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Yield of tomato fruits in relation to silicon sources and rates

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ABSTRACT

There is controversy about the benefits of silicon (Si) on tomato plants. This element has structural and metabolic functions in the physiology of plants, generating benefits that may result in increased productivity of various plant species. Thus, the aim of this study was to evaluate the phytotechnical characteristics and the productivity of tomato plants according to the rates and sources of Si. The design was established in randomized blocks with factorial 3x5, corresponding to three sources of silicate (calcium silicate, potassium silicate and sodium silicate) and five doses of Si (equivalent to 0, 100, 200, 400 and 800 kg ha^{-1} of SiO_2). The fertilization with Si increased the commercial productivity of tomato plants and reduced the occurrence of cracked fruits. Calcium and potassium silicates increased the Si levels on the leaves linearly with the increase of the doses, while sodium silicate reduced the levels in larger doses. Silicon fertilization increases the productivity of tomato plants with possible economic return on the use of this input.

Keywords: *Solanum lycopersycum*, cracked fruits, potassium silicate, calcium silicate, silicon fertilization.

RESUMO

Produtividade do tomateiro em função de fontes e doses de silício

Há controvérsias sobre os benefícios do silício (Si) no tomateiro. Este elemento possui funções estruturais e metabólicas sobre a fisiologia das plantas, gerando benefícios que podem resultar no aumento da produtividade de várias espécies vegetais. Assim, o objetivo foi avaliar características fitotécnicas e a produtividade do tomateiro em função de doses e fontes de Si. O delineamento foi em blocos casualizados em fatorial 3 x 5, correspondendo a três fontes de silicato (silicato de cálcio, silicato de potássio e silicato de sódio) e cinco doses de Si (equivalentes a 0, 100, 200, 400 e 800 kg ha^{-1} de SiO_2). A adubação com Si aumentou a produtividade comercial do tomateiro e reduziu a ocorrência de frutos rachados. Os silicatos de cálcio e de potássio aumentaram os teores de Si nas folhas linearmente com o aumento das doses, enquanto o silicato de sódio reduziu os teores nas maiores doses. A adubação silicatada aumenta a produtividade do tomateiro com possibilidade de retorno econômico na utilização desse insumo.

Palavras-chave: *Solanum lycopersycum*, frutos rachados, silicato de potássio, silicato de cálcio, adubação silicatada.

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Tomato is one of the most demanding vegetables in nutrients and responds to high doses of chemical fertilizers (Fayad *et al.*, 2002). Considering the mineral nutrition, 14 mineral elements are essential for the plants (Epstein & Bloom, 2006) and some elements are considered beneficial, because the lack of these elements is not considered a limiting factor to the normal growth and development of the plants. Among them, is silicon (Si), which has structural and metabolic functions in the plant physiology, generating numerous benefits which may result in the increase of the productivity of several plant species (Korndörfer & Datnoff, 1995; Carvalho *et al*., 2002; Lana *et al*., 2003; Almeida *et al*., 2009).

The beneficial effects of Si have been related to the tolerance to various biotic and abiotic stresses, such as salinity (Zhu *et al*., 2004), toxicity caused by zinc excess (Ramos *et al*., 2009), transpiration (Hattori *et al*., 2005) penetration and development of fungal hyphae (Ma & Yamaji, 2006) stresses by high and low temperatures (Ma & Yamaji, 2006). Moreover, the adequate nutrition with Si interferes in the plant architecture, by providing more erect leaves, increasing solar radiation interception and photosynthetic efficiency (Pereira *et al*., 2003; Al-Aghabary *et al*., 2004).

The ability of Si accumulation in tissues varies among species, which may be classified into accumulator (>4% Si), intermediate (2-4% Si) and non-accumulators of Si (<2% Si) (Ma & Yamaji, 2006). Generally, the accumulator species, such as the grasses (Poaceae), can increase the productive yield, promoting various desirable physiological and biochemical processes for plants (Hunt *et al*., 2008). The Si-non-accumulator species, such as the tomato (Lana *et al*., 2003), need more researches to improve the understanding of the physiological responses of the crop to Si fertilization.

In tomato, the addition of Si in the standard nutrient solution improved calcium concentrations in leaves and fruits, reducing the occurrence of blossom-end rot (Carvalho *et al*., 2002; Stamatakis *et al*., 2003), altered the metabolism of leaves exposed to salt stress (Al-Aghabary *et al*., 2004) and increased the total number of fruits and the productivity as the availability of Si in the soil (Fiori, 2006). Regarding pests and diseases, the application of Si reduced in approximately 50% the number of injuries caused by thrips (*Frankliniella schultzei*) (Almeida *et al.*, 2009) and in 56.2% the incidence of bacterial wilt (*Ralstonia solanacearum*) (Dannon & Wydra, 2004).

