horticultura brasileira

Pesquisa / *Research*

MARODIN, JC; RESENDE, JTV; MORALES, RGF; FARIA, MV; TREVIZAM, AR; FIGUEIREDO, AST; DIAS, DM. 2016. Tomato post-harvest durability and physicochemical quality depending on silicon sources and doses. *Horticultura Brasileira* 34: 361-366. DOI - http://dx.doi.org/10.1590/S0102-05362016003009

Tomato post-harvest durability and physicochemical quality depending on silicon sources and doses

Josué C Marodin[1]; Juliano TV Resende[1]; Rafael GF Morales[2]; Marcos V Faria[1]; Anderson R Trevisam[3]; Alex ST Figueiredo[4]; Diego M Dias[1]

[1]Universidade Estadual do Centro-Oeste (UNICENTRO), Guarapuava-PR, Brasil; josuemarodin@hotmail.com; jvresende@uol.com.br; [2]Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (EPAGRI), Itajaí-SC, Brasil; rafaelmorales@epagri.sc.gov.br; [3]Universidade Federal de Lavras (UFLA), Lavras-MG, Brasil; aanrt@hotmail.com; [4]Sakata Seeds Sudamerica, Bragança Paulista-SP, Brasil; alex.figueiredo@sakata.com.br

ABSTRACT

This study aimed to investigate the effect of silicon (Si) sources and doses on the physicochemical quality as well as post-harvest conservation of tomato fruits. Treatments were arranged in a 3 x 5 factorial scheme corresponding to sources [calcium silicate, potassium silicate and sodium silicate] and five doses of Si (equivalent to 0, 100, 200, 400 and 800 kg/ha SiO_2). Randomized blocks were the experimental design, with four replications. Soluble solids, vitamin C, lycopene, titratable acidity, mature fruit firmness, initial firmness, firmness half-life, time until reaching firmness equivalent to 3.0 x 10^4 N/m^2 and 2.0 x 10^4 N/m^2 and Si content in fruits were evaluated. Soluble solids, vitamin C and lycopene of fruits increased with increasing doses of Si, except for the highest dose. Calcium and sodium silicate provided the highest lycopene concentration in fruits. An increase in initial firmness, number of days until reaching firmness half-life and firmness equivalent to 3.0 and 2.0 x 10^4 N/m^2 were observed along with increasing doses of Si. Tomato fertilization with calcium silicate, potassium silicate and sodium silicate, used as sources of Si, increased the post-harvest conservation as well as the physicochemical quality of tomato.

Keywords: *Solanum lycopersicum*, post-harvest conservation, silicates, bioactive compounds.

RESUMO

Durabilidade pós-colheita e qualidade físico-química de frutos de tomateiro em resposta a doses e fontes de silício

O presente trabalho teve por objetivo avaliar o efeito de diferentes fontes e doses de silício (Si) sobre a qualidade físico-química e a conservação pós-colheita de frutos de tomateiro. Os tratamentos foram distribuídos em esquema fatorial 3 x 5, correspondendo às fontes de Si [silicato de cálcio, potássio e sódio] e cinco doses de Si (equivalentes a 0, 100, 200, 400 e 800 kg/ha de SiO_2). O delineamento experimental foi em blocos casualizados, com quarto repetições. Foram realizadas as seguintes avaliações nos frutos: teor de sólidos solúveis, vitamina C, licopeno, acidez titulável, firmeza de fruto maduro, firmeza inicial, meia vida da firmeza, firmezas em 3,0 x 10^4 N/m^2 e 2,0 x 10^4 N/m^2 e concentração de Si nos frutos. As concentrações de sólidos solúveis, vitamina C e licopeno nos frutos aumentaram em resposta às doses crescentes de Si, contudo, reduziram na maior dose. A aplicação de silicato de cálcio e de sódio proporcionou aumento na concentração de licopeno do fruto. Houve um aumento na firmeza inicial, número de dias para alcançar a meia vida da firmeza, firmeza de 3,0 x 10^4 N/m^2 e firmeza 2,0 x 10^4 N/m^2 dos frutos em resposta ao aumento das doses de Si. Com base nesses resultados, pode-se concluir que a adubação do tomateiro com silicato de cálcio, potássio e sódio, usados como fontes de Si, aumentam a conservação pós-colheita e a qualidade físico-química de frutos do tomateiro.

Palavras-chave: *Solanum lycopersicum*, conservação pós-colheita, silicatos, compostos bioativos.

(Recebido para publicação em 8 de dezembro de 2014; aceito em 11 de fevereiro de 2016)
(*Received on December 8, 2014; accepted on February 11, 2016*)

Productivity has been traditionally the main criteria considered for evaluating the effects of cultivation techniques for the tomato crop. However, factors related to fruit quality have been increasingly studied. For vegetable crops, quality is controlled genetically as well as influenced by environmental conditions, such as mineral nutrition.

