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Growth and Yield of Tomato Applied with Silicon Supplements with Varying Material Structures

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Abstract

The effect of varying material structure of silicon (Si) supplements on the growth and yield performance of tomato was investigated. The experimental design consisted of three Si sources (nanosilica, microsilica and sodium silicate) at 5 g/L Si concentration. Among the treatments, nanosilica posted the highest increase in tomato plants' height increment, fresh weights and dry weights of all plant organs, Si concentrations, and yield. Tomato plants grown with nanosilica had increased height increment and fresh weights of roots, stems and leaves by 23%, 48%, 9% and 22%, respectively. Likewise, dry weight contents among individual organs of plants treated with nanosilica showed 40% and 34% significant increase in roots and stems, respectively. Only nanosilica significantly increased the average fruit yield of tomato by 35% as affected by the 23% increase in the average number of fruits per plant. Hence, among the treatments investigated, Si supplementation using nanosilica powder is the most effective in improving the growth characteristics and yield of tomato. Si in root samples supplemented with nanosilica was 72%, 105% and 152% larger as compared to microsilica, sodium silicate and control samples, respectively, which led to the conclusion that the nanostructured scale of silicon supplement contribute to the effective uptake of silicon in the tomato plants, thereby improving growth and yield.

Keywords: tomato cv. Magilas, silicon supplement, rice hull ash, nanofertilizer, nanopowder, nanotechnology, silica nanoparticle

Introduction

Silicon (Si) fertilization of soils is essential in increasing the quality and quantity of agricultural crops such as rice and sugarcane (Korndorfer & Lepsch, 2001). Several beneficial effects of Si on agricultural crops have been pointed out, like improving tolerance to drought (Ahmed, Hassen, & Khurshid, 2011), resistance to pests and diseases (Dannon & Wydra, 2004; Savvas, Giotis, Chatzieustratiou, Bakea, & Patakioutas, 2009; Ghareeb et al., 2011), and improving quality, yield and shelf life (Gottardi et al., 2012). In addition, Ahmed et al. (2011) found out that Si has no side effects to the environment when supplied to crops.

Tomato is a crop of great economic importance. In the Philippines, tomato fruit is regarded as one of the most profitable crops for off-season production. The high price of tomato during off-season is attributed to the low production due to environmental conditions like high temperature, relative humidity and precipitation, low fruit set, and occurrence of major insect pests and diseases (Narciso & Balatero, 2008). According to Roselló, Díez, and Nuez (1996), tomato is susceptible to more than 200 diseases, thus crop protection must then rely on genetic resistance or on disease avoidance.

Si has been reported to have prophylactic effect against several pathogens in tomato plants. Dannon & Wydra (2004) noted the influence of Si in reducing the disease incidence of bacterial wilt and the population density in stems of tomato, while Ghareeb et al. (2011) concluded that Si alleviates biotic stress imposed by the pathogens in tomato plants. Si was also reported to ameliorate the negative effects of sodium chloride on tomato plants. Si improves the water storage of tomato which allows a higher growth rate for the plant (Romero-Aranda, Jurado, & Cuartero, 2006) and protects photosynthetic activity of tomato plants against the hazardous effect of salinity (Haghigni & Pessarakli, 2013).

Notwithstanding the reported benefits of Si supplementation on tomatoes, no attention has been paid to the varying material structures of Si supplements and their possible effects on plant uptake and, eventually, on growth and yield. Previous works on the development of nanostructured Si materials (Lu et al., 2013; Lu, De Silva, Peralta, Fajardo, & Peralta, 2015) raises interest on whether the material structure of the silicon supplement would affect how much silicon will be absorbed by the plant to better take advantage of the benefits of Si fertilization. This study has thus considered the effects of Si supplement from three different sources on the tomato plant's uptake of Si and their resulting morphological and developmental characteristics. Finding out which among the Si supplement sources gives the best results will help maximize the potentials of Si supplementation for tomatoes.

Material and Methods

Preparations of nanosilica powder and silicon supplements were conducted at the Agricultural and Bio-Processing Division, Institute of Agricultural Engineering and at Institute of Chemistry, University of the Philippines Los Baños (UPLB). Planting was done at the Agrometeorology station of the Farm Structures Division, Institute of Agricultural Engineering, UPLB.

Nanosilica and microsilica were synthesized from Rice Hull Ash using the methods described by Lu et al. (2013). The characteristics of nanosilica used in the study are shown in Table 1.

