Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online

PRODUCTIVITY OF TOMATO HYBRIDS DUE TO THE APPLICATION OF CALCIUM SILICATE

Pablo Wenderson Ribeiro Coutinho[1*], Márcia de Moraes Echer[2], Vandeir Francisco Guimarães[2], Maria do Carmo Lana[2], Thatiane Nepomuceno Alves[3], Adriano Mitio Inagaki[4]

SAP 24204 Received: 05/02/2020 Accepted: 15/06/2020
Sci. Agrar. Paraná, Marechal Cândido Rondon, v. 19, n. 3, jul./sep., p. 243-251, 2020

ABSTRACT - Silicon is a beneficial nutrient for the growth and production of many plant species, including tomatoes. The objective was to evaluate the influence of calcium silicate on the morphophysiological characteristics of tomatoes and the absorption of silicon, calcium, and magnesium. The experiment was conducted in a protected environment from August to December 2017, in a random block design, in a 2 x 5 factor scheme, with four repetitions. The first factor consisted of two hybrids (Ivety and Natalia) and the second factor by doses of calcium silicate (0, 150, 300, 450 and 600 kg ha^{-1}). The fruits were evaluated for number of fruits per plant, longitudinal and transversal diameter, average fruit mass, commercial, non-commercial, and total productivity. The plants were evaluated for number of leaves, stem diameter, plant length, leaf area, membrane integrity damage, lignin content, stem and leaves dry mass, silicon accumulation and content, calcium, and magnesium contents in the leaves and in tomato fruits. The morphometric characteristics of Ivety and Natalia tomato hybrids were not altered by increasing doses of calcium silicate. The increased doses of calcium silicate influenced the non-commercial productivity of the tomato fruits, showing a reduction of this with the increased doses. Calcium silicate influenced differently in each hybrid, and it is worth noting that these results may vary in terms of genetic material and cultivation environment.
Keywords: Protected cultivation environment, hybrids, nutrition, silicon, *Solanum lycopersicum* L.

PRODUTIVIDADE DE HÍBRIDOS DE TOMATEIRO EM FUNÇÃO DA APLICAÇÃO DE SILICATO DE CÁLCIO

RESUMO - O silício é um nutriente benéfico para o crescimento e produção de muitas espécies vegetais, incluindo o tomateiro. Objetivou-se avaliar a influência do silicato de cálcio nas características morfofisiológicas do tomateiro e a absorção de silício, cálcio e magnésio. O experimento foi conduzido em ambiente protegido de agosto a dezembro de 2017, em delineamento de blocos ao acaso, em esquema fatorial 2 x 5, com quatro repetições, sendo o primeiro fator constituído de dois híbridos (Ivety e Natália) e o segundo fator por doses de silicato de cálcio (0, 150, 300, 450 e 600 kg ha^{-1}). Os frutos foram avaliados quanto número de frutos por planta, diâmetro longitudinal e transversal, massa média do fruto, produtividade comercial, não comercial e total. As plantas foram avaliadas quanto ao número de folhas, diâmetro do caule, comprimento da planta, área foliar, dano da integridade de membrana, teor de lignina, massa seca do caule e folhas, o acúmulo e o teor de silício, cálcio e magnésio nas folhas e os teores nos frutos de tomate. As características morfométricas dos híbridos de tomateiro Ivety e Natália não foram alteradas pelas doses crescentes de silicato de cálcio. O aumento das doses de silicato de cálcio influenciou na produtividade não comercial dos frutos de tomate, apresentando uma redução desta com o aumento das doses. O silicato de cálcio influenciou de forma diferenciada em cada híbrido, valendo salientar que esses resultados podem variar quanto ao material genético e ao ambiente de cultivo.
Palavras-chave: Cultivo protegido, híbridos, nutrição, silício, *Solanum lycopersicum* L.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is considered a vegetable of great economic importance, for being one of the main vegetables in volume that is consumed *in natura* in the world. Brazil contributed with an average production of 2.21 million tons per year (CAMARGO FILHO; CAMARGO, 2017).

The product offer has a wide range, being available in various locations and times of year. However, in seasons such as spring-summer in the center-south, it is considered a challenge to grow tomatoes due to high temperature conditions, high incident radiation and water availability. These are some of the elements that combined with calcium deficiency, are directly related to one of the main physiological anomalies of tomatoes which is apical rot. Such physiological disorder is caused by low calcium pectate and phosphate deposition in fruits, which can cause necrotic tissue with cracks and coloring going from light brown to dark (FONTES, 2003).

[1]Eng. Agrônomo, Capitão Poço, Pará, Brasil. E-mail: pablowenderson@hotmail.com. *Corresponding Author.
[2]Universidade Estadual do Oeste do Paraná (Unioeste), Marechal Cândido Rondon, Paraná, Brasil.
[3]Universidade Estadual de São Paulo (UNESP), Botucatu, São Paulo, Brasil.
[4]Corteva Agriscience, Palmas, Tocantins, Brasil.

The breeding program of this culture aims at offering products at different times of year with lower production. Thus, the long-life tomatoes marketed in Brazil are of the structural type and those with the genes *rin, nor* or *alc* are specific alleles that delay the fruits ripening, due to its characteristic of greater post-harvest conservation (PEREIRA et al., 2012).

To improve the productivity, quality and appearance of the fruit, the adoption and improvement of appropriate fertilization techniques stands out, highlighting the silicate fertilization that aims mainly to reduce phytosanitary problems (MENDES et al., 2011) and at the post-harvest conservation (MARODIN et al., 2016).

Silicon (Si) is considered a beneficial element, because although it does not act directly in the main metabolic pathways of the plant, when present it can provide greater tolerance to biotic and abiotic stresses (RODRIGUES et al., 2011). Causing a series of biochemical and structural changes in the cell wall, with possibilities of increasing the hemicellulose and lignin contents, and increase in cell stiffness. The amount of silicon absorbed by plant species is related to the root system, where the contents can vary from 0,1 to 10% in the root dry mass (CAMARGO, 2016).