Application of mineral nutrients can influence nutritional and structural complexes of plants as a consequence of effects on biochemical and physiological processes, such as photosynthesis and translocation of photo assimilates.

Silicon is a beneficial and an important nutrient for plants (Stamatakis *et al*., 2003b). Silicon influences plant architecture by providing more erect leaves and then improving solar radiation interception as well as photosynthetic efficiency (Pereira *et al*., 2003; Al-Aghabary *et al*., 2004). Moreover, Si may reduce damages caused by abiotic and biotic stresses, such as salinity (Zhu *et al*., 2004), zinc toxicity (Ramos *et al*., 2009) manganese toxicity (Iwasaki *et al*., 2002), damages caused by high and low temperatures (Ma & Yamaji, 2006), besides making the cell wall more resistant to enzymatic degradation by hindering the penetration and development of fungal hyphae

(Almeida *et al*., 2009). In addition, silicon fertilization promotes an increase in fruit yield in the tomato crop (Marodin *et al*., 2014).

Despite the proven effects of Si on the mentioned metabolic processes, little information on its effects on traits related to post-harvest quality can be found. Resende *et al*. (2007) showed that foliar application of Si reduced oxidation in the outer leaves of lettuce, causing the formation of compact "heads", with a higher retention of the green coloration, compared to the control (without Si). Concerning tomato, Stamatakis *et al*. (2003a) observed an increase in concentration of soluble solids, vitamin C, lycopene and fruit firmness by adding Si to the nutrient solution.

The metabolic and structural activities carried out by Si in higher plants should be completely elucidated, so that fertilizers could be effectively managed for the improvement of productivity, nutrition, sanity, as well as post-harvest conservation. The present study aimed to evaluate the effect of different sources and doses of Si on physicochemical quality and post-harvest conservation of tomato fruits.

MATERIAL AND METHODS

The experiment was carried out from October 2009 to March 2010, in Guarapuava, Parana State, Brazil. The cultivar used was Kada Gigante VF 2500, Santa Cruz group, which has the following characteristics: indeterminate growth habit, cycle duration between 180 and 250 days, average fruit mass of 130 g and a poor post-harvest conservation. At 35 days after sowing, when seedlings showed two pairs of expanded leaves, they were transplanted into 7 dm^3 pots. Pots were filled with subsoil classified as Latossolo Bruno álico distrófico (Embrapa, 2006), clayey texture, sieved through a 4 mm mesh and homogenized. The pH level was managed based on the soil chemical analysis: pH ($CaCl_2$)= 5.0; organic matter = 37.6 g/dm^3; P (mehlich)= 1.1 mg/dm^3; 0.1; 3.4; 1.9; 0; 5.3; 11 $cmol_c/dm^3$ K, Ca, Mg, Al, H+Al and CEC, respectively. In relation to micronutrients B, Cu, Fe, Mn and Zn, their concentrations were 0.23; 1.00; 129.00; 43.20 and 1.40 mg/dm^3, respectively. The Si content in the soil was 11 mg/dm^3, extracted with 0.01 mol/L $CaCl_2$. Pots were kept in a protected environment, 1.0 m between lines and 0.4 m between plants. The basic fertilization was calculated according to the soil analysis using urea, calcium nitrate, triple superphosphate and potassium chloride, totalizing 300 kg/ha N, 500 kg/ha K_2O, 300 kg/ha P_2O_5 and 350 kg/ha Ca. The soil base saturation (V) was adjusted to 80%, by applying 3,500 kg/ha dolomitic limestone. Eight top dressing fertilizations were carried out weekly, starting one month after the seedlings were transplanted into pots, totalizing doses equivalent to 200 kg/ha N and 300 kg/ha K_2O (Alvarenga, 2004).

A randomized complete block design, with 15 treatments and 4 replications was used. Each plot consisted of four pots, containing one plant per pot. Treatments were arranged in a 3 x 5 factorial scheme, corresponding to three silicate sources [calcium silicate ($CaSiO_3$, 24.2% Si), potassium silicate (K_2SiO_3, 22% Si) and sodium silicate (Na_2SiO_3, 22% Si)] and five Si doses (equivalent to 0, 100, 200, 400 and 800 kg/ha SiO_2). Silicates, which were applied in the form of salts, were added to the soil at 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, at the issuing of the fifth raceme. To nullify the effect of the cation accompanying silicate (Ca, K and Na), calcium chloride, potassium chloride and sodium chloride were applied to the treatments which did not receive the respective cations in the form of silicate, so that all treatments were given the same quantities of these elements (229 kg/ha CaO, 361 kg/ha K_2O and 229 kg/ha Na_2O).