Table 1. Characteristics of nanosilica used in the experiments.

Properties	Values
Nanostructures size (nm)	46.5[a], 40[b]
Purity percentage (%)	98.33[c]
Surface area (m^2/g)	172.19[d]
Crystalline structure	amorphous[e]

Estimated with atomic force microscopy (AFM)[a], transmission electron microscopy (TEM)[b], energy dispersive x-ray fluorescence spectroscopy (EDXRF)[c], Brunauer-Emmett-Teller (BET)[d] method and x-ray diffractometry (XRD)[e]

Microsilica used in the experiment has an average size of 272 nm (Figure 1) examined using the zetasizer (Nano ZS90, Malvern Instruments, UK). Nanosilica and microsilica were dispersed in distilled water by sonicating using a sonicator (Heat Systems-Ultrasonics, USA) at 10 kHz for 15 min (Suriyaprabha, Karunakaran, Yuvakkummar, Rajendran, & Kannan, 2012).

Plant material and growth conditions

Five-week-old tomato seedlings cv. Magilas obtained from National Seed Foundation (NSF), UPLB were transplanted in 6 in-diameter clay pots filled with soil, one seedling per pot. The soil composition was vermicompost (50%) and garden soil (50%). The vermicompost (NSF, UPLB, Philippines) had a nutrient content of 1.97% N, 2.95% P and 1.0% K. Peters Professional (The Scotts Co., Marysville, Ohio, USA) at the rate of 15N-10P-30K was also applied one week after transplanting at 150 mg/L per plant. The same amount of N, P and K fertilizers was applied again 30 days after transplanting (Yang, Qu, Zhang, & Li, 2012).

Plants were grown in the greenhouse on 5 September 2014 – 13 November 2014. These were irrigated with tap water as necessary, and weeds were removed regularly when present. Trellis was installed between plants 30 days after transplanting in order to support growth and increase the light use efficiency of the plants. Figure 2 shows seven-week-old tomato plants with trellis.

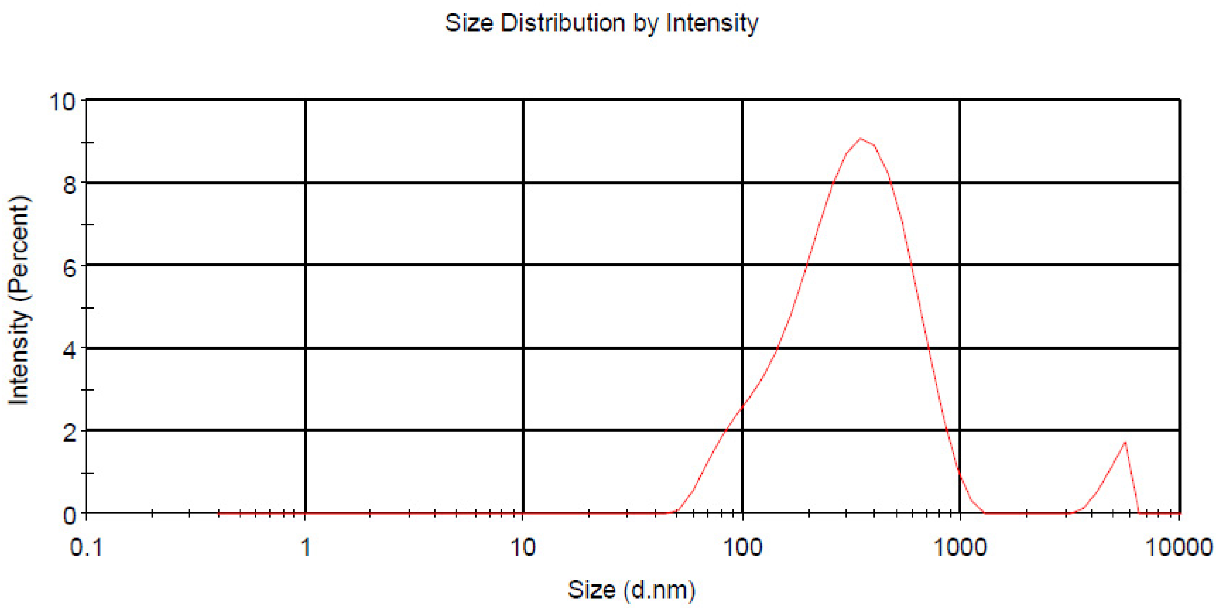

Figure 1. Size distribution of microsilica powder obtained using the Nano ZS90 zetasizer.

