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Use of silicon in the production of tomato (*Lycopersicon esculentum* Mill.) grape type in nutritive solution cultivation

Uso de silicio en la producción de tomate (*Lycopersicon esculentum* Mill.) Tipo grape en cultivo en solución nutritiva

SANCHEZ-MONTEON, Ana Luisa†*, JUAREZ-ROSETE, Cecilia Rocío, ALEJO-SANTIAGO, Gelacio and ABURTO-GONZÁLEZ, Circe Aidín

Universidad Autónoma de Nayarit. Mexico.

ID 1st Author: *Ana Luisa, Sanchez-Monteon* / **ORC ID:** 0000-0003-3781-2400, **CVU CONAHCYT ID:** 44857

ID 1st Co-author: *Cecilia Rocío, Juarez-Rosete* / **ORC ID:** 0000-0001-6186-3940, **CVU CONAHCYT ID:** 44883

ID 2nd Co-author: *Gelacio, Alejo-Santiago* / **ORC ID:** 0000-0003-2441-9116, **CVU CONAHCYT ID:** 38370

ID 3rd Co-author: *Circe Aidín, Aburto-González* / **ORC ID:** 0000-0002-1941-8795, **CVU CONAHCYT ID:** 96657

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Abstract

The objective of the research was to evaluate the effect of silicon concentration and application method on growth and yield of grape tomato plants. An experiment was established under shade net conditions in solution culture. The factors evaluated were silicon concentration (0, 4, 6, 6, 8 and 10 g.L^{-1}) and application methods (to the nutrient solution and foliar). Nutrition was applied by irrigation of the universal nutrient solution (Steiner, 1984), at a concentration of 75%. The total number of treatments was 10. The design was completely randomized with four replications per treatment and based on the treatments, the following variables: plant height, root length, stem diameter, number of leaves, leaf area, fresh and dry weight of aerial and root biomass, number of fruits per plant, total yield and fruit diameter, length and weight. For the variables evaluated, it was identified that the concentration of 8 g.L^{-1} of SiO_2 applied to the root was the one that obtained the best value to favor vegetative growth and to obtain a greater fruit development for grape tomato plants of the Primarino variety.

Solutions, Silicon, Tomato

Resumen

El objetivo de la investigación fue evaluar el efecto de la concentración de silicio y el método de aplicación sobre el crecimiento y el rendimiento de las plantas de tomate uva. Se estableció un experimento bajo condiciones de malla sombra en cultivo en solución. Los factores evaluados fueron la concentración de silicio (0, 4, 6, 6, 8 y 10 g.L^{-1}) y los métodos de aplicación (a la solución nutritiva y foliar). La nutrición se aplicó mediante riego de la solución nutritiva universal (Steiner, 1984), a una concentración del 75%. El número total de tratamientos fue de 10. El diseño fue completamente al azar con cuatro repeticiones por tratamiento y con base en los tratamientos, las siguientes variables: altura de la planta, longitud de la raíz, diámetro del tallo, número de hojas, área foliar, peso fresco y seco de la biomasa aérea y radicular, número de frutos por planta, rendimiento total y diámetro, longitud y peso del fruto. Para las variables evaluadas, se identificó que la concentración de 8 g.L^{-1} de SiO_2 aplicada a la raíz fue la que obtuvo el mejor valor para favorecer el crecimiento vegetativo y obtener un mayor desarrollo de fruto para plantas de tomate uva de la variedad Primarino.

Soluciones, Silicio, Tomate

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* Correspondence to Author (E-mail: analuisasm8@yahoo.com.mx)
† Researcher contributing first author.

Introduction

Within the vegetable group, tomato (*Solanum lycopersicum* Mill.) is a very dynamic crop due to the growing demand of the population. In Mexico, it is the first vegetable produced under protected conditions. Tomato is a herbaceous plant species of the genus *Solanum* of the Solanaceae family and species *Lycopersicum esculentum* Mill; it is native to Central America and Mexico. Tomato is one of the most cultivated Solanaceae in the world and has a large number of wild species (Reche, 2010).

One of the main problems faced by this crop is the affectation of diseases, for which different alternatives have been sought, finding a solution with the application of silicon. Silicon can be applied to the nutrient solution in different forms, such as monosilicic acid, potassium silicate, calcium silicate or sodium silicate.