Plants were trained with a single stem, managed weekly in vertical trellis system, and the apical pruning was carried out above the third leaf after the seventh raceme. A drip irrigation system with an irrigation water depth of 5 mm/day was used to irrigate plants daily. Control of pests and diseases was carried out weekly by alternating products with active ingredients recommended for the crop.

Si content in fruits was determined by sampling two ripe fruits per plot. Samples were dehydrated until they reached constant mass, in an oven with forced air circulation at 70°C. Determination of Si content was carried out using the methodology described by Korndörfer *et al*. (2004), with values expressed in g/kg of dry mass of fruits.

For post-harvest chemical analysis, three ripe fruits, picked from the second and third raceme, with intense red color, were used. Seeds were removed, and the pulp was kept in a freezer (-20°C), in the dark, protected with aluminum foil until the analysis was carried out. For determining chemical characteristics (soluble solids, titratable acidity, vitamin C and lycopene), fruit pulp samples were crushed and homogenized using a food processor at low speed (3,000 rpm) for two minutes each sample.

Soluble solids were determined by direct reading in a bench-top refractometer (Optech model RMT), at room temperature (±18°C), with values expressed in Brix (°BRIX).

Titratable acidity was determined by titration method, using 10 g of tomato pulp, 100 mL of distilled water and two drops of phenolphthalein. This solution was titrated with a 0.1 mol/L NaOH standard solution. Values were expressed in citric acid percentage (g of citric acid/100 g fresh tissue), according to the standard technique of Adolfo Lutz Institute (Instituto Adolfo Lutz, 2008).

Vitamin C was determined by the titration method described by Benassi & Antunes (1988). For this, 20 grams of a solution composed by 25 g tomato pulp and 50 g 2% oxalic acid were transferred to a 50 mL volumetric balloon and its volume was completed with oxalic acid. The solution was filtered in filter paper and a 10 mL aliquot was titrated with DCPIP (2,6 dichlorophenolindophenol). Results were expressed in mg vitamin C for 100 g sample.

Lycopene was determined by spectrophotometric analysis according to Rodriguez-Amaya (2001). A 5.0 g sample of tomato pulp with 40 mL acetone was agitated for one hour at

200 rpm (agitator Multi Shaker MMS). Afterwards, a vacuum filtration process was carried out with the aid of a Kitassato wrapped into aluminum foil in order to avoid pigment photo-oxidation. The sample was transferred to a separation funnel and 45 mL petrol ether was added to it. The pigment solution in petrol ether was transferred to a volumetric balloon and the 100 mL volume was completed with petrol ether. The reading on spectrophotometer (SP-2000UV Spectrum) was carried out using 470 nm wavelength and the results were expressed in μg/g. Lycopene content was obtained by the formula: Lycopene (μg/g) = [(A x V x 1.000.000)/($A^{1\%}_{1cm}$ x M x 100)] in which: A= solution absorbance in 470 nm wavelength, V= solution final volume, $A^{1\%}_{1cm}$ = coefficient of extinction or molar absorption coefficient of a pigment in a determined solvent and M= mass of sample taken for analysis. For lycopene in petrol ether, the extinction value is 3450.

Ripe fruit firmness was determined by destruction, with bench-top penetrometer (Soilcontrol/USA, model PDF-200), with 8 mm tip. Readings in opposed poles in the equatorial region of the fruit were taken, after peel removal, in ten ripe fruits per treatment. Results were expressed in Newton (N).

For evaluating the loss of fruit firmness during ripening, fruits were harvested weekly at the *breaker* stage (Faria *et al*., 2003). This stage is characterized by the breakage of the fruit green-color stage, with the appearance of reddish spots in the stylar scar region. Harvest began at the eleventh week after transplanting. Firmness was determined by the nondestructive applanation technique (Calbo & Nery, 1995). Five fruits of each treatment were stored into a cold chamber, with controlled temperature (15°C) and relative humidity (60%), during the entire evaluation period (20 days). Fruits were evaluated every two days, using the 'central leveler', under a 1,238 kgf pressure. This process is called proof point (F). On the basis of that evidence point, a small acrylic plate in the horizontal direction was pressed directly onto the surface of the fruit, always placed in the same previously marked point in the equatorial region, in which it remained for 15 seconds (Faria *et al*., 2003). Direct pressure on the fruit promoted the formation of a contact ellipsoidal surface layer, delimited by a mineral oil mark (a mineral oil drop was placed in a single point). The major diameter (a) and the smaller diameter (b) from the delineated ellipsoid were measured with a caliper. The surface area was calculated by the expression A= 0.7854 x a x b. Firmness (P) was determined by the ratio of the point of probe (F) to the flattened area (A). The results from this relation were expressed in N/m^2, in which higher values indicate firmer fruits. With these results, initial firmness of the fruit at the *breaker* stage, half-life of fruit firmness (after-harvest period of time during which the fruit has its firmness reduced to half the initial firmness value) and the number of days until the fruit reaches the firmness

