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Silicate fertilization in semi-hydroponic strawberry cultivation

José Augusto Pereira Neto[1], Juvenal Rodrigues da Silva Júnior[2], Denis Antônio Rocha Júnior[3], Filipe Cogo Andrade[4], Luis Lessi dos Reis[5], Jonathan Ribeiro de Araújo[6]

[1] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais. Graduandos em Agronomia. joseaugustoap37@gmail.com.

[2] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais. Graduandos em Agronomia. juvenaljunior11@gmail.com.

[3] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais. Graduandos em Agronomia. denis.paly@gmail.com.

[4] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais. Graduandos em Agronomia. fhilipecogo@gmail.com.

[5] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais – IFSULDEMINAS – Campus Machado.Rodovia Machado-Paraguaçu, km 03 – Bairro Santo Antônio. Machado-MG, Brasil, Docente, luis.reis@ ifsuldeminas.edu.br.

[6] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais – IFSULDEMINAS – Campus Machado. Rodovia Machado-Paraguaçu, km 03 – Bairro Santo Antônio. Machado-MG, Brasil, Técnico em agropecuária, jonathan.araujo@ifsuldeminas.edu.br.

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Abstract

Strawberry-producing technologies are rapidly developing for the cultivation of small red fruits. The Southern Minas Gerais stands out in Brazil's production. In this context, the search for production improvements via nutrition and quality maintenance is indispensable for cultivation. This study aimed to evaluate how different silicon doses can influence the production and quality of strawberry fruits from national and imported seedlings. For the experiment, strawberry seedlings from the 'San Andreas' cultivar, of national and Chilean origins, were used. The plants were grown in a semi-hydroponic system and corresponding silicon doses (0, 500, 1000, 1500 and 3000 mg L^{-1}) were tested via foliar application. A split-plot design was used, in a 5×2 factorial scheme, with four replications and 10 plants per plot. By physical and physicochemical evaluations, alterations in the production and quality of the fruits were analyzed. The foliar application of silicon – to complement the strawberry nutrition – did not increase the productivity or quality of the fruits, regardless of the nationality of the seedlings. The only difference regarding origin was associated the vigor of plants.

Keywords: *Fragaria x ananassa*; substrate; nutrient solution; production; quality.

Introduction

Currently, strawberry (*Fragaria × ananassa*) is cultivated in various states of Brazil and is an economically expressive activity for small and medium producers. Minas Gerais stands out in the production of this fruit, as well as Rio Grande do Sul and São Paulo (PALOMBINI, 2022). The South region of Minas Gerais is responsible for about 95% of the strawberry production of the state, since it presents the favorable edaphoclimatic conditions (PEREIRA et al., 2015). Around 5,200 ha of strawberries are grown in Brazil and the total production reaches approximately 200,000 tons (ANTUNES et al., 2021).

The production, quality and post-harvest conservation of strawberries are highly influenced by biotic and abiotic factors, including propagative material and fertilization. The use of adapted and productive varieties, from seedlings of proven origin and physiologically suitable for cultivation, provides higher productivity, profitability and quality of fruits (BRANDT et al., 2022). National seedlings, however, hardly meet the certification standard, limiting strawberry production and forcing Brazilian producers to import seedlings, mainly from Chile, Argentina, and Spain (CAMPO and NEGÓCIOS, 2022).

One of the mineral elements that has aroused interest in researchers is silicon (Si), used in fertilization due to the benefits it promotes to various agricultural crops. This element is the second most abundant in the Earth's crust and a constituent of several soil minerals (MARAFON, 2013). The soluble form of this nutrient, found in the soil, can come from the decomposition of residues, application of silicate fertilizers, or even the transformation of composts. Absorbed by vegetables in the form of mono-silicic acid, soluble silicon can be lost through the polymerization of silicic acid, leaching, and adsorption on iron (Fe) and aluminum (Al) oxides and hydroxides (PEREIRA et al., 2021). Therefore, for most cultivated plants, including the strawberry, Si is considered a beneficial element, but studies with vegetables are little known and the benefits arising from Si are in the structural and defense functions of plants (PEREIRA et al., 2021).