(a) (b)

Figure 2. (a) Seven-week-old tomato cv. Magilas seedlings used in the experiment and, (b) tomato plants with trellis during the vegetative stage.

The physical and chemical characteristics of the soils used in the experiment were determined using analytical methods (Table 2). Soil samples were taken before application of complete and silicon supplements.

Table 2. Physical and chemical properties of the soil used in the study.

Property	Values
pH	5.8
OM %	4.77
N %	0.16
P ppm (Bray)	285
K me/100g soil	2.59
Na me/100g soil	0.61
CEC me/100g soil	24.51
Ca me/100g soil	14.12
Mg me/100g soil	5.44
Fe ppm	62
Zn ppm	21
Cu ppm	13
Mn ppm	42
Cl ppm	925
WHC %	77
PD gm/cc	2.43
MC %	4
EC mS/cm	2.6
Percentage Sand	66
Percentage Silt	29
Percentage Clay	5
Textural Grade	Sandy loam

Treatments and Experimental Design

The pot experiment was conducted in a greenhouse. Three Si sources at the same rate were used. A total of 120 tomato seedlings were planted in four different treatments and were placed at random in the greenhouse while plant growth and yield were determined. The treatments consisted of three Si sources and a control (no Si added), with 30 replicate plants per treatment. The sources and concentrations of supplemental Si treatments were: 5 g/L nanosilica, 5 g/L microsilica and 5 g/L sodium silicate (Sigma-Aldrich, St. Louis, MO, USA). The Si concentration (5 g/L) used gave the best results among several concentrations examined on germination characteristics of tomato cv. Magilas (Lu et al., 2015). From the 10th day after transplanting, plants were irrigated every 2 weeks with or without 200 mL Si solutions (Rady, 2012).

Determination of plant growth parameters

At the end of the experimental period, data such as height increment (ΔHeight), days to anthesis (first flower) from transplant, number of leaves, shoot diameter, fresh weight (FW) and dry weight (DW) of separated roots, stems and leaves were measured on all plant samples (Rady, 2012). Root samples were washed with water prior to drying to remove all adhering soil particles. DWs were measured after drying plant parts for 3 days at 70 °C. Plant height, stem diameters and numbers of leaves were measured 40 days after transplanting.

Determination of yield

At harvest, fruit numbers, fruit weight and yield of tomato plant were recorded for each plant. Fruits were separated into marketable and non-marketable (cracked, damaged and diseased) and only marketable ones were used to calculate yields (Atiyeh, Arancon, Edwards, & Metzger, 2000). Tomato fruits were harvested when approximately 80% of the fruits were red or orange (Yang et al., 2012). The first, second and last fruit harvests were done at 54, 61 and 68 days, respectively after transplanting and cumulated yield of fruits was recorded. The results reported here are the means from 30 plants.

Determination of Si and other elements uptake and accumulation in roots

Si and other elements were extracted from the root tissue of the plants. Roots were separated from the soil by rinsing with distilled water. The roots were air-dried before oven drying at 70 °C until a constant weight was reached. Samples were burnt at 500 °C for five hours in a muffle furnace. Elemental analysis of root samples was analyzed using energy dispersive x-ray fluorescence (EDXRF) (EDX-720, Shimadzu, Japan).

Determination of nutritional status of tomato plants

The N, P, K, Ca and Mg were extracted from the whole plant. The whole plant samples were cleaned of soil particles and dried at 70 °C. The samples were cut into small pieces and ground in a mill fitted with 1-mm screen size sieve. After grinding, the samples were ashed at 500 °C in a muffle furnace. The P, K, Ca and Mg contents of the plant sample were determined from the ash extract. Total N was determined by modified Kjeldahl method, total P by Vanadomolybdate method, K content of the sample by flame photometer method, Ca and Mg contents were determined by ethylenediaminetetraacetic acid (EDTA) method.

Statistical Analysis

Data were statistically analyzed by one-way analysis of variance (ANOVA) using Minitab software, version 16 (Minitab Inc., USA). Differences among treatment means were tested for significance using the Tukey's test (honestly significant differences, HSD) at the 0.05 level (P<0.05).