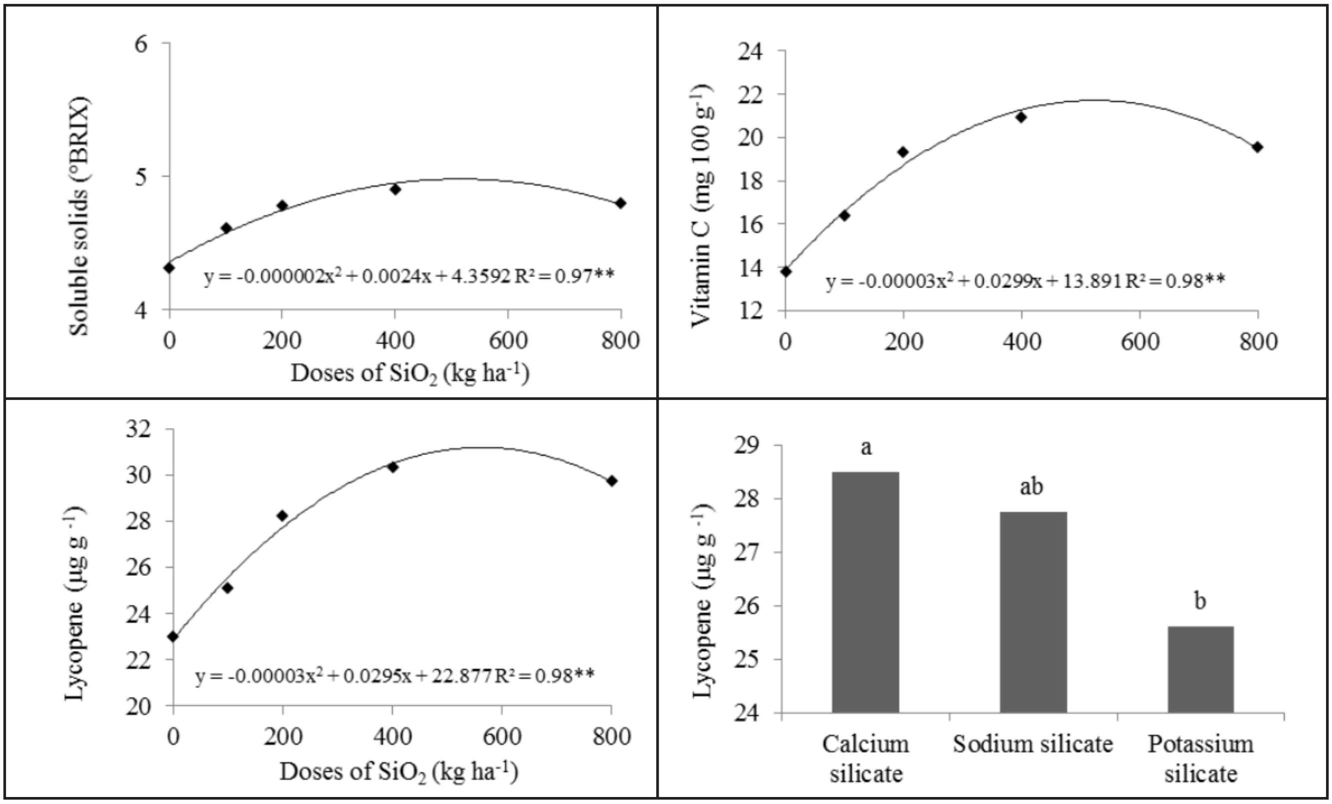

Figure 1. Effect of silicate fertilization on soluble solids, vitamin C and lycopene content in tomato fruits (*Solanum lycopersicum*) *and** p≤0.05 and p≤0.01, respectively. The same lowercase letters indicate no statistical difference by Tukey test (p≤0.01) {efeito do silício sobre os teores de sólidos solúveis, vitamina C e licopeno em frutos de tomate (*S. lycopersicum*). *e** p≤0,05 e p≤0,01, respectivamente. Mesma letra minúscula mostra que não há diferença estatística pelo teste de Tukey (p≤0.01)}. Guarapuava, UNICENTRO, 2010.

equivalent to 3.0 x 10^4 N/m² and 2.0 x 10^4 N/m² were determined, considering that fruits presenting firmness below these values are inappropriate for commercialization.