It is postulated that Si interferes in the architecture of plants and favors photosynthesis by providing them more erect leaves with greater photosynthetic efficiency and accumulating itself below the cuticle, thus constituting a protective barrier against fungal infections and excessive water loss (SIVANESAN and PARK, 2014). These aspects are important, given that strawberries demand pesticides to control pests and diseases (increasing production costs and environmental and human health risks) and considering the short shelf life of the harvested fruits. The post-harvest losses in strawberry fruits range from 25 to 50%: a high perishability degree and a reduced shelf life (one week) are characteristic of these fruits (TURQUETT et al., 2021).

Thus, it was hypothesized that the Si supply would increase strawberry production and quality. The possible interference of the origin of the seedlings in their response to these parameters was investigated by cultivating national and imported seedlings in a semi-hydroponic system, testing the best dose of Si with foliar application. This study aimed to evaluate how different silicon doses can influence the production and quality of strawberry fruits from Brazilian and Chilean seedlings.

Material and methods

The experiment was developed at the Federal Institute of Education, Science, and Technology of the South of Minas Gerais – Machado Campus, at coordinates 21° 41’ 57.09” S and 45° 53’ 11.01” W and 907 m above sea level. According to the Köppen classification, the climate of the region is Cfa, and its annual rainfall rate is 1,590 mm. The experiment was conducted in an arched-frame greenhouse that was 27 m long, 6 m wide, had a 3.5 m high ceiling, and was closed on the sides with a 50% shading screen.

In the experiment, *Fragaria* × *ananassa* seedlings of various origins from the ‘San Andreas’ cultivar were used. The national seedlings were provided by a private nursery from the city of Bom Repouso - MG, while the Chilean seedlings were produced by the Agrícola Llahuen S.A. exporter and imported by Bioagro Comercial Agropecuária Ltda, based in the municipality of Araucária-PR.

For the semi-hydroponic system, the seedlings were transplanted to V-shaped gutters, to be cultivated with an inert substrate. The rooted national and imported seedlings were transplanted to the gutters with a substrate based on *Sphagnum* peat - Pindstrup®. The substrate has a particle size of 20–40 mm, 5.5 pH, 0.3 mS cm^{-1} CE, 400% CRA, and 1.05 kg m^{-3} density.

Spacings of 0.15 m and 1.5 m were set between plants and between channels, respectively. Each plant had 3.5 L of substrate for full root development. For the mineral nutrition of the plants, a fertigation system with Venturi injections and automatic controllers was used. For nutritional monitoring, electrical conductivity (EC) and hydrogen potential (pH) was read using drain collectors and substrate solution extractors throughout the cultivation system.

For the experiment, a split-plot design was used in a band, with four replications, in a 5×2 factorial scheme (five corresponds to the silicon doses [0, 500, 1000, 1500, and 3000 mg L^{-1}], via foliar application, and two corresponds to the seedling types [Brazilian and

Chilean]). Each plot consisted of 10 strawberries. Silicon were applied on the leaves 30 days after transplantation, with a sprayer pressurized with CO_2 with a Teejet anti-tarnish fan tip DG11005-VS and 400 L ha^{-1} syrup volume, at a constant pressure of 2 kgf cm^{-2} The silicon source used was potassium silicate – Sifol® (12% Si) and (15% K). Other crop treatments, aiming at the minimum use of pesticides, were employed, in accordance with the current production of strawberry fruits. A field notebook based on the Integrated Production of Strawberry - PIMO was also used.

For the evaluations of the fruits, the commercial standard was adopted, that is, when 75% of red color was found in fruits. The following variables were evaluated in the fruits: longitudinal diameter (LD, cm); transverse diameter (TD, cm); average mass (AFM, g plant^{-1}) and yield (Y, kg 1000 plant^{-1}). The fruits were harvested twice per week, counted and weighed. Fruits with a mass greater than 10 g were considered commercial and fruits with a lower mass were not.

At the end of the production cycle of the experiment, all fruits and masses recorded were added together to determine the production per plant. To assess the quality of the fruits, the following variables were evaluated: titratable acidity (TA), soluble solids content (SS), potential of hydrogen (pH) and Ratio (SS/TA). All the data obtained were subjected to the F test in the analysis of variance. When significant, the types of seedlings were compared using the Tukey's test ($p<0.05$).