Plants are classified as accumulators, non-accumulators and intermediate, with grasses in general being said to be accumulators (KORNDÖRFER et al., 2010). Non-accumulators are characterized by low content in tissues, even with high levels of silicon. Intermediates are those in which plants absorb an intermediate quantity of silicon, in a medium with high doses, generally cucurbits (LANA et al., 2003).

The use of silicon in horticulture has been providing important benefits for plants such as resistance against pests and diseases, as well as improving and increasing the post-harvest quality, mainly as a result of the formation of a double layer in the cuticle of the cell wall, which can reduce water loss, decrease the transpiration flow and increase the storage period of vegetables (MARODIN et al., 2014; NETO et al., 2020). Fertilization with silicon also influences the architecture of the plant, increasing the exposure of the leaves to light and thus favoring photosynthesis (SIDDIQUI et al., 2018).

According to a study on tomatoes by Marodin et al. (2014), they found a reduction in the number of non-commercial fruits and increased productivity. Besides being associated with increased antioxidant defense capacity against water deficit (NUNES et al., 2019) and plants under saline stress (RODRIGUES et al., 2018).

The use of calcium silicate is an alternative in the nutritional management of tomatoes, seeking better quality products, higher productivity rates and lower production costs. In this sense, this work aimed to evaluate the influence of calcium silicate on the morphophysiological characteristics of tomatoes and the absorption of silicon, calcium, and magnesium.

MATERIAL AND METHODS

The experiment was conducted from August to December 2017 in a protected environment at the Protected Crop and Biological Control Station "Professor Dr. Mário César Lopes", belonging to the Universidade Estadual do Oeste do Paraná (Unioeste), Marechal Cândido Rondon *Campus* (Paraná State). The geographical coordinates of the site are 24º 46' S and 54º 22' W and average altitude of 420 m. According to Köppen's classification, the region's climate is Cfa type, subtropical humid mesothermal of dry winter, with well distributed rains throughout the year and hot summers (ALVARES et al., 2013).

The crop was installed under a galvanized iron structure with an arch-shaped ceiling of 7 x 30 m and 3.5 m in height, with a ceiling covered with low-density polyethylene film of 150 μm, with 80% transmissivity to solar radiation and sides closed with white screen of 40% shading. To record data on air temperature and relative humidity at each hour of the day a HOMIS datalogger model 494 was installed, which was placed in a weather shelter positioned at a height of 1.20 m from the ground, in the center of the protected environment.

The experimental design adopted was random of blocks, in a 2 x 5 factorial scheme, with four replicates, the factors consisted of two tomato hybrids from the salad group (Ivety and Natalia) and five doses of calcium silicate (0, 150, 300, 450 and 600 kg ha^{-1}). The tomato hybrids have undetermined growth habits with an average fruit mass between 220 and 230 g. The hybrid Natalia presents a "long life" characteristic with the *rin* gene, possessing a longer post-harvest life, causing the occurrence of the reduction of the ripening process and consequently the degradation of the fruit cell wall. The Ivety hybrid does not have this gene in its genetic constitution.

Calcium silicate doses were applied when the pots were filled with a mixture of commercial plant substrate and vermicompost in a 1:1 ratio. Calcium silicate has 20% silicon and 29% calcium in its composition. The 12 dm³ pots were arranged at 1,20 x 0.50 m spacing, using one plate per vessel to avoid the loss of nutrients by leaching. Each experimental plot was composed of four pots, arranged in a single row. The mixture of commercial and vermicompost substrate showed the following chemical characterization: P = 468.23 mg dm^{-3}, K = 2.19 $cmol_c$ dm^{-3}, Ca^{2+} = 13.72 $cmol_c$ dm^{-3}, Mg^{2+} = 4.40 $cmol_c$ dm^{-3}, Cu = 1.40 mg dm^{-3}, Zn = 44 mg dm^{-3}, Mn = 136.58 mg dm^{-3}, Fe = 91.10 mg dm^{-3}, OM = 51.95 g dm^{-3} and pH = 6.6. The plants were vertically conducted in a single stem, using plastic ribbons up to approximately 1,90 m from the pot. During the whole cycle, sprouting was performed in order to keep one single stem per plant and all were kept with six bunches, performing the removal of the apical bud after the third leaf above the sixth bunch.

Irrigation was done by drip irrigation four times a day according to the needs of the crop, that was evaluated with a tensiometer placed in all four blocks, applying around 1 to 2.5 L of water per day, keeping the humidity of the substrate above 80%, using flexible tape with flow rate of 1.6 L h^{-1} and emitters spaced at 0.50 m.

Fertilization was performed via fertirrigation, being applied a total of 3084 g of monoammonium phosphate (MAP), 3900 g of magnesium sulphate ($MgSO_4$), 1824 g of potassium nitrate (KNO_3), 8148 g of potassium sulphate (K_2SO_4), 7008 g of calcium nitrate [$Ca(NO_3)_2$] and 876 g of boric acid (H_3BO_3), being also applied during the cycle 320 g of Biomix® micronutrients (Mg 3,8%, S 12%, B 5%, Cu 0,5%, Fe 0,1%, Mn 7%, Mo 0,1%, Zn 7%).

The volume of the solution prepared for fertirrigation was 20 L per application, with 45 applications, where 27 were in the vegetative phase, full bloom and start of fruiting, applying in this initial phase a percentage between 50-60% of the total amount of macro and micronutrients. In full fruiting the first and second bunch were already being harvested and the rest of the fertilization corresponding to 40-50% of the macro and micronutrients were applied, with the fertirrigation being performed until one week before the last harvest.

For the control of whitefly (*Bemisia tabaci* biotype B) and tomato moth (*Tuta absoluta*) an application of the product Connect®, insecticide belonging to the chemical group, and another of DIPEL biological insecticide. These applications occurred at 15 and 44 DAT, following the recommendations for the crop. For the preventive control of diseases, Bordeaux mixture was applied at 20 DAT.