Regression analysis was used to adjust the loss of fruit firmness over time. The exponential decay model was used with logarithmic transformation followed by a linear regression, using the software SAS (Statistical Analysis System). Half-life of firmness (T) was obtained by the regression of firmness data (P), from each plot, in the number of elapsed days (X), by statistic model of exponential decaying: $P = P_0 \times (1/2)^{X/T}$, in which P_0= initial firmness (N/m²) of fruit in *breaker* ripening stage; T= half-life of firmness (days); P= firmness (N/m²) after X days elapsed. Based in the adjusted equation, we determined for each plot: initial fruit firmness at the *breaker* stage, firmness half-life and number of days to reach firmness equivalent to 3.0 x 10^4 N/m² and 2.0 x 10^4 N/m² (Faria *et al*., 2006).

Post-harvest physicochemical and conservation data were submitted to variance analysis. Data for the source of Si were subjected to analysis of variance and means were compared by Tukey 5 and 1%. Data referring to doses of Si were submitted to variance analysis and polynomial regression, and the R² values of regression equations tested by the "F" test. Coefficient r (Pearson) was determined and tested by "t" (t<5%) for establishing possible correlations among the analyzed factors.

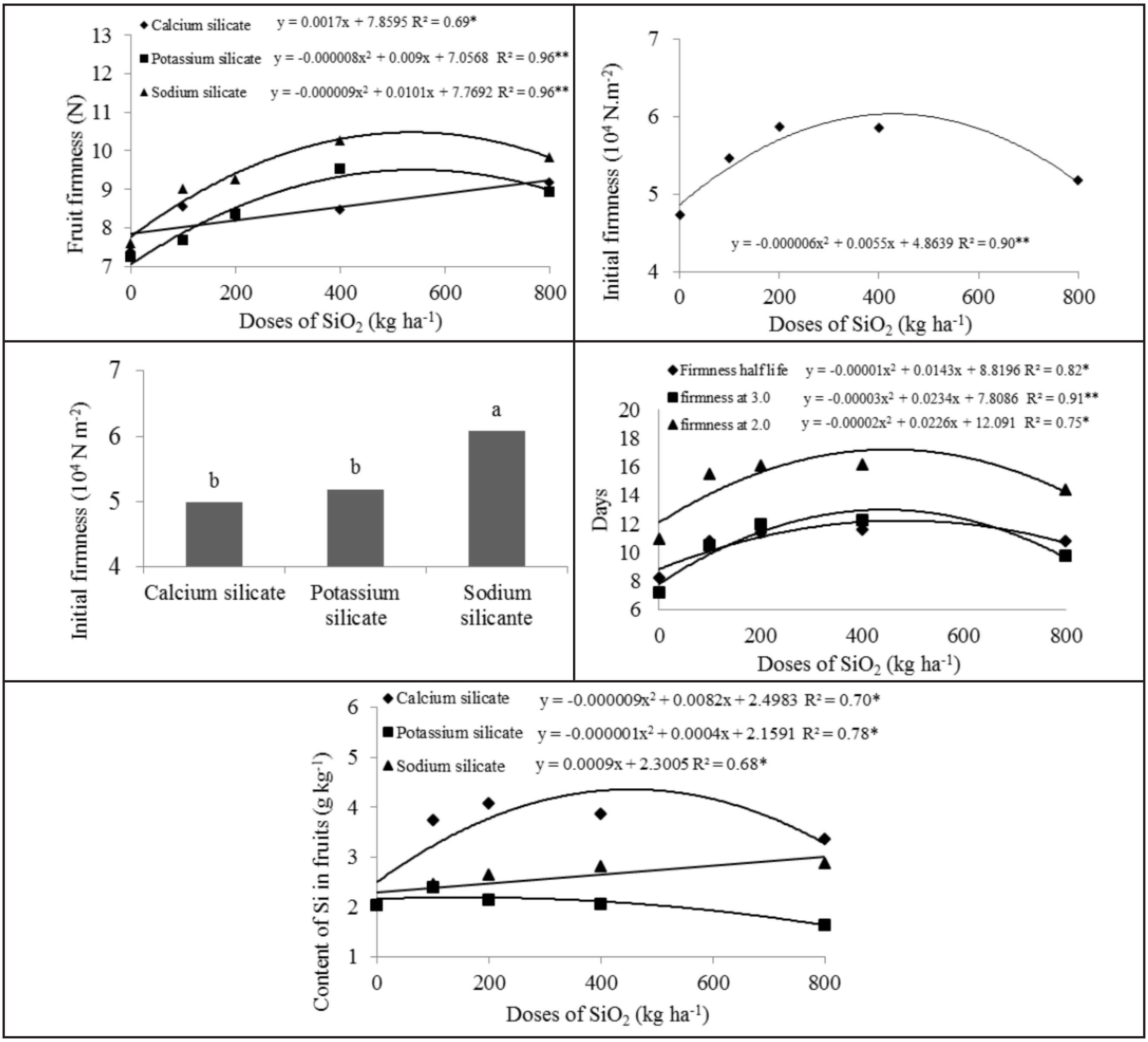

Figure 2. Effect of three silicon (Si) sources on firmness of ripe fruit, initial firmness, firmness half-life, firmness of 3.0 and 2.0 x 10^4 N/m² and Si content in tomato (*Solanum lycopersicum*) fruit *and** $p \leq 0.05$ and $p \leq 0.01$, respectively. The same lowercase letters indicate no statistical difference by Tukey test ($p \leq 0.01$) {efeito de três fontes de silício sobre a firmeza de fruto maduro, firmeza inicial, meia vida da firmeza, firmeza 3,0 e 2,0 x 10^4 N/m² e conteúdo de silício em frutos de tomate (*S. lycopersicum*). *e** p≤0,05 e p≤0,01, respectivamente. Mesma letra minúscula mostra que não há diferença estatística pelo teste de Tukey (p≤0.01)}. Guarapuava, UNICENTRO, 2010.

RESULTS AND DISCUSSION

Soluble solids in fruits increased with increasing Si doses, the maximum value 5.08°BRIX being recorded with a SiO_2 dose equivalent to 600 kg/ha (Figure 1a). The average soluble solids value recorded (4.7°BRIX) was superior to that reported for cultivar Kada Gigante (3.95°BRIX) (Valencia *et al*., 2003). These results are in accordance with those reported by Stamatakis *et al*. (2003b), in which the tomato soluble solids increased with application of Si. The Si beneficial effects are associated with an increase in photosynthetic efficiency (Pereira *et al*., 2003; Al-Aghabary *et al*., 2004), since the sugar produced in leaves is translocated to the fruits, increasing their soluble solids content (Valencia *et al*., 2003).

Vitamin C content in the fruits increased from 13.97 mg/100 g in the control treatment to 21.34 mg/100 g in the estimated Si dose of 498 kg/ha (Figure 1b). The average vitamin C content in fruits (18 mg/100 g) is within the range normally found for tomato (10 to 120 mg/100 g) (Fontes *et al*., 2004). These results corroborate those observed by Stamatakis *et al*. (2003b), in which vitamin C in tomato fruits increased as a result of Si addition to the nutrient solution. However, the role of Si in metabolic pathways related to biosynthesis of vitamins is still unclear.