Pozza *et al.* (2015), documented that the effect of silica application reduces the occurrence of diseases in dicots such as strawberry, soybean, rose and tomato; this is important, especially on safety and organic production (Gunes *et al*., 2007). The application of silica has reduced the incidence in tomato of diseases caused by pathogens such as *Ralstonia solanacearum (*Diogo and Widra, 2007) and *Pythium aphanidermatum (*Heine *et al*., 2007). In addition, Urrestarazu *et al*. (2016) reported, in a histological study conducted on tomato, that silica application increased cuticle thickness in leaves and stems.

The role of silicon in plant metabolism is not entirely clear and its essentiality as a nutrient is not proven, but the multiple benefits of silicon fertilization, especially in soilless cultivation, where this element is less accessible to plants, make some authors such as Sonneveld and Straver (1994) consider it an element in the basic solution in some crops (Urrestarazu, 2015).

A wide range of benefits that silicon provides to plants and the great role that it acquires as a protector against biotic and abiotic stresses have been described, making its addition to the nutrient solution used quite recommendable, being a useful tool for the sustainable agriculture that is currently demanded (Urrestarazu *et al*., 2016).

The supply of silicon depends exclusively on its concentration in the irrigation water used for the preparation of the nutrient solution, so if its concentration is low in the irrigation water, we can add an extra addition of silicon to the nutrient solution (Pozo *et al*., 2015).

Therefore, the objective of the present work was to evaluate the effect of the concentration and method of silicon application on the growth and yield of grape tomato plants, under the following hypothesis: The concentration and method of silicon application differ in their effect on the growth and yield of grape tomato plants.

Methodology

The experiment was conducted in a hybrid greenhouse, with a maximum height of 4.0 m and covered with plastic with 35% shading and 35% shade netting, it has wires for load support and is located at the Academic Unit of Agriculture of the Autonomous University of Nayarit, with the following coordinates: Latitude of 21˚ 25′ 36" N, Longitude 104˚ 53′ 28" W and a height above sea level 922 m.

The plants used were obtained from seeds of grape tomato variety Primarino from Rijk Zwaan®.

The seeds were placed for germination and development in a 200-cavity polystyrene container. The substrate used was sunshine peat® for germination.

Transplanting at the experimental site was performed when the seedlings had two true leaves and were five cm high. A solution culture system was used, which consisted of unicel cups with a capacity of two liters. An oxygenation system was installed in each of the containers.

The factors to be evaluated were the concentration of silicon to be supplied and the methods of application (to the nutrient solution and foliar). Nutrition was applied by irrigation of the universal nutrient solution (Steiner, 1984), at a concentration of 75% of all its ions. In this case, the total number of treatments was 10 (Table 1).

Treatment	Description
1	Nutrient solution (root) + 0 g.L^{-1} SiO_2
2	Nutrient solution (root) + 4 g.L^{-1} SiO_2
3	Nutrient solution (root) + 6 g.L^{-1} SiO_2
4	Nutrient solution (root) + 8 g.L^{-1} SiO_2
5	Nutritive solution (root) + 10 g.L^{-1} SiO_2
6	Nutrient solution (foliar) + 0 g.L^{-1} SiO_2
7	Nutrient solution (foliar) + 4 g.L^{-1} SiO_2
8	Nutrient solution (foliar) + 6 g.L^{-1} SiO_2
9	Nutrient solution (foliar) + 8 g.L^{-1} SiO_2
10	Nutrient solution (foliar) + 10 g.L^{-1} SiO_2

Table 1 Description of treatments

The design was completely randomized, with four replicates per treatment. The experimental unit was a pot with one plant.

The nutrient solution was maintained at a pH range of 5.5 to 6.5 during the evaluation period and soluble fertilizers were used for its preparation. The nutrient solution was renewed every two weeks during the vegetative stage and every week during the flowering and production stage. Constant oxygenation was maintained by means of an air compressor. The nutrient solution lost by evapotranspiration was renewed every 48 hours. Insect and disease control was done with preventive applications. The plants were trained on a transverse wire for load support using hooks, rings and raffia for this purpose.

Morphological variables s evaluated

Plant height

Plant height was evaluated in centimeters on days 24, 31 and 38 after transplanting (ddt) from the substrate level using a flexometer graduated in cm.

Root length

This variable was measured on the last day of the experiment using a flexometer graduated in cm.

Stem diameter

This variable was measured in centimeters on the last day of the experiment with a Foy analog vernier®.

Number of leaves as

The number of leaves per plant was counted at the time the experiment was concluded.

Leaf area r

Leaf area in cm^2 was determined at the end of the experiment using a CID Biosciences model CI-202 Portable Laser Leaf Area Meter®.

