2011].

The research on the amount of orthosilicic acid monomers released from sand during plant growth is divergent. Datnoff et al. [2001] report that at a temperature of 298 K (i.e. 25°C) from 8 to 11 mg kg^{-1} SiO_2 can be released from quartz. Liu et al. [2011] showed that silicon forms available to plants were released at an amount of 8–13 mg kg^{-1} of material. In turn, Dietzel [2000] proves that the release of silicates from sand quartz immersed in an acidic solution can be much higher.

In spite of the fact that silica (SiO_2) is dominant in the chemical composition of rockwool, accounting for as much as 47% of its weight, the amount of silicon released from this material to the rhizosphere in a form available to plants is small [Datnoff et al. 2001]. When investigating silicon release from new and used rockwool slabs after their immersion in a nutrient solution, Kipp et al. [2000] showed the silicon concentration to increase by 19.7 mg dm^{-3} in the extract from new slabs, whereas in the case of reused slabs this increase was 30.9 mg dm^{-3}.

When considering the issue of plant fertilization with silicon, one should also take into account the potential transformations of silicates in the root environment of plants grown in soilless culture. Currie and Perry [2007] think that this phenomenon is little known as yet. It is generally thought that a decrease in solution pH and an increase in the content of divalent cations, including primarily heavy metals, reduce the stability of orthosilicic acid monomers, thus stimulating the polymerization [Korzeniowska 2008]. Nevertheless, it should be emphasised that depolymerization can occur concurrently and as a result of that orthosilicates available to plants are released into the solution. As proven by Dietzel [2000], the degradation half-life of a polymer to degrade into a monomer in an aqueous solution with pH and chemical composition similar to the rhizosphere solution of the studied plants is from several hours to several days.

A confirmation of the beneficial effect of the application of this element on phosphorus supply to plants can be found in most literature reports on plant fertilization with silicon [Epstein 1994]. As proven by Ma and Takahashi [2002], orthosilicic acid taken up by plants in the form of undissociated molecules minimally affects the uptake of phosphate anions and this effectiveness cannot be thus explained by a direct interaction of silicon monomers and phosphates. Even more so that, with an increasing degree of dissociation of orthosilicates, the antagonism between silicate and phosphate ions intensifies. In the opinion of Junior et al. [2010], silicon introduced into the root environment of plants absorbs aluminium hydroxides reducing their mobility; thereby, the chemical sorption of phosphates is reduced from 40 to 70 percent. Savant et al. [1999] think that the presence of silicon in the root environment of plants also reduces the risk of formation of insoluble iron and manganese phosphates. In analysing the results of the present study, one can note a trend towards a higher content of this element in the leaves and fruit of tomato fertigated with the silicon-enriched nutrient solution, but these results were not confirmed statistically. Tomato plants grown in sand were characterized by significantly the highest leaf phosphorus content compared to plants grown in other media (0.39% DW).

The results of most studies on plant fertilization with silicon demonstrate a significant decrease in calcium content in plants with an increasing concentration of orthosilicic acid in the root environment [Epstein 1994, Jarosz 2013]. This effect can result from binding of calcium by silicates both in the rhizosphere and in the plant structures [Ma and Takahashi 2002]. One of the theories indicates the possibility that calcium cations may be incorporated into the structure of the phytolith, thus reducing the detectable amount of this element in plants [Datnoff et al. 2001, Ma and Takahashi 2002]. The present study does not confirm this, since it did not show statistically proven differences in calcium content in tomato fruit and leaves depending on the factors studied. In the case of tomato, proper calcium nutrition of plants is very important, since a decrease in the content of this element in the fruit increases the risk of blossom-end rot (BER) [Nurzyński and Jarosz 2012].

CONCLUSIONS

1. Significantly higher total fruit yield in the treatments fertilized with the silicon-enriched nutrient solution were found in this study.
2. The total fruit yield of sand-grown tomato was lower compared to that of plants grown in rockwool.
3. The fruit of tomato grown in sand was shown to have a higher dry matter, total sugars and potassium compared to rockwool culture as well as significantly the highest amount of silicon.
4. The leaves of tomato fertilized with the silicon-enriched nutrient solution contained more silicon as well as less manganese and zinc compared to control plants.

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WPŁYW STOSOWANIA KRZEMU ORAZ RODZAJU PODŁOŻA NA PLONOWANIE I SKŁAD CHEMICZNY POMIDORA

Streszczenie. Żywienie roślin krzemem jest szczególnie uzasadnione w systemie bezglebowym, w którym korzenie roślin nie mogą korzystać z zasobów tego pierwiastka znajdującego się w glebie. Krzem to jedyny pierwiastek nieszkodzący roślinom przy nadmiernym pobraniu, a jego stosowanie w żywieniu poprawia plonowanie roślin oraz ich odporność na różnorodne czynniki stresowe. Efektywność stosowania krzemu w uprawie roślin jest ściśle uzależniona zarówno od źródła tego pierwiastka, jak i od uprawianego gatunku i odmiany. Celem badań było określenie wpływu dokorzeniowego stosowania krzemu koloidalnego oraz trzech podłoży o zróżnicowanej zawartości krzemionki i różnej zdolności uwalniania monomerów ortokrzemianowych (wełna mineralna, piasek, słoma) na plonowanie i skład chemiczny pomidora szklarniowego. Badania przeprowadzono w latach 2008–2009 w szklarni. Uprawę prowadzono w cyklu wydłużonym (22 grona) z wykorzystaniem kroplowego systemu nawożenia i nawadniania z zamkniętym obiegiem pożywki. W badaniach wykazano istotnie większy plon ogólny owoców fertygowanych pożywką wzbogaconą w krzem (15,98 kg·roślina^{-1}) w porównaniu z roślinami uprawianymi w obiektach kontrolnych. Nie stwierdzono istotnych różnic w plonie ogólnym i handlowym, jak również w średniej masie owoców z roślin uprawianych w wełnie mineralnej i w słomie. Plon ogólny pomidorów uprawianych w piasku był mniejszy w porównaniu z roślinami uprawianymi w wełnie mineralnej. W owocach pomidora uprawianego w piasku stwierdzono więcej suchej masy (5,52%), cukrów ogółem (2,58% św. m.) i potasu (4,19% s.m.) w porównaniu z wełną mineralną oraz istotnie najwięcej krzemu. Liście pomidora nawożonego pożywką wzbogaconą w krzem zawierały więcej krzemu oraz mniej manganu i cynku w porównaniu z roślinami kontrolnymi.

Słowa kluczowe: uprawy bezglebowe, wełna mineralna, piasek, słoma, sucha masa, witamina C, cukry, składniki pokarmowe

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