Lycopene content of fruits varied with Si, the highest value, 30.13 µg/g, being recorded with a dose equivalent to 491 kg/ha of Si (Figure 1c). Among the three sources evaluated, calcium and sodium silicate provided the highest contents in fruits, from 2 to 3 times as high as the value recorded for plants fertilized with potassium silicate (Figure 1d). Stamatakis *et al*. (2003b) observed that Si significantly improved β-carotene and lycopene contents in tomato fruits. Some carotenoids are antioxidants whose nutritional value is recognized (Silva & Naves, 2001). Therefore, high concentrations of these pigments in tomato fruits increase their quality. Besides that, lycopene directly interferes in fruit appearance, influencing acceptance of consumers. The tomato external coloration results from pulp and peel pigmentation, which is conditioned by the total concentration of carotenoids, influenced by the relation lycopene/beta-carotene, which gives red color to fruits (Santos Junior *et al*., 2003; Carvalho *et al*., 2005).

Plants fertilized with sodium silicate produced the most firm fruits, the highest ripe fruit firmness value, 10.6 N, corresponding to a sodium silicate dose equivalent to 561 kg/ha. Doses higher than 561 kg/ha caused loss of firmness (Figure 2a), however. Similar results were observed using potassium silicate, which produced fruits with firmness equivalent to 9.5 N at the same dose. However, plants fertilized with calcium silicate increased their fruit firmness linearly up to the highest evaluated dose (800 kg/ha Si), corresponding to a firmness value of 9.2 N (Figure 2a). Initial firmness also increased in response to silicate fertilization, reaching a maximum value of 6.12 x 10^4 N/m^2 with a dose equivalent to 458 kg/ha Si (Figure 2b). Considering only the source and disregarding the dose used, sodium silicate provided fruits with the greatest initial firmness (6.09 x 10^4 N/m^2), higher than calcium and potassium silicate, which did not differ from one another (Figure 2c). The authors observed an increase in the number of days for reaching firmness half-life (13.9 days with 715 kg/ha SiO_2), firmness of 3.0 x 10^4 N/m^2 (12.4 days with 390 kg/ha Si O_2) and firmness of 2.0 x 10^4 N/m^2 (18.5 days with 565 kg/ha SiO_2) with increasing SiO_2 doses (Figure 2d). These results are directly correlated with Si content in fruits (r= 0.97**, 0.96* and 0.99**, respectively), indicating that Si exerts a beneficial effect on fruit firmness (Table 1). The increase of fruit firmness as a result of silicate fertilization was also observed by Stamatakis *et al*. (2003b) and considered as a result of Si deposition in the cell wall (Almeida *et al*., 2009). Thus, epidermal cells become thicker, with higher degree of silification. This may be the factor responsible for firmness increasing in the fruit. The Si fertilization in tomato plants reduces the occurrence of cracked fruits, which are classified as non-commercial (Marodin *et al*., 2014). Fruit firmness is an essential characteristic of post harvest conservation during transportation and commercialization, and it is related to shelf life.