The evaluations of the characteristics were performed at 70 days after the transplant (DAT), and the fruits were harvested when they had 90% of their surface red. After being harvested, the fruits per plant were counted, and later they were classified as commercial and non-commercial, being considered non-commercial the fruits with a diameter of less than 50 mm and with the presence of defects such as anomalies and cracks due to the presence of deformation in the fruit. Then the average mass of the fruit (g), transverse and longitudinal diameter of the fruit (mm) were evaluated, measured by weighing on a precision scale and by a digital caliper, respectively. The commercial, non-commercial and total productivity was estimated from the mass of the fruit, expressed in kg m^{-2}.

At the end of the crop cycle, the number of leaves of the plant was counted and the stem diameter measured by means of a digital caliper - measured at the base, height of the plant, with the help of a graduated trine. The leaves dry mass (LDM) and stem (SDM) was determined at the end of the crop cycle and the leaf area (LA) was determined by means of the Li-cor Area Meter device, model LI 3100C.

After the SDM was determined, the lignin content was determined, following the methodology proposed by Van Soest (1994). The membrane integrity damage was carried when the plant was in full bloom, from the removal of 10 discs of 10 mm diameter of young leaves, from each plant, following the methodology proposed by Lutts et al. (1996). The contents of Si, calcium (Ca) and magnesium (Mg) were determined in samples of two ripe fruits and eight leaves with petioles per plot, being removed from the tomato between the second and third bunch during flowering.

The samples were dried until they reached a constant mass, in a forced air circulation oven and after drying they were ground. The Si content in leaves and fruits was determined using the methodology described by Korndörfer et al. (2004), with values expressed in g kg^{-1} of dry mass. Ca and Mg were determined according to the methodology described by Malavolta et al. (1997), with values expressed in g kg^{-1} of dry mass. The Si, Ca and Mg contents were calculated with the data of dry mass of leaves and fruits. The experimental data were submitted to the Shapiro-Wilk normality test ($p \leq 0,05$). Then, variance and regression analysis were performed ($p \leq 0,05$), using the statistical software Sisvar (FERREIRA, 2014).

RESULTS AND DISCUSSION

The data of temperature, relative air humidity and radiation throughout the conduction period of the experiment are presented in Figure 1. The average temperature varied between 23 to 29ºC, relative humidity between 45,43 to 81.70% and solar radiation between 8,88 to 21.13 MJ m^{-2} day^{-1}. For each hybrid and phase of the tomato cycle there is an ideal temperature, so the climatic elements are within the recommended range. Although high temperatures have occurred in some days, this has not affected physiologically the Ivety hybrid, which unlike Natalia does not present the *rin* gene, because the hybrids that present this gene are an alternative for production in regions with higher temperatures, due to the wide adaptability and high stability of these hybrids (PEREIRA et al., 2012).

Satisfactory tomato production depends on the joint action of both intrinsic and extrinsic factors. Intrinsic factors can be mitigated by use of genetic improvements, such as the use of improved hybrids, while extrinsic factors depend on the management activities adopted, such as the use of mineral fertilizers, because the mineral elements influence the biochemical and physiological processes of plants and fruits.

The solar radiation from the inside of the protected environment is reduced in relation to the outside environment, and the covering material had 80% of transmissivity to solar radiation. The phenological and productive results of the experiment in protected environment only happen when the radiation level inside the environment is approximately 8.40 MJ m^{-2} day^{-1}, because lower quantities reduce the production of photoassimilates for the maintenance and development of the plant, and lower radiation can occur caused by days with cloudiness or even due to the time of use of plastic that can reduce transmissivity (BECKMANN et al., 2006). The luminous intensity inside the protected environment, was guaranteed, presenting superior results in some moments.

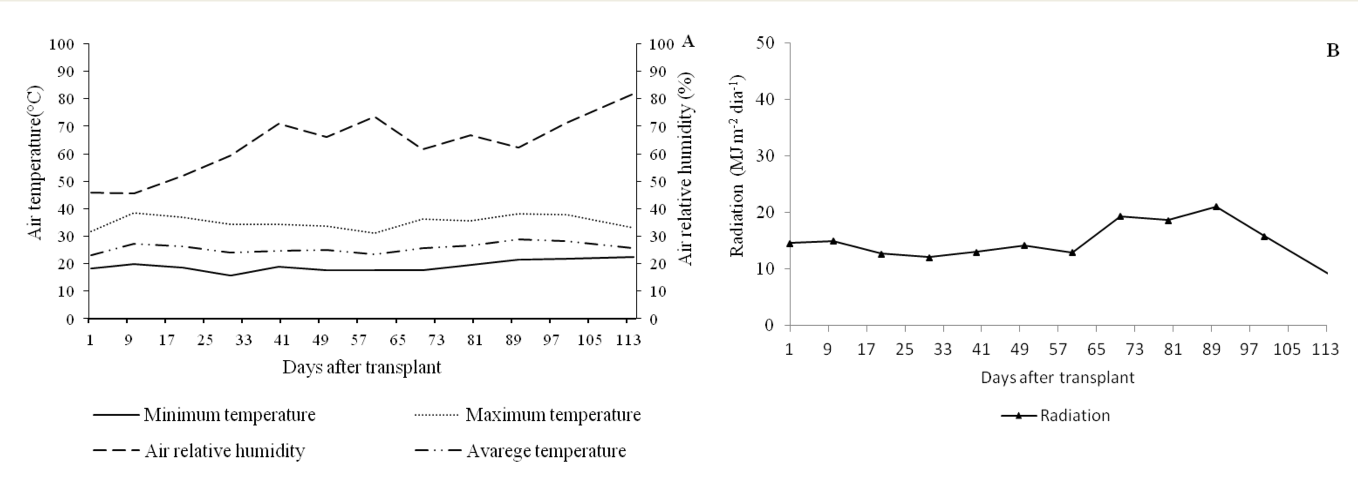

FIGURE 1 - Average, minimum and maximum values of air temperature, average relative humidity per day (A) and solar radiation (B), during tomato cultivation in a protected environment.