Results and Discussion

Plant growth parameters

The height increment (ΔHeight) of tomato plants increased with nanosilica treatment but was approximately the same as the microsilica treated plants (Table 3). Height of tomato supplemented with nanosilica was 23% higher than those of the control tomato plants. Days to anthesis significantly decreased with Si supplementation. The application of Si had no significant effect on the number of leaves among nanosilica, microsilica and control treatments. Plants treated with sodium silicate showed significant decrease in number of leaves compared to control. Shoot diameter was not significantly affected by Si.

The FWs were significantly affected with Si supplementation and the highest values were found under nanosilica followed by microsilica treatments. Plants treated with sodium silicate have the lowest FW among plant organs. Tomato plants grown with nanosilica increased their roots, stems and leaves FWs by 48%, 9% and 22%, respectively compared to control while microsilica increased the roots and stems FWs by 38% and 4%, respectively compared to control. Sodium silicate treatment showed significant decrease in tomato stems FW compared to control.

The DW of plants grown with Si was also examined by comparing the effects of Si on the DW among plant organs. DW among individual organs of plants changed when plants were supplemented with Si. Plants treated with nanosilica showed 40%, 34% and 16% significant increase in roots, stems and leaves DWs, respectively, compared to control. DW of plant organs treated with nanosilica was higher than in plants treated with microsilica, although differences were not significant. Plants treated with microsilica showed 33%, 23% and 4% increase in roots, stems and leaves DWs, respectively, compared to the control. Effects to FWs and DWs of plants treated with sodium silicate were reduced by 20%, 4% and 6% in roots, stems and leaves, respectively, compared to the control.

The positive effect of Si supplements on

Table 3. Effects of Si supplements on the horticultural parameters of tomato cv. Magilas.

Si Source	ΔHeight (cm)	Days to anthesis	Number of leaves	Shoot diameter (cm)	Fresh weight (g/plant)			Dry weight (g/plant)		
					Roots	Stems	Leaves	Roots	Stems	Leaves
Control	48.4b	18b	243a	1.9a	4.2b	35.1a	21.1a	1.5b	5.6bc	4.9a
Nanosilica	59.3a	16a	230a	2.0a	6.2a	38.1a	25.7a	2.1a	7.5a	5.7a
Microsilica	48.5b	15a	225a	2.0a	5.8a	36.4a	21.0a	2.0a	6.9ab	5.1a
Sodium Silicate	40.5b	16a	188b	2.0a	3.6b	26.5b	18.8a	1.2b	5.4c	4.6a
In a column, treatment means with common letters are not significantly different at 5% level.										

tomato growth parameters has been observed in experiments with nanosilicon (Haghighi & Pessarakli, 2013), potassium silicate (Romero-Aranda et al., 2006), calcium silicate (Marmiroli, Pigoni, Savo-Sardaro, & Marmiroli, 2014) and monosilicic acid (Kiirika, Stahl, & Wydra, 2013). The result of the study on the effect of nanosilica and microsilica on tomato plant growth parameters was consistent with the previous reports.

Supplementation with nano size Si and Si has been shown to be beneficial for tomato plants and improved salt tolerance of the plants (Haghigni & Pessarakli, 2013). Similarly, the study showed that supplementation of nanosilica and microsilica lessen days to anthesis and improved FW and DW of tomato. However, the study showed that tomato seedlings treated with sodium silicate were shorter, had significantly fewer leaves, and weighed less than those of control plants. The decline in the measured parameters of tomato treated with sodium silicate was probably due to salinity caused by the higher levels of Na. Excessive uptake of the element and their accumulation in the plants may have accounted for the reduced growth parameters of tomato. Similar responses of tomato plant to Na have been recorded elsewhere (Haghigni & Pessarakli, 2013; Romero-Aranda et al., 2006).

Tomato yield

The yields of marketable fruits were significantly greater in nanosilica treated plants as compared to those treated with microsilica, sodium silicate and control treatments (Table 4). The yield of marketable fruits per plant increased by 35% in response to the supplementation of nanosilica as compared to the control. Tomato yield was significantly diminished when the crop was exposed to sodium silicate, decreasing the yield by 8% as compared to the control. The highest fruit weight and number of fruits per plant were obtained from samples treated with nanosilica. With nanosilica treatment, average fruit weight and average number of fruits per plant were increased by 8% and 23%, respectively as compared to the control.