Although sodium silicate showed the best results for fruit firmness, calcium

Table 1. Correlation between physicochemical and post-harvest conservational characteristics of tomato (*Solanum lycopersicum*) fruits fertilized with silicate {correlação entre as características físico-químicas e de conservação pós-colheita de frutos de tomate (*S. lycopersicum*) adubados com silício}. Guarapuava, UNICENTRO, 2010.

		(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1)	Silicon in fruit (g/kg)	0.89*	0.77^{ns}	0.67^{ns}	0.88*	0.94*	0.97**	0.96*
(2)	Soluble solids (°Brix)		0.99**	0.96**	0.96**	0.88*	0.95*	0.89*
(3)	Vitamin C (mg/100 g)			0.99**	0.95*	0.78^{ns}	0.89*	0.85^{ns}
(4)	Lycopene (µg/g)				0.96**	0.67^{ns}	0.82^{ns}	0.75^{ns}
(5)	Firmness of mature fruit (10^4 N/m^2)					0.65^{ns}	0.92*	0.87*
(6)	Initial firmness (N)						0.92*	0.99**
(7)	Firmness half life (days)							0.96**
(8)	Days to firmness 3.0 x 10^4 N/m^2							

*and** p≤0.05 and p≤0.01, respectively, not different by test t. ns = not significant (*e**- p≤0,05 e p≤0,01 não diferem respectivamente pelo teste t. ns = não significativo).

silicate provided the highest Si content in fruit dry mass, with a maximum value of 4.36 g/kg corresponding to 455 kg/ha Si (Figure 2e). Despite the high correlation between firmness increase and Si content in fruit (r= 0.88*), firmness may be rather related to the Si participation in important metabolic pathways than to the Si accumulation in fruits.

Silicon fertilization improves physical and chemical quality of tomato fruits, increasing soluble solids, vitamin C, lycopene and firmness. Tomato shelf life and post-harvest conservation increased as a result of a higher firmness. The Si dose of 400 kg/ha is recommended for improving fruit quality.

REFERENCES

AL-AGHABARY, K; ZHU, Z; SHI, QH. 2004. Influence of silicon supply on chlorophyll content, chlorophyll fluorescence, and antioxidative enzyme activities in tomato plants under salt stress. *Journal of Plant Nutrition* 27: 2101-2115.

ALMEIDA, GD; PRATISSOLI, D; ZANUNCIO, JC; VICENTINI, VB; HOLTZ, AM; SERRÃO, JE. 2009. Calcium silicate and organic mineral fertilizer increase the resistance of tomato plants to *Frankliniella schultzei*. *Phytoparasitica* 37: 225-230.

ALVARENGA, MAR. 2004. *Tomate: produção em campo, casa-de-vegetação e em hidroponia*. Lavras: UFLA. 400p.

BENASSI, MT; ANTUNES, AJA. 1988. Comparison of methaphosphoric and oxalic acids as extractant solutions for the determination of vitamin C in selected vegetables. *Brazilian Archives of Biology and Technology* 31: 507-513.

CALBO, AG; NERY, AA. 1995. Medida de firmeza em hortaliças pela técnica de aplanação. *Horticultura Brasileira* 13: 14-18.

CARVALHO, W; FONSECA, MEDN; SILVA, HRD; BOITEUX, LS; GIORDANO, LDB. 2005. Estimativa indireta de teores de licopeno em frutos de genótipos de tomateiro via análise colorimétrica. *Horticultura Brasileira* 23: 819-825.

EMBRAPA. 2006. *Centro Nacional de Pesquisa de Solos (Rio de Janeiro, RJ). Sistema brasileiro de classificação de solos.* Brasília: Embrapa-SPI. 306p.