The calcium silicate ($CaSiO_3$), potassium silicate (K_2SiO_3) and sodium silicate (Na_2SiO_3) have variable SiO_2 solubility and availability. The benefits of the use of silicates are not always attributed to Si, such as the increase of soil pH, reduction of toxic aluminum (Al^{+3}), increase of soil base saturation, increase of exchangeable Ca and Mg and increase of phosphorus availability (Korndörfer *et al.*, 2002).

Although the results found in the literature confirm the benefits of Si for tomato, few studies highlighted if these benefits reflect an increase of productivity. Also, the lack of information about the best sources and doses of Si restrict the researches to clarify the mode of action of Si in the plant. Thus, the goal of this study was to evaluate the productivity of tomatoes related to doses and sources of Si and their effects on phytotechnical characteristics.

MATERIAL AND METHODS

The experiment was carried out from October 2009 to March 2010, in Guarapuava, Paraná state, Brazil, with the tomato cultivar Kada Gigante, of Santa Cruz group, which has the following characteristics: indeterminate growth habit, cycle between 180 and 250 days, average mass of fruits of 130 g, low post-harvest conservation and high susceptibility to the disruption of the fruit epicarp. The local climate is Cfb, Köppen classification, characterized as subtropical, mesothermal and humid, without definite dry season. The average annual rainfall is 1944 mm, annual average minimum temperature of 12.7°C, annual average maximum temperature of 23.5°C and relative humidity of 77.9% (Thomaz & Vestena, 2003).

The pots were filled with soil classified as Bruno Latosol distrophic (Embrapa, 2006), clayey texture, sieved through a 4 mm mesh and homogenized. The soil chemical analysis showed the chemical characteristics: pH ($CaCl_2$)= 5.0;. organic matter = 37.6 g dm^{-3}; P (Mehlich)= 1.1 mg dm^{-3}; K, Ca, Mg, Al, H + Al and CTC, respectively = 0.1, 3.4, 1.9, 0, 5.3, 11 $cmol_c$ dm^{-3}. The concentrations of B, Cu, Fe, Mn and Zn were 0.23, 1.00, 129.00, 43.20 and 1.40 mg dm^{-3}, respectively. The Si content in the soil extracted with $CaCl_2$ 0.01 mol L^{-1} was 11 mg dm^{-3}.

The experimental design was of randomized blocks, with four replications, with four pots and one plant per pot in each plot. The treatments were arranged in a 3x5 factorial, corresponding to three sources of silicate [calcium silicate ($CaSiO_3$), potassium silicate (K_2SiO_3) and sodium silicate (Na_2SiO_3)] and five doses of Si (equivalent to 0, 100, 200, 400 and 800 kg ha^{-1} of SiO_2). Silicates, applied in the form of salts, were added to soil to a depth of 5 cm and 5 cm from the base of the plant, fractioning each dose in three applications: before seedling transplanting, early flowering and during fruiting, on the occasion of issuing the fifth raceme. To nullify the effect of the accompanying ions (Ca, K and Na) of silicates, together with the other treatments were applied calcium chloride, potassium chloride and sodium chloride fertilizers, such that all treatments were given the same quantities of these elements (229 kg ha^{-1} CaO, 361 kg ha^{-1} K_2O and 229 kg ha^{-1} of Na_2O).

The seedlings were grown in polystyrene trays of 128 cells containing Plantmax® substrate. Thirty five days after sowing, when the seedlings showed two pairs of expanded leaves and about 5 cm high, these seedlings were transplanted to 7 L capacity pots.

The pots were kept in a protected environment, spaced at 1.0 m between lines and 0.4 between plants. The planting fertilization was calculated based on soil analysis, using urea, potassium chloride and triple superphosphate, totaling 300 kg ha^{-1} N, 200 kg ha^{-1} K_2O and 300 kg ha^{-1} of P_2O_5. The soil base saturation was adjusted to 80%, by applying 3500 kg ha^{-1} of dolomitic limestone. Eight side dressing fertilizations were done weekly, starting one month after transplanting the seedlings to pots, totalizing doses equivalent to 200 kg ha^{-1} of N and 300 kg ha^{-1} of K_2O (Alvarenga *et al.*, 2004).