The increase in marketable yield of tomato supplemented with nanosilica is due to larger number and weight of fruits per plant. An increase of crop yield following Si supplementation has already been reported either on tomato (Kleiber, Calomme, & Borowiak, 2015) and other crops, including squash (Savvas et al., 2009) and corn salad (Gottardi et al., 2012).

Si and other elements uptake and accumulation

Table 5 shows the effects of Si supplementation on root tissue nutrient of tomato plant. The EDXRF analysis of the root samples showed an increase in Si content of plants supplemented with silica. Root samples supplemented with nanosilica were 72%, 105% and 152%, higher than in microsilica, sodium silicate, and control samples. According to Rambo, Cardoso, Bevilaqua, Rizzetti, Ramos, Korndörfer, & Martins (2011), the application of silica sources as an additive ensures a greater availability of Si in the soil, where it can be absorbed into the plant root system. Si treatment has been reported to increase Si accumulation in tomato roots (Dannon & Wydra, 2004; Romero-Aranda et al., 2006; Kiirika et al., 2013). The

Table 4. Effects of Si supplements on average fruit yield, fruit weight and number of fruits per plant of tomato cv. Magilas.

Si Source	Average fruit yield (g/plant)	Average fruit weight (g)	Average number of fruits per plant
Control	106.2b	12.8ab	8.3ab
Nanosilica	143.9a	13.8a	10.2a
Microsilica	114.8b	11.5b	10.0a
Sodium Silicate	98.1b	13.7a	7.2b

In a column, treatment means with common letters are not significantly different at 5% level.

Table 5. Effects of Si supplements on root tissue nutrient of tomato cv. Magilas.

Analyte, %	**Control**	**Nanosilica**	**Microsilica**	**Sodium Silicate**
S	1.49	1.16	1.59	1.52
Zn	0.31	0.27	0.29	0.22
Sr	0.28	0.30	0.29	0.26
Fe	9.26	9.11	11.64	9.39
Cu	0.11	0.12	0.11	0.09
Ti	0.48	1.24	0.70	0.67
Ba	0.51	0.71	0.67	0.29
Mn	0.35	0.51	0.44	0.30
Si	**10.32**	**26.01**	**15.08**	**12.66**
Al	na	na	na	3.99
Na	na	na	na	**1.64**

Table 6. Effects of Si supplements on macronutrient concentration of tomato cv. Magilas.

Si source	Plant macronutrients				
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Control	3.00a	0.45ab	6.82ab	2.70a	0.65a
Nanosilica	4.33b	0.43a	7.00b	2.46b	0.64ab
Microsilica	3.41c	0.47b	6.57a	2.42b	0.61b
Sodium silicate	1.97d	0.45ab	6.07c	2.76c	0.65a

In a column, treatment means with common letters are not significantly different at 5% level.

EDXRF analysis of the root samples showed that only the sodium silicate treatment contains Na. It further confirms that Na present in sodium silicate treatment contribute towards the poor growth and yield of tomato plants.

Nutritional status of tomato plants

The nutrient content of the tomato plants are presented in Table 6. Statistically significant differences among the treatments were noted for N content. The highest N content was obtained from plants supplemented with nanosilica.

The increase in N content of tomato is in agreement with the study of Kamenidou, Cavins, and Marek (2010) on gerbera plant supplemented with silicon sources such as rice hull ash and potassium silicate that showed a significant increase in the N content of the plant. The use of Si as supplement had no significant effects on the content of P. P and Mg contents were higher in control plants compared to plants supplemented with nanosilica, although differences were not significant. Plants supplemented with nanosilica have the highest K content but not significantly different from the control. Plants applied with sodium silicate have the least N and K contents which are significantly lower than the control and other treatments. This could have been an important factor for the suppressed growth and yield of the tomato plant supplemented with sodium silicate. When either nanosilica or microsilica was used, almost the same results were observed for Ca and Mg contents of the plant.

Conclusions

The study investigated the effects of Si supplement from three different sources on the morphological and developmental characteristics of tomato plants. Among the three treatments, nanosilica powder had the highest height increment, FWs and DWs of all plant organs and higher yield, which can be related to higher Si contents in the plants. Supplementation of nanosilica powder on tomato led to considerable growth and yield benefits to the plants. It can be concluded that the beneficial effects of Si supplementation on tomato depends on the material structure of Si used, with nanosilica powder being the most effective in improving the growth characteristics and yield.

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