FARIA, MV; MALUF, WR; AZEVEDO, SM; ANDRADE-JÚNIOR, VC; GOMES, LAA; MORETTO, P; LICURSI, V. 2003. Yield and post-harvest quality of tomato hybrids heterozygous at the loci alcobaça, old gold-crimsom or high pigment. *Genetics and Molecular Research*, 2: 317-327.

FARIA, MV; MALUF, WR; RESENDE, JTV; ANDRADE-JÚNIOR, VC; NASCIMENTO, IR; BENITES, FRG; MENEZES, CB; AZEVEDO, SM. 2006. Mutantes rin, norA, ogc e hp em diferentes backgrounds genotípicos de tomateiro. *Pesquisa Agropecuária Brasileira* 41: 793-800.

FONTES, PCR; LOURES, JL; GALVÃO, JCC; CARDOSO, AA; MANTOVANI, EC. 2004. Produção e qualidade do tomate produzido em substrato, no campo e em ambiente protegido. *Horticultura Brasileira* 22: 614-619.

INSTITUTO ADOLFO LUTZ. 2008. M*étodos físicos e químicos para análise de alimentos*. São Paulo: Instituto Adolfo Lutz. 1020p.

IWASAKI, K; MEIER, P; FECHT, M; HORST, WJ. 2002. Effects of silicon supply on apoplastic manganese concentrations in leaves and their relation to manganese tolerance in cowpea (*Vigna unguiculata* (L.) Walp.). *Plant and Soil* 238: 281-288.

KORNDÖRFER, GH; PEREIRA, HS; NOLLA, A. 2004. Análise de silício: solo, planta e fertilizante. Uberlândia: GPSi-ICIAG-UFU (Boletim técnico 2: 34).

MA, JF; YAMAJI, N. 2006. Silicon uptake and accumulation in higher plants. *Trends in Plant Science* 11: 342-397.

MARODIN, JC; RESENDE, JTV; MORALES, RGF; SILVA, MLS; GALVÃO, AG; ZANIN, DS. 2014. Yield of tomato fruits in relation to silicon sources and rates. *Horticultura Brasileira* 32: 220-224.

PEREIRA, HS; VITTI, GC; KORNDÖRFER, GH. 2003. Comportamento de diferentes fontes de silício no solo e na cultura do tomateiro. *Revista Brasileira de Ciência de Solo* 27: 101-108.

RAMOS, JS; CASTRO, EMD; CARMO PINTO, SID; FAQUIN, V; OLIVEIRA, CD; PEREIRA, GC. 2009. Uso do silício na redução da toxidez de zinco em mudas de eucalipto. *Interciencia* 34: 189-194.

RESENDE, GMD; YURI, JE; SOUZA, RJD. 2007. Épocas de plantio e doses de silício no rendimento de alface tipo americana. *Horticultura Brasileira* 25: 455-459.

RODRIGUEZ-AMAYA, DA. 2001. *Guide to carotenoids analysis in food*. Washington: International Life Sciences Institute Press. 64p.

SANTOS JUNIOR, AMD; MALUF, WR; FARIA, MV; LIMA, LCDO; CAMPOS, KP; LIMA, HCD; ARAÚJO, FMMCD. 2003. Comportamento pós-colheita das características químicas, bioquímicas e físicas de frutos de tomateiros heterozigotos nos locos alcobaça e ripening inhibitor. *Ciência e Agrotecnologia* 27: 749-757.

SILVA, CRDM; NAVES, MMV. 2001. Suplementação de vitaminas na prevenção de câncer. *Revista de Nutrição* 14: 135-143.

STAMATAKIS, A; PAPADANTONAKIS, N; LYDAKIS-SIMANTIRIS, N; KEFALAS, P; SAVVAS, D. 2003a. Effects of silicon and salinity on fruit yield and quality of tomato grown hydroponically. In: STAMATAKIS, A; PAPADANTONAKIS, N; LYDAKIS-SIMANTIRIS, N; KEFALAS, P; SAVVAS, D (eds). *Proceedings of the International Symposium on Managing Greenhouse Crops in Saline Environment*. Leuven: International Society Horticultural Science. p. 141-147.

STAMATAKIS, A; SAVVAS, D; PAPADANTONAKIS, N; N, L-S; KEFALAS, P. 2003b. Effects of silicon and salinity on fruit yield and quality of tomato grown hydroponically. *Acta Horticulturae* 609: 141-149.

VALENCIA, J; BIECHE, B; BRANTHOME, X. 2003. Effect of fertilizers on fruit quality of processing tomatoes. *Acta Horticulturae* 613: 89-93.

ZHU, ZJ; WEI, GQ; LI, J; QIAN, QQ; YU, JQ. 2004. Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). *Plant Science* 167: 527-533.