Table 1. Mean data for biometric characteristics: longitudinal diameter (LD), transverse diameter (TD), average fruit mass (AFM) and yield (Y) of strawberry plants subjected to silicate fertilization. Machado, MG, 2023.

Source of variation	LD	TD	AFM	Y
	(cm)		(g)	kg (1,000 plants)
Origin of seedlings				
National	2.82 a	3.51 a	13.56 a	233.82 b
Imported	2.80 a	3.68 a	14.19 a	383.31 a
Silicon Doses mg L^{-1}				
0	2.82	3.52	13.95	324.98
500	2.83	3.54	13.92	318.11
1,000	2.82	3.56	13.89	311.29
1,500	2.80	3.59	13.86	304.47
3,000	2.76	3.66	13.77	284.02
F Test				
Origin of seedlings (OS)	0.16 ^{ns}	2.45 ^{ns}	0.80 ^{ns}	26.47*
Silicon Doses (S)	1.35 ^{ns}	0.01 ^{ns}	0.15 ^{ns}	0.46 ^{ns}
Repetition	0.59 ^{ns}	0.82 ^{ns}	0.73 ^{ns}	0.83 ^{ns}
OS x S	1.04 ^{ns}	0.87 ^{ns}	0.94 ^{ns}	1.21 ^{ns}
CV 1 (%)	5.85	6.76	15.90	29.78
CV 2 (%)	5.49	6.17	11.49	24.31
Overall mean	2.81	3.57	13.88	308.57

[1]Means followed by distinct letters in the columns differ from each other by Tukey's test at a 5% probability level. NS = not significant; *significant at a 5% probability level.

Results and discussion

Based on Table 1, it can be observed that the spraying of silicon concentrations in strawberries from the 'San Andreas' cultivar did not significantly alter their physical characteristics, regardless of the origin. This fact corroborates the results presented by Munaretto et al. (2018), in which the application of foliar silicon did not increase productivity of the Aromas and Albion cultivars, not altering the number of fruits and average fruit mass.

For the individualized study on the origin of the seedlings, significant means were observed at $p<0.05$ for the fruit yield characteristic. Chilean strawberry seedlings from the 'San Andreas' cultivar had the best average, 383.31 kg, while Brazilian ones had an average yield of 233.82 kg. Thus, Chilean seedlings obtained 63.9% higher productivity when compared to the national seedlings, which is a significant difference. In an experiment developed in São Lourenço, strawberry seedlings of national and imported origins were grown, and it was found that imported seedlings had fruit productivity per plant 66% higher than national seedlings (MARCHI et al., 2014).

Because our study used a day-neutral cultivar (insensitive to photoperiodic stimuli), it can be inferred that, during the evaluated period, the photoperiodic condition did not directly affect the vigor of the plants. However, the initial vigor of the seedlings and the physiological state of the rosette of the Chilean seedlings were superior to those of the seedlings acquired in the Bom Repouso municipality (MG). This difference in the vigor of the seedlings can be explained by their production models: Brazilian seedlings were produced in the soil and Chilean seedlings were produced in substrate, exposed to temperatures below 10°C. Then, this aspect explains the gain in productivity observed in the initial production period of this experiment: the higher vigor of the imported seedlings is related to their exposure to the cold, which provided them with natural vernalization.

In Minas Gerais, strawberry productivity is limited by the lack of cultivars adapted to climate and soil conditions and by the low physiological and phytosanitary quality of the seedlings. These limitations forces producers to import seedlings from countries such as Chile, where the seedlings are exposed to high latitudes, low precipitation, summers with mild average temperatures and significantly colder nights, sandy soils, and abundant solar radiation. Thus, the seedlings are naturally exposed to vernalization, that is, exposure to temperatures below 10°C for about 30 days.

These characteristics produces seedlings of high genetic, phytosanitary, and physiological quality, factors that give them high productive potential, directly influencing the accumulation of dry matter in the crown, roots, leaves and stolons, increasing the amount of reserve substances (DIEL et al., 2017).