Fresh and dry weight of aerial and root biomass

The aerial part of all plants was cut and the fresh weight of the aerial part and the fresh weight of the root were recorded with a digital balance (Ohaus® CS200, China). The material was dried in a forced air oven at 70 °C to constant weight to record the dry gram weight of the aerial part and the dry weight of the root.

Performance variables evaluated:

Number of fruits per plant

Fruits were counted during the evaluation period (3 weeks).

Total yield

The fruits harvested in each cut were weighed by treatment using a digital scale Joma Center® I-2000 (China).

Fruit diameter, length and weight

Fruit diameter was measured in cm with a Foy analog Vernier® . Fruit length was measured with a ruler graduated in cm. Fruit weight was recorded in grams using a digital scale Joma Center® model I-2000 (China).

Statistical analysis

Experimental data were analyzed under a factorial model with the statistical program SAS (2009) and means will be compared with Tukey's test (Steel and Torrie, 1960).

Results

The analysis of variance showed significance for the factor [Silicon] for the variables root length and leaf area. For the factor Method of application, it showed significant differences for the variables number of leaves and leaf area. And the interaction [Silicon] x application method only showed significant differences for the leaf area variable (Table 2).

Source of variation	G. L.	Root length (cm)	Stem diameter (mm)	Number of sheets	Leaf area $(cm)^2$
		Pr>F			
[Silicon]	4	0.0074 *	0.705	0.1021	<0.0001 *
Method of application	1	0.1769	0.3055	0.0493 *	<0.0001 *
[Silicon] x Method of application	4	0.554	0.559	0.1257	<0.0001 *
CME		15.31	0.023	1.788	24531.56
CV		16.18	14.79	14.35 *	12.54
C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences					

Table 2 Analysis of variance for morphological variables in grape tomato during the evaluated period

Plant height

During the different measurement dates, there were no differences in any of the different measurement dates (Table 3). These results differ from those reported by Borda *et al.* (2007) in the cultivation of forage oats (*Avena sativa* L.) where the contribution of silicon favored cell elongation, greater turgor and efficient conversion of assimilates. These three effects resulted in a greater increase in height and stem diameter.

SiO concentration$_2$ g.L^{-1}	24 ddt	31 ddt	38 ddt
0	68.875 a	99.625 a	124.750 a
4	72.875 a	105.625 a	131.875 a
6	64.875 a	98.375 a	128.625 a
8	68.938 a	104.250 a	132.000 a
10	64.750 a	91.959 a	121.959 a
Method of application			
Root	69.725 a	102.150 a	102.150 a
Foliar	66.400 a	97.784 a	97.784 a

Table 3 Mean values for height of grape tomato plants measured during the period evaluated. Means with different letters in each variable are significantly different (Tukey $P \leq 0.05$)

Root length

For the factor [Silicon], the one that obtained the highest value for root length was obtained with the treatment of 0 g.L^{-1} of silicon, while differences were found with the concentration of 10 g.L^{-1} where was reduced by 25.47 % with respect to the control. However, the treatments of 4 g.L^{-1}, 6 g.L^{-1} and 8 g.L^{-1} showed no significant difference with respect to the treatment of 0 g.L^{-1} (Table 4). This differs with the experiment of Villalón-Mendoza *et al.* (2018) in the cultivation of chile piquín (*Capsicum annuum* L. var. Glabriusculum) where fertilization with silicon at different concentrations did not obtain differences on root length.

Stem diameter

This variable did not show significant differences during the experiment. Contrary to the statements of Amador *et al.* (2013) where in sugarcane crops, the stems where silicon was applied showed a 14% thickening compared to the control. Quero (2008) mentions that, apart from grasses, silicon is often essential for crops such as tomato and cucumber, where he gives as an example the biological presence of silicon.

Number of leaves

The mean test showed no significant differences for the factor [Silicon] On the other hand, Bent (2008), affirms an increase in the number of leaves in cucumber (*Cucumis sativus*) due to the supply of silicon during the development of the crop.

For the application method factor, the highest number of leaves was obtained with root application, exceeding foliar application by 8.88%. Although no pest or disease damage occurred in the present work, Gómez-Camacho, *et al.* (2006) reported greater resistance in leaf tomato (*Physalis philadelphica*) plants to wilt caused by *Fusarium oxysporum*, where the plants were applied soluble silicon at 0.1 and 0.2%.