For the characteristics of the fruits there was no interaction between the hybrids and doses of calcium silicate, so they were evaluated alone. Differences between the hybrids were observed for the characteristics number of fruits per plant (NFP), transversal diameter of the fruit (TDF), average mass of the fruit (AMF), non-commercial productivity (NCP) and total (TP) of tomato fruits (Table 1).

TABLE 1 - Number of fruits per plant (NFP), transversal diameter of the fruit (TDF), longitudinal diameter of the fruit (LDF), average mass of fruits (AMF), productivity of normal fruits (NP), productivity of non-commercial fruits (PNC) and total productivity of fruits (TP), depending on the two hybrids of tomato.

Tomato hybrids	NFP	TDF (mm)	LDF (mm)	AMF (g)	NP (kg m^{-2})	PNC (kg m^{-2})	TP (kg m^{-2})
Ivety	30.88 b*	64.02 a	52.99	157.97 a	13.11	3.36 b	16.46 b
Natália	40.93 a	60.43 b	53.14	143.37 b	13.42	5.28 a	18.29 a
CV (%)	8.74	2.18	2.21	4.85	16.78	27.48	13.15

*Significant at 5% probability of error by F test.

The NFP feature showed a difference only between hybrids, where Natalia stood out from Ivety. However, there was less AMF per plant, increasing the competition for photoassimilates among the main drains which are the fruits for the Natalia hybrid. The increase in the number of fruits per plant caused an increase in the PNC of this hybrid, propitiating the growth and uneven development of several fruits out of pattern, and with the presence of cracks.

It was also observed a reduction of AMF per plant, according to the information obtained from the Ivety and Natalia hybrids company, has around 220 to 230 g, respectively. This reduction is probably due to the difference of NFP, showing that the fruits development is a powerful drain of carbohydrates, which can be observed in ‘Ivety’, which presented lower NFP and higher AMF which should present lower mass than 'Natalia', according to company's data. The TP of the crop was superior in the Natalia hybrid, due to the yield of the crop being determined by NFP, modifying the weight, size and quality of the commercial fruits.

The non-commercial productivity and the transversal diameter of tomato fruits were influenced by calcium silicate doses (Figure 2). The increase in calcium silicate doses promoted a reduction in the productivity of non-commercial tomato fruits (Figure 2A). This is due to the constitution of the cell wall, which plays an important role in the formation of cross bridges between the pectic substances, reducing the occurrence of cracked fruits and out the commercial standards.

The small cracks that may appear in the fruit, occur in the ripening process, in which the enzymes are released by the cell wall in different forms and at different times, where the pectic substances and other components act on the cell wall structure, thus reducing the elasticity of the cell wall due to the pressure of the solutes and water from the fruit inoculum (ILIC et al., 2018). The deposition of silicon on the cell wall reduces fruit cracking, according to Marodin et al. (2014), who studied sources of silicon in tomato crops, verified this reduction on non-commercial fruits with the increase of the dose, obtaining the best response in the dose 505 kg ha^{-1} of SiO_2. The increase of calcium silicate doses in this crop helped the ripening process of the fruits, reducing the PNC of the fruits with the increase of doses.

The ‘Ivety’ hybrid presented higher TDF, and no difference was observed between the hybrids (Table 1). Calcium silicate also influenced the TDF, because through the increase in doses there was an increase in diameter, which is confirmed by the commercial pattern of tomatoes in the salad segment (Figure 2B). Filgueira (2013), considers that the genetic materials of the salad group have a flattened globular shape, with a cross-sectional diameter larger than the longitudinal, thus the fruits of the hybrids tested proved to be within the desired pattern.

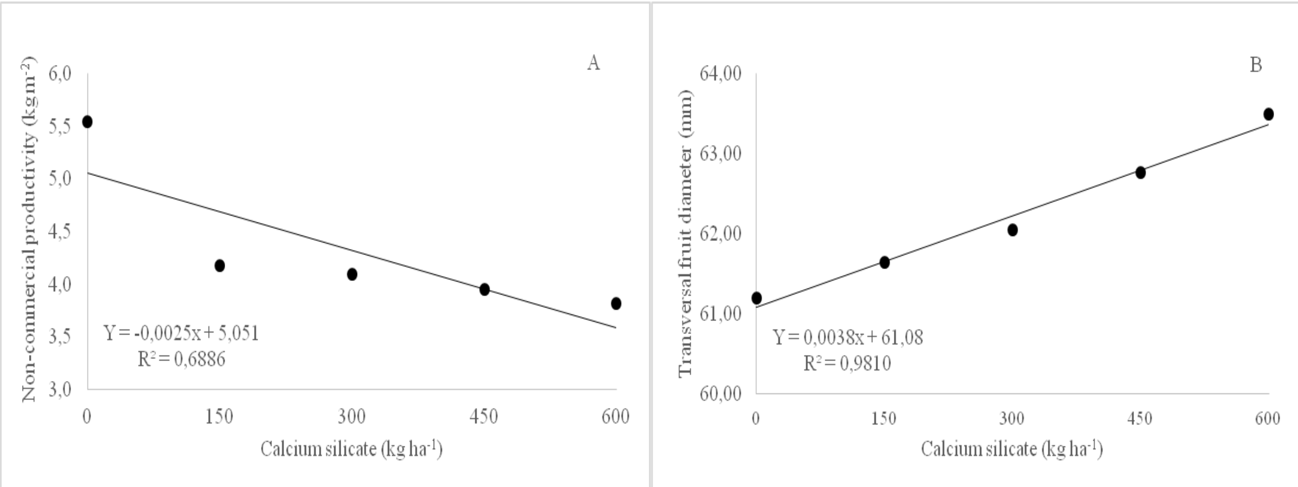

FIGURE 2 - Non-commercial productivity (A) and (B) transversal diameter of tomato fruits as a function of calcium silicate doses.

Besides the morphometric characteristics of the fruits, the plant characteristics were also analyzed, observing that there was no interaction between the tomato hybrids and the doses of calcium silicate, which were studied in isolation, showing differences between the hybrids for the characteristics plant height (PH) and stem dry mass (SDM) (Table 2).