In another experiment, Diel et al. (2017), found that the vernalization of seedlings resulted in higher productivity per plant: plants that underwent vernalization produced 1,007.50 g of fruits, while those that did not only produced 774.16 g. The authors attributed this increase to the greater vegetative development of plants, which consequently increased energy storing for fruit production (MASSA et al., 2015).

Several studies have shown and proven the efficiency of silicon absorption and this response is directly related to the genetic characteristics of plants. Several studies separated different cultivars as responsive and non-responsive to fertilization. The different response of each cultivar to the nutrient and to the form in which it is applied is evidenced by the fact that the Aromas cultivar had higher production when under silicon application, whereas the San Andreas did not (AGÜERO, KIRSCHBAUM, 2013).

All physicochemical analyses were performed considering the two seedlings, that is, the national and the Chilean ones. According to the biometric characteristics analyzed (Table 2), the foliar application of silicon, in any concentration, did not provide any benefit to the fruits regarding physicochemical aspects (pH, BRIX°, titratable acidity, and ratio). These data are in line with the experiment conducted by WURZ et al. (2020), in which Si also presented no benefit nor harm to the fruits.

However, for the pH variable, significant differences in means were observed at $p<0.05$. The Chilean seedlings from the 'San Andreas' cultivar had a 3.14 pH while the national ones had 3.23. These values are similar to those found by MUSA (2016). This attribute is important, because fruit intended for the industry should have a more acidic pH, while for *in natura* consumption, the low-acid pH is more acceptable and pleases the consumer's palate. The acid balance is highly important to the fruit and, combined with sugars, has an impact on its sensory quality (GUNDUZ, OZDEMIR, 2014).

Based on these results, both physical and physicochemical characteristics of the fruits suggested that Si absorption did not increase the efficiency of the 'San Andreas' cultivar under the conditions of the experiment. Nevertheless, the effect of silicon is very controversial: the literature has reached no consensus on it. This may be related to regional influences. AGÜERO, KIRSCHBAUM (2013), for example, evaluated the foliar application of silicon and obtained

Table 2. Mean values for physicochemical characteristics of the fruits of strawberry plants submitted to silicate fertilization, including the titratable acidity (ACIDITY), soluble solids (BRIX°), potential of hydrogen (pH), soluble solids, and titratable acidity ratio (Ratio SS/TA). Machado, MG — 2023.

Source of variation	Biometric characteristics			
	ACIDITY	BRIX°	pH	Ratio
	(g mol^{-1})	(degree)	(0 to 14)	(SS/TA)
Origin of seedlings				
National	1.03 a	3.34 a	3.23 b	3.19 a
Imported	1.02 a	3.26 a	3.14 a	3.24 a
Silicon Doses (mg L^{-1})				
0	0.99	3.34	3.19	3.37
500	1.10	3.23	3.19	2.93
1,000	1.00	3.26	3.18	3.22
1,500	1.01	3.43	3.17	3.41
3,000	1.03	3.25	3.19	3.14
F Test				
Origin of seedlings (OS)	0.93 ^{ns}	0.09 ^{ns}	27.34 *	0.07 ^{ns}
Repetition	0.58 ^{ns}	1.35 ^{ns}	2.07 ^{ns}	2.16 ^{ns}
Silicon Doses (S)	2.56 ^{ns}	0.31 ^{ns}	0.97 ^{ns}	1.76 ^{ns}
OS x S	1.55 ^{ns}	0.43 ^{ns}	1.03 ^{ns}	0.07 ^{ns}
CV 1 (%)	8.57	26.67	1.70	18.97
CV 2 (%)	7.57	12.49	1.11	12.91
Overall mean	1.02	3.30	3.18	3.22

[1]Means followed by distinct letters differ from each other by Tukey's test at a 5% probability level. NS = not significant; *significant at a 5% probability level.

positive results for fruit production. On the other hand, MUNARETTO et al. (2018) found no positive increase in quality or productivity after implementing foliar Si application.

Conclusions

The application of silicon did not increase strawberry production in the first 12 months and did not alter the physical and physicochemical characteristics of the fruits.

During experimental period, the Chilean strawberry seedlings from the San Andreas cultivar increased the production by 63.9%, compared to the national seedlings.

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