Leaf area

With the application of 8 g.L^{-1} of silicon via root, a greater leaf area was obtained with an increase of 39.67% with respect to the control, while the foliar application of 6 g.L^{-1} of silicon reduced the leaf area 35.42% with respect to the treatment of 0 g.L^{-1}. Therefore, if the leaf area is to be increased, the most appropriate treatments would be doses between 6 and 10 g.L^{-1} via root and 8 to 10 g.L^{-1} via foliar (Figure 1). The leaf area index provides information on the amount of photosynthetic surface present in relation to the total surface of the ecosystem or study area and is related to vital processes such as photosynthesis, respiration and productivity (Nafarrete, 2017).

The leaf area of plants changes once leaves reach maturity, after it has fully developed, the plant loses leaves because of ethylene synthesis and sensitivity to ethylene (Yepes & Buckeridge, 2011).

SiO$_2$ concentration g.l.$^{-1}$	Root length (cm)	Stem diameter (mm)	Number of sheets	Leaf area (cm)^2
0	25.7 a	1.07 a	9.12 a	1027.0 c
4	24,513 ab	1.05 a	10.25 a	1000.77 c
6	26.32 a	0.97 a	8.37a	1027.2 c
8	25.0 a	1.00 a	9.62 a	1763.77 a
10	19.2 b	1.02 a	9.20a	1423.04 b
Method of application				
Root	25.0 a	1.05 a	9.75 a	1363.34 a
Foliar	23.3 a	1.000a	8.8 b	1133.43 b

Table 4 Mean values of morphological variables in grape tomato plants by effect of silicon concentration and application method. Means with different letters in each variable are significantly different (Tukey P≤0.05)

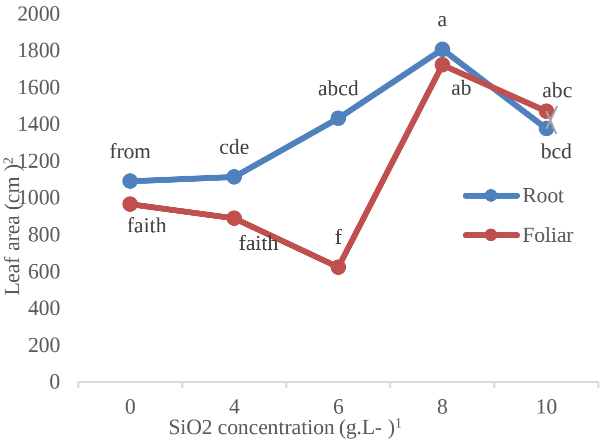

Figure 1. Interaction of different treatments and concentrations for leaf area

The analysis of variance showed no differences in any of the study variables for the factor [Silicon]. For the application method factor, there were significant differences for the variables of aerial biomass dry weight and root fresh and dry weight (Table 5).

Source of variation	G.L.	Fresh weight of aerial biomass (g)	Root fresh weight (g)	Dry weight of aerial biomass (g)	Root dry weight (g)
		Pr>F			
[Silicon]	4	0.5419	0.7444	0.7098	0.4539
Method of application	1	0.0802	<0.0001 *	0.0318 *	0.0016 *
[Silicon] x Method of application	4	0.2952	0.0913	0.0460 *	0.2524
CME		937.27	556.65	33.48	31.90
CV		19.57	23.48	20.19	37.19*

Table 5 Analysis of variance for fresh and dry weight of aerial and root biomass in grape tomato during the evaluated period. C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences

It was observed that the fresh weight of the root with the application of silicon via root had a weight gain of 32.41% compared to the foliar application. Similarly, in root dry weight, a weight increases of 33.90% was obtained with the application of silicon via the root as opposed to the foliar application.

For the variable of aerial biomass dry weight, the one that obtained the highest value was the silicon application to the root with 13.41% more weight compared to the foliar application (Table 6).

SiO concentration$_2$ g.L^{-1}	Fresh weight of aerial biomass (g)	Root fresh weight (g)	Dry weight of aerial biomass (g)	Root dry weight (g)
0	143.88 a	93.88 a	30.40 a	12.05 a
4	169.50 a	108.13 a	29.41 a	16.21 a
6	157.00 a	100.00 a	28.66a	16.16 a
8	160.38 a	104.25 a	28.42 a	16.87 a
10	151.42 a	96.08 a	26.35 a	14.62 a
Method of application				
Root	165.20 a	119.90 a	30.71 a	18.28 a
Foliar	147.66 a	81.03 b	26.59 b	12.08 b

Table 6 Mean values for fresh and dry weight of aerial and root biomass of grape tomato by effect of silicon concentration and application method . Means with different letters in each variable are significantly different (Tukey P≤0.05)

Performance variables

The analysis of variance showed significant differences for the factor [Silicon] in the fruit length variable. For the factor application method and the interaction [Silicon] x application method, no differences were found for any of the variables (Table 7).