Plant height is an inherent genetic characteristic of material, and in this study plants were conducted with single stem and the same number of bunches, observing, however, that ‘Ivety’ presented tall plants and consequently with higher dry mass of stem, which also shows that plant height does not change the number of leaves, dry mass of leaves and leaf area, because for these characteristics no difference was observed. The hybrid ‘Natalia’ presented plants with a lower height, reducing the expense of photoassimilates to plant height, which were probably translocated to fruit production, because it showed an increase in the number of fruits per plant.

TABLE 2 - Number of leaves (NL), stem diameter (SD), plant height (PH), stem dry mass (SDM), leaf dry mass (LDM), leaf area (LA) and membrane integrity damage (MID) of two tomato hybrids.

Híbridos de tomateiro	NL	SD (mm)	PH (m)	SDM (g)	LDM (g)	LA (cm^2)	MID (%)
Ivety	21.37*	16.22	1.70 a	54.77 a	113.25	5253.33	49.82 a
Natália	21.45	15.48	1.50 b	42.99 b	108.53	4618.77	30.25 b
CV (%)	4.90	8.84	5.57	16.14	15.04	21.69	26.12

*Significant at 5% probability of error by F test.

As the characteristics of the leaves of the plant did not present visual difference, for the damage of the membrane integrity of the plant no interaction between the hybrids and the calcium silicate doses were observed, however it was verified that the hybrid Natalia presents greater membrane integrity (Table 2), due to the reduction of rupture in the cellular wall, which results in the loss of cellular turgescence, thus changing the potential of water.

Calcium silicate also influenced the membrane integrity damage, where the model that presented the best fit was linear decreasing, presenting a reduction of ion release during the increase of doses, demonstrating that a deposition of silicon and calcium in the leaf cell wall occurred, thus reducing the damage caused by any type of stress (Figure 3A).

According to Guerrero et al. (2011), silicon accumulates in the epidermis of leaves and may accumulate in other parts of the plant depending on the species. While calcium is one of the essential nutrients to maintain cell wall structure and stabilization (MOSCHINI et al., 2017). Thus, it can be noted that these two nutrients are completely involved in the membrane integrity of the leaves and in the cell wall of the fruit, because the non-commercial productivity of the fruit showed the same performance as the damage of membrane integrity of the leaves, obtaining a reduction of this damage with the increase in the doses of calcium silicate, thus finding that this element significantly alters the cell wall of the leaves and fruits.

In addition, this accumulation of silicon in the plant interfered with the architecture due to the increase in lignin content in the stem in addition to raising the hemicellulose content, which increases cell stiffness, playing an important role in structuring the plants, thus increasing the plant's resistance to climate, soil and biological adversities (CAMARGO, 2016). Besides presenting more erect leaves when one has the accumulation in leaves, increasing the capture of incident radiation and photosynthetic efficiency. For the lignin content in the stem it was verified that there was interaction between tomato hybrids and doses of calcium silicate (Figure 3B). Only the hybrid Natalia showed an increase in lignin content in the stem as a function of calcium silicate doses, showing an increase along the doses. Natalia hybrid is recommended for rainy seasons, presenting resistance to bacterioses, stains and cracks.

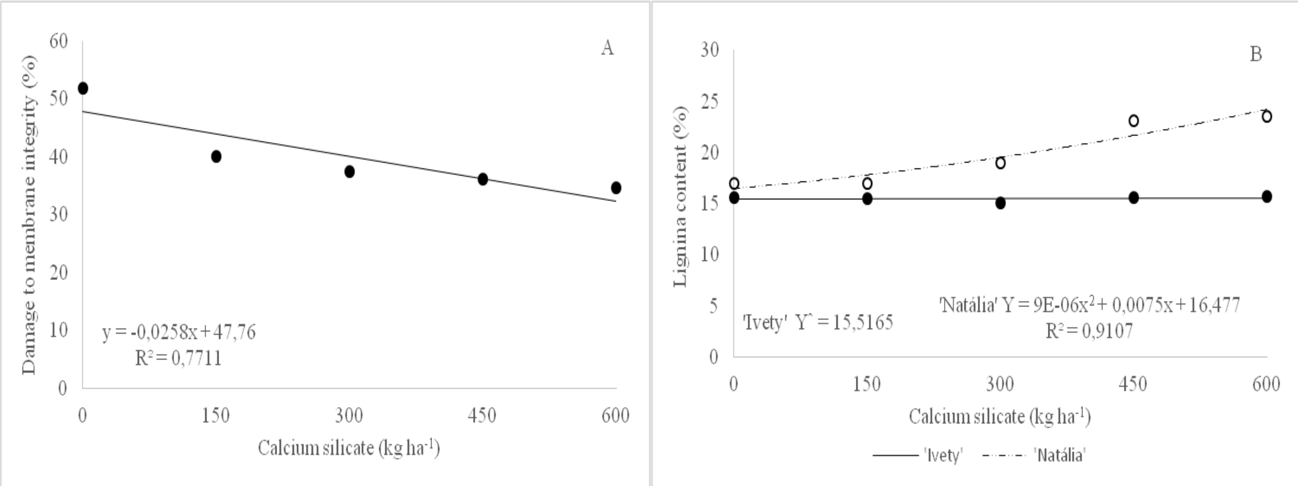

FIGURE 3 - Damage to the membrane integrity of the leaves (A) and the lignin content of the stem (B) of the two tomato hybrids, depending on the doses of calcium silicate.

When analyzing the Si, Ca and Mg contents in leaves and fruits and the Si, Ca and Mg contents in the tomato plant, interaction between hybrids and doses of calcium silicate was observed only for the Si and Ca content in fruits and Mg in leaves, and the other variables were studied separately (Table 3). The Ivety hybrid presented higher silicon content in the leaf, with no difference for calcium silicate doses, and reduced non-commercial productivity. Different from Pereira and Vitti (2004), when working with shale source that presents high silicon content (52%), they observed higher silicon contents in tomato leaves in treatments with the highest dose of 12 t ha^{-1}. This increase in the silicon content in leaves makes them more erect and rigid, thus facilitating, according to Ma et al. (2007), the greater interception of light, which increases photosynthetic efficiency.