Plants were conducted with one stem, tutored weekly in vertical trellis system, and apical pruning above the third leaf was carried out after the seventh raceme. A drip irrigation system with a water depth of 5 mm day^{-1} was used to irrigate the plants daily. The pest control (triflumuron, 250 g kg^{-1}, 15 g a.i. 100 L^{-1} of water, acephate, 750 g kg^{-1}, 100 g p.c. 100^{-1} L; pymetrozine, 500 g kg^{-1}, 40 g p.c. 100^{-1} L) and diseases (copper oxychloride, 250 g a.i. 100 L^{-1} of water, mancozeb + metalaxyl-m, 300 g p.c. 100^{-1} L; azoxystrobin, 16 g p.c. 100 L^{-1} of water; thiamethoxam 750 g kg^{-1}, 20 g 100^{-1} L of water; chlorothalonil 720 g L^{-1} 126 g a.i. 100 L^{-1} of water) was done weekly, alternating the products mentioned.

The fruits were harvested weekly, starting the harvest from the eleventh week after transplanting. For commercial fruit productivity, all the fruits with commercial standard were counted and weighed (t ha^{-1}) of each plot and, then, the occurrence of cracked fruits was determined (t ha^{-1}). During the productive period, samples of five marketable fruits and ten leaves per plot were weighed and dehydrated in an oven with forced air circulation at a constant temperature of 70°C, until constant weight was reached. The dry mass of the leaves and fruits was determined by the percentage of dry mass (%).

The leaf silicon was quantified in a sample of a leaf per plant, collecting the first leaf above the first cluster, according to the methodology described by Silva & Vale (2007). Due to sampling be performed during fructification of the first cluster, in order to avoid negative effects on the productivity of the fruits, just one leaf per plant was used. The samples were dehydrated until they reached constant mass, in an oven with forced air circulation at temperature of 70°C. The determination of Si content was performed using the methodology described by Korndörfer *et al.* (2004), with values expressed in g kg^{-1} of dry mass of leaves.

Data were subjected to analysis of variance and polynomial regression, and the R^2 values of the regression equations tested by F test. The coefficient r (Pearson) was determined, tested by the t test (5%), in order to establish correlations between the analyzed factors.

RESULTS AND DISCUSSION

An effect only of doses on commercial fruit productivity, fruit dry mass, leaf dry mass and number of cracked fruits was observed. For Si content in the leaves, an influence of the interaction between doses and sources was noticed.

The fertilization with Si increased the commercial productivity of tomato plants to 401 kg ha^{-1} of SiO_2 with an estimated productivity of 60.8 t ha^{-1} (Figure 1a). From this dose, a reduction on the productivity was observed. Probably, because of the nutritional imbalance caused by Si or by the accompanying ions (calcium, potassium and sodium) that compete for the same absorption sites of other nutrients (Korndörfer *et al*, 2002; Fernandes & Souza, 2006). These results are in accordance with those observed by Fiori (2006), in which the application of basic slag, as source of Si, promoted an increase in the total number of fruits and productivity. This fact was attributed to the increased availability of Si in the soil. The increase of the productivity of the tomato plants at the dose of 401 kg ha^{-1} of SiO_2 can be attributed to the benefit effects of Si in the plant, as an improve of the architecture for showing more erect leaves, which intercept higher solar luminosity increasing the photosynthetic efficiency (Pereira *et al.*, 2003) and higher chlorophyll content (Braga *et al.*, 2009). However, these results cannot be attributed to the reduction of damage caused by pests and diseases and reduction of water stress, because these factors were controlled in this experiment. Several authors did not observe differences in the productivity of tomato plants when the Si availability to the plants was increased (Lana *et al.*, 2003; Pereira *et al.*, 2003; Pereira & Vitti, 2004). For Pereira *et al.* (2003) the absence of significant results was due to high initial Si contents in the soil, which contributed to minimize the effects of Si on production.