Source of variation	G.L.	Number of fruits	Total yield (g)	Diameter (cm)	Length (cm)	Weight (g)
		Pr>F				
[Silicon]	4	0.9647	0.9951	0.7925	0.0087 *	0.4758
Method of application	1	0.5769	0.7705	0.0914	0.0781	0.2631
[Silicon] x Method of application	4	0.0441	0.0718	0.5475	0.1022	0.3327
CME		47.822	2499.6	0.0968	0.1770	1.5385
CV		22.611	27.003	21.508	18.659	25.509

Table 7 Analysis of variance for grape tomato fruit yield characteristics measured during the evaluated period. C.V.: Coefficient of variation Values with ¨*¨ in each variable show differences

Number of fruits per plant

The concentration of silicon and the method of application did not affect the number of fruits (Table 8). This differs with that reported by Quiroga (2016) in cucumber (*Cucumis sativus* L.) where foliar silicon supply presented higher number of fruits.

SiO concentration$_2$ g.L^{-1}	Number of fruits	Total yield (g)
0	30.500 a	187.51 a
4	30.000 a	182.58 a
6	32.125 a	179.51 a
8	29.750 a	187.24 a
10	30.541 a	188.90 a
Method of application		
Root	31.200 a	187.48 a
Foliar	29.967 a	182.82 a

Table 8 Mean values for grape tomato fruit yield . Means with different letters in each variable are significantly different (Tukey P≤0.05)

Total yield

This variable did not show significant differences for any of the three factors. Contrary to the results of Pinedo (2011) who found the highest values, supplying silicon in higher concentrations per hectare in the cucumber crop. In different crops, the benefits of silicon-based fertilizer applications for crop productivity and quality have been shown more clearly (Datnoff *et al.* 2001). Silicon helps to improve the efficiency of absorption of some elements such as phosphorus and calcium, where the latter mentioned, serves as a mediator with plant hormones, growth regulator and plant senescence, this favors better photosynthesis resulting in higher crop production and yield (Quiroga, 2016).

Fruit diameter, length and weight

It was observed that the treatment that obtained the best result in fruit length was the silicon treatment of 10 g.L^{-1} presenting a 27.23% greater length compared to the treatment of 4 g.L^{-1}, followed by a difference of 25.16% with the treatment of 0 g.L^{-1} ; where these were the lowest mean values. With this, it can be deduced that as the silicon intake is lower, the length values will decrease considerably. Likewise, with the treatments with 6 and 8 g.L^{-1} results similar to the other treatments were obtained. This effect was also observed by Pinedo (2011) in the cucumber crop where he obtained the highest values in quantity, diameter, length and weight, applying the highest concentration of silicon (Table 9).

SiO concentration$_2$ g.L^{-1}	Diameter (cm)	Length (cm)	Weight (g)
0	1.467 a	2.055 b	4.671 a
4	1.346 a	1.998 b	4.424 a
6	1.500 a	2,335 ab	4.913 a
8	1.401 a	2,140 ab	4.766 a
10	1.517 a	2.746 a	5.535 a
Method of application			
Root	1.532 a	2.376 a	5.086 a
Foliar	1.360 a	2.133 a	4.638 a

Table 9. Mean values for physical characteristics of grape tomato fruit. Means with different letters in each variable are significantly different (Tukey P≤0.05)

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Conclusions

For the grape tomato crop, Primarino variety, the best results for leaf area were obtained with a concentration of 8 g.L^{-1} of SiO_2.

The use of silicon supplied to the root favors the morphological variables of leaf number and leaf area. It also favors the fresh and dry weight of the root.

For the fruit length variable, better results were achieved with the concentration of 10 g.L^{-1} of SiO_2. This caused an increase in fruit length compared to the control. However, with the concentration of 8 and 6 g.L^{-1} of SiO_2 similar results were achieved.

Therefore, it is recommended to use the concentration of 8 g.L^{-1} of SiO_2 applied to the root since it was the one that obtained the best value to favor vegetative growth and this leads to obtain a greater fruit development for tomato plants grape variety Primarino.

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