TABLE 3 - Silicon (Si), calcium (Ca) and magnesium (Mg) content and their leaves content of two tomato hybrids.

Híbrido	Si leaf (g kg^{-1})	Ca leaf (g kg^{-1})	Mg leaf (g kg^{-1})	Content Si (g/plant)	Content Ca (g/plant)	Content Mg (g/plant)
Ivety	3.15 a*	10.39 b	3.45 b	0.36	1.16	0.39
Natália	2.89 b	12.22 a	3.71 a	0.31	1.33	0.40
CV (%)	11.21	18.37	6.31	18.52	24.51	15.47

*Significant at 5% probability of error by F test.

Plants are classified in relation to the accumulation of silicon in the leaves dry mass in accumulators, non-accumulators, and intermediates, with grasses in general being said to be accumulators (KORNDÖRFER et al., 2010). The non-accumulators are characterized by the low content in the tissues where the tomato is found (LANA et al., 2003). The same authors report that the crop behaved as a non-accumulating silicon plant in the leaves.

The study shows that the Si, Ca and Mg content did not present a significant difference between the hybrids and the doses of calcium silicate tested, thus evidencing that the tomato is not an accumulator of Si, Ca and Mg in the leaf (Table 3). Tomatoes, when absorbing calcium silicate, are easily translocated by the roots to the aerial part, via xylem, having a natural tendency to be associated with organic compounds such as proteins, polysaccharides and lignin. Thus, after absorption the calcium silicate is translocated to the main drains of the plant, which are the fruits, presenting as an alternative for the reduction of non-commercial production of fruits and Ca deficiency in the plant knowing that the calcium remains immobile in the plant and may present deficiency in tissues of the young fruits.

The silicon content in the fruit showed interaction between hybrids and doses (Figure 4A), where the model that best adjusted for 'Ivety' was quadratic and 'Natalia' linear, showing an increase in the silicon content in the fruit with an increase in the calcium silicate doses, with 'Natalia' standing out from 'Ivety'. The increase of silicon in the cell wall of the fruit collaborated with the reduction of non-commercial production of tomato fruits (Figure 2A). In the same way it was observed in a study by Marodin et al. (2014), where the increase of silicon content in the fruit promoted better post-harvest conservation, because there was an increase of the Si content in the fruit cell wall, increasing the stiffness of the epidermal cells, causing lignification, which will result in greater mechanical resistance.

The form of application of silicon can lead to greater absorption and the difference between the doses shows that the application in the substrate was viable, although no difference was observed between the doses in the foliar tissue, because this element was translocated to the fruit, being essential in summer cultivation because there is less translocation of solutes and water to the fruit. The temperatures recorded in protected environment in spring-summer cultivation was 31 to 39ºC (Figure 1A), being above the tolerable for the crop that, according to Filgueira (2013) is 18 to 24ºC at the flowering stage and beginning of fruiting.

The hybrid Natalia had the highest calcium content in the leaf (Table 3). Calcium in tomatoes is of utmost importance because in tomato cultivation this nutrient has little or no mobility in the phloem, which takes advantage of the transpiratory flow for its displacement to the fruits, as it often presents symptoms of deficiency and physiological anomalies in tomatoes (FONTES, 2003).