Besides increasing the commercial productivity of fruits, fertilization with Si decreased the occurrence of cracked fruits, that means, non-commercial fruits, with better response at a dose of 505 kg ha^{-1} of SiO_2 (Figure 1b). The main cause of the disturbance is the rapid influx of solutes and water in the fruit, usually at the time of ripening, when the strength and elasticity of the skin are reduced (Kinet & Peet, 1997) and the pressure of the locule is incremented (Almeida & Huber, 2001), occurring tiny cracks, expanding thereafter during ripening. Lana *et al.* (2003) observed that in a soil with no

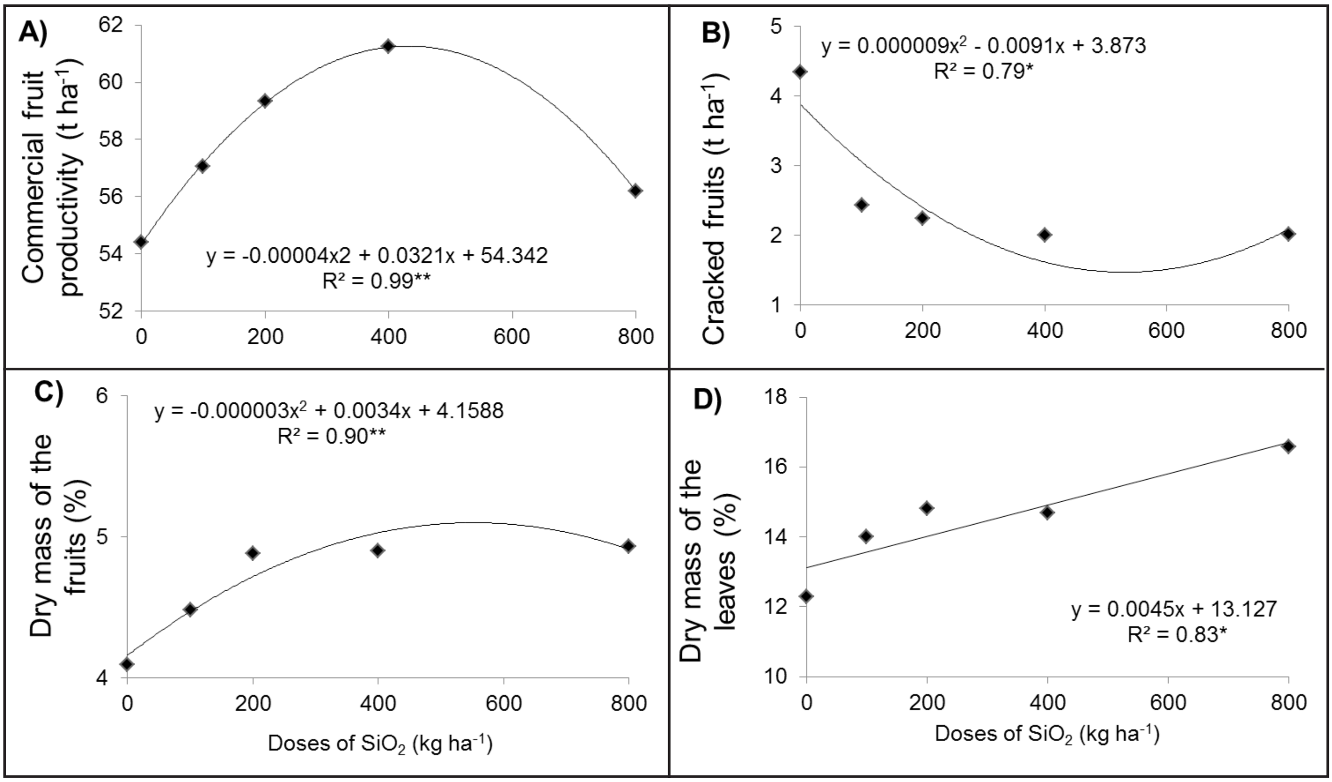

Figure 1. Fertilization doses on total fruit yield (a), cracked tomato fruits (b), dry mass of fruits (%) (c) and leaves (d) of tomato. *and**= $p \leq 0.05$ and $p \leq 0.01$, respectively (adubação com doses de SiO_2 sobre a produtividade de frutos comerciais (a) e de frutos rachados (b), percentagem de massa seca de frutos (c) e de folhas (d) do tomateiro. *e**= $p \leq 0,05$ e $p \leq 0,01$, respectivamente). Guarapuava, UNICENTRO, 2010.

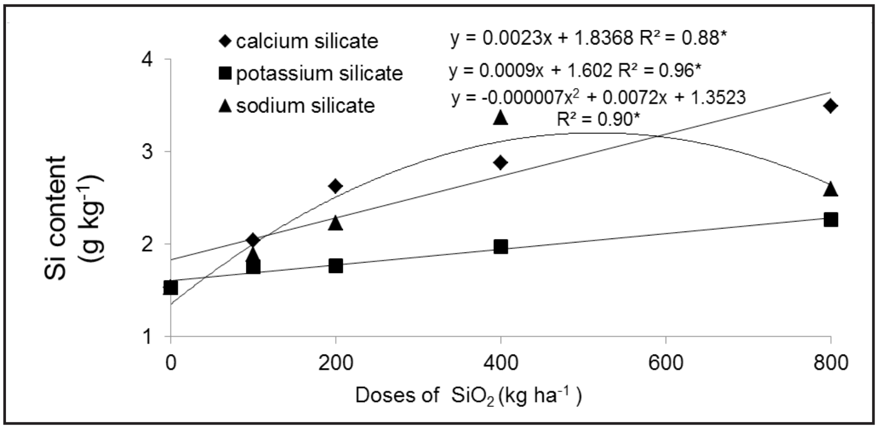

Figure 2. Silicon content of tomato leaves after application of three silicon sources in soil. *and**= $p \leq 0.05$ and $p \leq 0.01$, respectively (teor de silício nas folhas do tomateiro em função de três fontes de silício aplicadas via solo. *e**= $p \leq 0{,}05$ e $p \leq 0{,}01$, respectivamente). Guarapuava, UNICENTRO, 2010.

silicon fertilization, the productivity of commercial tomato fruits was 40.1 t ha^{-1} and non-commercial was 26.6 t ha^{-1}. However, when the calcium silicate was applied at the dose of 4000 kg ha^{-1}, the commercial productivity increased to 56.0 t ha^{-1} and non-commercial reduced to 15.1 t ha^{-1}, this values being statistically not different. The authors attributed the results to the beneficial effects of Si, mainly due to the increase of the mechanical strength of the cell wall.

The calcium and potassium silicates increased the Si content in the leaves linearly, with maximal response at the highest dose (800 kg ha^{-1} of SiO_2), with contents of 3.49 g kg^{-1} and 2.27 g kg^{-1} of Si, respectively (Figure 2). In contrast, the sodium silicate provided maximum response (3.2 g kg^{-1}) at a dose equivalent to 514 kg ha^{-1} of SiO_2, reducing its values in larger doses. The increase of Si content in the leaf in smaller doses of sodium silicate occurs due to greater solubility in water of this source, which favors absorption (Moraes *et al*., 2006). The increase of Si content in the tomato leaf (1.84 to 3.39 mg kg^{-1}) was also observed by Pereira & Vitti (2004) after the schist application (52% of Si) in the soil, showing that the tomato crop absorbs this nutrient according to the higher availability in the soil.

The fruit dry mass (MSFru) increased 20% in the dose of 566 kg ha^{-1} of SiO_2 in relation to the control, reducing from this dose (Figure 1c). In contrast, the leaf dry mass (MSFol) increased linearly up to the highest doses of Si, an increase of 25% (Figure 1d). The increase in absorption of Si and, consequently, the increase of its concentration in the leaf, explains the increase of 92% for MSFru and the increase of 88% for MSFol, by correlation analysis. The highest values of MSFru and MSFol in response to doses of Si are probably related to the action of this element in cell metabolism. The Si increases the photosynthetic efficiency of the plant, resulting in greater accumulation of solids in leaf tissues (Pereira *et al.*, 2003; Al-Aghabary *et al*., 2004). These photoassimilates can be translocated to the fruits, which are strong metabolic drains (Peluzio *et al.*, 1999); it may be one of the factors responsible for the increase in the productivity.

With the increase in the productivity to approximately 6.4 t ha^{-1} of the tomato obtained at the estimated dose of 401 kg ha^{-1} of SiO_2, the estimated gross financial return would be R$ 7,300.00 ha^{-1}, if one takes into account the average price of R$ 1.15 kg^{-1} obtained in the last eight months in Ceasa of Belo Horizonte (Ceasaminas, 2012). However, taking into account the calcium silicate (22.4% of SiO_2 and 34.9% of CaO), deducting the amount of R$ 146.45 ha^{-1} by 400 kg of SiO_2 and the average cost of R$ 900.00 ha^{-1} on the use of this input, similar to management adopted in this experiment, net economic return would be R$ 6,253.60 ha^{-1}, without considering shipping. The calcium silicate, besides having low cost, has low solubility, which assures the gradual and continuous supply of nutrients. Moreover, potassium and sodium silicates, sources of high solubility, when applied to the soil at high doses, can cause nutritional imbalance, damaging the soil and the plant.

Thus, the authors concluded that the fertilization with Si increases the tomato productivity and, consequently, the economic return of the crop. However, more studies under field conditions are necessary, in other soils and with other tomato cultivars in order to recommend or include this element in the fertilization of this crop.

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