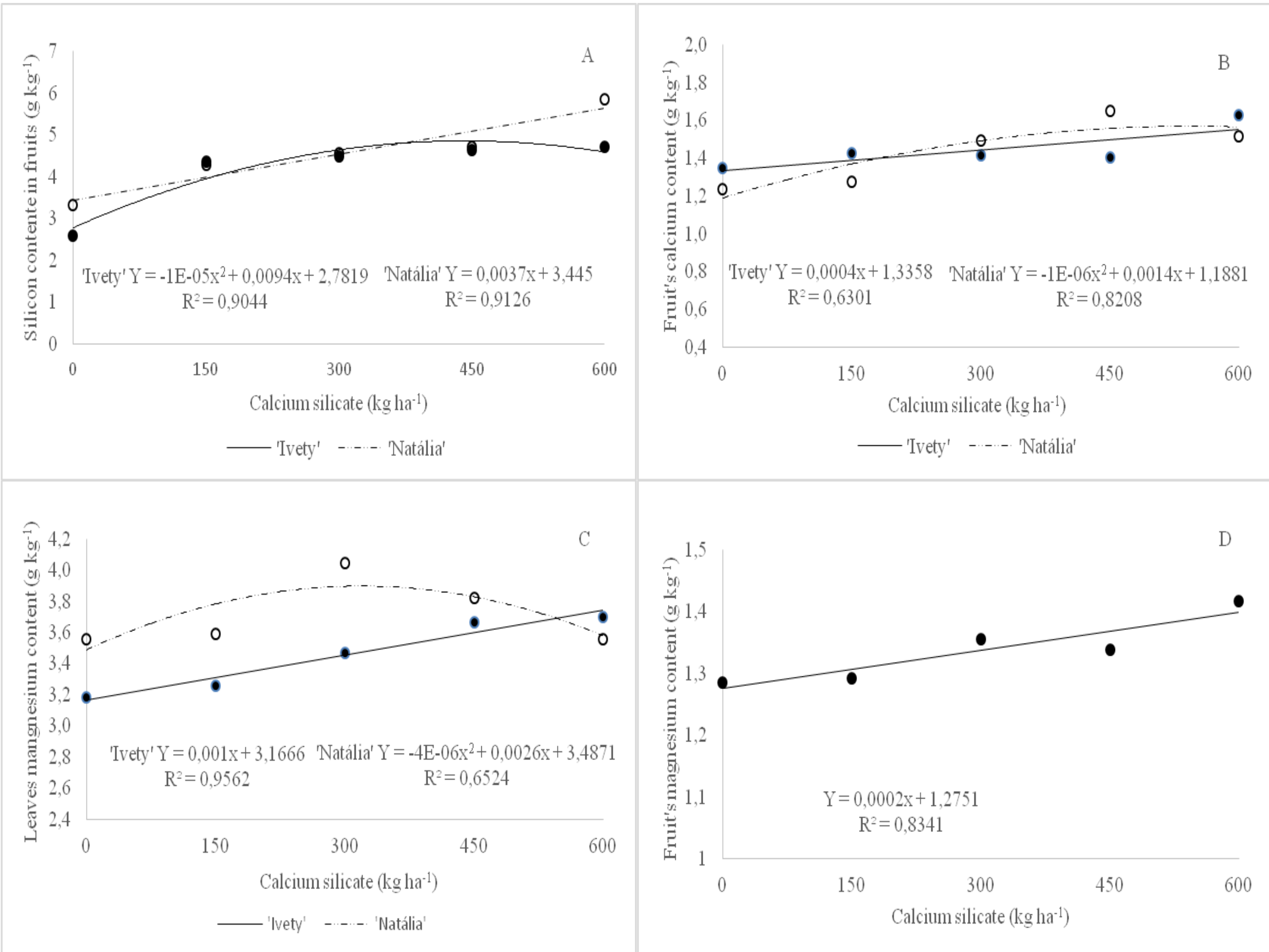

FIGURE 4 - Silicon (A) and calcium (B) content magnesium content in leaves (C) and fruit (D) of two tomato hybrids depending on doses of calcium silicate.

The calcium content in the tomato fruit showed significant interaction between the hybrids and doses of calcium silicate (Figure 4B) and the model that best fitted was linear for 'Ivety' and quadratic for the Natalia hybrid, showing a small increase in the calcium content in the fruit during the increase in calcium silicate doses. According to Moschini et al. (2017), Ca deficiency results in low growth of meristematic tissues, which may reflect on the plant in regions of greater cellular expansion such as in tomato fruits. This fact can be observed in this study, when analyzing the non-commercial productivity of the fruits, it can be verified that there was a reduction with the increase of calcium silicate doses.

The increase of calcium content in the tomato fruit of the two hybrids may have caused a nutritional imbalance, displacing the calcium from the leaf to the fruit (Figure 4B), thus reducing the damage to the membrane integrity of the leaves (Figure 3A), since this nutrient is linked to the plasmatic membranes, altering their structural and functional integrity (SILVA et al., 2011). Calcium and magnesium are two essential elements for the growth and development of crops, and both need an equilibrium, because the imbalance can cause calcium, magnesium or potassium deficiency. Potassium absorption by plants is related to the availability of divalent Ca and Mg cations (RODRIGUES et al., 2011).

The magnesium content in the foliar tissue showed an increasing increase for 'Ivety', differentiating itself from 'Natalia' where the model that presented the best fit was the quadratic (Figure 4C). For the magnesium content in the tomato fruit, no difference was observed between the hybrids, proving a difference only for the dose that presented an increasing linear behavior (Figure 4D). The foliar tissue showed higher concentrations of magnesium than the fruit, also showing that the leaves of the tomato indicate a higher concentration of calcium in relation to the magnesium. It is known that these nutrients are interrelated in plant nutrition, where the presence of one can impair the adsorption and absorption of the other (MALAVOLTA et al., 1997).

In view of the results, it can be considered that the application of calcium silicate did not interfere in the productivity of the hybrids tested, although an increase in the content of silicon, calcium and magnesium in the tomato fruit was observed as a function of the calcium silicate doses. Although no effect of the calcium silicate doses on the silicon content in the leaves was observed, there was accumulation in the stem, because there was an increase in the lignin content of the stem during the increase in doses resulting in greater lignification or silicification of the cells, which improves the structure of the plants, increasing resistance to weather adversities and pathogens.

CONCLUSIONS

The morphometric characteristics of Ivety and Natalia tomato hybrids were not altered by the increasing doses of calcium silicate.

The calcium silicate doses provided higher silicon and calcium content in the fruits of Natalia hybrid, and increased in a linear way the magnesium contents in the leaves and fruits for 'Ivety'.

The increase of silicon and calcium content in the fruit cell wall provided a reduction in the non-commercial productivity of the fruit, thus contributing to post-harvest durability. It is worth mentioning that these results can vary, mainly due to the genetic material and the cultivation environment.

ACKNOWLEDGEMENTS

To the Universidade Estadual do Oeste do Paraná (Unioeste) and the and the Post-Graduation Program in Agronomy (PPGA), for the opportunity to hold the course; to the Conselho de Aperfeiçoamento de Pessoal de Nivel Superior (CAPES), for the grant of the scholarship, the Sakata company, for the donation of seeds and Agronelli company, for the donation of calcium silicate.

REFERENCES

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.; GONÇALVES, J.L.M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v.22, n.6, p.711-728, 2013.

BECKMANN, M.Z.; DUARTE, G.R.B.; PAULA, V.A.; MENDEZ, M.E.G.; PEIL, R.M.N. Radiação solar em ambiente protegido cultivado com tomateiro nas estações verão-outono do Rio Grande do Sul. **Ciência Rural**, v.36, n.1, p.86-92, 2006.

CAMARGO FILHO, W.P; CAMARGO, F.P. Evolução da produção e da comercialização das principais hortaliças no mundo e no Brasil, 1990-2015. **Informações Econômicas**, v.47, n.3, p.5-15, 2017.

CAMARGO, M.S.D. Efeito do silício na tolerância das plantas aos estresses bióticos e abióticos. **Informações Agronômicas**, v.1, n.155, p.1-8, 2016.

FERREIRA, D.F. Sisvar: a guide for its Bootstrao procedures in multiple comparisons. **Ciência e Agrotecnologia**, v.38, n.2, p.109-112, 2014.

FILGUEIRA, F.A.R. Solanáceas II, Tomate: a hortaliça cosmopolita. **Novo manual de olericultura:** agrotecnologia moderna na produção e comercialização de hortaliças. 3a. ed. Viçosa: UFV, p.194-241, 2013.

FONTES, P.C.R. Podridão apical do tomate, queima dos bordos das folhas de alface e depressão amarga dos frutos em maçã: deficiência de Ca?. **Horticultura Brasileira**, v.21, n.2, p.145-145, 2003.

GUERRERO, A.C.; SILVA BORGES, L.; FERNANDES, D.M. Efeito da aplicação foliar de silício em rúcula cultivada em dois tipos de solos. **Bioscience Journal**, v.27, n.4, p.591-596 2011.

ILIĆ, Z.S.; MILENKOVIĆ, L.; ŠUNIĆ, L.; MANOJLOVIĆ, M. Color shade nets improve vegetables quality at harvest and maintain quality during storage. **Contemporary Agriculture**, v.67, n.1, p.9-19, 2018.

KORNDÖRFER, G.H.; PEREIRA, C.S.; NOLLA, A.; PEREIRA, A.; NOLLA, A. **Análise de silício:** solo, planta e fertilizante. Instituto de Ciências Agrárias, Uberlândia, MG: GPSi-ICIAG-UFU, 34p. Boletim Técnico, n.2, 2004.

KORNDÖRFER, P.H.; SILVA, G.C.; TEXEIRA, I.R.; SILVA, A.G.; FREITAS, R.S. Efeito da adubação silicatada sobre gramíneas forrageiras e características químicas do solo. **Pesquisa Agropecuária Tropical**, v.40, n.2, p.119-125, 2010.

LANA, R.M.Q.; KORNDÖRFER, G.H.; ZANÃO JÚNIOR, L.A.; SILVA, A.F.; LANA, A.M.Q. Efeito do silicato de cálcio sobre a produtividade e acumulação de silício no tomateiro. **Bioscience Journal**, v.19, n.2, p.15-20, 2003.

LUTTS, S.; KINET, J.M.; BOUHARMONT, J. NaCl-induced senescence in leaves of rice (*Oryza sativa* L.) cultivars differing in salinity resistance. **Annals of Botany**, v.78, n.3, p.389-398, 1996.

MA, J.F.; YAMAJI, N.; MITANI, N.; TAMAI, K.; KONISHI, S.; FUJIWARA, T.; KATSUHARA, M.; YANO, M. An efflux transporter of silicon in rice. **Nature**, v.448, n.7150, p.209-212, 2007.

MALAVOLTA, E.; VITTI, G.G.; OLIVEIRA, S.A. **Avaliação do estado nutricional das plantas:** princípios e aplicações. 2a ed. Piracicaba: Potafos, 1997. 201p.

MARODIN, J.C.; RESENDE, J.T.; MORALES, R.G.; SILVA, M.L.; GALVÃO, A.G.; ZANIN, D.S. Yield of tomato fruits in relation to silicon sources and rates. **Horticultura Brasileira**, v.32, n.2, p.220-224, 2014.

MARODIN, J.C.; RESENDE, J.T.V.; MORALES, R.G.F.; FARIA, M.V.; TREVISAM, A.R.; FIGUEIREDO, A.S.T.; DIAS, D.M. Tomato post-harvest durability and physicochemical quality depending on silicon sources and doses. **Horticultura Brasileira**, v.34, n.3, p.361-366, 2016.

MENDES, L.S.; SOUZA, C.H.E.; MACHADO, V.J. Adubação com silício: influência sobre o solo, planta, pragas e patógenos. **Cerrado Agrociências**, v.2, n.2, p.51-63, 2011

MOSCHINI, B.P.; COELHO, V.A.T; PECHE, P.M.; SOUZA, F.B.M.; COUTINHO, G.; ALCANTRA BARBOSA, C.M.; FREIRE, A.I. Crescimento e diagnose de deficiências nutricionais em *Physalis peruviana* L. **Agropecuária Técnica**, v.38, n.4, p.169-176, 2017.

NETO, H.S.L.; GUIMARÃES, M.A.; SAMPAIO I.M.G.; RABELO, J.S.; VIANA, C.S.; MESQUITA, R.O. Can silicon (Si) influence growth, physiology and postharvest quality of lettuce?. **Australian Jornal of Crop Science**, v.14, n.1, p.71-77, 2020.

NUNES, A.M.C.; LIMA NUNES, L.R.; RODRIGUES, A.J.O.; UCHÔA, K.S.A. Silício na tolerância ao estresse hídrico em tomateiro. **Revista Científica Rural**, v.21, n.2, p.239-258, 2019.

PEREIRA, H.S.; VITTI, G.C. Efeito do uso do xisto em características químicas do solo e nutrição do tomateiro. **Horticultura Brasileira**, v.22, n.2, p.317-322, 2004.

PEREIRA, M.A.B.; AZEVEDO, S.M.; FREITAS, G.A.; SANTOS, G.R.; NASCIMENTO, I.R. Adaptabilidade e estabilidade produtiva de genótipos de tomateiro em condições de temperatura elevada. **Revista Ciência Agronômica**, v.43, n.2, p.330-337, 2012.

RODRIGUES, F.D.A.; OLIVEIRA, L.D.; KORNDÖRFER, A.P.; KORNDÖRFER, G.H. Silício: um elemento benéfico e importante para as plantas. **Informações Agronômicas**, v.134, n.1, p.14-20, 2011.

RODRIGUES, A.J.O.; LIMA NUNES, L.R.; NUNES, A.M.C.; UCHÔA, K.S.A. Efeito da adubação silicatada no cultivo de tomateiro sob estresse salino. **Agropecuária Científica no Semiárido**, v.14, n.2, p.141-148, 2018.

SIDDIQUI, H.; YUSUF, M.; FARAZ, A.; FAIZAN, M.; SAMI, F.; HAYAT, S. 24-Epibrassinolide supplemented with silicon enhances the photosynthetic efficiency of *Brassica juncea* under salt stress. **South African Journal of Botany**, v.118, n.1, p.120-128, 2018.

SILVA, S.A.; MORAES, W.B.; SOUZA, G.S. Doses de cálcio no crescimento do feijoeiro cultivado em solução nutritiva, na presença de alumínio. **Idesia**, v.29, n.3, p.53-58, 2011.

VAN SOEST, P.J. **Lignin. Nutritional ecology of the ruminant.** Ithaca: Cornell University Press, v.2, p.177-195, 1994.